TRAUMA AND SPORTS INJURIES OF THE ELBOW

Izaäk F. Kodde

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Colophon

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”Kleine mannen worden groot, grote mannen worden klein”

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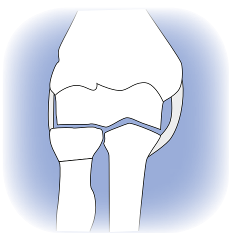
INTRODUCTION

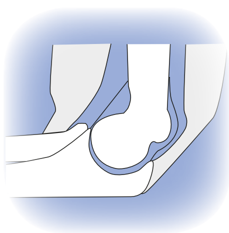
I

CHAPTER 1

General introduction

Izaäk F. Kodde





Function of the elbow

Stable and painless motion of the elbow is important for activities in daily living, sports activities and occupational tasks. Optimal elbow motion is essential for stable positioning of the hand in space. In order to provide this freedom for the hand, the elbow consists of three distinct joints (the ulnohumeral, the radiohumeral and the proximal radioulnar joint) allowing for flexion and extension of the arm in combination with supination and pronation of the forearm. Because there is also a slight medial and lateral mobility (abduction and adduction in frontal plane) and medial and lateral rotation (about the ulna in the transverse plane)[1], the elbow is one of the most 'complex joints' in the human body.
The evolution of the current complex elbow joint can be traced back to the Pelycosaurs that lived about 300 million years ago and gave rise to more advanced mammals such as humans and apes[2]. The configuration of the elbow adapted to the specific needs of a species with different forms of limb use. It appears, for instance, that in the beginning during the quadrupedal locomotion of our fossil ancestors, stability in flexion rather than mobility was the major functional characteristic of the elbow. Later on, the use of overhead suspensory postures and locomotion in apes has presumably led to the evolution of the capacity for complete elbow extension. As the human forearm became less involved in locomotion, it underwent modifications to increase performance during a range of motion. It is therefore suggested that the morphologic structure of the elbow developed in response to the need for stabilization throughout flexion-extension and pronation-supination range of motions to allow for a more all-round form of forearm use of humans today[2, 3].
Daily functional movements of the elbow include 1) flexion coupled with supination to bring the hand to the body and face, or carry objects, and 2) extension coupled with pronation to reach, throw or push[4]. By performing these motions, the elbow functions in both open chain conditions (the elbow is used to place the hand in an appropriate position) and closed chain conditions (the elbow is fixed into position in order to transmit forces from proximal muscles to the hand, or external loads that are applied to the hand or forearm are transmitted to the elbow and arm)[4].

Elbow motion

The normal arc of flexion-extension of the elbow is highly variable[5, 6]. The range of flexion-extension is influenced by several individual-dependent factors. Thin individuals have approximately 10° more flexion than muscular or obese individuals. Range of motion declines with increasing age[7]; children have a hyperextension and from the fourth decade there is loss of flexion and later extension. Gender of the person is the final factor that influences range of motion, with more hyperextension for females compared to males[5, 8]. Normal range of motions for males and females are provided in table 1. Several studies have looked for side-to-side differences between dominant and non-dominant arms with conflicting results. Gunal et al. found a significant diminished range of motion for the dominant side[9]. Macedo et al. also noted a difference, however, they concluded that these differences were clinically insignificant as the confidence interval of the difference between the dominant and non-dominant side was within the range of the minimal detectable change of range of motion[10]. Overall the results suggest that loss of motion after trauma can be calculated by comparison with the contralateral uninjured limb.

Table 1: normal elbow range of motion in different gender and age groups[5].

	Age 2-8 years		Age 9-19 years		Age 20-44 years		Age 45-69 years	
Joint ROM	Female	Male	Female	Male	Female	Male	Female	Male
Flexion°	153	151	150	148	150	145	148	144
Extension°	7	2	6	5	5	1	4	-1
Pronation°	85	80	81	80	82	77	81	78
Supination°	94	86	90	88	91	85	87	82

The pronation-supination motion is usually measured from a neutral position with the upper arm alongside the trunk and the elbow in 90° of flexion. The neutral position is defined as when the extended thump is parallel to the humerus. Pronation is approximately 80° and supination 90°[8]. The amount of forearm rotation depends on the degree of flexion in the elbow[11, 12]. Flexion of the elbow allows for a significant increase in forearm supination, whereas extension allows for more pronation. The greatest range of forearm rotation is with the elbow in mid-range of flexion[12]. See figure 1. In accord to flexion-extension motion, forearm rotations vary between normal subjects and can therefore, when measured after injury or surgery, be compared to the contralateral normal limb.

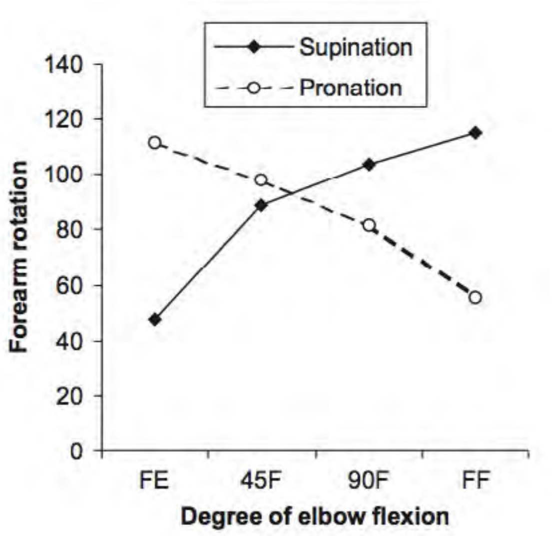


Figure 1: The relationship between active supination and active pronation in different positions of the elbow joint (FE, full extension; 45F, 45° flexion; 90F, 90° flexion; FF, full flexion); reproduced with permission of Sage from[12].

Despite the significant differences in elbow motion between individuals, the full range of possible motion is rarely used in daily life. Morrey et al. evaluated normal elbow motion required for 15 regular activities of daily living and concluded that most activities can be accomplished with 100° of elbow flexion (30°/130°) and 100° of forearm rotation (50°/50°) [13] (figure 2). However, more recently, Sardelli et al. found that contemporary tasks like using a cell phone or keyboard requires more flexion (147°) and pronation (65°), respectively, than the degrees stated before[14]. Additionally, the influence of diminished elbow motion in patients with posttraumatic elbow stiffness on the quality of life has been evaluated. Patients that underwent open contracture release showed improved elbow motion and improved health status. However, the increase in health status was correlated to the reduction in pain, rather than the increase in motion[15, 16]. In the end, the disability one experiences from diminished range of motion will mainly depend on the activities (sports, occupational, etc.) required by some, whereas others will easily adjust to less motion.

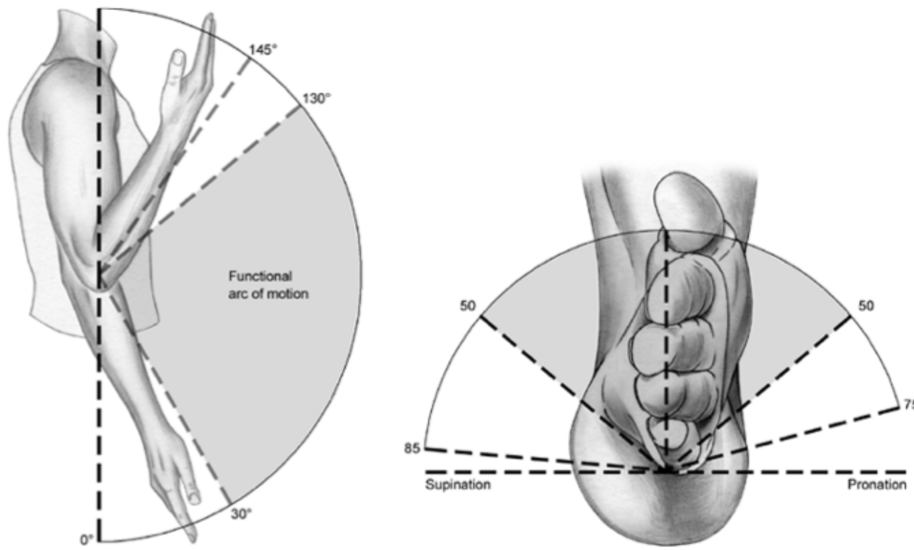


Figure 2: Functional range of motion; reproduced with permission of Wolters Kluwer from[17].

Stability

The elbow is one of the most congruous and therefore stable joints of the musculoskeletal system[18]. Elbow stability is provided by both static and dynamic constraints.

The dynamic constraints consist of the muscles across the elbow joint. By compressing the radiocapitellar and ulnohumeral joint surfaces against each other, the muscular forces across the elbow add stability to the joint[19]. The ability and relative contribution of these muscles to add stability is dependent on position of the forearm[19, 20]. The muscles that arise from the lateral aspect of the distal humerus (anconeus, brachioradialis, extensor carpi radialis, extensor carpi ulnaris and extensor digitorum communis) play a role in varus stability of the elbow by producing a valgus moment. On the other side, the muscles on the medial side (pronator teres, flexor carpi radialis, flexor carpi ulnaris and flexor digitorum superficialis) produce a varus moment and thus can resists valgus forces[19, 21].

The static constraints consist of osseous structures, joint capsule and the collateral ligaments. On the medial side, the Ulnar Collateral Ligament (UCL) or Medial Collateral Ligament (MCL) complex is divided into the anterior oblique ligament, the posterior oblique ligament and the transverse ligament. This anatomy is discussed below. The anterior bundle of the UCL is the primary constraint to valgus stress and internal rotatory forces[20, 22, 23]. The posterior ligament and transverse ligament have less influence on elbow stability. Morrey and An found that the UCL resisted approximately 30% of the valgus stress applied to the extended elbow, with the capsule and articular constraints being responsible for the remainder. However, when the elbow is flexed to 90°, the UCL resists almost 55% of the valgus forces to the elbow[24]. See table 2. On the lateral side the Lateral Collateral Ligament (LCL) complex is composed of the radial collateral ligament, annular ligament and lateral ulnar collateral ligament[25]. In general, the LCL is less important for elbow stability than the UCL. See table 3. The structures of the LCL resist varus stress and posterolateral rotatory forces[19, 26]. The principal clinical problem associated with LCL disruption is posterolateral subluxation or instability. Posterolateral instability is a condition in which the radial head dislocates posteriorly to the capitellum, together with subluxation of the ulna relative to the trochlea and without associated instability of the proximal radioulnar joint. Dunning et al. found that both the radial collateral ligament and lateral ulnar collateral ligament had to be transected to produce posterolateral instability. When the annular ligament is intact, either the radial collateral ligament or the lateral ulnar collateral ligament can be transected and the elbow will remain stable[27]. Morrey and An showed that the anterior capsule provides stability to varus and valgus stress and distraction of the extended elbow[24]. It is hypothesized that the posterior capsule resist flexion and posteriorly directed forces, although there is no literature supporting this assumption[19].

Table 2: Contribution to resist applied valgus stress (%)[24].

	Extended	90° Flexion
UCL	31	54
Soft tissue, capsule	38	10
Osseous, articulation	31	33

UCL = ulnar collateral ligament

Table 3: Contribution to resist applied varus stress (%)[24].

	Extended	90° Flexion
LCL	14	9
Soft tissue, capsule	32	13
Osseous, articulation	55	75

LCL = lateral collateral ligament

There are three main structures involved in the osseous articular stabilization of the elbow joint: the radiohumeral articulation, and the olecranon and coronoid in the ulnohumeral articulation. The radial head is an important secondary stabilizer of the elbow in resisting valgus force. When the distal radioulnar joint is compromised or the MCL has been disrupted, the radial head is critical to elbow function and stability[23]. See figure 3. The major stabilizer of the ulnohumeral joint is the coronoid. Both the flexor musculature and extensor musculature have a posteriorly directed component. Thus, the forearm has a tendency to displace posteriorly with elbow flexion or extension. This explains why the coronoid is crucial to resist posterior displacement[28]. Experiments by Closkey et al. indicated that a minimum of 50% of the coronoid is necessary for functional elbow stability[29]. The contribution of the olecranon to elbow stability has been examined by An and Morrey in biomechanical studies in which the humerus was axially loaded into the trochlear notch of the flexed elbow with internal-external rotation forces[30]. They found that elbow stability diminished in proportion to the amount of resection of the olecranon. Excision of the olecranon up to 50% would result in acceptable functional stability of the elbow according to the authors. O'Driscoll et al. pictured the static and dynamic constraints of the elbow as the defenses of a fortress with primary and secondary constraints[31] (figure 4). An elbow with its three primary constraints intact will be stable.

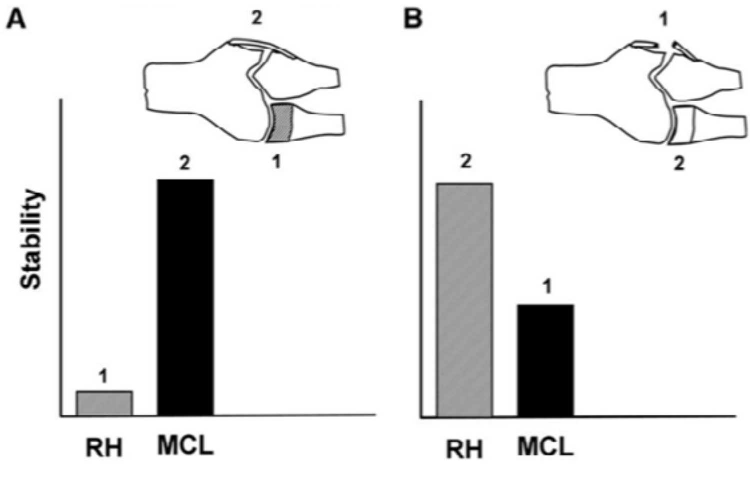


Figure 3: [A], Removing the radial head (RH) and placing the elbow in valgus when the MCL is intact results in relatively little displacement of the forearm. When the medial collateral ligament is then removed, marked instability is demonstrated. [B], On the other hand, when the sequence is altered and the medial collateral ligament is released, some valgus instability is noted. After this, removal of the radial head results in subluxation of the elbow. This defines the radial head as an important secondary stabilizer of the elbow to resist valgus stress. Reproduced with permission of Elsevier from[28].

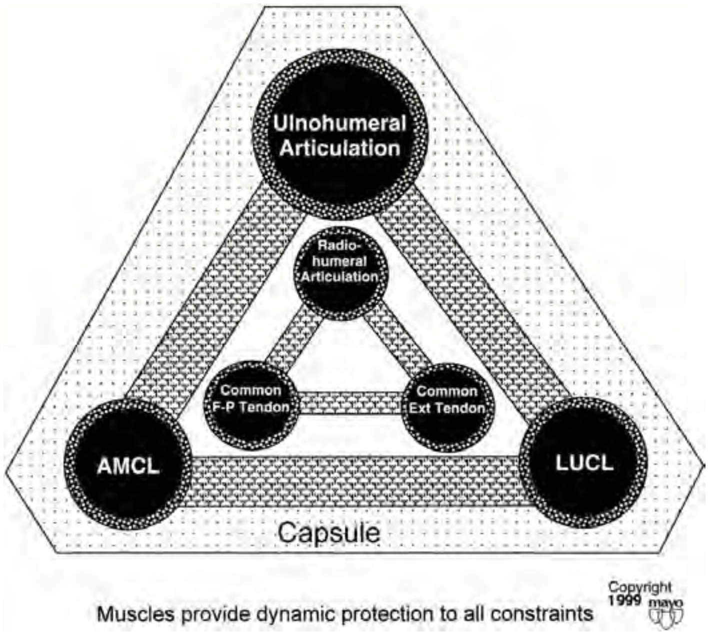


Figure 4: The static and dynamic constraints to instability can be considered analogous to the defenses of a fortress. The three primary static constraints are the anterior ligament of the MCL, the LCL and the ulnohumeral articulation, especially the coronoid process. The secondary constraints include the radial head, the common flexor and extensor origins and the capsule. Dynamic stabilizers included the muscles across the elbow joint. F-P = flexor-pronator. Reproduced with permission of the Mayo Foundation for Medical Education and Research from[31].

Strength

Based on motion in the sagittal plane, the elbow may be considered as a hinge joint. The major elbow muscles acting in the sagittal plane, and thus contributing to elbow flexion-extension, consist of biceps, brachialis, brachioradialis, triceps, and anconeus[2]. Although the upper limb is 'non-weight bearing', external forces may heavily load the elbow joint. In general, loads (at the hand) act at a large distance from the axis of rotation of the joint (elbow), and thus have a large lever arm. The major elbow muscles are set against these loads. However, since the muscles themselves are acting at small moment arms, they perform at a great mechanical disadvantage. Their tensions, therefore, must be scaled up in order to achieve equilibrium across the joint. As a result, the joint forces will be much larger than the external loads[8] (figure 5).
Since muscle strength is affected by the change in length of the muscle when it contracts, the maximum strength of a muscle can be seen within a specific range of muscle lengths[32]. Furthermore, the change in muscle length is related to the change in joint angle. Elbow flexion strength has therefore been investigated at various degrees of elbow flexion. The maximum isometric elbow flexion strength varies from 60°-90° of elbow flexion in the literature[32-34]. An explanation for these differences may be the different angles at which elbow strength was measured in the various studies. For elbow extension maximal strength

was seen at approximately 90° of flexion[32, 34]. Provins and Salter found that both flexion and extension strength depend on the position of the forearm, with a maximum strength in elbow flexion and extension with the forearm in neutral position[34]. Amis et al. have studied the effects of disease on flexion strength in patients with rheumatoid arthritis and found that flexion strength was reduced to approximately 45% of that of normal persons[35]. Other factors affecting reduced elbow strength include the nondominant side, older age and female gender[7, 8, 36].

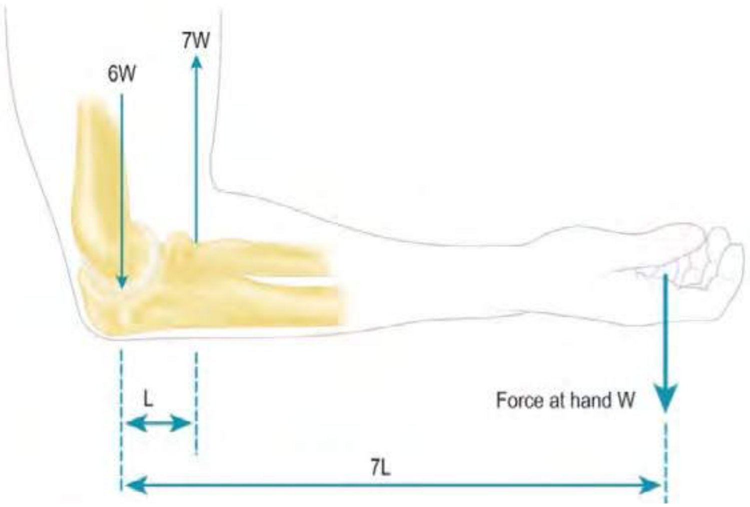


Figure 5: Simplified representation of elbow flexion, to show how the muscle tension must be a multiple of the load in the hand, resulting in most of the elbow joint force being caused by the muscle, not the load itself. Reproduced with permission of Elsevier from[8].

With regard to rotational strength, Salter and Darcus noted that the greatest supination strength is generated from the pronated position, whereas the greatest pronation strength is produced from supination (with the pronator muscles stretched)[37]. This association between forearm position and isometric torque developed for attempted pronation and supination showed a linear relationship. In the same study was showed that the strongest position for pronation and supination was with the elbow flexed to 90°. Moreover, the degree of elbow flexion had a more obvious effect on supination strength than on pronation strength, which may be explained by the fact that flexion of the elbow affects mostly the length of the supinator and biceps muscles rather than the pronator teres muscle[37].

Anatomy of the elbow

Bone

The elbow is composed of three bones: the humerus, the radius and the ulna. These bones articulate in three joints: the radiohumeral, the ulnohumeral and the proximal radio-ulnar joint (figure 6). The humerus diaphysis ends in a lateral and medial ridge, which forms more

distally the lateral and medial epicondyles. Between the ridges, the coronoid fossa on the anterior side of the distal humerus prevents impingement from the coronoid during flexion of the elbow. At about the same position on the posterior side, the olecranon fossa is formed to provide space for the olecranon during extension. The medial condyle forms the trochlea, which articulates with the olecranon of the ulna. The lateral condyle forms the capitellum, which is orientated anteriorly and articulates with the radial head. The radial head is a concave shaped disc which is angled 15° from the long axis of the radius by the radial neck. The circumferential surface of the radial head articulates with the lesser sigmoid notch of the ulna. About 280° of the circumference is therefore covered with cartilage. The lateral 80° of the radial head is part of the so-called 'safe zone' for the insertion of screws during surgery, that does not articulate with the lesser sigmoid notch[38] (figure 7). The radial head can be divided in four quarters: anterolateral, anteromedial, posterolateral and posteromedial, with the forearm in neutral position. It was noted that most fractures of the radial head occurred in the anterolateral quarter[39]. This anterolateral quarter has a decreased density and volume compared to the posteromedial quarter. It was hypothesized that this was the result of increased joint reactive forces of the posteromedial quarter with the lesser sigmoid notch, resulting in enhanced bone density that may prevent this part from fractures[40]. Although the safe zone allows for easy fixation of fractures of the anterolateral quarter, one should keep in mind that the bone quality of this part may be compromised.
The radial bicipital tuberosity is located about 23mm distal to the radiocapitellar joint line and serves as attachment side for the distal biceps tendon[41]. The proximal ulna consists of two processes, the olecranon and the coronoid, which forms the greater sigmoid (trochlear) notch and articulates with the distal humerus. While most of the surface of the greater sigmoid notch is covered with cartilage, there is an area in the center where the cartilage is thin or absent. This is a normal finding and should not be interpreted as osteochondral damage. The lateral side of the proximal ulna that articulates with the radial head is the lesser sigmoid (radial) notch.

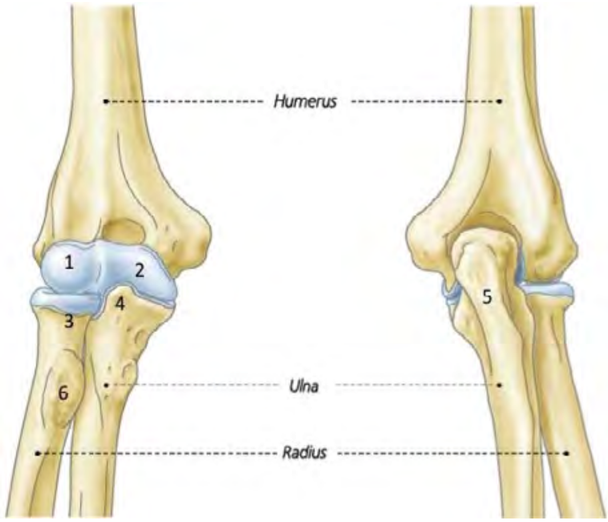


Figure 6: Bony anatomy of the elbow.

1 = capitellum;
2 = trochlea;
3 = radial head;
4 = coronoid;
5 = olecranon;
6 = radial bicipital tuberosity.

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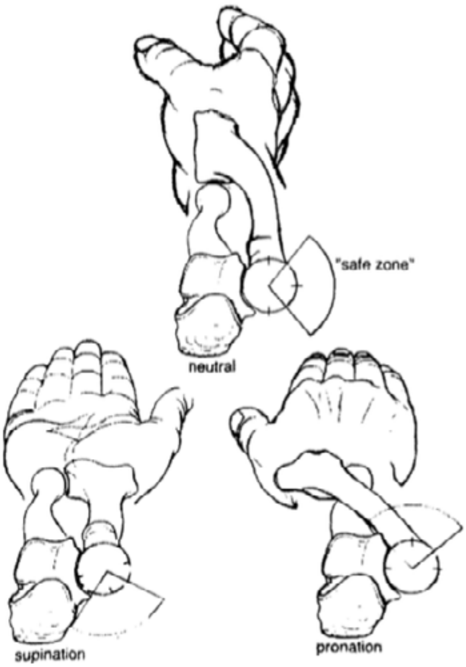

Figure 7: The 'safe zone' of the radial head allows for insertion of hardware without impingement with the lesser sigmoid notch of the ulna. Reproduced with permission of Elsevier from[38].

Capsule

The elbow joint is surrounded by a joint capsule, which attaches to the articular margins of the three joints. On the anterior side it includes the coronoid and the radial fossa, while posteriorly it includes the olecranon. On the sides the humeral epicondyles are located just outside the elbow capsule. On the medial and lateral sides, the capsule is thickened to form the LCL and UCL. The average volume of the elbow joint is about 25ml[18].

Ligaments

On the medial side of the elbow, the UCL is comprised of three bundles: anterior, posterior and transverse parts[25,43] (figure 8). The anterior bundle originates from the medial epicondyle and inserts distally from the sublime tubercle of the proximal ulna[44]. The posterior bundle is located between the medial epicondyle and the posteromedial olecranon. The transverse ligament connects the insertion points of the anterior and posterior bundles. The anterior bundle has been shown to be the primary restrained to valgus stress. The transverse ligament contributes little or nothing to elbow stability[25]. On the lateral side of the elbow, the LCL is comprised of three main bundles that may vary from person to person: radial collateral, lateral ulnar collateral and annular ligaments[24, 25, 45] (figure 9). The lateral ulnar collateral ligament originates from the lateral epicondyle and inserts onto the tubercle of the supinator crest. The radial collateral ligament is located between the lateral epicondyle and the annular ligament. The annular ligament encircles the radial head and insert on the anterior and posterior margins of the lesser sigmoid notch of the ulna. The annular ligament binds the radial head to the lesser sigmoid notch and stabilizes the proximal radioulnar joint. Although the lateral ulnar collateral ligament is considered to be the most important part of the LCL complex, it is not able to stabilize the elbow joint by itself[26]. Seki et al. therefore suggested that all three parts of the LCL play a role as a Y-shaped structure that stabilizes the elbow to varus and external rotationally forces[26].

Figure 8: Anatomy of the Ulnar Collateral Ligament Complex. Reproduced with permission of Elsevier from[45].

Figure 9: Anatomy of the Lateral Collateral Ligament Complex. Reproduced with permission of Elsevier from[45].

Muscles and tendons

The primary flexor muscles of the elbow are the brachialis, brachioradialis and biceps. The brachialis muscle has the largest cross-sectional area and consists of two heads: a superficial head and a deep head[46]. The origin is on the anterolateral aspect of the humerus and inserts on the anterior aspect of the ulna, just distal to the coronoid process. The larger superficial head has the mechanical advantage of a more proximal origin and more distal insertion, and may therefore provide the major portion of flexion strength[46]. The biceps also consists of two heads: the long head has an origin on the superior aspect of the glenoid and the short head on the corocoid process[41] (figure 10). Originally it was thought that the biceps distally inserted on the radial bicipital tuberosity (RBT) as one tendon. However, more recent studies described the distal part as two distinct tendons, that have both their own orientation on the RBT[41, 47-50] (figure 11). The short head of the distal biceps tendon is inserted more distally on the RBT than de long head and acts predominantly as a flexor of the elbow. The long head inserts at a point farthest away from the rotation of the radius and provides greater supination strength[51]. From proximal to distal, the biceps rotates about 90° externally[41, 50]. The distal biceps tendon has been divided into three zones, dependent on their vascular blood supply[52] (figure 12). As the middle zone is a transitional

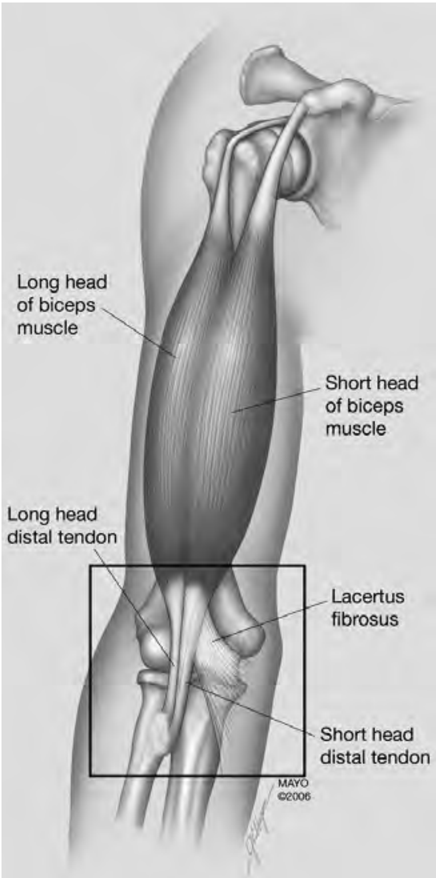

Figure 10: The biceps muscle consists both proximal, as well as distally, of two heads: the long head and short head. Reproduced with permission of Elsevier from[41].

area that receives its blood supply only by its paratenon cover, it is suggested that tendon repair mechanisms are limited and this zone is more prone to rupture[52]. The origin of the brachioradialis muscle is along the lateral supracondylar ridge and it inserts on the styloid process of the distal radius.

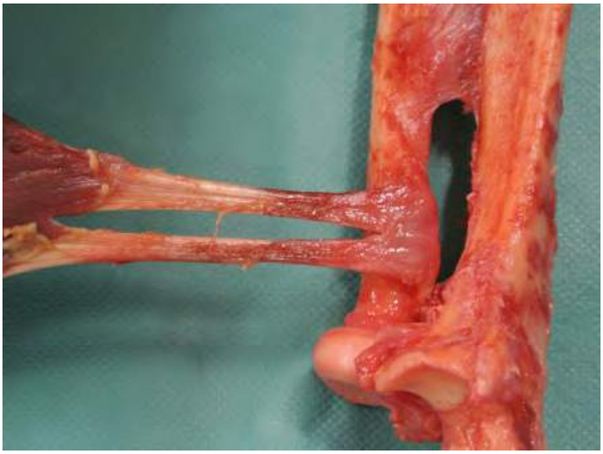

Figure 11: The distal biceps muscle consists of two distal tendons. Reproduced with permission of Springer from[51].

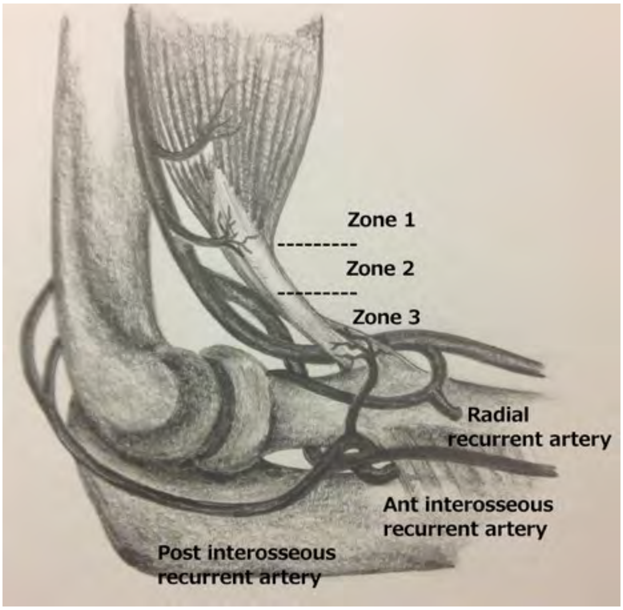

Figure 12: The arterial blood supply of the three zones of the distal biceps tendon. Reproduced with permission of Springer from[51].

The triceps and anconeus muscles are the primary extensors of the elbow. The triceps has three origins on the humerus: the lateral, long and medial heads. Distally the medial head has a separate insertion deep to the common insertion of the lateral and long heads on the olecranon[53]. The average width of the triceps at the insertion is about 35mm. A one-third strip of the medial or central part of the triceps has been shown to have failure strengths of 704 Newton, which is more than enough to serve as an autograft for ligament reconstructions[54]. The anconeus muscle is located from the lateral epicondyle to the superior ulna on the posterolateral side of the elbow.
The superficial flexors of the forearm all originate from the medial epicondyle, whereas the superficial forearm extensors originate from the lateral epicondyle.

Nerves
The most important nerves that cross the elbow are the median, radial and ulnar nerves. The median nerve lies medial to the biceps tendon and anterior to the brachialis muscle[8]. The radial nerve lies between the brachialis and brachioradialis muscles and bifurcates into posterior interosseous nerve (PIN) and superficial sensory radial nerve at the level of the cubital crease. The PIN pierces the supinator muscle in the proximal forearm, wrapping around the radius, just distal to the RBT[51]. The PIN is a motor nerve, innervating the extensor muscles of wrist and fingers. The nerve is at risk during distal biceps tendon surgery. The ulnar nerve passes the elbow subcutaneously, posterior to the medial epicondyle. The lateral antebrachial cutaneous nerve (LABCN) is a terminal branch of the musculocutaneous nerve that runs with the cephalic vein in the anterior aspect of the elbow and provides the sensibility of the lateral aspect of the forearm. Usually it lies on the deep fascia, lateral to the route of the distal biceps tendon[51].

Trauma and sports injuries of the elbow

Surgical procedures about the elbow of adults were historically predominately performed for inflammatory arthritis or traumatic conditions. With the introduction of modern therapeutic drug regimens for patients with inflammatory arthritis, the number of surgical procedure for this indication has declined last decades[55,56]. The indications for elbow surgery in adults are nowadays most frequently (post)traumatic conditions including sports injuries. Trauma to the elbow can result in fractures, dislocations, soft tissue injuries and combinations of these that may produce pain, dysfunction, instability, stiffness or arthritis in the long term. Fractures are usually the result of falls or traffic incidents, whereas soft tissue injuries are frequently seen following sports or overuse activities.
Common elbow injuries in adult athletes are epicondylitis, articular anterior or posterior impingement, ligamentous injuries or insufficiency, and tendon ruptures[57]. The most affected ligament in the elbow is the ulnar collateral ligament. The UCL is often ruptured after hypervalgus or hyperextension injuries, or after a posterolateral dislocation of the elbow. Chronic UCL insufficiency is seen in overhead throwing athletes[57]. Historically, an injury of the UCL was career ending for the professional sports player. The first description of

successful UCL reconstruction was from Jobe on major baseball pitcher Tommy John[58]. Since that publication in 1986, the anatomy, pathophysiology, (surgical) treatment and rehabilitation of UCL injuries became a very popular area of research. This is reasonable, as about 10% of the professional baseball players will get an UCL reconstruction during their career[59]. Over the years, many different reconstruction techniques have been developed, all with their pros and cons. However, the optimal surgical technique for UCL reconstruction is currently still subject to debate[60].

Rupture of the distal biceps tendon is rare in overhead throwing athletes, but more common in weightlifting, bodybuilding and contact sports[61, 62]. They are typically seen in middle-aged men who endure a sudden eccentric force on the flexed elbow. Epidemiologic studies revealed an incidence of distal biceps tendon ruptures of 1.2 – 5.4 per 100.000 persons per year[63, 64]. Theories about the pathophysiology are limited to observational studies and can be subdivided in two aspects: hypovascular / degenerative causes and mechanic causes[65]. It has been shown that nicotine abuse increases the risk on distal biceps tendon ruptures, possibly due to negative effects on the micro-vascularity of the tendon[64]. Drugs that are considered to impair tendon quality are steroids and statins, as those may influence collagen metabolism[66, 67]. More recently, also obesity has been identified as a risk factor to distal biceps tendon ruptures as the load on tendons are increased and the immune response on micro-traumata of the tendon may be decreased[63]. Seiler et al. in 1995, hypothesized about mechanical factors that may be involved in the pathophysiology of distal biceps tendon ruptures[52]. They found that the distal biceps tendon might impinge between the proximal radius and ulna. Moreover, it was shown that the space available for the biceps tendon decreases with pronation of the forearm[52]. Back in 1956, Davis and Yassine already supposed that hypertrophic changes of the radial bicipital tuberosity might predispose to impingement of the tendon[68]. In athletes, surgical reconstruction is favored as nonoperative treatment fails to restore flexion and supination strength[69, 70]. In classic textbooks the distal biceps tendon was described as a single homogenous tendon. However, more recent studies described the distal biceps as two distinct tendons inserting on the radial bicipital tuberosity[41, 48-50]. With these new insights in distal biceps tendon anatomy, also various reconstruction techniques (with new implants) were developed. In general four different reconstruction techniques are used to fixate the distal biceps tendon to the radial bicipital tuberosity: 1) suture anchors, 2) bone tunnels, 3) cortical buttons, and 4) interference screws. These fixation methods can be performed using a single anterior incision approach or a double incision approach. Currently, it is still unclear which fixation technique and which approach is superior.

Fractures about the elbow most commonly involve the radial head, and the radial head accounts for almost 4% of all fractures in humans[71]. Fractures of the radial head are common with an incidence of 25-55 per 100.000 persons per year[72, 73], and are frequently categorized according to the Mason classification. Mason type-1 fractures are nondisplaced fractures of the radial head, Mason type-2 fractures are displaced and Mason type-3 are comminuted fractures[74] (figure 13). The trauma mechanism leading to a radial head fracture is usually of a fall on the outstretched hand with the elbow partially flexed and pronated[75]. The distal humerus and proximal ulna are less frequently fractured in elbow trauma. A fracture of the distal humerus or proximal ulna usually requires surgical management with open reduction and internal fixation of the fracture or arthroplasty in the case of severely comminuted distal humerus fractures. The management of radial head fractures on the contrary remains open to debate. Whereas Mark Mason in his keynote paper[74] about radial head fractures in 1954 stated 'in doubt – resect', the radial head was later on increasingly recognized for its stabilizing function and therefore repaired or replaced. In addition to this stabilizing function, it was found that fractures of the radial head are frequently associated with other injuries to the ipsilateral arm[76-78]. In order to maximize elbow stability, surgical management (reconstruction or replacement) of the fractured radial head (with or without ligaments repair) has been promoted. However, the superiority of operative management has also been questioned as it has been shown to lead to complications and similar results compared to nonoperative treatment for partial articular fractures of the radial head[79]. Currently, there is consensus that the management of nondisplaced radial head fractures should be nonoperative, but the management of displaced and comminuted fractures remains unclear, as RCT's and long-term follow-up studies are unavailable. Especially the long-term results of radial head arthroplasty have been insufficiently reported, as compared to arthroplasty of for instance the hip or knee joint. Currently, many different kinds of radial head prosthesis are available for implantation. Radial head prostheses may be categorized according to material (silicone, polyethylene, pyrocarbon, metal), modularity (monoblock vs. modular), fixation technique (cemented, uncemented press fit, intentional loose fit or fixation with an expandable stem), or polarity (uni- or monopolar vs. bipolar). The bipolar articulation theoretically allows for free rotation and therefore reduced abrasion of the capitellar cartilage, reduced stress at the implant-cement and cement-bone interfaces, and may accommodate to some degree if there is any question about the alignment of the radius on the capitellum. However, up-to-date there is no clinical data supporting one design over the other.

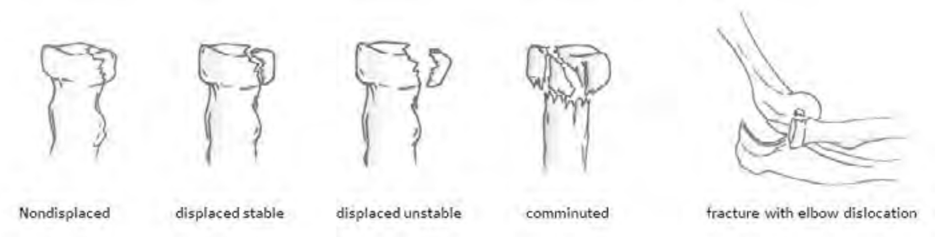

Figure 13: Radial head fractures can be classified into nondisplaced, displaced, comminuted and a fracture in combination with elbow dislocation.

Aim and Outline of the Thesis

The general aim of this thesis is to evaluate contemporary knowledge on the pathophysiology and treatment of common traumatic elbow conditions. The thesis is structured in four parts; **part I** is a general introduction, **part II** focusses on sports related injuries and **part III** deals with traumatic injuries. **Part IV** is the general discussion, summary and overall conclusion of this thesis.

Part I

The elbow is one of the most complex joints in the human body. A basic understanding of elbow anatomy, biomechanics and function is essential to appreciate factors that may contribute to the pathophysiology of elbow injuries and the successful treatment of sports related or posttraumatic conditions. In the current chapter, **chapter 1**, elbow anatomy and function are discussed and an introduction to the subject of this thesis is given.

Part II

This part focuses on rupture of the distal biceps tendon and the UCL, as the optimal surgical treatment of these potentially career-ending injuries remains unclear. One of the aspects that are considered to play a role in the pathophysiology of distal biceps tendon ruptures is impingement of the tendon between the proximal radius and ulna during forearm pronation. Additionally, the space available for the distal biceps tendon may be diminished by hypertrophic changes of the radial bicipital tuberosity (RBT). Although the size of the ridge of the radial bicipital tuberosity varies between individuals, the theoretical involvements of mechanical factors have never been evaluated. In **chapter 2**, we evaluated whether or not the size of the RBT was different between patients with and without a rupture of the distal biceps tendon. Active patients with a rupture of the distal biceps tendon are presumably better off with a reconstruction[69]. There are four different techniques for anatomic repair of the distal biceps tendon. Chavan et al. in 2008 evaluated and found no significant clinical difference between the different reconstruction techniques in a systematic review. A biomechanical comparison showed the highest load and stiffness for cortical button reconstructions[80-82]. However, the cortical button was only used in one clinical study with only 10 patients by that time[82, 83]. The clinical results of the cortical button reconstruction technique were therefore examined in **chapter 3**. From the time when the systematic review by Chavan et al. was published, the results of many other clinical studies about distal biceps tendon reconstructions have been reported. In addition, a new approach for distal biceps tendon repairs had been described in the meantime[84]. As clinical results are considered more leading in clinical practice when compared to biomechanical studies, we performed a systematic review of the recent literature in **chapter 4.** Some of the fixation techniques (bone tunnels, interference screws, cortical buttons) that are commonly used for distal biceps tendon reconstruction are also effective in surgical repair of UCL lesions. However, it is unclear whether for UCL reconstruction one implant is superior to the other[85]. Also, the origin and insertion anatomy is different than for distal biceps repair, and a graft is necessary for UCL reconstruction. Most studies on the clinical outcome were from centers in the USA, and it is unclear if the same results apply for European athletes. The purpose of **chapter 5** was therefore to describe the long-term results of a new reconstruction technique of the UCL in European athletes with a triceps fascia autograft and interference screw technique fixation.

Part III

This part focuses on radial head fractures, a frequently encountered fracture. The evaluation and management of these fractures remains indefinite. Epidemiological studies revealed a higher age of females with a radial head fracture compared with males[73]. It is suggested that the radial head fracture is therefore a potentially osteoporotic fracture[86]. Although radial head fractures are commonly seen as isolated injuries, associated fractures or ligamentous injuries have a high prevalence[76, 87]. It is undecided whether the mechanism of injury is of influence on the risk on associated injuries. The purpose of **chapter 6** was to define whether mechanism of injury and patient related factors were of influence on (Mason) type of radial head fracture and associated injuries. The treatment of Mason type-1 fractures is nonoperative with early mobilization of the elbow. The treatment of Mason type-2 fractures is subject to debate. Long-term results for both nonoperative and surgical treatment are comparable in case series and reviews. However, there is no high-level of evidence supporting one treatment over the other. **Chapter 7** is the protocol of a randomized controlled trial in which open reduction and internal fixation (ORIF) with screws will be compared with nonoperative management for stable partial articular fractures of the radial head.

The treatment of Mason type-3 fractures is also variable. David Ring suggested treating comminuted fractures with 3 or less fragments with ORIF and more comminuted fractures with radial head arthroplasty[88]. Radial head prosthesis allow for restoration of elbow stability and may function as a spacer that supports healing of associated ligamentous injuries[89]. Long term results are however, not available for most implants. The purpose of **chapter 8** was to evaluate the results of the press-fit bipolar radial prosthesis, which was introduced on the market more recently. The cemented version of the bipolar prosthesis is available for a longer time. Although the survival of this implant has been reported in previous articles, it is unknown whether the theoretical advantages of the bipolar head also exist in clinical practice. In **chapter 9** we therefore evaluated the cemented radial head prosthesis according to the before mentioned aspects. In order to compare the results of the different types of implants we performed in **chapter 10** a systematic review of the literature on the fixation of radial head arthroplasty.

Part IV

In **chapter 11**, all previous chapters are put into perspective in a general discussion and a summary in the English and Dutch language in **chapter 12**.

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SPORTS RELATED INJURIES

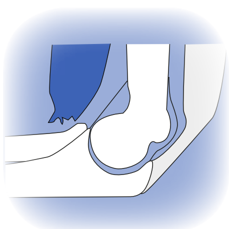
II


12

Chapter 2

The size of the radial tuberosity is not related to the occurrence of distal biceps tendon ruptures: a case-control study

Izaäk F. Kodde; Michel P.J. van den Bekerom; Paul G.H. Mulder; Denise Eygendaal



Open Orthop J. 2016 Feb;10:1-6.

Abstract

Introduction: Hypertrophic changes at the radial biciptal tuberosity (RBT) have traditionally been related to distal biceps tendon degeneration and rupture. From supination to pronation of the forearm, the space available for the distal biceps tendon between de lateral ulna and radial bicipital tuberosity decreases by almost 50%. A hypertrophic change at the radial tuberosity further reduces this space with impingement of the distal biceps tendon as a result. The purpose of this study was to evaluate whether the size of the RBT plays a role in the pathophysiology of distal biceps tendon ruptures.

Materials and Methods: Twenty-two consecutive patients with a surgically proven distal biceps tendon rupture were matched to controls, in a 1:1 ratio. The size of the RBT was expressed as a ratio of the maximum diameter of the radius at the RBT to the diameter of the diaphysis just distal to the RBT (RD ratio), measured on standard radiographs of the elbow. The RD ratio of patients and matched controls were compared.

Results: The mean RD ratio in control group was 1.25 and not significantly different from the mean 1.30 in the group of patients with a distal biceps tendon rupture. Each 0.1 point increase in RD ratio results in an estimated 60% increase of the rupture odds, which was not significant either.

Conclusions: Based on the RD ratio on conventional radiographs of the elbow, there was no significant difference in RBT size between patients with a distal biceps tendon rupture and matched controls without biceps tendon pathology.

Keywords: anatomy; distal biceps tendon; elbow; pathophysiology, radial bicipital tuberosity; rupture.

Introduction

Distal biceps tendon ruptures are most commonly seen in the dominant elbow of men who are in the fourth decade of life[1]. Abuse of tobacco and steroids and the use of statins are associated with an increased risk on rupturing the biceps tendon[2, 3]. Ruptures of the distal biceps tendon have also been described in athletes[4, 5].
In 1956, Davis and Yassine proposed that hypertrophic changes of the radial tuberosity decreased the available space between the lateral ulna and Radial Bicipital Tuberosity (RBT), causing irritation of the tendon, predisposing it to degenerative changes and finally rupture[6]. In 1995, Seiler et al. did some basic anatomical studies to evaluate potential mechanisms involved in the rupturing process. They found a hypovascular zone in the distal biceps tendon near its insertion at the RBT. Furthermore, they recognized that the space available for the distal biceps tendon between the lateral ulna and RBT decreased by almost 50% from supination to pronation of the forearm[7]. However, this assumption was not supported with clinical data.
With recent developments in distal biceps tendon reconstructions, there is also an increasing interest in surgical anatomy of the distal biceps tendon. In 2007 Mazzocca et al. identified different tuberosity ridge types (single, smooth or bifid)[8]. The distal biceps tendon is recently described as two distinct tendons with their own functional roles. Moreover, anatomical studies have revealed the insertional footprint anatomy on the RBT, the orientation of the distal biceps tendons to their insertion site and the anatomy of the lacertus fibrosis[9-14]. Although these studies provide potential causative factors that might contribute to the rupturing process, most of these recent studies were primarily performed to facilitate a more anatomical reconstruction in reinsertion procedures.
Despite these recent anatomic and biomechanical studies, the definitive cause of tears has yet to be delineated; and Seilers' theory continue to be cited most frequently in the literature as the cause of rupture. However, no clinical data have ever supported the role of a hypertrophic radial tuberosity in the pathophysiology of distal biceps tendon ruptures. The purpose of this matched control study was to evaluate whether the size of the RBT, measured on standard radiographs of the elbow, plays a role in the pathophysiology of distal biceps tendon ruptures. Our hypothesis was that patients with a larger RBT endure more impingement of the distal biceps tendon between ulna and RBT during pronation and are therefore more at risk for rupturing the distal biceps tendon.

Materials and methods

Between November 2007 and November 2010, 22 consecutive patients with 24 distal biceps tendon ruptures underwent surgical repair. Two patients had bilateral ruptures, of which only the first occurring rupture was included in the study. All patients had a surgical refixation using a single incision technique with cortical button fixation. All operations were performed by or under supervision of the senior author. The medical records were reviewed to identify baseline characteristics and known predictors for a distal biceps tendon rupture (age, gender, nicotine abuse). This study was reviewed and approved by the institutional review board.

Standard radiographs were made just after trauma according to local protocol. The patient was seated close to the radiographic table with the entire arm in the same horizontal plane. The arm was fully supinated and the elbow extended for the anteriorposterior (AP) view. If necessary, the patient was asked to lean laterally in order to enable the elbow to be in a true AP position. The long axis of the forearm was aligned to the long axis of the image receptor, and the central ray was directed to the middle of the elbow. The RBT was independently determined at standardized AP view by two of the authors. The size of the RBT was expressed as a ratio of the maximum diameter of the radius at the RBT to the diameter of the diaphysis just distal to the RBT (RD ratio). A mean RD ratio was calculated from the measurements of the two researchers. See figure 1.

Each patient with a distal biceps tendon rupture was matched to a control patient, with a radial head fracture, without distal biceps tendon pathology, in a 1:1 ratio. Radiographs of the control patients were made according to the same local protocols. Subjects were matched by age, gender and nicotine abuse. The control group was retrieved from a database with 450 patients that sustained a radial head fracture for which they received treatment in the same hospital. The final case-control sample consisted of 22 matched pairs.

Figure 1: Example of calculation of RBT – Diaphysis ratio.

Statistical analysis

Differences between cases and controls were analyzed using the paired t-test for continuous variables and McNemar's test for dichotomous variables. A dose-effect relationship between the RD ratio and distal biceps tendon rupture (yes/no) while taking account of the 1:1 matching was analyzed using a conditional logistic regression model stratified by case-control pair. Statistical analyses were performed using SPSS (version 16.0). A p-value smaller than 0.05 was considered significant.

Results

Baseline characteristics of patients with a distal biceps tendon rupture and controls are summarized in table 1.

Table 1: Baseline characteristics of patients with a distal biceps tendon rupture and controls.

	Distal biceps tendon rupture (N=22)	Controls (N=22)	Significance (p-value)
Age (years) [sd]	45.7 [9.38]	45.1 [8.26]	0.23
Gender (% male)	95	95	1.00
Nicotine (% users)	18*	41*	0.34
RDR [sd]	1.30 [0.10]	1.25 [0.07]	0.15

* N=17; RDR = radial bicipital tuberosity to diaphysis ratio.

Distal biceps tendon rupture group

The mean age at time of rupturing the biceps tendon was 46 years old (range 18 – 59); distribution is shown in figure 2. Of the 22 patients, 5 patients (23%) were smokers. The dominant arm was involved in 56.5% of the cases. The mean RD ratio in this group was 1.30 (range 1.15 – 1.57).

Control (radial head fracture) group

The 22 controls had a mean age of 45 years old (range 24 – 60). Seven patients (32%) were smokers.

The mean RD ratio in control group was 1.25 (range 1.09 – 1.35) and not significantly different from the mean 1.30 in the group of patients with a distal biceps tendon rupture (p = 0.15). The dose-effect relationship as estimated using conditional logistic regression analysis is expressed by means of an odds ratio per 0.1 point increase in RD ratio. The rupture odds is defined as the ratio of the probability of rupture to the probability of no-rupture. Each 0.1 point increase in RD ratio results in an estimated 60% increase of the rupture odds, which is not significant (95 % CI: from a 16 % decrease to a 204 % increase; p = 0.15).

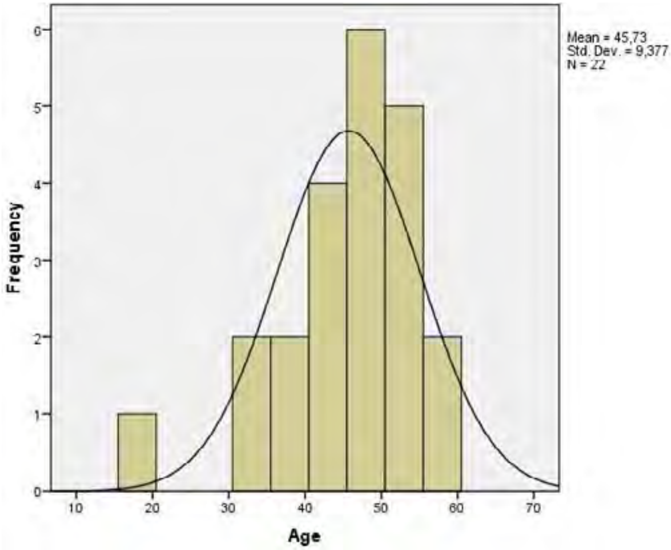


Figure 2: Age distribution of patients with a distal biceps tendon rupture.

Discussion

The pathophysiology of distal biceps tendon ruptures is subject of an ongoing debate for the last decades. Epidemiological studies identified some potential chemical risk factors for distal biceps tendon ruptures, including abuse of nicotine, steroids and statins[1-3]. Hypertrophic changes at the radial tuberosity have traditionally been related to distal biceps tendon degeneration and rupture[6]. No clinical or radiographic data have ever supported this theory. Davis and Yassine described enlarged and irregular margins of the radials tuberosity on conventional radiographs of their patients. However, to our knowledge, no standard methods to measure the RBT on radiographs had been described.

To determine the RBT we have introduced the RD ratio. The RD ratio is easily calculated from standard elbow radiographs in a standardized way, the outcome is unrelated to magnification; so calibrated radiographs are not necessary. Previous research on the RBT was from cadavers or CT-scans of the elbow. The RD ration is a parameter that may be useful in daily clinical practice. It may be included in a risk calculation for distal biceps tendon rupture in for instance body-builders together with other known risk factors (male, smoking, steroids, etc.). The radial tuberosity may also be reduced during distal biceps tendon surgery in order to minimize the risk on a re-rupture. Although radiographs provide some information on the size of the RBT, it does not give fully accurate three-dimensional and volume data of the tuberosity. However, the traditional idea that enlarged margins of the RBT caused impingement of the distal biceps tendon was based on a paper from 1956, with no CT-scans available.

Seiler et al. reported in 1995 on two possible mechanisms involved in the rupturing process of the distal biceps tendon; a hypovascular zone and impingement of the tendon[7]. Since their original report, numerous other studies has been performed that provided more insight in the anatomy of the distal biceps tendon and it's insertion on the RBT. Eames et al. presented a clear anatomical study on the lacertus fibrosis[13]. They showed that the lacertus fibrosis is a fixed-length structure, which comprises the forearm flexor muscles. As these muscles contract, the cross-sectional area increases and it tenses the aponeurosis, thereby pulling the distal biceps tendon medially. This force on the distal biceps tendon might play a role in the rupturing process. Additionally, it could also increase the potential impingement of the tendon between the RBT and the ulna. Although these studies provide important knowledge and theories on the distal biceps tendon anatomy and pathophysiology, no comparison of the patient related anatomy was performed. Recently, Krueger et al. evaluated the amount of radioulnar space available for the distal biceps tendon following four different fixation techniques for distal biceps tendon repair on fresh-frozen cadavers[15]. They hypothesized that differences in space could increase the risk of impingement after repair. Next to the rotation of the forearm (pronation-supination), the amount of space available was dependent on the type of reconstruction. Although the authors suggested that reduced radioulnar space or impingement might be a reason for failure of biceps tendon repair, there is no clinical evidence that supports this theory.

The assumed role of hypertrophic changes at the radial tuberosity causing distal biceps tendon pathology in the past could not be verified in this study. Although it is hypothesized that the size of the RBT affects the distal biceps tendon, it is also possible that the shape of the RBT is influenced by the function of the biceps tendon. Previously in 1892, Julius Wolff introduced 'the law of bone transformation', in which he stated that the every change in the function of a bone is followed by changes in architecture of the bone according to mathematical laws[16]. In other words, compression and tension forces produced by the distal biceps might influence the surface of the RBT. Overload of the biceps could lead to microtraumata in the tendon itself, but also lead to the proposed enlargement of the RBT, resulting in impingement of the tendon and even more microtraumata.

The current study was limited by the fact that the groups of cases and controls might have been too small. Using the standard error based on 22 case-control pairs of the estimated log odds ratio from this study it can be calculated that the number of case-control pairs needed to detect a rupture odds ratio of 1.6 per 0.1 unit increase in RD ratio with 80% power would equal 87, given a two-sided test size of 0.05. With 115 case-control pairs a 90% power would be reached. Secondly, conventional radiographs do not provide adequate information to calculate volumes. Also, this is a retrospective study that does not take into account all possible confounders. Ideally, it would be a prospective study in which patients with a distal biceps tendon rupture have a MRI or CT-scan with three-dimensional reconstructions to evaluate the space between RBT and ulna in a pronated position of the forearm.

In conclusion, there was no significant difference in RBT size between patients with a distal biceps tendon rupture and matched controls without a rupture, based on conventional radiographs of the elbow. Although there have been a lot of studies on distal biceps tendon anatomy last decades, the pathophysiology of the rupturing process remains unclear.

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BARCLAYS

Chapter 3

Reconstruction of distal biceps tendon ruptures with a cortical button.

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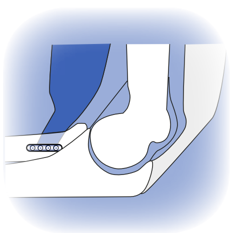

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Abstract

Purpose: Reconstruction of the ruptured distal biceps tendon is best done with a cortical button technique according to recent biomechanical studies. However, clinical outcome studies that evaluate the cortical button reconstruction technique are scarce. The purpose of this study was to evaluate the results of a cortical button reconstruction technique in patients with a traumatic distal biceps tendon rupture.

Methods: Twenty-two patients with 24 traumatic distal biceps tendon ruptures underwent surgical treatment. Reconstructions were done using the Endobutton or Toggle Loc. Postoperative evaluation consisted of ROM, strength, stability, neurological status and standard radiographs in AP view and lateral direction. The Mayo Elbow Performance Score (MEPS) and quick Disabilities of Arm, Shoulder and Hand (qDASH) questionnaires were also obtained.

Results: At a median follow-up of 22 months the mean strength for flexion was 100% (SD 21.3) and for supination 97% (SD 7.8), compared to the contralateral side. There were complications in 8 patients (36%) and heterotopic ossifications were seen on radiographs in 23% of patients. Heterotopic ossifications were symptomatic in one patient.

Conclusions: The results after distal biceps tendon refixation with a cortical button were good according to ROM, MEPI and qDASH scores, and strength. However, this procedure was accompanied with complications; in particular the formation of heterotopic ossifications was frequently seen, though clinically relevant in only one patient.

Keywords: complications; cortical button; distal biceps tendon; elbow; heterotopic ossifications; rupture.

Introduction

The incidence of distal biceps tendon ruptures is estimated at 1.2 per 100,000 persons per year[1]. Ruptures are most commonly seen in the dominant elbow of men who are in the fourth decade of life. Abuse of tobacco and steroids and the use of statins are associated with an increased risk on distal biceps tendon ruptures[1-3]. Since non-operative treatment of distal biceps tendon ruptures leads to a functional loss, reconstruction is favoured in most age groups[4, 5]. The surgical treatment of distal biceps tendon ruptures has evolved from transosseous suture repair[6, 7] towards techniques using suture anchors[7, 8], interference screws[9], or a cortical button[10]. The cortical button technique has been shown superior in biomechanical studies[11-13]. Moreover Chavan et al. performed a systematic review and concluded that a cortical button using a single incision approach is currently the preferred surgical technique[14]. However, clinical outcome studies that evaluate the cortical button reconstruction technique are scarce.

The purpose of this study was to evaluate the results of a cortical button reconstruction technique in patients with a traumatic distal biceps tendon rupture. The hypothesis was that reconstruction with a cortical button would result in good elbow function with normal strength.

Materials and methods

Between 2007 and 2010, 22 patients with 24 traumatic distal biceps tendon ruptures underwent surgical refixation. Inclusion criteria for this study were: distal biceps tendon insufficiency based on total or subtotal traumatic rupture and age between 18-65 years. Exclusion criteria for reconstruction were: poor patient compliance and upper extremity paralysis.

The median age at time of injury was 49 (range 18–59) years and the dominant arm was involved in 55% of the patients. There were 21 men and one woman and 25% abused nicotine. Because of delayed referral to our clinic, reconstruction was performed after a median 8 (range 1–108) weeks following trauma. A single incision technique with a cortical button for refixation was used in all cases. Before May 2009 the repair was done using the Endobutton (Smith & Nephew Inc., Andover, MA, USA)[10] and thereafter the repairs were performed using the Toggle Loc (Biomet, Warsaw, IN, USA)[15]. In two patients (8 and 43 weeks after trauma), the distal biceps tendon stump was retracted for more than 7cm, which made it necessary to use a fascia lata allograft interposition. This study was reviewed and approved by the institutional review board.

The diagnosis was based on history and physical examination consisting of range of motion (ROM) assessment, assessment of stability and performing the 'hook test'[16]. A MRI was performed in 58% of the cases and an ultrasound evaluation was done in 25%. In the other cases the clinical signs and symptoms were such that additional imaging was not necessary. Radiographs (anterior-posterior (AP) and lateral) of the affected elbow were obtained before surgery. All procedures included in this study were performed or supervised by the senior author.

All patients were postoperatively evaluated in a standardized prospective way at 8 weeks, 6 months, 1, 2, 3 and 4 years. Evaluation consisted of ROM, strength, stability, neurological status and standard radiographs in AP view and lateral direction. The Mayo Elbow Performance Score (MEPS) and quick Disabilities of Arm, Shoulder and Hand (qDASH) questionnaires were also obtained. During the last evaluation, the strength of the biceps tendon was determined by one of the authors using a Hand Held Dynamometry (Hoggan Health Industries Inc., West Jordan, UT, USA). Strength was measured with the shoulder in 45° forward flexion and the elbow in 90° flexion. Flexion strength was measured with the forearm in full supination and supination strength was measured with the forearm in neutral position. The arm was fixed to prevent shoulder movement and the peak force during flexion and supination was measured 3 times to calculate a mean for both arms. The mean peak forces for both arms were compared and results were expressed as a percentage of the uninjured side. Six patients were unable to return for a final clinical assessment and they completed the outcomes questionnaires by telephone. All six patients who were unable to revisit for strength measurements had prior postoperative elbow function assessments and radiographs made. AP and lateral radiographs were assessed for fractures surrounding the radial tunnel, heterotopic ossifications (HO) and position of the cortical button.

Surgical Technique

The patient was placed in supine position with the arm on a surgical hand table. The arm was routinely prepared and draped from shoulder to hand and a sterile tourniquet was applied. A longitudinal incision was made 1-cm distal of the elbow skin crease to distal. If the tendon was retracted too much, a second small, more proximal, incision over the end of the tendon was made. If the quality of the tendon was very poor, an augmentation with a fascia lata allograft was performed. The lateral antebrachial cutaneous nerve was identified and protected. Blunt dissection onto the proximal radius was done with protection of the radial nerve. With the elbow in full extension and supination, the radial bicipital tuberosity was exposed. Debridement of the footprint and the end of the tendon was performed. In case of subtotal ruptures, the tear was completed to a total rupture to allow adequate refixation of the whole tendon. With the arm in full supination, a guide wire was drilled into the anatomic insertion location of the biceps tendon, aiming just slightly distal and ulnarly to angle away from the posterior interosseous nerve. A 4.5-mm cannulated drill was advanced over the guide wire, through the posterior cortex. The anterior cortex was drilled based on the size of the tendon (usually 8-mm). Fixation of the cortical button on the distal biceps tendon was done with an orthocord suture (DePuy Orthopaedics Inc., Warsaw, IN, USA). The cortical button was pulled through the radius using a Beath pin to pass the sutures. The cortical button was engaged to the posterior cortex and locked into place. The fixation was tested and intraoperative fluoroscopy was used to confirm the correct the position of the cortical button. The passing sutures were removed.

Rehabilitation protocol

Postoperatively, a long arm cast was applied for one week. An oral NSAID (meloxicam) was routinely prescribed for one week. After one week physical therapy was started. Both passive and active ROM exercises were allowed. Patients were advised to prevent flexion against resistance for the first three months. After three months patients were allowed to resume normal activities, as prior to the biceps tendon injury.

Statistical analysis

Statistical analysis (SPSS 20.0 IBM Corporation, Armonk, NY, USA) was performed using the paired T-test, sign test and Wilcoxon signed ranks test to compare preoperative and postoperative changes in numerical data. Changes in time in categorical data were analyzed using the McNemar's test. The independent T-test and the Mann-Whitney U test were used to compare numerical data between groups of patients and the Fisher's exact test and Chi-squared test for categorical data. In order to provide mutual independency between cases, only one of the cases with bilateral reconstructions was included in analyzes between groups. Because of multiple testing a P-value below 0.01 per test was considered to denote significance.

Results

Of the 22 patients included in this study, two patients were lost to follow-up and excluded from further analysis. The median follow-up was 22 (range 10–48) months. The rupture of the distal biceps tendon was complete in 15 patients. A comparison between complete and subtotal ruptures showed a significant longer time between trauma and reconstruction for subtotal ruptures (P= 0.002). Mean postoperative flexion was 135° (range 130–140; SD 5.0), extension 0° (range -10 to 5), supination 76° (range 60–90) and pronation 79° (range 60–90). The mean strength for flexion was 100% (SD 21.3) and for supination 97% (SD 7.8), compared to the contralateral side. The non-dominant elbow was reconstructed in 7 patients with mean flexion strength of 98% (SD 19.4) and supination strength of 101% (SD 5.7) compared to the uninjured side. The dominant elbow was reconstructed in 8 patients with mean flexion strength of 101% (SD 24.1) and supination strength of 93% (SD 7.7) compared to the uninjured side.

Bilateral distal biceps tendon reconstructions were performed in two patients. Both were 49 years old and one abused nicotine. We were not aware of steroid use by any of the included patients. The first patient had bilateral reconstructions with an Endobutton and worse outcomes of the non-dominant arm because of entrapment of the lateral antebrachial cutaneous nerve. The second patient had bilateral repairs with a Toggle Loc and subjective equal outcomes for both arms. Only one elbow per patient was included in comparative tests between groups of patients.

The follow-up after refixation with an Endobutton was significant longer than follow-up after refixation with a Toggle Loc (P= 0.005). In table 1 were patients with an Endobutton compared to patient with a Toggle Loc. At latest follow-up the mean MEPS was 94 (range

50–100) and qDASH score 10 (range 0–52). In three patients a second more proximal incision was used to mobilize the retracted tendon. There were no significant differences in ROM, strength, MEPS, qDASH score and complications between groups of patients with one versus two incisions.

Table 1: Comparison of patients with a reconstruction done with a Toggle Loc versus Endobutton.

	Toggle Loc N=13 (SD)	Endobutton N=7 (SD)	P-value
Baseline characteristics			
Age (years)	43 (10.7)	50 (5.8)	n.s.
Gender (% male)	92%	100%	n.s.
Complete rupture (%)	77%	71%	n.s.
ROM (flexionarc, degrees)	136 (7.7)	136 (4.8)	n.s.
Time from injury to operation (weeks)	44 (41.4)	26 (38.5)	n.s.
Outcome measures			
ROM (flexionarc, degrees)	135 (6.2)	134 (7.5)	n.s.
Flexion strength (%)	101 (11.0)	104 (28.7)	n.s.
Supination strength (%)	95 (7.6)	98 (8.3)	n.s.
HO (N)	1	4	n.s.
MEPS	91 (17.9)	98 (5.7)	n.s.
qDASH	12 (19.1)	4 (7.8)	n.s.
Follow up (months)	19 (7.5)	37 (12.1)	0.005

HO: heterotopic ossifications; n.s.: not significant; ROM: range of motion; SD: standard deviation.

No postoperative wound problems or infectious complications were observed. The most frequent complication was a dysfunction of the posterior interosseous nerve (2 patients, 9%) which was transient in both patients. Other complications consisted of a symptomatic partial re-rupture of the distal biceps tendon (1 patient) which was treated conservatively with a temporary splint, awareness of the cortical button (1 patient) which resolved after the button was removed, entrapment of the lateral antebrachial cutaneous nerve (1 patient) which resolved after neurolysis, crepitus from HO (1 patient) (see figure 1), irritation from the fixation sutures of an allograft (1 patient), and one patient had an elongated biceps tendon which required a reconstruction. Only the latter three patients had persistent complaints, whereas the other complications resolved (after treatment). There were 5 patients (23%) with radiographic signs of HO around the insertion area after average 2 years. All 5 patients had a flexion arc of >125°. The HO was minimal in four patients, but as mentioned above, resulted in crepitus in one other patient. The position of the Endobutton or Toggle Loc was good in all patients. There were no signs of fractures around the bone tunnels.

Figure 1: Extensive HO formation after distal biceps tendon reconstruction.

Discussion

The most important finding of present study was that distal biceps tendon reconstructions with a cortical button, either Endobutton or Toggle Loc, result in good postoperative ROM, MEPS and qDASH scores, and strength. Despite the good function there were eight (36%) complications in six patients. Five complications resolved spontaneously or following treatment. Furthermore, HO was observed in 23% of the radiographs and was symptomatic in only one patient.

Our functional outcomes are in accordance with previous reports on the Endobutton technique[10, 17-20]. However, strength after reconstruction was not measured in most other series. In comparison with other studies, the current study focused on complications of this technique seen in the short-term follow-up (since we do not expect much more new complications after this follow-up period). Moreover, we made standard radiographs of the elbow during follow-up, which revealed a noteworthy number of HO formation postoperatively.

Anatomic reconstruction of the ruptured distal biceps tendon is the first choice of treatment when restoration of strength is desired. Most techniques report good results with respect to restoration of flexion and supination power. Chavan et al. performed a systematic review in 2008 and concluded that repairs using a cortical button performed better than other repair methods (transosseous tunnel, interference screw or suture anchors)[14]. The fixation of the cortical button is based on the cortical bone on the dorsal aspect of the radius. This is probably the explanation for the superior biomechanical characteristics over other types of fixation. Based on these biomechanical characteristics the cortical button reconstruction provides a firm tendon refixation with good strength and little chance on loosening, as is shown in the current study. Besides this biomechanics, the biology is also important in tendon refixation. The biceps tendon rests in a medullary canal of the radius, increasing the contact area between the bone and the tendon[21]. Therefore the healing process is not solely dependent on the hypovascular and degenerated distal end of the tendon[22].

Grewal et al. recently reported the results of the first prospective randomized trial comparing single versus double incision techniques for distal biceps tendon ruptures[23, 24]. Their protocol included prophylactic prescription of indomethacin following surgery and they noticed HO in only 2% of the 91 patients after 24 months. The prevalence of HO was similar in both groups. They recommended further research on the use of indomethacin on HO formation following distal biceps tendon surgery[23]. Peeters et al. reported 8.7% HO after a retrospective mean follow-up of 16 months[19]. Greenberg et al. reported HO in 5 of 14 patients (35.7%) after a mean follow-up of 20 months[25]. However, both studies do not mention the use of prophylactic medication. Studies by Bain et al., Dillon et al., and Ranelle on the Endobutton technique do not mention the occurrence of HO at all[10, 18, 20]. It is also unclear whether standard radiographs of the elbow were made during follow-up and whether prophylactic medication was given. A recent study on complications following distal biceps tendon repair by Cain et al. reported 3% HO in 69 elbows with a cortical button reconstruction. However, radiographs were not made in a routinely fashion in this retrospective study; thus, cases of potentially asymptomatic HO were not included[26]. Five patients with HO were observed in the current series; one patient with HO had complaints. This patient had no limitation in ROM but only crepitus, hence operative removal was therefore not performed. We routinely prescribed an oral NSAID for one week following surgery in all distal biceps tendon repairs. Another point of debate is the length of this prophylaxis period. Anakwenze et al. prescribed indomethacin for 6 weeks after distal biceps tendon repairs and noted no cases of HO[27].

All surgical techniques require an anterior incision in the antecubital flexion crease of the elbow to retrieve the ruptured tendon stump. Dissection through the subcutaneous tissue requires identification and protection of the lateral antebrachial cutaneous nerve (LABCN) of the forearm. In chronic retracted distal biceps tendon ruptures, the LABCN can become entrapped within reactive inflammatory and scar tissues, as it exits between the biceps and brachialis muscle. While one case with this type of nerve injury was observed in the current study, this complication is reported in up to 4-11% of cases[28, 29].

Although some authors[30, 31] advocated division of the arcade of Frohse and visualization of the nerves, we used a limited single anterior approach with the forearm in full supination. The bursal cavity directs the surgeon onto the radial tuberosity, and handheld right-angle retractors are easily positioned to expose the radial tuberosity and are less likely to cause injury to the radial nerve or posterior interosseous nerve. Two cases of transient posterior interosseous nerve injury were observed in current study. Injury to the posterior

interosseous nerve has been reported in up to 5% of cases of distal biceps repairs using a single anterior incision[32, 33]. Fortunately, most injuries are neurapraxia that ultimately recover. Stretch injuries of the posterior interosseous nerve typically recover in 8-12 weeks[34, 35].
Cain et al. reported a large retrospective series on complications following different distal biceps tendon reconstruction techniques. They found an increased risk of complications when the reconstruction was performed more than 4 weeks post-trauma compared to reconstructions performed within 4 weeks post-trauma. Injuries to the LABCN, posterior interosseous nerve, and the radial sensory nerve were more common when repair was delayed[26]. In table 2, the reconstructions were divided in an acute and chronic group. There were no significant differences in outcome between the groups in this series, although HO formation was more frequently seen following acute ruptures.

3

Table 2: Comparison of patients with a reconstruction done within 4 weeks following trauma and after more then 4 weeks following trauma.

	Operation < 4 weeks N=5 (SD)	Operation > 4 weeks N=15 (SD)	P-value
Baseline characteristics			
Age (years)	48 (5.4)	45 (10.8)	n.s.
Gender (% male)	100%	93%	n.s.
Complete rupture (%)	100%	67%	n.s.
ROM (flexionarc, degrees)	136 (7.5)	136 (7.0)	n.s.
Time from injury to operation (weeks)			<0.001
Outcome measures			
ROM (flexionarc, degrees)	132 (5.7)	136 (6.8)	n.s.
Flexion strength (%)	95 (10.4)	104 (21.5)	n.s.
Supination strength (%)	101 (8.7)	95 (7.3)	n.s.
HO (N)	3	2	0.032
MEPS	97 (6.7)	92 (16.9)	n.s.
qDASH	4 (8.9)	11 (17.9)	n.s.
Follow up (months)	29 (12.6)	24 (13.0)	n.s.

HO: heterotopic ossifications; n.s.: not significant; ROM: range of motion; SD: standard deviation.

After distal biceps tendon repair, a re-rupture of the tendon is extremely rare[36]. Re-rupture is most likely owing to surgical technique (lack of adequate tendon tissue, inadequate initial attachment, very tight repair) or a poorly compliant patient who forcibly flexes or supinates against resistance in the early postoperative period. Therefore no flexion against resistance is allowed for the first three postoperative months. To avoid this complication, patients must be educated on the need to protect their repair after reconstruction. In the current series we observed one partial re-ruptured tendon and one elongated tendon which was reconstructed during a second procedure.
There are technical challenges associated with fixation to the cortical button and tendon tensioning in a muscular forearm. The Toggle Loc is a modification on the Endobutton and allows the surgeon to attach the tendon to the implant by pulling on the sutures away from the wound. Furthermore it is possible to adjust the tension of the suture loops and subsequently the repair[15]. Therefore the Toggle Loc requires a potentially less demanding

surgical technique. To our knowledge the Toggle Loc has only been evaluated by DiRaimo et al. on 4 patients[15]. In the current study we describe results from both the Toggle Loc and Endobutton fixation. The Toggle Loc was used in 14 elbows with good results. There was more HO in patients treated with an Endobutton; however, the follow-up was also significant longer in this group (see table 1). If HO formation comes with time, this might be a explanation.

The strength of the current study is the extensive number of outcome measures. We describe the outcome of distal biceps tendon reconstructions in terms of 1) subjective patient reported outcome measures (MEPS and qDASH); 2) objective outcome measures (ROM, strength, complications) and 3) radiographic outcome measures (HO formation, fractures, position cortical button). The current study had several limitations in addition to its retrospective nature. First is the relatively small group of patients in this cohort. Although other clinical outcome studies included a comparable number of patients, it is necessary to evaluate the cortical button technique in larger cohorts[10, 15, 20, 25, 37]. Secondly, with a mean follow-up of 24 months (median 22 months), the current study presents a short-term follow-up. A comparison of patients with a follow-up of more or less than two years (see table 3) was made to determine the influence of length of follow-up on outcome. There were no significant differences between these groups. Thirdly, the cohort consisted of patients with complete and subtotal ruptures. Although the time between trauma and diagnosis/reconstruction is longer for patients with a subtotal rupture, the outcomes between the groups were comparable. It seems therefore justified to report on both groups in the current series. Fourthly, final strength measurements were not performed in six patients (32%). However, these patients were evaluated by physical examination and questionnaires.

The current study indicates that distal biceps tendon reconstructions with a cortical button results in good clinical and radiological outcome in the short term. However, this procedure was associated with complications; predominantly, neuropraxia, biceps tendon problems (partial re-rupture, elongation, and irritation from allograft) and HO. It is therefore important for the surgeon to limit the dissection and to drill the hole in the most optimal direction, in order to prevent neurological complications. To avoid tendon problems it is essential to instruct a clear rehabilitation protocol. The patient should be informed prior to surgery about limitations in usage of the arm after the reconstruction. Since HO was commonly seen in the current study, we would advise to prescribe prophylactic medication. Further prospective research on prevention of HO following distal biceps tendon reconstruction surgery in large groups of patients is necessary.

Table 3: Comparison of patients with a follow up of <24 months of follow up versus >24 months of follow up.

	Follow up <24 m N=11 (SD)	Follow up >24 m N=9 (SD)	P-value
Baseline characteristics			
Age (years)	43 (10.4)	49 (8.3)	n.s.
Gender (% male)	91%	100%	n.s.
Complete rupture (%)	73%	78%	n.s.
ROM (flexionarc, degrees)	135 (7.6)	138 (5.0)	n.s.
Time from injury to operation (weeks)	44 (38.6)	30 (43.5)	n.s.
Outcome measures			
ROM (flexionarc, degrees)	136 (6.6)	133 (6.6)	n.s.
Flexion strength (%)	101 (11.9)	103 (26.2)	n.s.
Supination strength (%)	95 (7.9)	98 (7.6)	n.s.
HO (N)	1	4	n.s.
MEPS	89 (19.1)	98 (5.0)	n.s.
qDASH	14 (20.1)	3 (7.0)	n.s.
Follow up (months)	15 (4.5)	38 (7.2)	<0.001

HO: heterotopic ossifications; n.s.: not significant; ROM: range of motion; SD: standard deviation.

Conclusion

The results of distal biceps tendon refixation with a cortical button were good according to ROM, MEPS and qDASH scores, and strength. However, this procedure was accompanied with complications in 36%. In particular the formation of HO (23%) was frequently seen, though clinically relevant in only one patient that experienced crepitus.

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Chapter 4

Refixation techniques and approaches for distal biceps tendon ruptures: a systematic review of clinical studies

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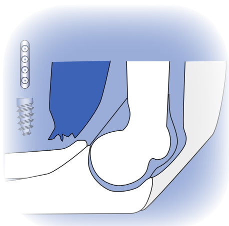

J Shoulder Elbow Surg. 2016 Feb;25(2):e29-37.

Abstract

Background: Surgical fixation is the preferred method of treatment for the ruptured distal biceps tendon in active patients. To date, no fixation technique has been proven superior in a clinical setting. The purpose of the study was to systematically review the available literature regarding approach and fixation methods of distal biceps tendon repair in a clinical setting and to determine the optimal fixation methods of the distal biceps tendon on the radial tuberosity. Our hypothesis was that the outcomes would not be significantly different among the various fixation techniques and approaches.

Methods: A systematic review of the available literature regarding anatomical reconstruction methods for distal biceps tendon ruptures was performed. The outcome measures evaluated were postoperative range of motion, elbow flexion and supination strength, and complication rates and types.

Results: Forty articles were included, representing 1074 patients divided into four fixation groups: suture anchors, bone tunnels, interference screws, and cortical buttons. There was no significant difference in range of motion and strength between the different approaches and fixation techniques. Complications were significantly less common after the double-incision approach with bone tunnel fixation ($P<0.0005$).

Conclusions: There were significantly fewer complications after the double-incision approach with bone tunnel fixation. The double-incision approach had significant fewer complications than the single-incision anterior approach, and the bone tunnel fixation had significant fewer complications than the other three fixation techniques. However, as the double-incision approach was used with bone tunnel fixation in 84% of cases, there was a strong interrelationship between these variables.

Keywords: distal biceps tendon; elbow; fixation technique; repair; rupture; surgical approach

Introduction

The reported incidence of distal biceps ruptures is approximately 1.2 to 5.4 per 100,000 persons per year[1, 2]. Acute rupture of the distal biceps tendon is typically seen in middle-aged men (40-60 years old) and is generally the result of an unexpected extension of the actively flexed elbow[3]. A second group is older patients with chronic, degenerative, partial rupture, without a clear history of a traumatic moment[4]. In the elderly, especially with a sedentary life style, nonsurgical treatment can be considered. Nonanatomic attachment, by tenodesis on the brachialis muscle tendon fails to restore the supination function, and leaves considerable residual loss of flexion force[5, 6]. Therefore, in most patients, anatomical repair has become the standard of care to obtain optimal strength and function of the elbow[7, 8]. However, in the chronic setting, retraction and scarring may limit the ability to achieve enough surgical length, and reconstruction on the radial tuberosity carry a greater neurovascular risk. Hence, most authors advise to perform an anatomic reconstruction in the acute setting[9, 10].

Several surgical procedures for anatomical repair of the distal biceps tendon on the radial tuberosity have evolved during the last decade[11]. Despite numerous publications on fixation methods (suture anchors, bone tunnels, interference screws, or cortical buttons) for the ruptured distal biceps tendon on the radial tuberosity, controversy remains about the best fixation technique[12-17].

Common complications after biceps fixation are loss of motion or strength, heterotopic ossification, elbow pain, rerupture, and (transient) neurapraxias[11]. The single-incision approach is related to more neurapraxias (especially the lateral antebrachial cutaneous nerve [LABCN]), whereas the double-incision approach is more commonly complicated by loss of motion[18]. In 2008, Chavan et al. performed a systematic review on fixation methods and recommended the use of the cortical button (highest load tolerance and stiffness), on the basis of biomechanical analysis[18]. Yet, until today there is no clinical evidence supporting one fixation technique over another[11]. The purpose of this study was therefore to systematically review and summarize the available literature on the approach and fixation methods of distal biceps tendon repair in a clinical setting, and determine the optimal fixation method of the distal biceps tendon on the radial tuberosity. Our hypothesis was that the outcomes would not be significantly different among the various fixation techniques and approaches.

Materials and methods

Identification of studies

A research protocol was developed as described by Wright et al., and used throughout the study process[19]. This protocol was not registered. A literature search was performed through the Pubmed/Medline, Cochrane clinical trial register and Embase databases on October 4, 2013, with the help of a clinical librarian. The following subject headings and text words and their synonyms were used: "distal biceps tendon" and "rupture" linked with "repair" and "fixation". Because the methods of anatomic reconstruction techniques evolved quickly last decade with the introduction of new fixation implants, the publication date was limited to the last 10 years. Language was limited to Dutch, English and German. All titles and abstracts were reviewed to identify potentially relevant articles. The full manuscript was retrieved for all potentially relevant articles and when the title, keywords, or abstract revealed insufficient information to determine appropriateness for inclusion. The bibliographies of the retrieved studies were manually checked for potential relevant articles that were missed in the initial search. Second-stage screening of the full text articles was performed unblinded by two of the authors. Duplicates were deleted. On January 30, 2015, we updated the search to provide a complete up-to-date interpretation of available data as several new articles were published during the time of initial statistical analysis and preparation of the manuscript.

Inclusion and exclusion criteria

The full text of the original prospective or retrospective studies (level of evidence I–IV) had to be available. Articles had to describe the results of at least 5 living human subjects, and these articles had to report results with a minimal follow-up of one year.

Studies had to describe a distal biceps tendon rupture, and all available surgical techniques and approaches for an anatomical reconstruction of the distal biceps tendon were included. Conservative treatment and nonanatomic reconstruction of the distal biceps tendon were exclusion criteria. Biomechanical and cadaveric studies were also excluded. Both articles reporting the results of acute (within 6 weeks of injury), as well as, delayed (after 6 weeks of injury) anatomical reinsertion of the tendon, were included.

Studies had to describe at least one of the following functional outcome measures: 1) range of motion (ROM), flexion-extension, pronation-supination; 2) strength of the elbow after and before surgical treatment or strength of the elbow after surgical treatment compared with the contralateral side (unaffected elbow); and 3) complication type and rates.

Data extraction

Included studies were divided into 4 groups based on the fixation method used: suture anchors, bone tunnels, interference screws, and cortical buttons, which were classified A, B, C, and D, respectively (figure 1). Group A included all suture anchors derivates: Titan Corkscrew (Arthrex GmbH, Karlsfeld, DE), Suture Anchor (Statac; Zimmer Inc, Warsaw, IN), Mini-Anchor, G2 Anchor, G4 Super Anchor, Super Quick Anchor Plus, or Panalok Anchor (all Mitek Surgical Products Inc., Westwood, MA, USA). Group B included all variations of bone tunnels fixation using sutures: Fiberwire (Arthrex, Naples, FL, USA) and Ti-Cron (Covidien, Dublin, IR). Group C included all studies using a biotenodesis interference screw (Arthrex, Naples, FL, USA). Group D included all studies using a cortical button, such as the Endobutton (Smith & Nephew, Andover, MA, USA) or Toggle Loc (Biomet, Warsaw, IN, USA). Within studies comparing several fixation methods, those methods were analyzed as separate groups.

In accordance with Chavan et al. the functional outcome of ROM and strength was divided into satisfactory or unsatisfactory and scored 1 or 0[18]. A loss of at least 30° in motion - flexion, extension, pronation, or supination - and a loss of at least 20% of strength were considered an unsatisfactory result and scored 0. A loss of <30° in motion and a loss of <20% of strength was considered a satisfactory result and scored 1[18].

Multiple complications occurring in the same patient were scored separately and summarized into a dichotomous complication (yes/no) score before analysis. The approach (single anterior incision or double incision) used in the repair was recorded and analyzed for all study groups.

Following the data extraction process, final inclusion and exclusion decisions were made about the manuscripts.

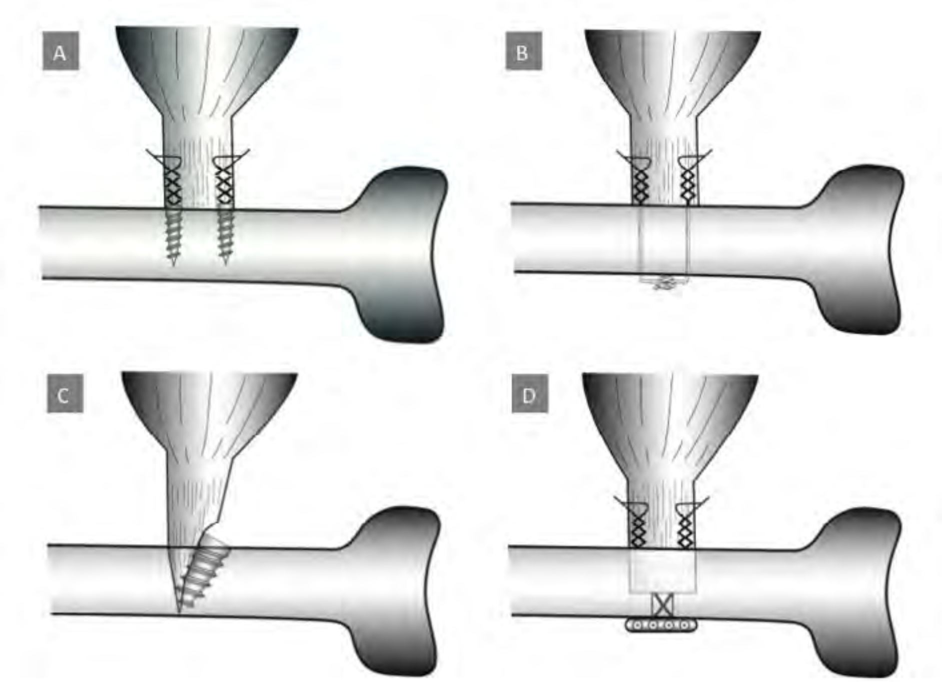

Figure 1: A, B, C, and D - Fixation techniques used to reconstruct the ruptured distal biceps tendon: [A] suture anchor, [B] bone tunnel, [C] interference screw, or [D] cortical button.

Methodological quality

The methodological quality of the included studies was judged by assigning levels of evidence as described by Marx et al.[20]. Two authors assigned levels of evidence. Disagreement was resolved by consensus. The risk of bias for the individual studies or across studies was not assessed. On the basis of the underlying levels of evidence, grades of recommendation were formulated according to Wright[21]. Grade A meant treatment options were supported by good evidence (Level I studies with consistent findings); grade B meant treatment options were supported by fair evidence (Level II or III studies with consistent findings); grade C meant treatment options were supported by poor-quality evidence (Level IV or V studies with consistent findings); and grade I was used when insufficient evidence existed to make a recommendation.

Statistics

Statistical analysis was performed on the data aggregated to study level. Generalized linear modeling with a logit link function and with study as subject was used for the binary (on the patient's level) outcome variables ROM deficit, strength diminishment and the occurrence of any complication. These outcome variables were represented in the aggregated dataset by a numerator (number of patients with the event) and a denominator (number of all patients) per study, so that numbers per study were appropriately taken account of in the analyses. Fixation method (four categories) and approach (two categories) were the independent variables of interest, adjusted for average age (years) and follow-up time (months). Robust estimates of the co-variances of the estimated log odds ratios were calculated to take account of the between-studies variability. Effects were presented as odds ratios. The fourth outcome variable was number of complications per study. This variable was assumed to have a negative binomial distribution across studies and was analyzed through generalized linear modeling using a log link function and the logarithm of the number of person-years of follow-up in a study as offset. Effects were presented as rate ratios. The negative binomial distribution was used in order to take account of the extra-Poisson variability across studies. Throughout this paper, confidence intervals and P-values were calculated using the generalized linear models as described. A P-value < 0.05 was considered to be significant. Data were analyzed using SPSS 20.0 (IBM Corporation, Armonk, NY, USA) and SAS 9.2 (SAS institute Inc., Cary, NC, USA).

Results

The final trial selection identified a total of 630 study records. After screening of the abstracts and removal of duplicates, the literature search yielded 59 studies that were eligible for full-text assessment. Forty of the reviewed articles met our inclusion and exclusion criteria[14-16, 22-59]. Six of the included articles reported on two study groups. Finally, 46 different study groups remained and were used in the generalized linear model analyses. The included studies represented 1074 patients divided into four fixation groups (figure 2). Study and patient characteristics are summarized in table 1. The numbers of patients varied among the included study groups, with a minimum of 5 patients, and a maximum of 84 per fixation method.

In each of the 46 included study groups, one of the four different fixation types was used: (A) in 565 patients, suture anchors were used; (B) bone tunnel fixation was applied in 321 patients; (C) in 42 patients, interference screws were used; and (D) in 146 patients, cortical fixation buttons were used.

The anterior approach was used in 35 of the 46 study groups, including 764 patients. The double-incision approach (310 patients) was used in 11 study groups and only in combination with either suture anchors (in 37 of 565 patients) or bone tunnel techniques (in 271 of 321 patients). Hence, refixation by cortical buttons (146 patients) or interference screws (42 patients) was performed only through an anterior approach in the included studies. This illustrates the strong association between fixation technique and approach in the data set. Furthermore, this causes a high collinearity between these variables in the model so that the effect of either one is not significant when adjusted for the other. In the generalized linear models, we therefore also tested their simultaneous contribution.

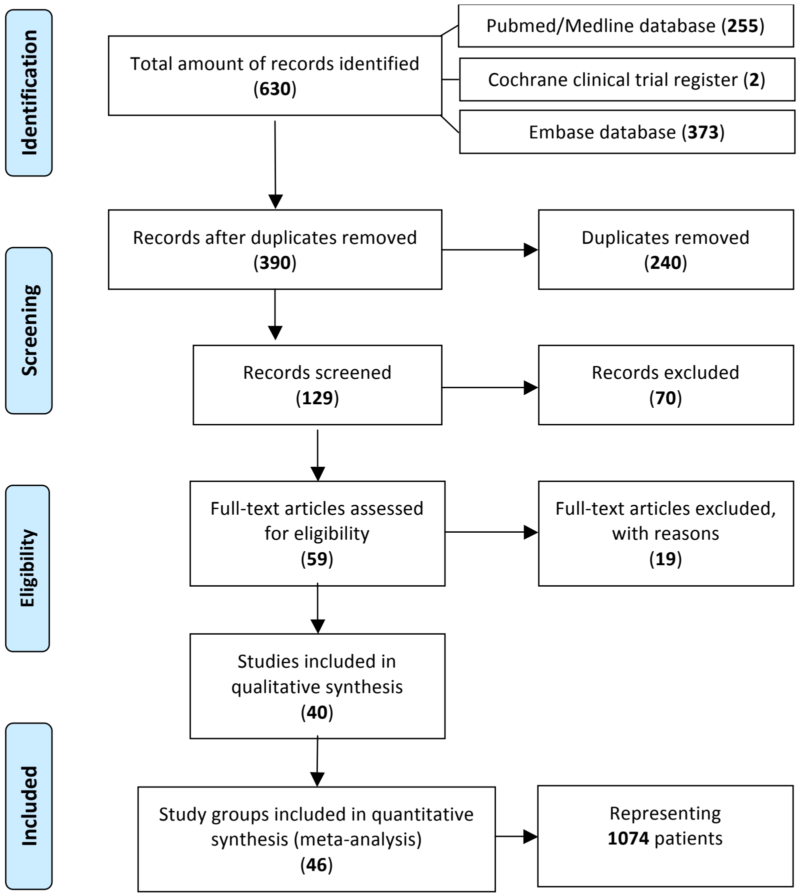

Figure 2: Flow diagram. Study group selection after the identification-, screening-, and inclusion phase of the literature search.

Outcome

The functional outcomes, ROM, and strength are displayed in table 2.
Overall ROM was measured in 85% of patients. There was a ROM deficit of >30 degrees in flexion-extension in 18 of 909 patients (2.0%) and a ROM deficit of >30 degrees in pronation-supination in 24 of 909 patients (2.6%). There was no difference in ROM deficit between the four different fixation techniques (P=0.42 for flexion-extension; P=0.88 for pronation-supination). There was no difference in ROM deficit between the two different approaches (P=0.84 for flexion-extension; P=0.90 for pronation-supination), nor was there any correlation between age and ROM deficit (respective P-values 0.50 and 0.85).

Table 1: study characteristics.

								Patient Characteristics			
Study	Authors	Year	Study group	Study Type	Fixation group*	Surgical approach	No. of patients	Average Age (year)	Dominant Arm injured	Time from injury to surgery	Mean Follow-up (months)
1	Al-Taher et al	2014	1	Retrospective	A	Anterior	6	42	-	Acute	35
2	Austin et al	2009	2	Retrospective	B	2-incision	84	44	65%	-	12
3	Balabaud et al	2004	3	Prospective	A	Anterior	9	41	44%	Acute	15
4	Banerjee et al	2013	4	Retrospective	D	Anterior	27	48	44%	Acute	36
5	Bosman et al	2012	5	Retrospective	D	Anterior	6	47	50%	Acute	20
6	Carita et al	2009	6	Retrospective	A	Anterior	12	51	92%	Delayed	66
7	Carrol et al	2014	7	Retrospective	D	Anterior	51	45	-	-	11
8	Cheung et al	2005	8	Retrospective	B	2-incision	13	39	62%	-	38
9	Chillemi et al	2007	9	Retrospective	A	2-incision	5	49	-	Acute	24
10	Cil et al	2009	10	Retrospective	B	2-incision	21	49	67%	Acute	57
11	Citak et al	2011	11	Retrospective	A	Anterior	39	48	42%	Acute	30
			12	Retrospective	B	2-incision	15	48	40%	Acute	37
12	Cross et al	2014	13	Retrospective	A	Anterior	7	44	57%	Acute	16
13	El-Hawary et al	2003	14	Prospective	A	Anterior	9	47	63%	Acute	12
			15	Prospective	B	2-incision	10	44	63%	Acute	12
14	Ensslin et al	2004	16	Prospective	A	Anterior	24	47	79%	Acute	16
15	Fenton et al	2009	17	Retrospective	C	Anterior	14	39	71%	Acute	29
16	Gallinet et al	2011	18	Retrospective	A	Anterior	28	49	57%	Acute	22
17	Gasparella et al	2015	19	Retrospective	A	Anterior	14	45	-	Acute	26
18	Gregory et al	2009	20	Retrospective	A	Anterior	25	43	64%	Acute	30
19	Grewal et al	2012	21	Clinical trial	A	Anterior	47	45	66%	Acute	24
			22	Clinical trial	B	2-incision	44	45	59%	Acute	24
20	Hansen et al	2014	23	Retrospective	A	Anterior	27	47	-	-	12
21	Hetsroni et al	2008	24	Retrospective	B	Anterior	12	46	75%	Acute	24
22	John et al	2007	25	Retrospective	A	Anterior	53	47	-	Acute	38
23	Johnson et al	2008	26	Retrospective	A	Anterior	12	49	83%	Acute	26
			27	Retrospective	B	2-incision	14	42	71%	Acute	31
24	Khan et al	2008	28	Retrospective	A	Anterior	13	49	-	Acute	46
25	Klonz et al	2003	29	Retrospective	A	Anterior	6	45	50%	Acute	40
26	Kodde et al	2013	30	Retrospective	D	Anterior	20	49	55%	-	25
27	McKee et al	2005	31	Retrospective	A	Anterior	53	42	64%	Acute	29

28	Morrey et al	2014	32	Retrospective	B	2-incision	23	50	-	-	12
29	Niemeyer et al	2008	33	Retrospective	B	Anterior	18	50	89%	Acute	18
30	Olsen et al	2014	34	Retrospective	A	Anterior	17	51	35%	Acute	32
31	Peeters et al	2009	35	Retrospective	D	Anterior	23	52	48%	Acute	16
32	Ryhänen et al	2006	36	Retrospective	A	Anterior	14	41	-	-	29
33	Schmidt et al	2012	37	Retrospective	D	Anterior	19	49	58%	Acute	49
34	Siebenlist et al	2014	38	Retrospective	A	Anterior	49	47	51%	-	44
35	Silva et al	2010	39	Prospective	C	Anterior	28	46	39%	Acute	19
36	Stuby et al	2007	40	Retrospective	A	Anterior	35	49	65%	-	48
			41	Retrospective	B	Anterior	13	49	65%	-	48
37	Tarallo et al	2014	42	Retrospective	B	2-incision	47	45	91%	Acute	18
38	Vastamaki et al	2008	43	Retrospective	A	Anterior	7	45	79%	Delayed	133
			44	Retrospective	B	Anterior	7	45	79%	Delayed	133
39	Weber et al	2011	45	Prospective	A	Anterior	20	41	70%	Acute	12
40	Weinstein et al	2008	46	Retrospective	A	2-incision	32	53	56%	Delayed	42
							Average per Fixation group / Surgical approach				
					A		565	46	61%	-	32
					B		321	46	69%	-	24
					C		42	43	50%	-	23
					D		146	48	51%	-	24
						Anterior	764	46	60%	-	30
						2-incision	310	46	66%	-	24

* Fixation group: A) Suture Anchor, B) Bone Tunnels, C) Interference screw, D) Cortical button.

Table 2 : Functional outcomes.

				Unsatisfactory outcomes					
					ROM			Strenght	
Fixation group*	Authors	Study group	No. of patients	ROM Tested	Flexion Extension	Pronation Supination	Strenght Tested	Flexion strenght	Supination strenght
A	Al-Taher et al	1	6	6	0	0	-	-	-
A	Balabaud et al	3	9	9	0	0	9	0	0
A	Carita et al	6	12	12	0	0	12	0	0
A	Chillemi et al	9	5	-**	-	-	-	-	-
A	Citak et al	11	39	39	0	0	-	-	-
A	Cross et al	13	7	7	0	0	-	-	-
A	El-Hawary et al	14	9	9	0	0	9	0	0
A	Ensslin et al	16	24	24	4	3	0	-	-
A	Gallinet et al	18	28	28	0	1	28	0	0
A	Gasparella et al	19	14	14	0	0	14	0	0
A	Gregory et al	20	25	25	0	1	25	4	4
A	Grewal et al	21	47	47	0	0	47	0	0
A	Hansen et al	23	27	-	-	-	19	0	0
A	John et al	25	53	53	0	2	-	-	-
A	Johnson et al	26	12	14	1	0	-	-	-
A	Khan et al	28	13	13	1	1	13	4	4
A	Klonz et al	29	6	6	0	1	6	1	3
A	McKee et al	31	53	53	0	0	53	0	0
A	Olsen et al	34	17	17	0	0	17	0	0
A	Ryhänen et al	36	16	16	0	1	16	5	7
A	Siebenlist et al	38	49	49	0	0	49	0	0
A	Stuby et al	40	35	35	0	0	35	0	0
A	Vastamaki et al	43	7	7	1	1	7	0	0
A	Weber et al	45	20	20	3	3	20	3	3
A	Weinstein et al	46	32	32	1	2	32	1	2
		Total	**565**	**535**	**11**	**16**	**411**	**18**	**23**
B	Austin et al	2	84	-	-	-	-	-	-
B	Cheung et al	8	13	13	0	0	13	1	2
B	Cil et al	10	21	21	0	0	21	2	11
B	Citak et al	12	15	15	0	0	-	-	-
B	El-Hawary et al	15	10	10	0	0	10	0	10
B	Grewal et al	22	44	44	0	0	44	0	0
B	Hetsroni et al	24	12	12	0	0	12	0	2
B	Johnson et al	27	14	14	0	0	-	-	-
B	Morrey et al	32	23	23	1	0	23	0	0
B	Niemeyer et al	33	18	18	2	2	18	0	4
B	Stuby et al	41	13	13	0	0	13	0	0
B	Tarallo et al	42	47	47	3	3	-	-	-
B	Vastamaki et al	44	7	7	0	0	7	0	0
		Total	**321**	**237**	**6**	**5**	**161**	**3**	**29**
C	Fenton et al	12	14	14	0	0	14	2	2
C	Silva et al	26	28	28	0	0	28	0	0
		Total	**42**	**42**	**0**	**0**	**42**	**2**	**2**
D	Banerjee et al	2	27	27	0	0	27	2	2
D	Bosman et al	3	6	6	0	1	-	-	-
D	Carrel et al	51	51	-	-	-	-	-	-
D	Kodde et al	21	20	20	0	0	20	0	0
D	Peeters et al	24	23	23	1	2	23	10	11
D	Schmidt et al	25	19	19	0	0	17	-	13
		Total	**146**	**95**	**1**	**3**	**87**	**12**	**26**

* Fixation group: A) Suture nchor, B) Bone Tunnels, C) Interference Screw D) Cortical Button. ** '-': outcome not reported in study.

Strength was reported for 65% of the patients in the included studies. Flexion strength was diminished with >20% compared to the contralateral elbow in 35 of 701 patients (5.0%), and supination strength was diminished with >20% compared to the contralateral elbow in 80 of 701 patients (11.4%). There was no significant difference in supination strength deficit between the four different fixation techniques (P=0.34) and two approaches (P=0.65). The simultaneous effect of fixation technique and approach on diminished flexion strength was significant (P=0.022). However, after deleting fixation technique from the model, the effect of approach on diminished flexion strength was not significant (P=0.26); and after deleting approach from the model, the effect of fixation technique was not significant either (P=0.14); nor was there any significant correlation between age and strength-deficit (P-values 0.66 [flexion strength] and 0.85 [supination strength]).

Complications

Complications were documented in all included studies. There were 357 complications (33.2%), of which 147 neurological disorders (13.7%). All neurological complications are listed in table 3. Neurapraxias of the LABCN was the most common complication, with 89 cases. The majority of the other complications consisted of heterotopic ossification that did not significantly affect ROM (table 4). The simultaneous effect of fixation technique and approach on the chance of any complication was significant (P<0.0005), adjusted for age and follow-up time. After deleting fixation from the model, the effect of double-incision compared with anterior approach on any complication became significant (odds ratio, 0.35; 95% confidence interval, 0.20-0.62; P<0.0005); after deleting approach from the model, also the effect of bone tunnels fixation compared to the other three fixation techniques became significant (P=0.011). Furthermore, complications were significantly affected by age. An increase of 1 year in mean age gave a 12% increase in complication odds (95% confidence interval, 1%-24%; P=0.036). The mean age of patients was 46.3 years with an anterior approach and 45.9 years for the double-incision approach, which was not significantly different (P=0.44).

Table 3: Neurological complications.

Group**	Patients N	Neuropraxia* Deep branch of radial nerve > 6 months N	< 6 months N	Posterior interosseous nerve > 6 months N	< 6 months N	Superficial branch of radial nerve > 6 months N	< 6 months N	Lateral antebrachial cutaneous nerve > 6 months N	< 6 months N	Median nerve > 6 months N	< 6 months N	Unspecified nerve > 6 months N	< 6 months N	Total N (%)
A	565	1	6	0	2	1	8	8	40	1	0	1	5	**73 (13%)**
B	321	0	1	0	3	0	1	0	13	1	0	0	1	**20 (6%)**
C	42	0	0	0	2	2	8	0	8	0	0	0	0	**20 (48%)**
D	146	0	4	1	7	0	2	1	19	0	0	0	0	**34 (23%)**
Anterior	764	1	9	1	12	3	18	9	66	2	0	1	5	**127 (17%)**
2-incision	310	0	2	0	2	0	1	0	14	0	0	0	1	**20 (6%)**
Acute***	670	1	7	0	8	3	17	7	41	2	0	1	6	**91 (14%)**
Delayed	90	0	1	0	1	0	2	0	9	0	0	0	0	**13 (14%)**
>6 month		1		1		3		9#		2##		1		**17 (2%)**
<6 month			11		14		19		80		0		6	**130 (12%)**
Total	**1074**	**1**	**11**	**1**	**14**	**3**	**19**	**9**	**80**	**2**	**0**	**1**	**6**	**147 (14%)**

* Neuropraxia are ordered depending on the duration of the complication (< or > than 6 months);** Fixation group: A) Suture Anchor, B) Bone Tunnels, C) Interference Screw, D) Cortical Button;
*** Not all included studies reported the delay between injury and surgery; therefore only 760 patients were used for these calculations.;
# Surgical exploration was performed in one case; ## Surgical exploration was performed in both cases.

Table 4: Other complications.

		Heterotopic ossification**		Infection					
Fixation group*	Patients N	Severe N	Mild N	Deep N	Superficial N	Re-rupture N	Wound healing disorder	Other*** N	Total N (%)
A	565	10	73	2	4	12	5	24	**130 (23%)**
B	321	3	19	1	1	5	9	4	**42 (13%)**
C	42	0	0	0	0	1	0	3	**4 (10%)**
D	146	2	17	0	2	2	4	7	**34 (23%)**
Anterior	764	12	101	3	6	16	8	31	**177 (23%)**
2-incision	310	3	8	0	1	4	10	7	**33 (11%)**
Total	**1074**	**15**	**109**	**3**	**7**	**20**	**18**	**38**	**210 (20%)**

* Fixation group: A) Suture Anchor, B) Bone Tunnels, C) Interference Screw, D) Cortical Button
** Heterotopic ossification was classified as 'Severe' if it was associated with pain or caused a loss of greater than 30° of motion in any plane, and 'Mild' if it was associated with no pain or caused a loss of lesser than 30° of motion in any plane.
*** Other complications consisted of stiffness (N=4), complex region pain syndrome (N=4), radioulnar synostosis (N=1), persistent pain (N=11), displacement of fixation material (N=9), tendinitis (N=3), capsulitis of ipsilateral shoulder (N=1), awareness of fixation material (N=2), elongation of the biceps tendon (N=1), and carpal tunnel syndrome (N=2).

Discussion

The purpose of this study was to determine the optimal approach and surgical fixation technique for repair of distal biceps tendon ruptures based on a systematic review of the current literature. There were no significant differences in postoperative ROM and strength among the four fixation methods and approaches. The main finding was that there were significantly fewer complications after the double-incision approach with bone tunnel fixation (grade of recommendation, C). The double-incision approach had significant fewer complications than the single-incision anterior approach, and the bone tunnels fixation had significant fewer complications than the other three fixation techniques. As the double-incision approach was used with bone tunnel fixation in 84% of cases, there was a strong interrelationship between these variables, and we were unfortunately not able to efficiently disentangle the effects of these variables. The most reported complications were neurapraxias of the LABCN, and heterotopic ossifications. Historically, nerve palsies have been associated with the anterior exposure, whereas heterotopic ossifications and synostosis were more frequently associated with the double-incision (Boyd-Anderson) approach. However, in the current study both complications had a higher occurrence in the single anterior incision group. We suppose that the risk of complications after the double-incision decreased after introduction of the 'Morrey modification' muscle-splitting approach. This technique, described in 2000, involves a posterior exposure through the extensor carpi ulnaris and avoids exposure of the ulna[10]. In their series, there were no cases of synostosis and most complications (neurapraxias) were related to a more extensive anterior exposure in some cases.

To our knowledge, this is the second systematic review that presented clinical results after distal biceps tendon reconstructions. Watson et al. reported a review of 22 studies including 494 patients[60]. The current review included 40 articles, describing results of 1074 patients who underwent anatomic repair of the distal biceps tendon; subsequently more data on

ROM, strength and complications following the different refixation techniques were available for analyses. Watson et al. concluded that bone tunnels and cortical buttons had the lowest complication rates, but their sample size lacked statistical power to draw firm conclusions. They also included older articles that mostly reported about the bone tunnels technique with more complications. The appraisal of the systematic review of Watson et al. was limited, as many items of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines checklist[61] are not reported. It is, for instance, unclear whether a review protocol was used, which years of publication were considered for inclusion, on what date the search was performed, and which statistical tests were performed to compare studies or individual patients. Chavan et al. reviewed the biomechanical and clinical literature on distal biceps tendon reconstructions in 2008[18]. They concluded that there were more patients with unsatisfactory outcome after the double-incision approach based on the existence of loss of motion, loss of strength or persistence of a major complication. This conclusion is in contrast with the results of the current review. We contemplate that the differences are explained by the older studies that were included in their review, whereas we included only the more recent series. The older studies used the original Boyd and Anderson double-incision approach, whereas the recent studies used the muscle-splitting Morrey approach. It appears that this modification resulted in fewer complications.

We included and summarized data from 1 randomized clinical trial, 1 prospective comparative study, 4 retrospective comparative studies, 4 prospective case series and 30 retrospective case series. The one randomized clinical trial was performed by Grewal et al. and was designed to compare the two different approaches[27]. However, in addition to the differences in approach between the groups, there was also a difference in fixation technique[62]. This raises the question whether the differences found between the groups were caused by the approach or the fixation technique, or a combination of both. Unfortunately, we encountered the same question after analysis of the results in this review. The current report included and compared 46 different treatment groups, of which 35 groups used the single-incision technique and 11 groups the double-incision technique. Overall, the double-incision technique was used in 29% of the patients and resulted in significant fewer complications. The approach was compared in four of the included articles[14, 15, 27, 44]. All four articles performed the single-incision approach using suture anchors and compared it with the double-incision approach using bone tunnels. The outcomes were slightly better for the two-incision approach, with fewer cases of transient neurapraxias and a better flexion strength (grade of recommendation, B). The higher amount of neurapraxias in the single-incision group can be explained by the amount of traction on the LABCN during this approach. In most cases, the neurapraxia was only transient and of limited significance as it resulted in only 3 cases (0.3%) of secondary surgery in this review. Moreover, it is important to evaluate the function of the LABCN preoperatively, as compression of this nerve by the biceps aponeurosis and tendon may occur after rupture[63].

There is no clear explanation for the differences found in flexion strength between the two approaches. One would expect that the type of reconstruction and location of the reconstruction on the proximal radius would predominantly affect supination strength. Hasan et al. compared both approaches in 20 cadaveric elbows and concluded that the double-incision exposure resulted in significantly improved anatomic repair of the biceps tendon to the original insertion site on the radial tuberosity[64]. Henry et al. compared both approaches with bone tunnels fixation in a biomechanical study and hypothesized that the double-incision approach allowed for more anatomic refixation on the posterior part of the radial tuberosity, resulting in better function[65]. However, there were no significant differences between the 2 groups for elbow flexion and supination force[65].

The knowledge about distal biceps tendon anatomy and reconstruction techniques has evolved last decades[66]. Numerous products were introduced on the market to repair the ruptured distal biceps tendon. All of these new products were based on three kinds of fixation techniques: suture anchors, interference screws and cortical buttons. The different fixation techniques have been compared in laboratory studies. Mazzocca et al. evaluated the four techniques under cyclic loading and ultimate failure in 63 cadaveric elbows[67]. The cortical button demonstrated a significantly higher load to failure than bone tunnels, suture anchors and interference screws. There were no significant differences between the last three methods[67]. Kettler et al. compared bone tunnels with 12 other different repair techniques in 130 cadaveric elbows[68]. Only the cortical button had a significantly higher failure load. They found no differences between bone tunnels and most other demonstrated techniques, and concluded therefore that the bone tunnel technique is still an adequate procedure, especially because it is less expensive than are the other implants[68].

This report has several limitations. At review level there may be a publication bias of the included articles. The included articles may also be biased by the inclusion and exclusion criteria. At study level, the level of evidence of the included articles (mainly level IV studies) limited the strength of this report. At outcome level the relatively small number of patients in the double-incision group (310 vs. 764) may possibly affect the complication rate comparisons. Another weakness is that we were unable to compare Patient Reported Outcome Measures (PROMs) between the groups. Because there were different PROMs, or no PROMs reported at all in the included studies, it was not realistic to perform a statistical analysis on this outcome measure. The strengths of this report included the relatively large number of included patients and the inclusion criteria that resulted in analysis of recent published articles of at least some methodological quality. The current review implies that the double-incision approach and bone tunnels fixation may be a safer technique than previously thought. It also appears that the risk on complications increases with higher age. Future research may include the effect of age on outcome of distal biceps tendon reconstructions, although the focus should be on the comparison of surgical techniques in a randomized controlled trial with identical approaches. Another area of interest involves the effects of the various fixation methods on rehabilitation (in sports) programs.

Conclusion

The current study reviewed the different fixation techniques and approaches used for distal biceps tendon reconstruction in the last decade. There were significant fewer complications following the double-incision approach compared to the single-incision anterior approach and for the bone tunnel fixation compared to the other fixation techniques. As the double-incision approach was used with bone tunnel fixation in 84% of cases, there was a strong interrelationship between these variables; and we were unfortunately not able to efficiently disentangle the effects of these variables. The current results are in contrast with the historical conception that the double-incision approach is associated with more complications (radioulnar synostosis formation). We therefore advise reconsideration of a muscle-splitting double-incision approach with bone tunnel fixation for the reconstruction of distal biceps tendon ruptures.

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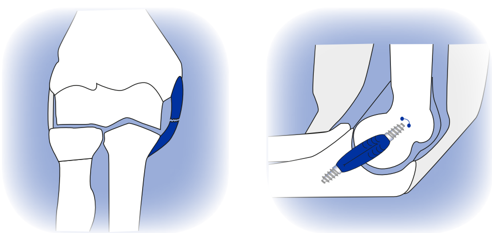
Chapter 5

Long-term results after ulnar collateral ligament reconstruction of the elbow in European athletes with interference screw technique and triceps fascia autograft

Izaäk F. Kodde; Frank T.G. Rahusen; Denise Eygendaal



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Abstract

Background: In the last decade, there has been increasing interest in medial ulnar collateral ligament (MUCL) reconstruction techniques for MUCL insufficiency of the elbow. All case series are based on American and Asian athletes and use primarily a palmaris longus tendon or gracilis tendon as an autograft in reconstructions. A new technique is the interference screw fixation. Evidence that supports the use of this technique is mainly from controlled laboratory studies. The purpose was to evaluate the interference screw technique for MUCL reconstructions in a European, clinical setting, with a triceps tendon fascia autograft.

Methods: Twenty consecutive athletes with diagnosed MUCL insufficiency who underwent a MUCL reconstruction using the interference screw technique were reviewed retrospectively. Indications for reconstruction were medial elbow pain and/or instability caused by insufficiency of the MUCL that prevented the athlete from sport activity after a minimum of 3 months of conservative treatment.

Results: At a mean follow-up of 55 months (range, 36–94), the mean Mayo Elbow Performance Score (MEPS) improved from 82 to 91 points (range, 80–100); $P < .001$. In the end, six patients (30%) quit the sport activities they were preoperatively participating in, all because of reasons unrelated to the MUCL reconstruction. There were excellent results on the Conway scale in 18 patients.

Conclusion: Good results are reported based on the postoperative MEPS and Conway scores with clinically stable MUCL reconstructions without signs of break-out or fractures on radiographic follow-up. However, the dropout, even after successful reconstruction in European athletes, is high.

Keywords: Medial ulnar collateral ligament; medial collateral ligament; elbow; reconstruction; triceps graft; interference screw; European athletes

Introduction

The anterior bundle of the medial ulnar collateral ligament (MUCL) is the primary constraint to valgus stress between 25° and 125° of flexion[1-3]. Injury to the MUCL can be the result of an acute traumatic moment or is the result of repetitive microtraumata to the MUCL caused by overhead athletic activities. During the late cocking phase of throwing there is a valgus load of up to 64 Nm, resulting in tensile forces medially, which exceed the native strength of the MUCL[1]. Thus injury of the MUCL of the elbow occurs most frequently in overhead athletes.

Before Jobe et al. described a reconstruction technique for the MUCL in 1986, this injury was often career ending[4]. Conservative treatment of MUCL injuries in baseball players was indeed successful in only 42%[5]. Since Jobe's original article, the interest in MUCL injuries has increased substantially and involved different kinds of sports activities such as baseball, football, soccer, tennis, javelin throwing, and gymnastics[6-9]. According to a recent systematic review by Vitale et al.[10] the results of MUCL reconstruction evolved from 68% good results in the earliest study[11] to 95% in the most recent study[12]. During this period there was an evolution of reconstruction techniques from Jobe's figure-of-8 technique[4] to the docking technique[13] and subsequent modifications[12, 14] to the docking technique. Most reports are based on American, Australian, or Asian athletes; reports on MUCL reconstruction in European athletes are rare. More recently, new fixation techniques were introduced such as the bioabsorbable interference screw fixation and interference knot fixation[15-17].

For reconstruction of the MUCL, palmaris longus tendon or gracilis tendon in absence of the palmaris longus is most often used[4, 6, 12-14, 16, 18, 19]. Based on worldwide population studies, the prevalence of absence of the palmaris longus tendon varies from 4.6% in Chinese[20] to 37.5% in Serbian[21] people. Using the gracilis as graft is less attractive, as an uninjured knee is harmed by means of a technically demanding operation only to harvest a graft, with the risk of inadequate graft length[22]. Moreover, the gracilis cannot be used anymore in future anterior cruciate ligament surgery. As an alternative, the fascia overlying the triceps muscles can be used as an autograft. Biomechanical studies by Baumfeld et al. showed that the fascia overlying the triceps is strong enough to serve as a graft for MUCL reconstruction[23]. Previous reports using triceps tendon fascia graft have shown promising results[24-26]. The post-operative triceps strength was not diminished significantly according to Olsen et al. and Martin et al.[25, 27]. However, these conclusions are based on retrospective studies with small sample sizes of patients not performing overhead sport activities. Eygendaal et al. used triceps fascia grafts in athletes with good results by means of return to previous levels of sports, but did not specifically report on post-operative triceps strength[24].

The purpose of this study was to evaluate the long-term results of MUCL reconstructions in a cohort of European athletes using the interference screw technique and triceps fascia as an autograft. The interference screw technique was used because of the easy and safe approach with minimal muscle dissection and risk to the ulnar nerve. The graft is fixated in more reliable anatomic bone tunnels according to the anterior bundle of the MUCL, with easy tensioning and without the risk of any bone bridge fractures. We hypothesized that there would be good results after this easier and safe MUCL reconstruction with triceps fascia autograft and bioabsorbable interference screw fixation.

Material and methods

From 2001 through 2007, 20 consecutive athletes with MUCL insufficiency were treated with a surgical reconstruction by the senior author. Indications for reconstruction were medial sided elbow pain and/or symptomatic valgus instability caused by insufficiency of the MUCL. In all athletes a conservative treatment was attempted for at least 3 months under supervision of a physical therapist. The interference screw technique, with bioabsorbable screws (Arthrex Inc., Naples, FL, USA) was performed in all patients.
The diagnosis was based on the history, physical examination, standard radiographs, and magnetic resonance imaging (MRI). All patients underwent a preoperative clinical assessment consisting of range of motion (ROM), assessment of (valgus) stability, and calculation of Mayo Elbow Performance Score (MEPS). Radiographs in anteriorposterior (AP) and lateral direction of the effected elbow were obtained before surgery.
Postoperative clinical evaluation took place at 8 weeks, 6 months, and 1, 3, and 5 years, and consisted of ROM, strength, stability, neurological status, and standard radiographs in AP view and lateral direction. MRI arthrography was not routinely performed during postoperative evaluation. The MEPS questionnaires were completed. AP and lateral radiographs were assessed for fractures around the drill holes, heterotopic ossifications (HO), and position and absorption of the bioabsorbable interference screw. HO were classified according to Hastings and Graham[28].
Final results were graded on the Conway scale[11]:
- Excellent: return to pre-injury level of competition for more than one season;
- Good: return to play at a lower level of competition for more than one season;
- Fair: able to play regularly at a recreational level;
- Poor: unable to play at any level.

Statistical analysis was performed using SPSS 16.0 for windows (SPSS Inc., Chicago, IL, USA) software. Statistical analysis was done using the paired t, sign, and Wilcoxon signed ranks tests to compare preoperative and postoperative changes in numerical data between groups. The results were considered statistically significant at $P < .050$.

Surgical technique

The patient is placed in supine position with the arm on a surgical hand table. The arm is routinely prepared and draped up to the shoulder and a sterile tourniquet is applied. An incision over the medial epicondyle is made and carried down through subcutaneous tissues while the ulnar nerve is protected. For harvesting of the graft, the incision is 3-4cm longer in comparison to traditional techniques. A release of the ulnar nerve was not routinely per- formed, unless there was a preoperative ulnar nerve dysfunction. A longitudinal split is made in the common flexor bundle[29]. The anatomic origin and insertion of the MUCL are exposed. The triceps graft is collected through the same incision and measures about 8-10cm in length and 1.5cm in width. It is harvested from the middle third part of the triceps fascia overlying the muscle bellies of the triceps tendon without damaging the lamina splendens (the muscular septum between the lateral head and the medial/long head of the triceps). The defect of the triceps fascia is not closed. The thickness of the graft averages 2-mm. The graft is folded along its long axis and both ends of the graft are braided with Mersilene 000 Krakow stitches (figure 1). A 5-mm ulna drill hole is made just at the tubercle of the supinator crest with optimally a 2- or 3-mm distance between the articular surface and the ulna tunnel. The drill hole should be directed towards a point distal of the supinator crest on the lateral ulna. The drill hole is debrided with a curette to remove sharp bony edges to prevent trauma to the graft by the screw. The graft is fixed in the ulna with a 5.5-mm bioabsorbable interference screw using the Bio-Tenodesis cannulated screw Driver (Arthrex Inc., Naples, FL, USA) (figures 2 and 3). Isometry is determined by holding the graft at the origin of the MUCL on the humerus during flexion and extension. At that point on the medial epicondyle a 5-mm tunnel is created and debrided with a curette to prevent blow out of the medial epicondyle. Two 1.5-mm exit holes are drilled from proximal to distal in the medial epicondyle, connecting to the larger tunnel and preserving a 5- to 8-mm bone bridge between the 2 smaller tunnels. In maximal supination with varus stress and 60-70° of flexion, the graft is fixed with a second bioabsorbable 5.5-mm interference screw and the 2 suture ends are fixed to each other over the bone bridge. Any remnants of the original ligament are sutured over the graft for additional protection. The flexor muscle fascia is closed, the tourniquet is released, haemostasis is performed as necessary, and the skin is closed (see figure 4 for the final result).

Figure 1: Triceps fascia graft prepared with Mercilene stitches.

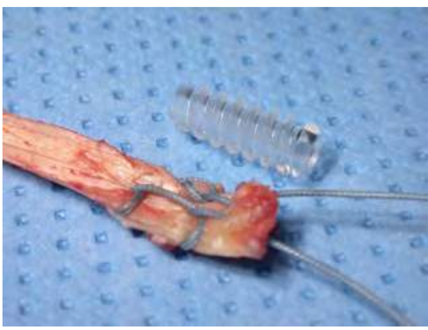

Figure 2: Triceps fascia graft and a bioabsorbable interference screw in detail.

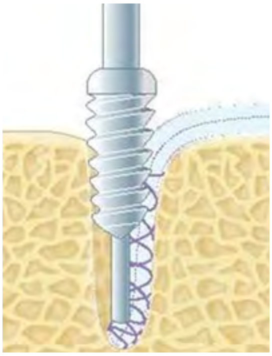

Figure 3: Graft fixation by a bioabsorbable interference screw.

Rehabilitation

The arm is placed in 90° of flexion with neural rotation in a plaster splint for 1 week. After 1 week, the ROM is steadily increased without restriction until full under strict guidance of a physical therapist. Muscle-building exercises were started, while care was taken not to apply a valgus stress at the elbow during this phase of rehabilitation. After 4 months, patients could gradually start with sporting activities according to sport specific protocols.

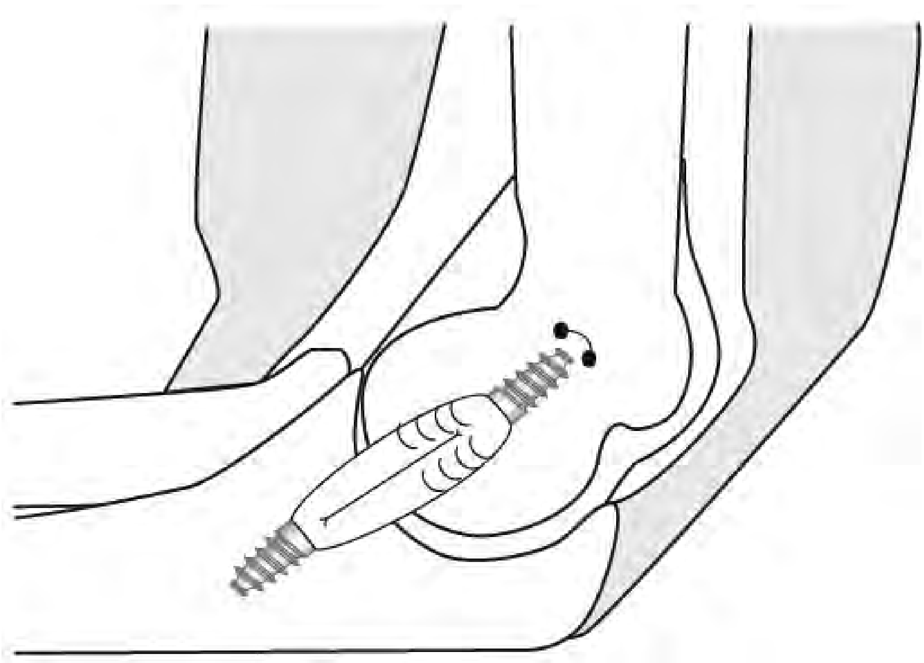

Figure 4: Reconstruction overview of the MUCL with triceps fascia autograft fixated in the humerus and ulna by 2 bioabsorbable interference screws.

Results

Of the 20 patients included in this study, the mean age at time of reconstruction was 22 years (range, 18–35). Seven patients (35%) were men and 65% were female. The study group included 6 javelin throwers, 4 gymnasts, 3 judo players, 3 handball players, 2 baseball players, 1 swimmer, and 1 horseman. All had medial sided elbow pain and all had a grade 3 valgus instability, consistent with MUCL insufficiency. Ulnar nerve symptoms were present in 4 patients (20%), but there were no nerve conduction studies performed as the symptoms in all cases decreased spontaneously. An acute trauma was the cause of MUCL rupture in 12 patients (60%). The mean preoperative MEPS was 82 points (range, 70–90). There were no significant differences in gender distribution, age, and Conway scale between patients with or without an acute trauma of the MUCL. Demographic data are presented in table 1. The mean time between onset of symptoms and MUCL reconstruction was 19 months (range, 3–40). During this period, most patients participated in a rehabilitation course consisting of rest, physical therapy, and a structured attempt to return in sporting activities. No patients were lost to follow-up, and at a mean follow-up of 55 months (range, 36–94) the mean MEPS improved to 91 points (range, 80–100); $P < 0.001$ (95%CI of the difference 3.96–13.54). The mean MEPS improved significantly more in patients who had an acute MUCL trauma compared to the patients who had attritional tears; $P = 0.022$.

Table 1: demographic data.

Case	Gender	Age	Acute trauma	Sport	Follow-up (months)	MEPS Pre-op	MEPS Post-op	Quitted (after … months)	Conway scale
1	F	18	1	Judo	49	90	100	N	E
2	M	24	1	baseball	50	80	100	Y (>30)	E
3	M	19	1	Javelin	66	80	90	N	E
4	F	18	0	Gymnast	58	90	90	N	E
5	F	19	1	Handball	36	70	90	N	E
6	F	18	0	Gymnast	60	90	100	N	E
7	F	25	0	Javelin	94	80	90	Y (>24)	E
8	M	18	0	Javelin	64	80	70	N	E
9	M	31	0	Handball	46	80	90	N	E
10	F	18	0	Baseball	60	90	80	N	E
11	F	35	0	Judo	60	90	90	N	E
12	F	20	1	Gymnast	64	80	85	N	E
13	F	18	1	Javelin	42	80	90	N	E
14	M	18	1	Gymnast	47	90	80	Y (<12)	E
15	F	20	1	Swimmer	54	90	100	Y (>36)	E
16	M	29	0	Javelin	46	80	90	Y (>36)	P
17	F	28	1	Handball	48	80	100	N	E
18	F	26	1	Horseman	47	60	80	Y (<12)	P
19	M	20	1	Javelin	49	80	100	N	E
20	F	26	1	Judo	59	80	100	N	E

E = excellent, F = female, M = male, N = no, P = poor, Y = yes. MEPS = Mayo elbow performance score.

Six patients (30%), of whom 3 were female, quit the sport activities they were preoperatively participating in, all because of reasons unrelated to the MUCL reconstruction. Two patients left sports within 1 year after reconstruction (1 because of persistent posterior impingement and 1 because of financial reasons) and 4 patients stopped after they returned at their pre-injury level for 2 or more years following surgery. This group consisted of 2 javelin throwers, 1 baseball player, 1 gymnast, 1 swimmer, and 1 horseman. The other 14 patients returned and continued to play at their pre-injury sports level. Of the 20 patients, 18 (90%) had excellent results on the Conway scale while 2 experienced poor results. All patients had a clinically stable MUCL.
There were no postoperative infectious complications. One patient had a persistent ulnar nerve dysfunction. At radiological follow-up, there were 2 patients (10%) with signs of HO classified as Hastings and Graham class 1. The latter 2 patients had an arc of ulnohumeral motion of 100° (turner, continued playing) and 120° (horseman, quit within 1 year). There were no signs of malposition of the bioabsorbable interference screws or fractures around the bone tunnels. None of the patients required additional surgeries later on their elbows.

Discussion

The interference screw technique was first described by Ahmad et al.[15] in a controlled laboratory study in 2003, where they tested 10 matched pairs of elbows divided in a control group and reconstruction group with a metal screw in the ulna and humerus. The elbows were tested for a maximum load at 70° flexion. Pair wise comparison of the control and reconstructed elbow showed that the ultimate moment of the constructed elbow was 95% of the intact elbow. In 60% was the mode of failure graft rupture. Furthermore, they suggested that this technique is technically less demanding with one ulna tunnel, and the risk to damage the ulnar nerve is lowered.
Two years later, Armstrong et al.[30] reported about a biomechanical comparison of 4 MUCL reconstruction techniques. The 4 reconstruction techniques included figure-8 reconstruction, docking technique, Endobutton fixation, and the interference metal screw technique. The interference screw technique was inferior to the docking technique and the Endobutton in means of peak load. They found it difficult to introduce the interference screw in the ulna without damaging the graft, because the graft was cut by the screw threads. A possible explanation for this is the use of metal screws that are too hard and sharp. Also, they used a single-strand graft. Subsequently, there were 3 laboratory studies published in 2007 that evaluated the interference screw technique[31-33]. Furukawa et al.[31] compared the docking technique with the interference metal screw technique with the use of a palmaris longus graft versus a GraftJacket (modified dermal allograft tissue) graft. With the use of a palmaris longus graft the results for the docking technique and interference screw technique were comparable. Modes of failure were graft slippage (46%) and graft rupture in 15%. Large et al.[32] compared the interference metal screw technique with Jobe's figure-8 technique and found the latter to be superior for reconstruction stiffness and work required to produce 10° of angular displacement.

The last group that biomechanically evaluated the interference screw technique was McAdams et al.[33] They compared the interference bioabsorbable screw technique with the docking technique after cyclic loading.The interference screw reconstruction was significantly more stiffer than the docking technique with regard to resistance to valgus torque. Based on the previously mentioned 5 biomechanical studies, it is unclear which MUCL reconstruction technique is the best (table 2). Only McAdams et al. used bio- absorbable screws, and they found no failures at the interference screw site[33]. In contrast, Armstrong et al., Furukawa et al., and Large et al. used metal screws to prevent graft slippage and noticed graft slippage in 70% and 100% of cases, respectively[30-32]. A biomechanical study by Hurbanek et al.[34] evaluating the addition of a bioabsorbable interference screw at the humeral side of the docking technique, resulted in a laxity no different than the intact native MUCL. Among the failures, the graft slipped past the undersized screw 4 times[34]. Interestingly, Ahmad et al.[15] and Armstrong et al.[30] used 5.0-mm screws for 5.0-mm tunnels, Large et al.[32] used 5.0-mm screws for tunnels with a diameter of 5.5-mm, and Hurbanek et al.[34] used a 4.75- mm screw for a 5.0-mm tunnel, whereas McAdams et al.[33] used an oversized screw of 4.75 mm for a tunnel of 4.5 mm.

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Table 2: comparison of the interference screw technique in the literature.

Author	Year	Test	Graft	Screw	Comparison	Results
Ahmad et al	2003	1. failure load. 2. stiffness.	Palmaris longus	Metal	1. Intact UCL	1. IST failure load of 95% of intact UCL. 2. intact UCL sig. greater stiffness than IST.
Armstrong et al	2005	1. failure load. 2. cycles.	Palmaris longus	Metal	1. figure-of-8 2. docking 3. endobutton	1. docking sig. greater failure load than IST. 2. no sig. difference in cycles between IST and other techniques.
Furukawa et al	2007	1. failure load. 2. cycles.	Palmaris longus*	Metal	1. docking	1. no sig. difference for failure load. 2. no sig. difference in number of cycles.
Large et al	2007	1. stiffness. 2. work to achieve 10° ang	Hamstring allograft	Metal	1. intact UCL 2. figure-of-8	1. intact UCL sig. greater stiffness than IST. 2. sig. more work in figure-of-8 compared to IST.
McAdams et al	2007	1. cyclic failure number. 2. valgus angle opening.	Palmaris longus	Bioabs.	1. intact UCL 2. docking	1. no sig. difference in number of cycles. 2. at cycle 10 and 100 sig. more valgus opening of docking compared to IST. 3. at cycle 1000 sig. more valgus opening of docking and IST compared to intact.

Ang, angular displacement; bioabs, bioabsorbable; IST, Interference Screw Technique; sig., significant;
* comparison with Graftjacket as graft is not presented since it has not been used in clinical studies.

To our knowledge, this is the first clinical outcome study evaluating the interference screw technique to reconstruct the MUCL at the elbow. At a mean follow-up of 55 months there were no clinical signs of graft failure. Radiological evaluation showed no complications at the interference screw site. In this study, we have used 5.5-mm bio-absorbable screws for 5.0-mm tunnels. This might create a better graft fixation in the tunnel to prevent slippage, while the stress in the tunnel is within limits in relation to fractures around the tunnel. We believe that oversized screws are safe as long as they are bioabsorbable, as there were no fractures associated with screw insertion both in this study as well as McAdams et al.[33]. Based on the previously mentioned biomechanical studies and this study is graft fixation with oversized bioabsorbable screws superior, as the combination of oversizing and bioabsorbable screws was the only one that resulted in no complications. Furthermore, we prefer bioabsorbable interference screws, as these screws can be replaced by normal bone. However, in all patients, the drill holes are still visible on radiographs at latest follow-up and replacement by normal bone was not seen in any case.

In this study, there were no complications related to the triceps tendon graft. The use of a triceps fascia autograft for reconstructions around the elbow was first described by Olsen et al. in 2003[27]. The use of triceps tendon fascia autograft overcomes the problem of patients with an absent palmaris longus tendon. As previously mentioned, this problem might occur in up to 37.5% of patients; it is also suggested that this tendon might be even disappearing in humans[21]. Biomechanical studies evaluating tendon property found failure load of 706 N for the triceps fascia, which exceed the palmaris longus (357 N) and the anterior band of the MUCL (260 N)[23, 26, 35]. This indicates that a triceps tendon autograft is able to withstand sufficient forces when used to reconstruct the MUCL. Furthermore, the use of triceps autograft has the advantage that it can be harvested by using the same incision. This last advantage also counts for the flexor carpi ulnaris (FCU) aponeurosis autograft. Slulittel et al. described a MUCL reconstruction technique using this graft in 12 patients with 3 postoperative complications: 1 patient with an ulnar nerve hyperesthesia, 1 with a flexion contracture, and 1 with residual instability[36]. Unfortunately, they did not describe clinical outcome measures or return to sports. The FCU aponeurosis, to our knowledge, has not been biomechanically tested. It is therefore unknown whether it is strong enough to serve as a MUCL graft. However, it is an interesting graft source and deserves further investigation to its clinical usefulness.

This cohort of patients had a relatively high percentage of athletes who had quit their sport activities, even after a successful 'come-back' surgery, without elbow complaints. One possible explanation is that most athletes in this study did not play at a professional level and, therefore, did not financially depend on their sport performances. The surgeon treating European athletes should be aware of this phenomena, as the rehabilitation after MUCL reconstruction is long, and the time of successful playing after reconstruction in this specific group of European athletes is short. These phenomena should be taken into consideration in the decision to advice an MUCL reconstruction in all European athletes. All European surgeons and athletes should be aware that the indication for and results after MUCL surgery are not comparable to those in American and Asian reports.

In previous reports, 99% of the MUCL reconstructions was done on male patients[10]. Male patients represent a 35% minority in this study. However, among the patients who quit sports were 3 male and 3 female patients. Thus 43% of the male and 23% of the female patients gave up sports activities. The relatively high amount of patients that quit sports seems to be unrelated to the male-female distribution in this cohort. Another point of interest is the wide variety of sports practiced in this study, with throwing sports accounting for 55% (11 patients). In this subgroup of throwing athletes, 1 patient stopped within 1 year because of persistent posterior impingement and 2 patients stopped after 2.5 and 3 years, respectively, because of financial reasons and low back pain. The good results in this varied population may not guarantee good results in pitchers and other high demanding overhead athletes.

The current study has several limitations. First, with 20 patients included, the sample size is small and the surgeon performed just around 3 MUCL reconstructions each year. Second, it is a retrospective analysis, not comparing different techniques. Third, the MEPS score focuses primarily on elbow function during daily life activities and not on sport activities. The Conway score describes the level to which the patient returns in sports, but lacks in patient reported outcome and may therefore report a discrepancy between the actual result of the reconstruction and postoperative level of sports. Unfortunately, patient-reported outcome measures such as the sport DASH and Andrews-Carson elbow outcome scores were not validated for Dutch practice in 2001.

This is the first clinical outcome study to evaluate the bioabsorbable interference screw and a triceps tendon fascia autograft for MUCL reconstructions. Although the number of patients included is limited, good results were obtained in most cases with good postoperative MEPS scores and clinically stable MUCL.

Conclusion

Triceps fascia can be used for MUCL reconstruction as an alternative graft for the palmaris longus tendon. The interference screw technique is a simple and safe technique to restore valgus stability in the elbow. The technique and graft should be further evaluated for its use in high-level pitchers or overhead sports performers. The dropout in European athletes, even after successful reconstruction, is high and should be taken into account during the decision making for MUCL surgery.

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FRACTURES OF THE RADIAL HEAD

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Chapter 6

The effect of trauma and patient related factors on radial head fractures and associated injuries in 440 patients

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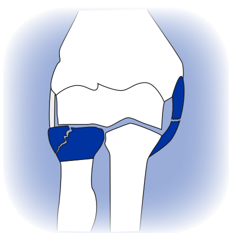

BMC Musculoskelet Disord. 2015 Jun 5;16:135.

Abstract

Background: Radial head fractures are commonly interpreted as isolated injuries, and it is assumed that the energy transferred during trauma has its influence on the risk on associated ipsilateral upper limb injuries. However, relationships between Mason classification, mechanism of injury, and associated injuries have been reported only once before in a relatively small population. The purpose of this study was to define whether trauma mechanism and patient related factors are of influence on the type of radial head fracture and associated injuries to the ipsilateral upper limb in 440 patients.

Methods: The radiographs and medical records of 440 patients that presented with a fracture of the radial head were retrospectively analyzed. The medical records of all patients were searched for (1) the trauma mechanism and (2) associated injuries of the ipsilateral upper limb. The mechanism of injury was classified as being low-energy trauma (LET) or high-energy trauma (HET).

Results: Associated injuries to the ipsilateral upper limb were present in 46 patients (11%). The mean age of patients with associated injuries (52 years) was significantly higher compared to patients without associated injuries (47 years) (P = 0.038), and female patients with a radial head fracture were older than males. Injury patterns were classified as LET in 266 patients (60%) and as HET in 174 patients. HETs were significantly more common in young men. Associated injuries were not significantly different distributed between HET versus LET (P = 0.82).

Conclusions: Injuries concomitant to radial head fractures were present in 11% of patients and the risk for these associated injuries increases with age. Trauma mechanism did not have a significant influence on the risk of associated injuries. Complex elbow trauma in patients with a radial head fracture seems therefore to be suspected based on patient characteristics, rather than mechanism of injury.

Keywords: Associated injury, Elbow, Mechanism of injury, Radial head fracture, Trauma.

Background

Radial head fractures are common with an estimated incidence of 28-39 per 100.000 inhabitants per year[1, 2]. The trauma mechanism of radial head and neck fractures is by indirect impact along the radius, usually caused by a fall on the outstretched hand in pronation and elbow in slight flexion[2, 3]. Previous epidemiological studies by Duckworth et al. and Kaas et al. revealed a mean age of 43–48 years and a significantly higher age of female patients compared to males. Both authors questioned whether this phenomenon could be caused by osteoporosis[1, 2]. In a subsequent case-control study including peripheral bone mineral density (BMD) measurements, radial head fractures in female patients above 50 years old were defined as potentially osteoporotic fractures[4].

Although radial head fractures are commonly seen as isolated injuries, associated injuries are reported in up to 92% of cases[5]. More complex injuries according to the Mason classification seem to be associated with other associated ipsilateral upper limb injuries[2]. Both the complexity of the fracture pattern as per the Mason classification and the risk of associated ipsilateral upper limb injuries are assumed to be related to the energy transferred during trauma. However, little is known about the effects of patient and trauma related factors on the complexity of the radial head fracture and associated injuries.

Because significant symptomatic associated injuries are present in only a minority of radial head fractures, it might be helpful for the clinician to increase the a priori suspicion for more complex elbow trauma based on patient and injury characteristics. The purpose of this study was therefore to define whether trauma mechanism and patient related factors are of influence on the type of radial head fracture and associated injuries to the ipsilateral upper limb. We hypothesized that associated injuries are more common in the elderly and patients that sustained a high-energy trauma. In order to answer these study questions, the current report describes the assessment and analysis of 440 patients with a fracture of the radial head.

Methods

Consecutive patients who presented with a fracture of the radial head at the emergency department (ED) of our hospital during a 4-year period were retrospectively identified. This level 2 trauma center provides a region of 400,000 inhabitants with acute medical care and is annually visited by approximately 44,000 patients. Trained residents in general and/or orthopedic surgery performed primary assessment and management of all patients at the ED. A trauma surgeon and an orthopedic surgeon reviewed the diagnosis and treatment. Inclusion criteria were radiographically confirmed acute fracture of the radial head and skeletal maturity. Patients with missing data about the mechanism of injury in their medical record or absence of initial radiographs were excluded. Approval for this study was waived by the ethics committee of the Amphia Hospital.

Radial head fractures on initial radiographs of the elbow obtained at the ED were classified according to the Mason classification[6]. The medical records (e.g. emergency notes) of all patients were searched for (1) the trauma mechanism and (2) diagnosis of associated injuries of the ipsilateral upper limb. Data extraction was performed by two of the authors. All radiographs of the ipsilateral upper limb and medical records were reviewed to identify possible associated injuries. Standardized radiographs with anteroposterior and lateral views were made in all patients. An additional radial head view was made in 120 patients and a CT-scan of the elbow in 30 patients. Additional imaging studies were not performed on a regular basis, but only if clinical assessment (e.g. physical examination) or primary radiographs indicated the probability of associated injuries. Retrospective assessment of radiographs was done by a senior orthopedic resident specially trained in radial head fractures. The mechanism of injury was noted as being low-energy trauma (LET) or high-energy trauma (HET), see table 1[2].

Table 1: classification of mechanism of injury.

Trauma mechanism	Examples
LET	Fall from standing position, fall from chair, fall during walking.
HET	Fall from roof, motor vehicle accidents, fall from bicycle or horse with speed, contact sports trauma.

HET = high energy trauma; LET = low energy trauma.

Statistical analysis (SPSS 20.0 IBM corporation, Armonk, NY, USA) was performed using the independent T-test and one-way ANOVA test to compare numerical data between groups of patients and the Fisher's exact test and Chi-squared test for categorical data. Odds ratios were obtained by logistic regression. In order to provide mutual independency between cases, only one of the cases with bilateral fractures was included in analyzes between groups. Results were considered statistically significant at $P < 0.05$.

Results

Over the selected period, the records of 450 patients that presented with a radial head fracture were reviewed. Ten patients were excluded since there was no information about the mechanism of injury reported. The mean and median age of the remaining 440 patients was 47 years (range 14–88, SD 16.5), and there were 278 (63%) female patients. The mean age was 40 years for male patients, which was significant younger than the 52 years for female patients ($P < 0.001$) (figure 1). Mason type-1 fractures were identified in 319 patients (73%), type-2 fractures were seen in 84 patients (19%) and type-3 fractures in 37 patients (8%). Associated injuries to the ipsilateral upper limb were present in 46 patients (11%) and are summarized in table 2 and an example of an associated injury (coronoid fracture) on radiographs in figure 2. Injury patterns were classified as LET in 266 patients (60%) and as HET in 174 patients. Ten patients (2%) had a radial head fracture following elbow dislocation. Thirteen patients (3%) sustained two radial head fractures during the inclusion period. Since mutual independency between cases was required, only one fracture per patient was included in statistical analyzes between groups.

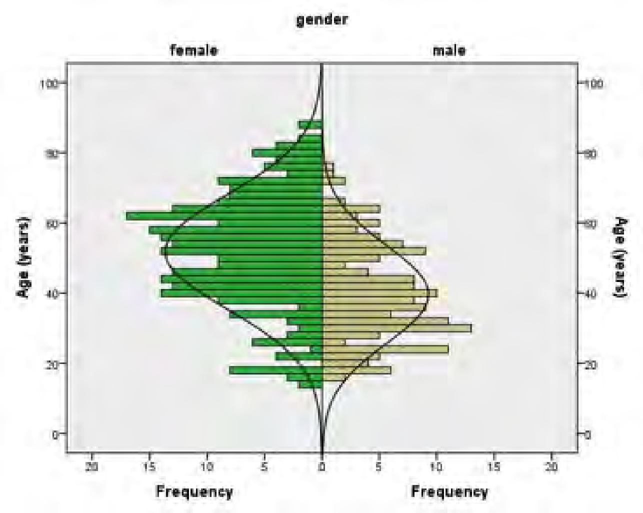

Figure 1: Age distribution of patients with a radial head fracture.

Table 2: Types and frequencies of associated injuries.

	Mechanism of injury			
Types of associated injuries.	LET	HET	Total (%)	Cumulative percent
Distal radius fracture	4	0	4 (8.7)	8,7
Carpal fracture	9	3	12 (26.1)	34,8
SL dissociation	1	1	2 (4.3)	39,1
Proximal ulna fracture	3	1	4 (8.7)	47,8
Coronoid fracture	7	7	14 (30.4)	78,3
UCL injury	0	1	1 (2.2)	80,4
LCL injury	1	1	2 (4.3)	84,8
Coronoid + LCL injury (dislocation)	0	3	3 (6.5)	91,3
Capitellum injury	1	1	2 (4.3)	95,7
DRUJ dislocation (Essex Lopresti injury)	1	0	1 (2.2)	97,8
Humeral fracture	0	1	1 (2.2)	100,0
Total	**27**	**19**	**46**	

DRUJ = distal radioulnar joint; HET = high energy trauma; LCL = lateral collateral ligament; LET = low energy trauma; SL = scapholunate; UCL = ulnar collateral ligament.

The mean age of patients with associated injuries (52 years) was significantly higher compared to patients without associated injuries (47 years) (P= 0.038). The odds for an associated injury for each year increase in age in females was 1.031 (95 % CI: 1.006-1.057; P= 0.015) and in males 0.989 (95 % CI: 0.950-1.029; P= 0.59). These odds ratios did not significantly differ between females and males (P= 0.082). The age-adjusted odds ratio of females to males was 1.189 (95 % CI: 0.532-2.660; P= 0.67).
Table 3 illustrates the distribution of Mason fracture types for associated injuries. There was a significant difference in Mason fracture type comparing patients with and without associated injuries (P< 0.001). Associated injuries were not significantly different distributed between HET versus LET (P= 0.82) (table 4).

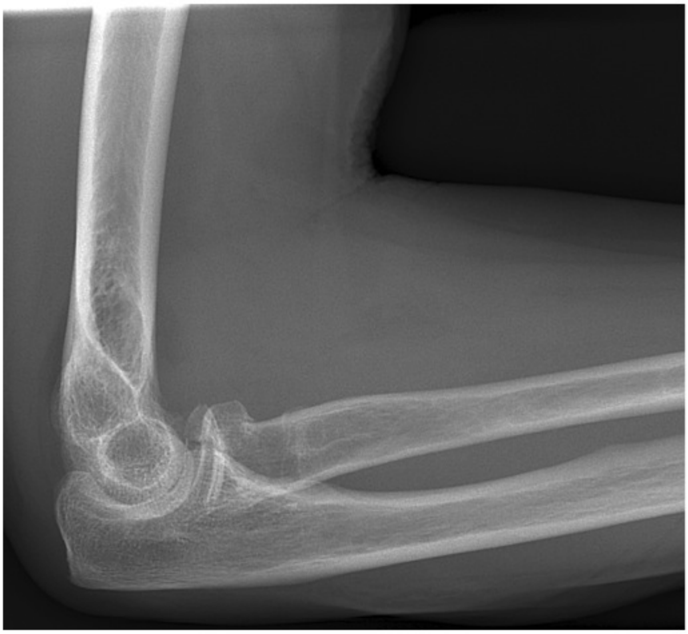

Figure 2: associated injury (coronoid fracture) on radiograph.

Mean age of patients with a HET was 43 years compared to 51 years for LET (P< 0.001). The distribution of HET versus LET was significantly different for males versus females, with more HET for male patients (P< 0.001). There was no significant difference in Mason fracture type for HET versus LET. There were no age-specific differences for the type of Mason fracture (P= 0.23).

Table 3: Distribution of Mason fracture types for associated injuries.

		Associated injury		
		-	+	Total
Mason type	1	289	19	308
	2	72	10	82
	3	20	17	37
Total		381	46	427

Table 4: Distribution of HET versus LET for associated injuries.

		Associated injury		
		-	+	Total
Mechanism of injury	LET	230	27	257
	HET	151	19	170
Total		381	46	427

HET = high energy trauma; LET = low energy trauma.

Discussion

The radial head is an important secondary stabilizer of the elbow[7]. Especially in combination with deficiency of the collateral ligaments or coronoid fractures, elbow stability heavily relies on an intact radial head[8]. Accurate recognition and assessment of all associated injuries are necessary to initiate the correct treatment of the injury; early adequate management is mandatory to improve the clinical outcome[8, 9]. The radial head fracture is, in general, believed to be an isolated, simple injury with a benign outcome. However, associated injuries with radial head fractures are increasingly recognized for their clinical significance[10-12]. The current study revealed an 11% risk of symptomatic associated injuries, which increases with age and Mason fracture type.

It is thought that the complexity of the injury is related to the amount of energy transferred during the trauma. However, in this study energy transfer during trauma was not related to associated injuries or Mason fracture type. Radial head fractures following HET occurred most frequently in young men. HET did not lead to more associated injuries or more complex radial head fractures than LET in the current study. The only predictors for more associated injuries were a higher Mason fracture type and a higher age. High-energy transfers through the elbow joint during trauma did not result in more concomitant injuries in young patients, in contrast to older patients that sustain LET more commonly. Based on these observations, we assume that additional injuries, next to radial head fractures, were also dependent on the intrinsic quality of bone and soft tissues and a frailty phenotype of the elderly patient. Therefore, complex elbow trauma in patients with a radial head fracture should be suspected based on patient characteristics rather than the mechanism of injury.

Mechanism of injury of radial head and neck fractures have been categorized by Duckworth et al. in low-energy (e.g. fall from standing height) and high-energy (e.g. sports trauma or fall from height), as is done in the current study[2]. They observed significant more HETs in males, and HET was defined as a significant risk factor for associated injuries. HETs occurred in 43% of the 285 patients in their series and associated injuries were present in 7% of patients. The current study identified 40% of injuries as HET, and 11% of patients had associated injuries. However, HETs were no significant risk factors for additional injuries in this series. One explanation for this difference might be that Duckworth et al. analyzed both radial head and neck fractures, whereas we included only radial head fractures. They suggested that radial neck fractures were – more than radial head fractures – low-energy fragility fractures. Another explanation might be that associated injuries occur by the direction of impact during trauma rather than by the amount of energy transferred during trauma. McGinley et al. found that axial impact in neutral position of the forearm resulted in isolated radial head fractures, whereas loading in pronation resulted in more comminuted fractures with associated lesions of the interosseous membrane[13]. Thus, *how* the energy is transferred may be more important than *how much* energy is transferred during trauma.

In this study, associated injuries were more frequently observed in the elderly, and female patients with a radial head fracture were older than males. These findings are in agreement with suggestions that radial head fractures are potentially osteoporotic fractures[4]. Gebauer

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et al. recently performed cadaveric studies on the microarchitecture of the radial head[14]. BMD and histomorphometric analysis were performed on radial heads of three different groups of cadavers; aged 20-40 years, 41-60 years, and 61-80 years. They showed a significant decrease in BMD with increasing age for men and women. Trabecular thickness significantly decreased with age, whereas trabecular separation significantly increased with age, leading to more radiolucency of the radial head on radiographs with aging. These age-related changes in microarchitecture of the radial head were suggested to reduce the biomechanical stability of the bone[14]. Since associated injuries were more commonly observed in older patients in the current study, we assume that older female patients with a radial head fracture overall have a diminished bone quality. As the extent of the injury varies with the position of the forearm during a fall, the way elderly fell may also account for the higher amount of associated injuries. Overall, a frailty phenotype is associated with a greater risk of fracture, disability and falls in elderly women[15]. It seems therefore critical to maintain optimal bone and soft tissues qualities, as well as overall physical condition, in the aging population in order to prevent more complex elbow injuries.

The more complex the radial head fracture is according to the Mason classification, the higher the frequency of associated injuries in the current study. Associated injuries were identified in almost half of the patients with a Mason type-3 fracture of the radial head. Kaas et al. noticed associated injuries on MRI in even 100% of patients with a Mason type-3 fracture[16]. Therefore, thorough evaluation of the elbow by a preoperative CT- or MRI-scan and/or intraoperative stability testing using fluoroscopy might be preferable to adequately deal with possible associated injuries in all Mason type-3 fractures. With regard to Mason type-2 fractures, Rineer et al. identified concomitant injuries in 77% of patients[17]. They divided Mason type-2 fractures in two groups based on the existence of cortical contact between the fracture fragment and the radial head. Fracture fragments without cortical contact led to a 21-times greater risk for associated injuries. Loss of cortical contact was in the current study seen in 37% (17 of 46) of patients with associated injuries, versus 6% (24 of 381) of patients without associated injuries. However, the distribution of radial head fractures among the Mason fracture types in the study from Rineer et al[17] is variant to those of Kaas et al.[1], Duckworth et al.[2], and the current study, as is the amount of associated injuries for Mason type-2 fractures. Nevertheless, as Rineer et al. concluded: 'if imaging studies fail to demonstrate the presence of a complex elbow injury pattern, the surgeon should still have a high suspicion that some degree of occult instability may be present' in Mason type-3 fractures and Mason type-2 without cortical contact[17].

The current study was with 440 included patients one of the largest studies on the epidemiology of radial head fractures[1, 2, 18, 19]. The influences of mechanism of injury on radial head and neck fractures and associated injuries have only been once reported before[2]. The current study focused both on modes of injury and patient related factors on associated injuries for radial head fractures, leading to other findings. This study had several limitations in addition to its retrospective nature. First, associated injuries were documented based on available imaging studies instead of standardized radiographic studies for all patients.

For instance, a standard MRI was not performed, and the LCL lesions in this study were identified as avulsion fractures from the epicondyle or during surgical reconstruction of Mason type 3 fractures. However, since most associated injuries are not clinically relevant, it is not advised to perform MRI scans on a regular basis for radial head fractures[10]. Second, the interobserver reliability of the Mason classification is known to be only moderate[20]. In addition, it might be difficult to take standardized radiographs of the elbow in the acute setting because of pain. Third, there is no clear definition of amounts of energy that are transferred during different mechanisms of injury. Moreover, the direction of impact (axial, direct, rotation of forearm, etc.) during trauma, may be more important to sustain associated injuries than the kind of trauma[21].

Future research should concentrate on Mason type-2 and type-3 fractures and the association with clinically and therapeutically relevant associated injuries. The impact of energy transfer during trauma and its consequences on associated injuries should be established. The indications for additional imaging studies for these fractures need to be explored.

Conclusions

Injuries concomitant to radial head fractures were present in 11% of patients and the risk for these associated injuries increases with age. Furthermore, the risk for associated injuries increases with complexity of the radial head fracture according to the Mason classification. Trauma mechanism did not have a significant influence on the risk of associated injuries. Complex elbow trauma in patients with a radial head fracture seems therefore to be suspected based on patient characteristics, rather than mechanism of injury. Associated injuries should be actively be explored in older patients with Mason type-2 or type-3 fractures by means of physical examination of the whole ipsilateral arm and potential additional radiographic studies.

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CHAPTER 7

A randomized controlled trial of nonoperative treatment versus open reduction and internal fixation for stable, displaced, partial articular fractures of the radial head: the RAMBO trial

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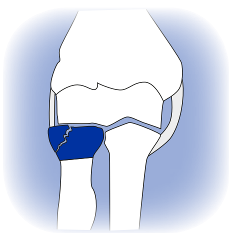

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Abstract

Background: The choice between operative or nonoperative treatment is questioned for partial articular fractures of the radial head that have at least 2 millimeters of articular step-off on at least one radiograph (defined as displaced), but less than 2 millimeter of gap between the fragments (defined as stable) and that are not associated with an elbow dislocation, interosseous ligament injury, or other fractures. These kinds of fractures are often classified as Mason type-2 fractures. Retrospective comparative studies suggest that operative treatment might be better than nonoperative treatment, but the long-term results of nonoperative treatment are very good. Most experts agree that problems like reduced range of motion, painful crepitation, nonunion or bony ankylosis are infrequent with both nonoperative and operative treatment of an isolated displaced partial articular fracture of the radial head, but determining which patients will have problems is difficult. A prospective, randomized comparison would help minimize bias and determine the balance between operative and nonoperative risks and benefits.

Methods/Design: The RAMBO trial (Radial Head – Amsterdam – Amphia – Boston - Others) is an international prospective, randomized, multicenter trial. The primary objective of this study is to compare patient related outcome defined by the 'Disabilities of Arm, Shoulder and Hand (DASH) score' twelve months after injury between operative and nonoperative treated patients. Adult patients with partial articular fractures of the radial head that comprise at least 1/3rd of the articular surface, have ≥ 2 millimeters of articular step-off but less than 2 millimeter of gap between the fragments will be enrolled. Secondary outcome measures will be the Mayo Elbow Performance Score (MEPS), the Oxford Elbow Score (OES), pain intensity through the 'Numeric Rating Scale', range of motion (flexion arc and rotational arc), radiographic appearance of the fracture (heterotopic ossification, radiocapitellar and ulnohumeral arthrosis, fracture healing, and signs of implant loosening or breakage) and adverse events (infection, nerve injury, secondary interventions) after one year.

Discussion: The successful completion of this trial will provide evidence on the best treatment for stable, displaced, partial articular fractures of the radial head.

Trial registration: The trial is registered at the Dutch Trial Register: NTR3413.

Keywords: Radial head, Mason type 2, Operative, Nonoperative, Open reduction, Internal fixation, Randomized controlled trial

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Background

In 1953, Mark Mason wrote his landmark paper on the classification of radial head fractures[1]. Despite several modifications, the classification is still limited with regards to the description of stability of the fractured fragments. Fracture stability is potentially important because unstable fractures are typically associated with other injuries to the elbow or forearm[2-4]. We therefore prefer describing the characteristics of the fracture we are addressing; stable, displaced, partially articular fractures of the radial head.

Open reduction and internal fixation (ORIF) of fractures of the radial head became popular after the advent of implants and techniques for the fixation of small articular fracture fragments[5-10]. Subsequently, enthusiasm grew with reports of good results on operative treatment of isolated, displaced, partial articular fractures[7, 9, 11].

Members of our study group described satisfactory long-term elbow function following ORIF of these fractures, but with a high complication rate of 44%[12]. A limitation of this study is the fact that many of the screws used were of a larger diameter than those that would be used today.

A recent meta-analysis by Kaas et al. compared the results of operative and nonoperative treatment of isolated, displaced, stable, partial articular fractures of the radial head[13]. Nine retrospective case series describing 224 patients met their inclusion criteria. Successful treatment was defined as an excellent or good result according to various performance scores. Nonoperative treatment was successful in 114 of 142 patients (80%) pooled from the studies. Subsequent operative treatment after failed nonoperative treatment was reported in three patients (2%). Open reduction and internal fixation was successful in 76 of 82 patients (93%), with subsequent surgery in four patients (5%). These differences were statistically significant; however, the authors noted that the level of evidence of the included studies was too low to support any firm conclusions.

There is currently no consensus as to the optimal treatment of patients with isolated, displaced, stable, partial articular fractures of the radial head. This multicenter prospective randomized trial compares DASH scores twelve months after screw fixation vs. nonoperative treatment and will help to find the balance between operative and nonoperative risks and benefits.

Methods

Study design

The RAMBO trial is a prospective, international multicenter, randomized controlled trial. Two academic and six teaching hospitals in the Netherlands as well as a teaching hospital in the United States and a teaching hospital in Canada will participate.

Recruitment and consent

All adult patients with partial articular fractures of the radial head that comprise ≥1/3rd of articular surface have ≥2 millimeters of articular step-off but less than 2 millimeters of gap between the fragments presenting to either the emergency department or the

outpatient departments of the participating hospitals will be invited to participate in the trial. The fractures are evaluated on standard anteroposterior (AP) and lateral radiographs with optional Greenspan view. An additional Computed Tomography (CT)-scan with axial, coronal and sagittal reconstructions will be made for post-hoc analysis.
The treating surgeon or a member of the study staff will introduce and explain the trial to the patient and address any questions the patient might have. The patient will receive a written information form and a consent form. After receiving informed consent, eligible patients will be randomized. We will use a block randomization strategy with random blocksize and stratify for participating country and age of the patients. Age groups will be 18-49 and ≥50 years old. Applicants will be allocated to either operative or nonoperative treatment using a web-based randomization program. This web-based program is secure and only members of the study staff have login credentials. It is not possible to blind surgeons and patients for the allocated treatment.

Study population

Patients with the following inclusion criteria are eligible for enrollment:

- ≥18 years of age.
- Partial articular fractures of the radial head that comprise at least 1/3rd of the articular surface, have at least 2 millimeter of articular step-off but less than 2 millimeter of gap between the fragments.
- Diagnosis based on an anteroposterior and lateral radiograph (with additional Greenspan view if necessary).
- A CT-scan will be obtained after enrollment/ randomization.
- Fracture amenable to screw fixation according to pre-operative judgment of operating surgeon.
- Definitive treatment initiation <10 days after date of injury.

If any of the following criteria apply, patients will be excluded:

- Polytraumatized patients (ISS >15).
- Other fractures or dislocations of the ipsilateral or the contralateral upper extremity.
- Radial head fracture as part of an elbow dislocation or associated fractures of the ipsilateral elbow or forearm.
- A nondisplaced or comminuted fracture (also known as Mason type-1 or -3).
- Open fracture.
- Pathologic fracture.
- Previous ipsilateral olecranon/distal humerus/radial head fracture.
- Pre-existent neurological disorders affecting the upper extremity.
- Patient unable to follow treatment protocol.
- Unfit for general anaesthesia and/or operative management.

Intervention

Patients that are assigned to nonoperative management will receive a sling for comfort and are instructed to start active and active-assisted range of motion exercises after a resting period of 48 hours. Patients that are assigned to ORIF will be treated by screw fixation of the radial head. The approach as well as the number and type of screws used is subject to the preference of the treating surgeon and will be recorded in our study log. Patients in both cohorts will be given a leaflet containing instructions for exercises to regain motion. Patients that prefer to do their exercises with coaching and supervision can work with an occupational or physical therapist or see their surgeon more frequently.

Outcome measures

The primary outcome measure is the DASH outcome measure; a validated, self-reported questionnaire designed to help describe the disability experienced by people with upper-limb disorders and also to monitor changes in symptoms and function over time[14-16]. The DASH outcome measure is scored in two components: the disability/symptom section (30 items, scored 1-5) and the optional high performance Sport/Music or Work section (4 items, scored 1-5). The DASH gives a score out of 100, in which a higher score indicates greater disability. The DASH outcome score is validated in both the English and Dutch language.

Secondary outcome measures consist of:
– The Oxford Elbow Score (OES), which reflects both function and pain following elbow surgery. The OES consists of three domains; pain, function and social-psychological. Each domain comprises of 4 questions with 5 response options per question. Each response is scored 0 to 4, with 0 representing greater severity. Scores for each domain are calculated as the sum of each individual item score within that domain. These scores are then converted to a metric score between 0 and 100 (a lower score represents greater severity)[17, 18].
– The Mayo elbow performance score (MEPS), which is based on 4 domains (pain, range of motion, stability and elbow function). A total score between 90 and the maximum 100 points is considered excellent; 75–89 is good; 60–74 is fair and less than 60 points is poor[19].
– Elbow pain; Pain level will be determined using the Numeric Rating Scale, an 11–point scale for patient self-reporting of pain.
– Active and passive range of motion (flexion, extension, pronation, supination) of both elbow joints will be measured on both sides using a universal goniometer.
– Crepitance or block to motion will be assessed with elbow and forearm motion at admission and every follow up visit.
– Number of complications (infection, neurovascular compromise, subsequent or secondary intervention, arthrosis).
– Determining the need for and number of secondary interventions.
– Radiographic appearance of the elbow joint will be evaluated on the anteroposterior and lateral radiographs at one year. Heterotopic ossification will be classified as a bone

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exostosis or as soft tissue ossification of a ligament, capsule or muscle ("myositis ossificans") according the classification scheme of Broberg and Morrey[20]; degenerative changes of the radiocapitellar and ulnohumeral joints will be classified as grade zero (no change), grade 1 (slight narrowing of the joint space with small osteophytes), grade 2 (moderate narrowing of the joint space, osteophytes and subchondral sclerosis), or grade 3 (severe narrowing of the joint space, large osteophytes, subchondral sclerosis and cystic deformation). The final radiographs will also be evaluated for fracture healing and signs of hardware failure or other complications.

Study procedures

Clinical assessment will be performed at admission (baseline), three, six months and one year after treatment initiation. At each follow-up visit the surgeon will perform a physical examination of both elbows and complete the MEPS and NRS scores. Simultaneously, the patient will be sent a link to the online, patient-specific DASH and OES questionnaires: this will be monitored by the study coordinator. At the two weeks and twelve months follow-up visit an anteroposterior and lateral radiograph of the elbow will be made. At the last follow-up visit, an independent and blinded researcher will record any interventions, complications and physical therapist visits.

Sample size calculation

The primary outcome variable will be the DASH, which has a minimal clinically important difference of 17 for the elbow[16]. Consequently, a 2-sided unpaired T-test with an alpha-level of 0.05, a beta-level of 0.1, and an allocation ratio of 1, requires 31 patients in each group to detect an effect size of 0.85. Anticipating a dropout rate of 25%, a sample size of 39 patients in each arm is required.

Statistical analysis

Normality of continuous data will be tested with the Shapiro-Wilk and Kolmogorov-Smirnov test as well as by inspecting the frequency distributions (histograms). Homogeneity of variances will be tested using the Levene's test. The analysis will be performed on an intention to treat basis. Patients with protocol violations will remain in follow-up, and data will be recorded. Data will be analyzed with and without inclusion of patients with a protocol violation. Descriptive analysis will be performed to report baseline characteristics in both treatment groups. For continuous data (e.g. age), means and standard deviations (parametric data) or medians and percentiles (nonparametric data) will be calculated. For categorical data (e.g. gender) frequencies will be calculated.

Patients will be analyzed according to the intention-to-treat protocol. The primary outcome, DASH at one year will be corrected for age and assessed using an analysis of covariance (ANCOVA). Trends in DASH scores among the different time points will be assessed using a repeated measures ANOVA if the data is normally distributed. The secondary outcomes; MEPI, OES, pain as indicated on a Numerical Rating Scale (NRS), Range of Motion (ROM) will be analyzed in a similar manner. The radiological outcome, number of conversions and complication rate will be determined using either a Fisher Exact or a Chi square test, depending on the order of magnitude of the results.

Ethical considerations

Considering current evidence, no clear preference exists for either one of the treatment allocations in this study. Both treatment modalities are regularly applied for these fractures in each of the participating institutions. All surgeons participating in this study are familiar with nonoperative and operative management of patients with radial head fractures. Except for the assignment of treatment, management will not differ from patients with similar conditions that are not enrolled in the study. Patients will be exposed to radiation from radiographs. However, this exposure is part of routine clinical care and represents no increased risk. No additional radiographs will be made as part of this study. The risks and discomfort of participating in this study do not exceed those of expected of standard treatment for this condition. Patients may be inconvenienced by the questionnaires, but we consider this a minor inconvenience, as they will take approximately 10 minutes to complete and can be filled in online.

There is no incentive for patients to participate in this trial. The motivation for the study is a potential benefit to all patients with radial head fractures, as we increase our knowledge on optimal treatment of these fractures.

Monitoring and quality assurance

This study has been approved by the Institutional Review Board of the principal investigators hospital under the number: NL38903.008.11. Approval of local Medical Ethical Committees will be obtained in all participating hospitals separately. At the time of press, local approval was already obtained for 5 out of 9 participating hospitals. All signed informed consent forms will be filed in locked cabinets in research offices. Any personal information collected during this study will be placed in a research folder, and not added to the patient's medical record unless expressly requested by the patient. Functional results (range of motion, complications) and questionnaires will be collected digitally and stored on a password-protected, secured server to which only study staff will have access. Apart from date of birth of included patients, no personal data will be stored digitally.

A member of the study staff will be responsible for monitoring outcomes. No independent monitoring will occur. All investigators and study staff will be responsible for reporting adverse effects to the coordinating investigator. Our coordinating investigator will report adverse events to the ethical committee in accordance with the ethical committee adverse event reporting procedures. The coordinating investigator and the principal investigator are responsible for adherence to all ethical committee rules and guidelines and for the accuracy and completeness of all forms, entries, and informed consent.

Discussion

To date there have been no prospective randomized trials comparing nonoperative treatment and ORIF for stable, displaced, partial articular fractures of the radial head. The RAMBO trial will compare management of these fractures of the radial head by nonoperative treatment and ORIF. ORIF may lead to a better ROM, but may also carry a higher risk of complications. Patient enrollment has started in November 2012 and we expect to enroll 4 patients per month. Considering the one-year follow-up, publication of data will be expected in 2016.

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Chapter 8

Press-fit bipolar radial head arthroplasty, mid-term results

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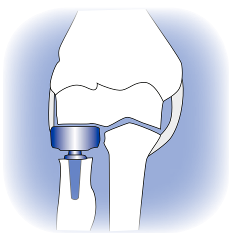

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Abstract

Background: Theoretical advantages of bipolar compared with monopolar radial head arthroplasty include better accommodation of radiocapitellar malalignment, reduction of capitellar abrasion and reduction of stress at the bone-implant interfaces. Our purpose was to report the mid-term results of press-fit bipolar radial head arthroplasty

Methods: Thirty patients were treated by press-fit bipolar radial head arthroplasty for acute fracture of the radial head, failed earlier treatment or posttraumatic sequelae. Three patients were lost to follow-up. Results are presented for the remaining 27 patients.

Results: At mean follow-up of 48 months (range, 28–73) there had been 3 (11%) revisions. Two involved conversion to prosthetic radiocapitellar hemiarthroplasty for symptomatic capitellar abrasion, a third involved exchange of the articular component (i.e. head) for instability. In all, the stems appeared well fixed. A prosthesis in a subluxated position accounted for the one (4%) additional radiological failure. The average flexion-extension arc was 136° (range, 120°-145°) and the average pronation-supination arc was 138° (range, 70°-180°). According to the Mayo Elbow Performance Score the combined excellent and good results accounted for 70%.

Conclusions: The overall mid-term outcome of this series of 30 press-fit bipolar radial head arthroplasties can be considered favorable. Although the revision rate was 11%, the stems were well fixed in all. There was one (4%) additional radiological failure. We would suggest considering a press-fit bipolar radial head prosthesis for acute comminuted radial head fractures with limited bone loss of the proximal radius.

Keywords: elbow; fracture; prosthesis; radius; replacement; trauma.

Introduction

The radial head is an important secondary stabilizer of the elbow and forearm and its integrity becomes crucial to elbow stability especially in the case of disruption of the medial collateral ligament (MCL), the lateral ulnar collateral ligament (LCL) or interosseous membrane and/or large fractures of the coronoid process[1, 2]. Approximately 36% of all radial head fractures are Mason types-2 to -4 and are frequently associated with injury of the aforementioned stabilizing structures[3, 4]. Consequently, prosthetic replacement of the radial head is to be considered for comminuted fractures of the radial head that are not amenable to adequate reconstruction[5].

In general, radial head arthroplasty has been associated with about 85% favorable results when it is performed in the acute situation, but with only about 50% favorable results when it is performed in delayed fashion[6]. Although associated injuries about the elbow may have a significant effect on prosthetic function and survival, hardly any clinical study is of such methodology that it can contribute to quantifying this.

Radial head prostheses may be categorized according to material (silicone, polyethylene, pyrocarbon, metal), modularity (monoblock vs. modular), polarity (unipolar or monopolar vs. bipolar) or method of fixation (cemented, uncemented press fit, intentional loose fit, or fixation with an expandable stem).

The rationale of the bipolar prosthesis is the freedom of movement of the articulating component on the intramedullary component. This may theoretically reduce abrasion of the capitellar cartilage and reduce stress at the implant-bone and bone-cement interfaces during forearm rotations. In addition, radiocapitellar contact may be facilitated and consequently contact pressures be reduced during flexion and extension of the elbow[7]. Also, malalignment of the radius onto the capitellum, which may be the case in longstanding injuries with soft-tissue contracture, may be compensated for to some degree.

Initially, the bipolar radial head prosthesis was cemented[8]. Only more recently, has a short-stemmed, press-fit design become available. The rationale for the press-fit design is to obtain biologic fixation by bone ongrowth onto the stem for optimal long-term fixation. Loosening of cemented implants at the cement-bone interface had been observed in up to 10% of cases with cemented prostheses[7]. In addition, because of the shorter stem, the press-fit prosthesis is easier to implant and may be easier to revise[9]. The literature on bipolar radial head arthroplasty is limited and consists of several mid-term follow-up cases series of cemented arthroplasties[7, 10-14]. To our knowledge, no results have been published on press-fit bipolar radial head arthroplasty.

The purpose of this study was to report our experience with 30 patients who were treated by uncemented (press-fit) bipolar metallic radial head replacement for acute fracture of the radial head, failed earlier treatment or post-traumatic sequelae. We hypothesized that the results would not be different from the results of other types of radial head arthroplasty reported in the literature.

Materials and methods

Approval for this study was waived from our institutions' Medical Ethical Committee since data was collected as part of routine clinical care and each patient was informed that data concerning their case could be submitted for publication.

This is a retrospective case-control study of 30 press-fit bipolar radial head arthroplasties that were performed in our institution between September 2007 and June 2011. All were treated for acute fracture of the radial head or failed earlier treatment or posttraumatic sequelae. The inclusion period was set to ensure minimum follow-up of 2 years for each individual case. The senior author performed all surgeries. Initially, we treated these cases routinely with a cemented bipolar prosthesis. When press-fit designs became available, we started placing a press-fit prosthesis if bone quality was good and the trial components showed a good press-fit and a cemented prosthesis if there was any doubt about bone quality or fixation of the trial components. This is still the algorithm we use in our clinic today.

Implant

The press-fit RHS® bipolar radial head prosthesis (Tornier, Montbonnot-Saint-Martin, France, figure 1) is a modular system and consists of 2 parts. The stem is made of cobalt-chrome and is titanium plasma sprayed. The head is made from high-density polyethylene (PE) encased in cobalt-chrome. The head is available in 4 sizes and articulates with the stem by means of a low-friction, snap-on ball-and-socket joint with 10 degrees bipolarity. The stem is available in 4 length sizes (21, 22, 23 and 24mm) and each size is available in 5 diameters (6-10mm, with 1mm increments). Neck length options are 13mm and 16mm.

Surgical technique

During surgery, the patient was supine with the arm rested on an arm-table. Prophylactic antibiotic coverage consisted of 2000mg of cefazolin intravenously. A tourniquet was used. An extensor split approach (Kaplan interval) was used. The annular ligament was transected and tagged with a stay suture; it was repaired at the end of the procedure. The level of the radial neck osteotomy was visually determined and guided by the lesser sigmoid notch of the ulna[15]. The medullary canal was prepared, a trial prosthesis was inserted to assess the correct height of the prosthesis and the elbow was tested for stability and range of motion. The trial components were then removed and the definite implant was pressed-fit in place. In 22 patients it was necessary to perform additional procedures (table 1). Postoperatively, a pressure bandage was applied for 48 hours and mobilization was started under guidance of a physiotherapist on the first postoperative day. Continuous passive motion was not used. When additional procedures had been performed, this postoperative regimen was adjusted accordingly. Prophylaxis for heterotopic ossifications was not routinely used.

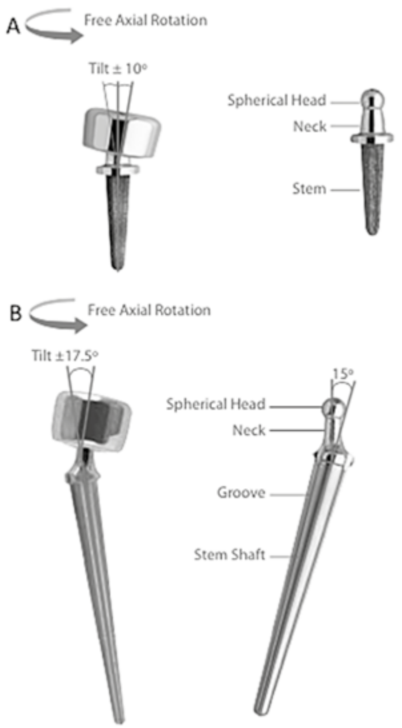

Figure 1: The press-fit RHS® bipolar radial head prosthesis [A] (Tornier, Montbonnot-Saint-Martin, France). For comparison, the cemented prosthesis is also depicted [B].

Follow-up

Medical records were reviewed and each patient was seen in the office for a clinical assessment and radiologic evaluation. Postoperative range of motion was determined using a goniometer, and elbow function was evaluated with use of the Mayo Elbow Performance Score (MEPS)[17]. The MEPS is based on 4 items (pain, range of motion, stability, and elbow function) and has a maximum score of 100 points. A score of 90 to 100 is considered an excellent result; 75 to 89, a good result; 60 to 74 a fair result; and less than 60 a poor result. Radiographs of the elbow were evaluated for signs of loosening, radiocapitellar alignment, osteolysis of the radial neck, lucency, periarticular ossifications, and ulnohumeral degeneration. Osteolysis was evaluated in terms of regions about the radial neck as postulated by Grewal et al.[16] (figure 2). Osteopenia and abrasion of the capitellum were noted to be present or absent. Degenerative changes of the ulnohumeral joint were graded as none, slight, moderate or severe as previously described by Broberg and Morrey[18]. The position of the head of the prosthesis on the capitellum was assessed and possible failure of the snap-on mechanism was evaluated for as described by O'Driscoll and Herald[19].

Table 1: Demographic data of all 30 patients treated by press-fit bipolar radial head arthroplasty.

Case	Sex	Age (years)	Injured side	Dexterity	Indication	Timing	Time since fracture (months)	Previous surgical procedures about the injured elbow	Concomitant surgical procedures
1	F	42	L	R	Mason type-3 RH fracture with persistent dislocation.	Acute	0	None.	LCL reconstruction.
2	M	53	L	L	Terrible triad injury with forearm instability.	Delayed	5	External fixation.	LCL reconstruction.
3	F	42	R	R	Failed ORIF RH.	Delayed	27	ORIF RH, debridement and later removal of fixation material.	Debridement capitellum.
4	F	55	L	R	Failed ORIF RH and lateral humeral condyle.	Delayed	39	ORIF RH and lateral humeral condyle.	Removal fixation material RH and lateral humeral condyle.
5	F	48	L	L	Failed ORIF and RH excision.	Delayed	29	ORIF ulna, RH excision and later removal fixation material.	None.
6	M	61	R	R	Failed RH excision.	Delayed	15	RH excision.	None.
7	F	59	L	L	Failed silicone RH arthroplasty.	Delayed	156	Silicone RH arthroplasty and later removal of the prosthesis.	Debridement capitellum and arthrolysis.
8	M	48	R	R	Terrible triad injury with OCD of the capitellum.	Acute	0	None.	LCL reconstruction and refixation coronoid fracture.
9	F	39	R	R	Malunion RH with valgus instability.	Delayed	6	Ulnar nerve release.	UCL reconstruction, debridement capitellum and ulnar nerve release.
10	M	54	R	R	Failed ORIF RH.	Delayed	9	ORIF RH.	None.
11	M	51	R	R	Pain and limited ROM after Mason type-2 RH fracture.	Delayed	7	None.	Arthrolysis.
12	F	52	R	R	Pain and limited ROM after Mason type-2 RH fracture.	Acute	0	None.	None.
13	F	60	R	R	Failed RH excision.	Delayed	144	RH excision.	Debridement ulnohumeral joint.
14	F	24	L	R	Pain and valgus instability after elbow dislocation.	Delayed	10	None.	Arthrolysis.
15	F	43	R	L	Pain after elbow dislocation with Mason type-3 RH fracture.	Acute	1	None.	LCL reconstruction.
16	F	53	L	L	Mason type-3 RH fracture with valgus instability and positive pivot shift.	Acute	0	None.	LCL reconstruction and debridement capitellum.
17	F	45	L	L	Failed silicone RH arthroplasty.	Delayed	46	Silicone RH arthroplasty.	None.
18	F	57	L	R	Pain and valgus instability after Mason type-2 RH fracture.	Delayed	19	None.	Debridement capitellum.
19	F	46	L	R	Failed silicone RH arthroplasty.	Delayed	216	Silicone RH arthroplasty.	LCL reconstruction.
20	F	49	R	R	Failed RH excision.	Delayed	8	RH excision.	None.

21	M	60	L	R	Terrible triad injury with forearm instability.	Delayed	9	None.	LCL reconstruction and arthrolysis.
22	F	45	L	R	Pain and limited ROM after Mason type-2 RH fracture.	Delayed	3	None.	None.
23	F	56	R	R	Failed ORIF RH and proximal ulna.	Delayed	10	ORIF RH and ulna.	None.
24	M	24	R	R	Terrible triad injury.	Acute	0	None.	LCL reconstruction.
25	F	36	R	R	Failed external fixation and debridement after terrible triad injury.	Delayed	41	External fixation and joint debridement, later LCL reconstruction.	LCL reconstruction.
26	M	63	L	R	Failed ORIF RH.	Delayed	5	ORIF RH.	LCL reconstruction.
27	M	29	L	R	Failed ORIF RH.	Delayed	61	ORIF RH.	LCL reconstruction.
28	F	39	L	R	Failed ORIF RH.	Delayed	5	ORIF RH.	Arthrolysis.
29	F	53	L	R	Failed ORIF and external fixation after open elbow fracture dislocation.	Delayed	16	ORIF ulna and external fixation.	LCL reconstruction.
30	F	57	R	R	Pain and valgus instability after Mason type-2 RH #.	Delayed	10	None.	Arthrolysis.

LCL = lateral collateral ligament; ORIF = open reduction internal fixation; RH = radial head; UCL = ulnar collateral ligament..

Demographic data are presented in table 1. There were 21 women and 9 men. Mean age at surgery was 48 years (range, 24–63 years). There were 16 right and 14 left, and 18 dominant arms involved. Six were operated on for acute fracture, and 5 of those underwent an additional procedure about the elbow at the time of surgery. Twenty-four were operated on for failed earlier treatment of post-traumatic sequelae and 17 of those underwent an additional procedure at the time of surgery. Eighteen of those 24 had undergone previous surgery about the elbow. The average time between initial trauma and press-fit radial head replacement for the delayed cases was 37 months (range, 3 months to 18 years). Three patients were lost to follow-up. End follow-up results are presented and calculated for the remaining 27 patients. Although 3 patients did not complete the follow-up of at least 24 months, their follow-up times were still included in the person-months at risk as denominator to obtain a proper estimate of the failure rate.

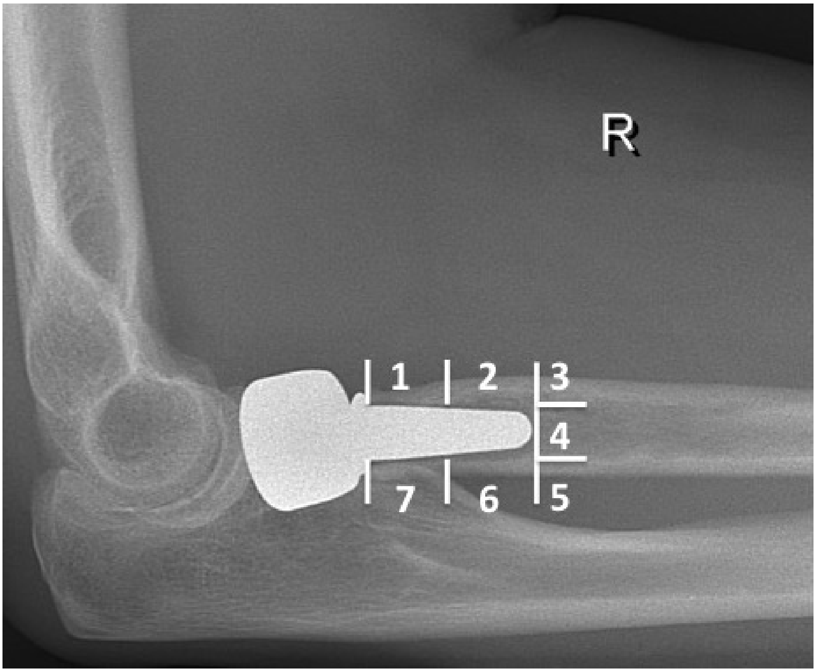

Figure 2: Zones of radiolucency as described by Grewal et al.[16].

Statistical analysis

Clinical results are reported using descriptive statistics (SPSS 21.0 IBM Corporation, Armonk, NY, USA). In addition, prosthetic failure rate is evaluated using a failure rate analysis. Failure was defined as symptomatic radiographic loosening of the prosthesis or scheduled or completed revision surgery. Implant failures were assumed to follow a Poisson distribution.

Results

At mean follow-up of 48 months (range, 28–73 months) there had been 3 (11%) revisions (table 2). There was 1 conversion to a cemented bipolar prosthesis for persistent instability (case 4). Later, a capitellar resurfacing arthroplasty and reconstruction of the lateral collateral ligament (LCL) would be performed in the same patient for persistent instability. There was a second conversion to a cemented bipolar prosthesis, this time with concomitant capitellar resurfacing arthroplasty, for symptomatic abrasion of the capitellum (ie, pain on the capitellum at palpation with erosion of the capitellum at radiography; case 14). In both the stems appeared well fixed during the operation, but in the second case it had to be revised because of incompatibility with the capitellar resurfacing arthroplasty. In a third, the articulating component (ie, head) of the prosthesis was exchanged for a larger size for instability (case 3). The stem was well fixed and left alone. One prosthesis was in a subluxed position in relation to the capitellum and was considered a radiologic failure (case 29; figure 3). In the failure analysis there were then 3 prosthetic revisions in 1207 person-months of follow-up. The 3 patients with a follow-up of less than 24 months had experienced no complications during 35 person-months at risk included in the total follow-up of 1207 person-months. Assuming the number of failures follows the Poisson distribution, there was a 5% probability of finding a number of failures of equal to or less than 3 with a true failure rate of equal to or less than 0.0064 per person-month of follow-up.

Average flexion was 136° (range 120°–145°); average extension-deficit was 9° (range 0°-45°); and average flexion-extension arc was 126° (range, 85°-145°). Average pronation was 71° (range 50°–90°); average supination was 67° (range 0°-90°); and average pronation-supination arc was 138° (range, 70°-180°). Seventeen patients had no pain, 3 had mild pain, and 7 had moderate pain. None had gross instability. According to the Mayo Elbow Performance Score (MEPS) there were 17 (63%) excellent results, 2 (7%) good results, 7 (26%) fair results and 1 (4%) poor result.

At end follow-up, none of the 25 press-fit prostheses that were still in situ showed radiographic signs of loosening. Radiographic osteolysis around the radial neck was observed in 23 (92%) patients (figure 3). This osteolysis involved both zones 1 and 7 in seventeen patients, only zone 7 in 4 patients, only zone 1 in 1 patient and only zone 6 in 1 patient. In two patients in which both zones 1 and 7 were involved, zone 2 was also involved. One prosthesis with osteolysis in zones 1 and 7 had been revised (exchange of the articular component [ie, head], case 3) and appeared well fixed during surgery. Nine patients (cases 6, 18, 21, 23, 25-28 and 30) had developed grade 1, and 4 patients (cases 13, 19, 24 and 29) had developed grade 2 ulnohumeral degeneration. Twelve showed occurrence or progression of osteopenia of the capitellum. Seven showed erosion of the capitellum. Heterotopic ossifications were seen in 5 (20%) patients and were asymptomatic in all. There was preexisting malalignment of the radius onto the capitellum in 1 patient (case 25). In none the snap-on mechanism had failed.

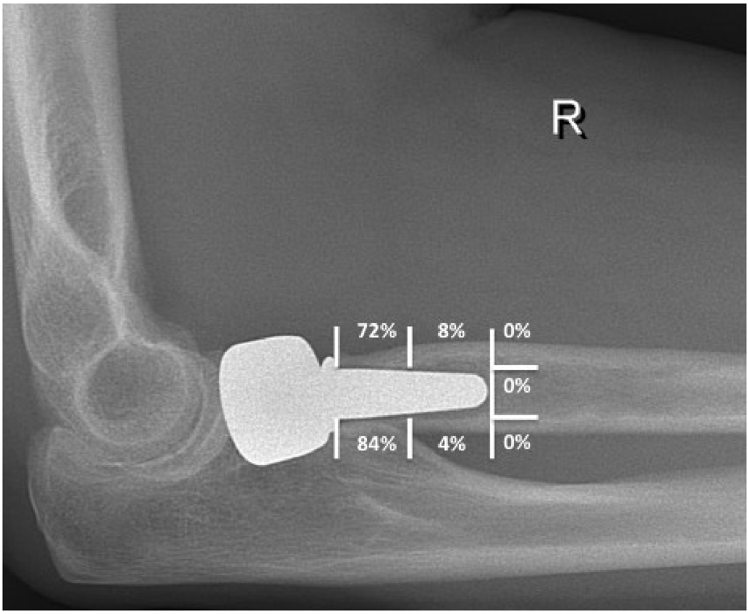

Figure 3: Incidence of radiolucency per zone.

In addition to the aforementioned 3 revisions, there were 9 additional patients with a complication that required surgical intervention in 5. All complications were in patients who were treated in a delayed fashion. Two had signs of ulnar nerve dysfunction and required ulnar nerve release (cases 10 and 19). One had symptomatic degeneration of the distal radioulnar joint (DRUJ), which was treated by a Sauvé-Kapandji procedure (case 21). One had posttraumatic elbow stiffness and was treated by open arthrolysis (case 23). The one patient with preexisting malalignment of the radius onto the capitellum underwent additional reconstruction of the LCL, but the outcome remained fair according to the MEPS (case 25). One patient had subluxation of the prosthesis and degenerative changes of the ulnohumeral joint resulting in persistent elbow pain (case 29, figure 4). Conversion to total elbow arthroplasty was contemplated, but the patient was unfit for operation. There were no infections; 1 had persistent pain due to lateral epicondylitis (case 30), 1 due to medial epicondylitis (case 9) and 1 for unexplained reasons (case 5).

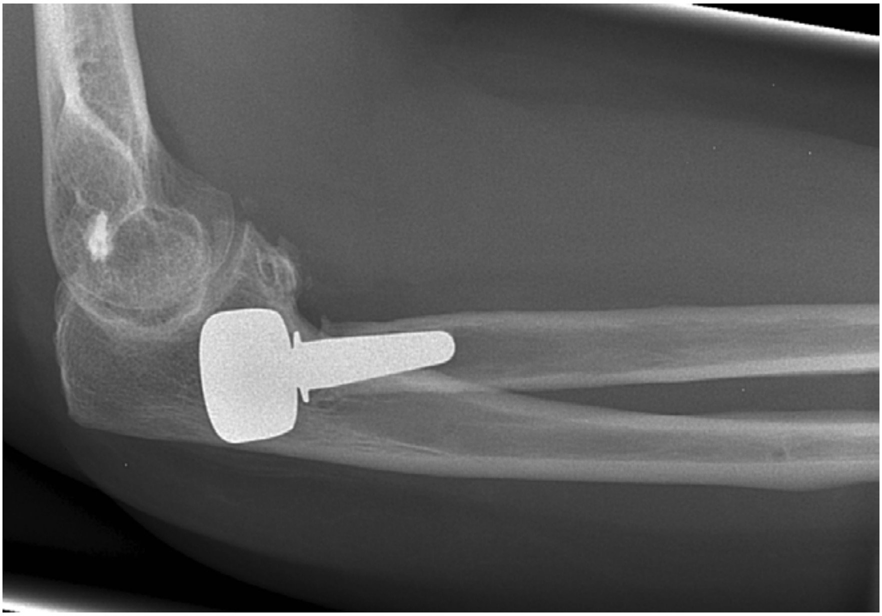

Figure 4: lateral radiograph of case 29 show the subluxed position of the press-fit bipolar radial head prosthesis onto the capitellum. There is distinctive proximal osteolysis around the implant.

Discussion

The bipolar radial head prosthesis may theoretically have advantages over the monopolar prosthesis in terms of reduced abrasion of the capitellar cartilage and reduced stress at the implant-bone interfaces during forearm rotations. In addition, radiocapitellar contact may be facilitated and consequently contact pressures may be reduced during flexion and extension of the elbow[7]. In addition to the cemented bipolar prosthesis, a press-fit design was more recently introduced to obtain biologic ongrowth onto the stem for optimal long-term fixation. To date, there are no clinical outcome data on press-fit bipolar radial head arthroplasty in the literature. The current study reports the mid-term clinical and radiographic outcome of a series of 30 patients treated by press-fit bipolar radial head arthroplasty for acute fracture of the radial head, failed earlier treatment or post-traumatic sequelae. Overall, the outcomes can be considered favorable. However, there are concerns of a relatively high revision rate of 11% (1 conversion to a cemented prosthesis, 1 exchange of only the articulating head for instability, and 1 conversion to a cemented bipolar prosthesis that was compatible with the simultaneously performed capitellar resurfacing arthroplasty for abrasion of the capitellar cartilage). It is noted that none of the stems had come loose, suggesting the press-fit fixation with subsequent bone ongrowth results in adequate fixation.

8

Table 2: Clinical outcome data for all patients treated by press-fit radial head arthroplasty.

Case	F/U (months)	Pain	Flexion (degrees)	Extension deficit (degrees)	Flexion-extension arc (degrees)	Pronation (degrees)	Supination (degrees)	Pronation-supination arc (degrees)	Instability [1]	Mayo Elbow Performance Score [2]	Complications and treatment.
1	47	None	120	40	80	70	70	140	Mild	95 / Excellent	None.
2	34	None	130	0	130	70	80	150	Stable	100 / Excellent	None.
3	44	None	145	0	145	80	80	160	Stable	100 / Excellent	Instability -> revision head of RHP (good fixation of stem RHP)
4	74	Moderate	130	0	130	80	70	150	Mild	60 / Fair	Instability -> revision to cemented RHP with capitellum resurfacing and LCL reconstruction.
5	65	Moderate	140	0	130	80	50	130	Stable	65 / Fair	Pain -> removable splint.
6	40	Mild	130	5	125	70	90	160	Stable	70 / Fair	None.
7	41	Mild	140	0	140	70	70	140	Stable	80 / Good	None.
8*	1	-	-	-	-	-	-	-	-	-	
9	73	Moderate	140	0	130	70	70	140	Mild	65 / Fair	Degeneration capitellum and medial epicondylitis.
10	35	None	135	0	135	60	80	140	Stable	100 / Excellent	Ulnar nerve dysfunction -> ulnar nerve release.
11	61	None	130	0	120	70	70	140	Stable	100 / Excellent	None.
12	49	None	140	0	140	70	70	140	Stable	100 / Excellent	None.
13	63	None	140	5	135	70	70	140	Mild	95 / Excellent	None.
14	68	None	140	0	140	70	80	150	Stable	100 / Excellent	Proximal osteolysis and degeneration capitellum -> revision to cemented RHP with capitellum resurfacing.
15	68	None	140	0	140	70	70	140	Stable	100 / Excellent	None.
16	37	None	140	0	140	70	70	140	Stable	100 / Excellent	None.
17*	20	None	130	5	125	70	70	140	Stable	100 / Excellent	None.
18	28	None	130	20	110	60	60	120	Stable	100 / Excellent	None.
19	40	Moderate	140	10	130	60	60	120	Mild	65 / Fair	Ulnar nerve dysfunction -> ulnar nerve release.
20*	15	None	140	0	140	70	50	120	Mild	95 / Excellent	None.
21	47	None	140	10	130	60	70	130	Mild	95 / Excellent	Forearm instability with degeneration DRUJ -> stabilization with Sauvé-Kapandji procedure.
22	60	None	135	0	135	90	90	180	Stable	100 / Excellent	None.

23	37	None	130	0	100	70	0	70	Stable	100 / Excellent	Stiffness -> arthrolysis.
24	36	Mild	140	0	140	50	70	120	Stable	85 / Good	None.
25	36	Moderate	140	0	130	70	30	100	Mild	55 / Poor	Preexistent malalignment radius with degeneration ulnohumeral joint -> LCL repair.
26	49	None	140	0	140	70	70	140	Stable	100 / Excellent	None.
27	31	None	145	0	145	90	90	180	Stable	100 / Excellent	None.
28	45	None	130	20	110	70	70	140	Stable	100 / Excellent	None.
29	51	Moderate	120	30	90	80	45	125	Mild	60 / Fair	Luxation RHP with degeneration ulnohumeral joint -> patient unfit for reoperation.
30	33	Moderate	130	45	85	90	60	150	Stable	65 / Fair	Lateral epicondylitis

* Lost to follow-up; [1]graded as stable, mild instability or severe instability; [2] MEPS is classified as excellent (>90 points), good (75-89 points), fair (60-74 points) or poor (<60 points);
DRUJ = distal radioulnar joint; LCL = lateral collateral ligament; RHP = radial head prosthesis.

The current study has several limitations. It is retrospective in nature. Although associated injuries almost certainly affect outcome it has to be recognized that variation in presence, nature, severity and treatment of those associated injuries and the fact that some associated injuries go unrecognized and therefore remain untreated make it difficult if not impossible to perform a meaningful analysis stratified for associated injury. There is variation in duration of follow-up between patients. Because of the referral nature of our practice, the majority of cases involved delayed reconstructions. This does, however, reflect the population in which a bipolar prosthesis is postulated to be beneficial.

Flinkkilä et al. have recently reported the survival of press-fit monopolar radial head arthroplasty[20]. They observed loosening of the prosthesis in 12 of 37 (32%) cases at a mean follow-up of 11 months. This was significantly worse than the reported long-term survival of loose-fit and cemented monopolar implants[7, 10, 21, 22]. The authors hypothesized that poor bone ongrowth onto the stem of the press-fit prosthesis due to micromotion of the prosthesis within the medullary canal was one of the factors explaining this inferior implant survival[20, 23]. Possibly, the bipolar design results in reduced stress and micromotion at the implant-bone interface. Van Riet et al. reviewed radial head prosthesis revisions and observed a lower incidence of loosening of fixed-stem bipolar prostheses compared to monopolar prostheses[24]. In the current study, none of the prostheses had come loose.

Popovic et al. extensively reported radiographic changes around bipolar radial head prostheses[7]. They observed 3 different kinds of radiolucency around the prosthetic stem: complete radiolucent lines, balloon-shaped radiolucent zones and proximal bone resorption at the radial neck. Migration of the prosthesis was observed in only 5 of 51 (10%) cases with obvious balloon-shaped osteolysis and not in the other forms of radiolucency. The authors explained the radiographic changes as the result of stress shielding or particle disease[7]. Subsequent studies on different types of radial head prostheses found that the progression of radiolucencies tends to stabilize within 2 years after implantation[5, 22, 25, 26]. As proximal osteolysis occurs early and has been described for different prosthetic designs (monobloc, modular, bipolar) and diverse fixation techniques (loose fit, press-fit, expansion stem, cemented), it is probably the result of stress shielding, rather than an effect of particle wears. In the current study, osteolysis of the proximal radius to some degree was observed in 92%. It was not associated with prosthetic loosening.

The reported incidence of additional elbow or forearm surgery after radial head arthroplasty varies from 0–29%[10, 22, 25, 27-29]. In the current series, such secondary surgery was performed in 30%, and all patients who required a secondary surgical procedure had the prosthesis implanted in a delayed fashion. The primary indication for secondary surgery was instability; all 3 revisions were related to instability resulting from poor condition of the soft tissues. Moon et al. and Chanlalit et al. found superior stability of monopolar radial head arthroplasty compared with bipolar radial head arthroplasty in biomechanical studies[30-32]. They suggested that monopolar implants mimic the native radial head during compression loading, in contrast to bipolar implants, which may show tilting of the radial head during compression, leading to subluxation of the implant. However, comparative clinical studies by

Rotini et al. and Berschback et al. failed to show a difference in stability between monopolar and bipolar implants[25, 28]. Moreover, all elbows were found to be stable at follow-up. Thus, the biomechanical theory has not been confirmed in clinical studies. We were unable to draw firm conclusions on stability in the current study. Second, in 2 patients a capitellar resurfacing arthroplasty had been performed for symptomatic abrasion of the capitellum. We consider erosion of the capitellum at radiographs or in case of instability a poor quality of the capitellum (ie, a capitellum that is unable to host the radial head in a stable way) indications for revision to a radiocapitellar implant. Our recommendation is therefore to be prepared to perform a capitellar resurfacing arthroplasty during the index operation if capitellar bone or cartilage quality is poor.

Conclusion

The overall mid-term outcome of this series of 30 radial head arthroplasties can be considered favorable. The revision rate was 11%, which compares favorably with the only reported series of monopolar press-fit implants in the literature. Despite the aforementioned revisions, none of the stems had come loose, suggesting that the press-fit stem results in sufficient bone ongrowth and adequate fixation. We would suggest considering press-fit bipolar radial head prosthesis for acute comminuted radial head fractures with limited bone loss of the proximal radius.

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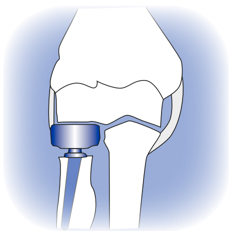
Chapter 9

Cemented bipolar radial head arthroplasty, mid-term results

Andras Heijink; Izaäk F. Kodde; Laurens Kaas; Paul G.H. Mulder;
C. Niek van Dijk; Denise Eygendaal



Submitted

Abstract

Background: Theoretical advantages of bipolar over monopolar radial head arthroplasty include better accommodation of radiocapitellar malalignment, reduction of capitellar abrasion and reduction of stress at the bone-cement and cement-implant interfaces. Our purpose was to report the mid-term results of cemented bipolar radial head arthroplasty.

Methods: Twenty-five patients were treated by cemented bipolar radial head arthroplasty for acute fracture of the radial head, failed earlier treatment or posttraumatic sequelae. One had refused follow-up after surgery. Results are presented for the remaining twenty-four.

Results: At mean follow-up of 50 months (range, 24-72) one (4%) prosthesis had been removed 2 years after implantation for dissociation of the prosthesis due to failure of the snap-on mechanism. There were two (8%) additional radiological failures; one prosthesis was in a subluxed position due to malalignment of the radius onto the capitellum and another was in a subluxated position due to ulnohumeral erosion. The average flexion-extension arc was 129° (range, 80°-140°) and the average pronation-supination arc was 131° (range, 40°-180°). According to the Mayo Elbow Performance Score the combined excellent and good results accounted for 83%. In 8 the bipolar design compensated for radiocapitellar malalignment.

Conclusions: The overall mid-term outcome of this series of 25 cemented bipolar radial head arthroplasties can be considered favorable. There was one (4%) revision and 2 (8%) additional radiological failures. The bipolar design has shown to be able to compensate for suboptimal radiocapitellar alignment. We would suggest considering cemented bipolar radial head prosthesis in case of concerns about radiocapitellar alignment.

Keywords: elbow; fracture; prosthesis; radial head; replacement; trauma.

Introduction

It is generally accepted that, when treating radial head fractures, preserving or restoring the integrity of the native radial head is preferred, but that when this is not feasible or not advisable, prosthetic replacement should be considered[1]. In general, Mason type-1 fractures are treated conservatively with early range of motion, Mason type-2 fractures are treated by open reduction-internal fixation or conservatively, and Mason type-3 fractures are replaced in most cases. Particularly, the radial head should be replaced when the secondary stabilizing function of the radial head is required, as is the case with fracture of 25% to 50% of the coronoid process, disruption of the medial collateral ligament (MCL), disruption of the lateral collateral ligament (LCL) or acute longitudinal radioulnar dissociation (ALRUD). It has been demonstrated in MRI-studies that associated injuries are common[2, 3]. Radial head arthroplasty can also be a salvage procedure after failed osteosynthesis or failed conservative treatment.

Despite the growing amount of data, evolving surgical technique and improving implant design and rationale, prosthetic radial head replacement can be a challenge. Comparing reported results is difficult, due to the considerable variation in indications and associated injuries, timing of surgery, implant design, duration of follow-up and outcome surveillance. Generally, with immediately treated isolated radial head fractures satisfactory outcome can be expected in about 85% of cases, while with cases treated in a delayed fashion this is at best about 50%[1]. Although associated injuries about the elbow may have a significant effect on prosthetic function and survival, hardly any clinical study is of such methodology that it can contribute to quantifying this.

Radial head prostheses may be categorized according to material (silicone, polyethylene, pyrocarbon, metal), modularity (monoblock vs. modular), polarity (uni- or monopolar vs. bipolar) or fixation (cemented, uncemented press fit, intentional loose fit or fixation with an expandable stem).

A bipolar design is thought to have several theoretical advantages. The bipolar articulation theoretically allows for free rotation and therefore reduced abrasion of the capitellar cartilage and reduced stress at the implant-cement and cement-bone interfaces during forearm rotations as compared to monopolar designs. In addition, radiocapitellar joint contact area may be increased and consequently radiocapitellar contact pressure reduced, which may also reduce radiocapitellar cartilage abrasion[4]. Also, a bipolar prosthesis may accommodate to some degree if there is any question about the alignment of the radius on the capitellum, which may be the case in certain posttraumatic conditions where contraction and scaring have occurred[5]. The cemented prosthesis might be better able to do this than the more recently introduced press-fit version (figure 1). A disadvantage may be that bipolar prostheses have been shown not

to provide as much stability as monopolar prostheses in cadaveric models[4, 6, 7]. The English, peer-reviewed literature on bipolar metallic radial head arthroplasty is limited[8-17] (table 1). Short- to mid-term results seem favorable, however, there are no studies available

methodologically sound to compare comparing bipolar and monopolar prostheses. Long-term results are not available.
The purpose of this study is to report our experience with 25 patients that were treated by cemented bipolar metallic radial head replacement for acute fracture of the radial head, failed earlier treatment or posttraumatic sequelae. We hypothesized the results would not be different than those reported in the available literature.

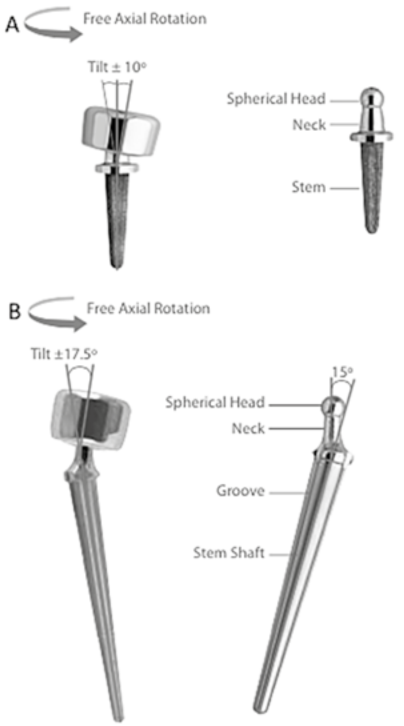


Figure 1: The cemented RHS® bipolar radial head prosthesis (B)(Tornier, Montbonnot-Saint-Martin, France). The design of the cemented prosthesis [B] allows for more tilting of the articular component (i.e. head) than the press-fit design [A].

Materials and Methods

Approval for this study was waived from our institutions' Medical Ethical Committee since data was collected as part of routine clinical care and each patient was informed that data concerning their case would be submitted for publication.
Twenty-five cemented bipolar radial head arthroplasties were performed in our institution between March 2005 and March 2012. All were treated for acute fracture of the radial head fracture or failed earlier treatment or posttraumatic sequelae. The inclusion period was set to assure minimum follow-up of 2 years for each individual case. The senior author performed all surgeries. Initially we treated these cases routinely with a cemented bipolar prosthesis. When press-fit designs became available we started placing a press-fit prosthesis if bone quality was good and the trial components showed a good press-fit, and a cemented

prosthesis if there was any doubt about bone quality or fixation of the trial components. This is still the algorithm we use in our clinic today.

Table 1: Overview of the current English, peer-reviewed literature on bipolar metallic radial head arthroplasty.

Author	Year	Level of evidence	Inclusion period	N	Lost to f/u	Type, fixation [(1)]	Follow-up (mean, range)	Delay (mean, range)	Revision (N, %)	MEPS
Current study	2015	IV	2005-2012	25	1 (4%)	RHS (Tornier), cemented	50 months (24-72 months)	43 months (0 days-312 months)	0 (0%)	E 14, G 7, F 3, P 1
Berschback	2013	IV	2004-2001	21	7 (33%)	Katalyst (Integra Life Sciences Coorporation), uncemented	36 months (24-46 months)	Range 1 day-23 years	0 (0%)	E 9, G 3, F 2, P 0
Rotini	2012	IV	2009-2010	19	0 (0%)	Radial Head Implant (SBi), uncemented	n/a [(2)]	Range 1-130 days [(2)]	2 (7%)	E 13, G 5, P 0, F 1
Burkhart	2010	IV	1997-2001	19	2 (12%)	RHS (Tornier), cemented	106 months (78-139 months)	100 days (0-515 days)	1 (5.3%)	E 10, G 6, F 1, P 0
Celli	2010	IV	2000-2007	16 [(3)]	0 (0%)	RHS (Tornier), cemented	42 (12-86) months	9 days (0-20 days)	0 (0%)	W 12, G 2, F 0, p 2
Popovic	2007	IV	1994-2001	55	4 (7%)	RHS (Tornier), cemented	8.4 years (4-13 years)	"All acutely treated"	0 (0%)	E 14, G 25, F 9, P 3
Dotzis	2006	IV	1992-2003	14	2 (14%)	RHS (Tornier), cemented	5.3 years (1-12 years)	Within 8 days, 2 exceptions	0 (0%)	E6, G4, F1, P1
Brinkman	2005	IV	1999-2003	11	0 (0%)	RHS (Tornier), cemented	22.5 months (12-48 months)	8 years (2 weeks -31 years)	2 (18%)	Not provided
Smets	2000	IV	1995-1999	18	3 (17%)	RHS (Tornier), cemented	25.8 months (6-48 months)	13 acutely treated, 2 delayed	1 (7%)	E 7, G 3, F 4, P 1
Popovic	2000	This study reports the short-term results of the first 11 patients of the series reported by Popovic et al. in 2007.								
Judet [(4)]	1996	IV	1988-1995	5 [(5)]	0 (0%)	RHS (Tornier), cemented	49 months (24-65 months)	0-2 days [(6)]	0 (0%)	E 2, G 3, F 0, P 0
Judet [(4)]	1996	IV	1988-1995	7 [(7)]	0 (0%)	Judet CRF II, cemented RHS (Tornier), cemented	43 months (24-72 months)	29 (7-156) months	0 (0%)	E 1, G 4, F 2, P 0

[(1)] The RHS bipolar radial head system (Tornier) was previously referred to as CRF II (Capule Radiale Flottante) or simply Judet bipolar radial head prosthesis.
[(2)] The article provides a pooled duration of follow-up of 2 years (range 13-36 months) for a combined group of 19 bipolar and 12 monopolar prostheses. Duration of follow-up for the individual patients or all bipolar prostheses combined is not provided. Likewise for the delay from initial trauma to placement of the bipolar metallic prosthesis.
[(3)] Those 16 were selected from a consecutive series of 73 bipolar radial head prosthesis (see text).
[(4)] Reported as one study.
[(5)] Those were the first 5 patients of a series of 18 patients treated acutely for comminuted, non-reconstructable radial head fracture.
[(6)] One patient was treated within two days with a silicone prosthesis, which was replaced 17 days after trauma with a cemented bipolar metallic prosthesis.
[(7)] Those were the first 7 patients of a series of 20 patients treated in a delayed fashion for complications following radial head excision.

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Implant

The cemented RHS® bipolar radial head prosthesis (Tornier, Montbonnot-Saint-Martin, France) is a modular system and consists of two parts. The smooth stem is made of cobalt-chrome. The head is made of polyethylene encased in cobalt-chrome. The head articulates with the neck of the stem by means of a low friction, snap-on ball-and-socket joint. The stem has a built-in 15° neck angle to reproduce the anatomical offset of the native radial shaft, which, however, has not been formally reported in the literature to date. Stem length varies with diameter: 55mm or 60mm for a respective 6.5mm or 8mm tapered stem width. Neck length options are 19mm or 22mm.

Surgical technique

During surgery the patient was supine with the arm rested on an arm table. Prophylactic antibiotic coverage consisted of 2000mg cefazolin intravenously. A tourniquet was used. An extensor split (Kaplan interval) was used. The annular ligament was transected and tagged with a stay suture; it was repaired at the end of the procedure. The level of the radial neck osteotomy was visually determined and guided by the proximal radioulnar joint. The medullary canal was broached and reamed, a trial prosthesis was inserted to assess the correct height of the prosthesis and the elbow was tested for stability and range of motion. The trial component was removed and a small bone plug was inserted as cement stop and pulse lavage was used to clean the medullary canal. The stem of the definite implant was cemented in place with the angled neck aligned with the radial styloid process and the head was snapped on the neck. At closure, medial collateral ligament (MCL) injury was tested for, which was repaired if present and deemed necessary via an additional medial incision. Postoperatively, a pressure bandage was applied for 48 hours and mobilization was started under guidance of a physiotherapist on the first postoperative day. Continuous passive motion (CPM) was not used. When additional procedures had been performed, this postoperative regimen was adjusted accordingly. Prophylaxis for heterotopic ossification (HO) was not routinely used.

Follow-up

Medical records were reviewed and each patient was seen in the office for a clinical assessment and radiographic evaluation. Postoperative range of motion was determined using a goniometer and elbow function was assessed using the Mayo elbow performance score (MEPS)[18, 19]. Radiographs of the elbow were reviewed for signs of loosening, radiocapitellar alignment, osteolysis of the radial neck, lucency, osteopenia and erosion of the capitellum, periarticular ossifications and ulnohumeral degeneration. Osteolysis was evaluated in terms of regions about the radial neck as postulated by Grewal et al.[20]. Osteopenia and abrasion of the capitellum were noted to be present or absent. Degenerative changes of the ulnohumeral joint were graded as none, slight, moderate or severe as previously described by Broberg et al.[21].

Clinical results are reported using descriptive statistics. In addition, prosthetic failure rate is evaluated using a failure rate analysis. Failure was defined as symptomatic radiographic loosening or scheduled or completed revision surgery. Implant failures were assumed to follow a Poisson distribution.

Results

Demographic data and overall clinical outcome data are presented (tables 2 and 3, respectively). There were 18 females and 7 males. Mean age at surgery was 55 years (range, 31 to 77 years). There were 16 left and 9 right, and 4 dominant elbows involved. Eight were operated for acute fracture and 5 of those underwent an additional procedure at the time of radial head arthroplasty. Seventeen were operated for failed earlier treatment or posttraumatic sequelae and 9 of those had additional procedures performed about the elbow at the time of surgery. The average time between initial trauma and cemented bipolar radial head arthroplasty in those operated in delayed fashion was 64 months (range, 2-312 months). One patient (4%) had refused follow-up after surgery. End follow-up results are presented and calculated for the remaining 24 patients, but the particular patient that refused follow-up was still included in the failure analysis.

At mean follow-up of 50 months (range, 24-72 months) one (4%) prosthesis had been removed 2 years after implantation for frank luxation due to dissociation of the prosthesis resulting from failure of the snap-on mechanism with poor clinical performance (case 25, figure 2). Another (4%) was subluxed due to uncompensated malalignment of the radius on the capitellum with excellent clinical outcome (case 15). A third (4%) was subluxed due to pronounced ulnohumeral erosion with fair clinical outcome (case 17). Altogether, there were three (13%) radiological failures, one of which also being a clinical failure. In the failure analysis there was then one prosthetic revision (ie, removal) in 1202 person-months of follow-up. Assuming the number of failures follows the Poisson distribution there was a 5% probability of finding a number of failures equal to or less than 4.74 with a true failure rate of equal to or less than 0.00395 per person-month of follow-up.

Thirteen patients had no pain, 7 had mild pain, 3 had moderate pain and 1 had severe pain. Average flexion was 135° (range, 110°-140°); average extension deficit was 6° (range, 0°-30°); and average flexion-extension arc was 129° (range, 80°-140°). Average pronation was 70° (range, 20°-90°); average supination was 61° (range, 20°-90°); and average pronation-supination arc was 131° (range, 40°-180°). None had gross instability. According to the MEPS there were 13 excellent (54%), 7 good (29%), 3 fair (13%) and 1 (4%) poor results. Two patients had a radial nerve neuropraxia that fully recovered over time. Two (8%) had ulnar nerve paresthesia. One (4%) underwent additional open arthrolysis of the elbow for stiffness. There were no postoperative infections.

Table 2: Demographic data for all patients treated by cemented bipolar radial head arthroplasty.

Case	Sex	Age (years)	Injured side	Dexterity	Indication	Timing	Time since fracture (months)	Previous surgical procedures about the injured elbow	Concomitant surgical procedures	Additional comment
1	F	55	Left	Right	Posttraumatic degeneration RH	Delayed	17	None	None	
2	F	53	Right	Left	Posttraumatic degeneration RH	Delayed	7	None	None	Ulnohumeral and radiohumeral degeneration
3	F	64	Left	Right	Posttraumatic degeneration RH + valgus instability with subluxations	Delayed	10	None	None	
4	F	50	Right	Left	Failed silicone RH arthroplasty	Delayed	168	Silicone RH arthroplasty (Swanson prosthesis) for fracture	Debridement + microfracturing OCD capitellum	
5	F	50	Left	Right	Nonunion RH fracture + valgus instability	Delayed	14	ORIF RH fracture (T-plate)	None	
6	M	62	Right	Right	Acute Mason 3 RH fracture + diaphyseal humerus fracture + ulna fracture (floating elbow)	Acute	0	None	None	ORIF ulna fracture 2 days later, humerus fracture conservative
7	F	55	Left	Right	Acute Mason 3 RH fracture + ulnohumeral luxation	Acute	0	None	None	
8	F	62	Right	Left	Acute Mason 3 RH fracture + coronoid fracture + LCL rupture	Acute	0	None	LCL reconstruction (triceps graft) + fixation coronoid fracture	
9	M	51	Left	Left	Overstuffed RH prosthesis with beginning ulnohumeral degeneration	Delayed	30	Metallic RH arthroplasty (uncemented, bipolar) for fracture with ALRUD	Arthrolysis via lateral column procedure	
10	F	60	Left	Right	Acute Mason 3 RH fracture + ulnohumeral luxation	Acute	1	ORIF RH fracture (K-wire)	Removal K-wire	
11	M	51	Left	Right	Longstanding longitudinal radioulnar dissociation with status after RH resection	Delayed	16	RH resection for fracture	Arthrolysis via lateral column procedure + ulnar shortening osteotomy + arthrotomy and debridement DRUJ	
12	F	56	Left	Right	Acute Mason 3 RH fracture + olecranon fracture	Acute	0	None	Tension band wiring olecranon fracture	Radial nerve neuropraxia, fully recovered over time
13	F	70	Left	Left	Overstuffed RH prosthesis (cemented, bipolar)	Delayed	7	Metallic RH arthroplasty (uncemented, bipolar) for fracture, ORIF comminuted olecranon fracture	Removal hardware olecranon + arthrolysis via lateral column procedure	Radial nerve neuropraxia, fully recovered over time
14	F	36	Left	Left	Failed silicone RH arthroplasty + insufficiency LCL	Delayed	132	Silicone RH arthroplasty (Swanson prosthesis) for fracture	Synovectomy, repair LCL	
15	M	45	Right	Left	Ulnohumeral degeneration secondary to RH resection	Delayed	240	RH resection for fracture	Arthrolysis via lateral column procedure + debridement ulnohumeral joint	
16	F	55	Left	Right	Acute Mason 3 RH fracture + coronoid chip fracture + LCL rupture	Acute	0	None	Reinsertion LCL + debridement and microfracturing OCD capitellum	

17	M	50	Right	Left	Nonunion Mason 2 RH fracture	Delayed	24	Arthroscopic debridement.	Arthrolysis via lateral column procedure	
18*	F	31	Left	Right	Acute Mason 3 RH fracture	Acute	<1	None	None	
19	F	63	Right	Left	Longstanding longitudinal radioulnar dissociation with status after RH resection	Delayed	19	RH resection for fracture	Debridement and microfracturing OCD capitellum	
20	F	65	Left	Right	Acute Mason 3 RH fracture	Acute	0	None	Reinsertion LCL	
21	F	65	Right	Left	Longstanding longitudinal radioulnar dissociation with status after RH resection	Delayed	180	RH resection for fracture	Debridement and microfracturing OCD capitellum	
22	F	52	Left	Right	Valgus angulation with lateral elbow pain and traction ulnar nerve neuropraxia, wrist pain and flexion contracture secondary to RH resection	Delayed	12	RH resection for fracture	None	
23	F	60	Right	Left	Longstanding longitudinal radioulnar dissociation with status after RH resection	Delayed	24	RH resection for fracture	None	
24	M	77	Left	Right	Acute Mason 3 RH fracture + ulnohumeral luxation + LCL insufficiency	Acute	2	None	None.	
25	M	40	Left	Left	Failed silicone RH arthroplasty	Delayed	180	Silicone RH arthroplasty for fracture	None	Arthrolysis 1 year after RH arthroplasty

* This patient had refused follow-up after surgery. ALRUD: Acute longitudinal radioulnar dissociation (i.e. Essex-Lopresti type injury).
DRUJ: distal radioulnar joint. LCL: lateral collateral ligament. OCD: osteochondral defect. ORIF: open reduction-internal fixation; RH: radial head..

Table 3: Clinical outcome data of all patients treated by cemented bipolar radial head arthroplasty.

Case	F/U (months)	Pain	Flexion (degrees)	Extension deficit (degrees)	Flexion-extension arc (degrees)	Pronation (degrees)	Supination (degrees)	Pronation-supination arc (degrees)	Instability[1]	MEPS[2]	Additional comment
1	63	None	140	0	140	80	80	160	None	100 / Excellent	
2	62	None	130	0	130	80	80	160	Valgus, mild	100 / Excellent	
3	72	Mild	130	10	120	70	70	140	None	85 / Good	
4	59	Mild	140	10	130	80	60	140	Valgus, mild	85 / Good	
5	65	None	120	0	120	20	20	40	None	100 / Excellent	
6	58	None	140	5	135	30	20	50	Valgus, mild	100 / Excellent	
7	66	None	140	0	140	80	80	160	None	100 / Excellent	
8	63	None	140	0	140	70	45	115	None	100 / Excellent	
9	60	None	140	15	125	70	30	100	None	100 / Excellent	
10	60	None	130	5	125	70	70	140	None	100 / Excellent	
11	56	Mild	140	0	140	70	40	110	None	85 / Good	
12	61	None	140	10	130	70	50	120	None	100 / Excellent	
13	61	Mild	140	0	140	70	70	140	Valgus, mild	85 / Good	
14	42	Moderate	140	5	135	60	60	120	None	70 / Fair	
15	64	None	130	0	130	70	50	120	None	95 / Excellent	
16	60	Mild	140	3	137	90	90	180	None	85 / Good	
17	24	Moderate	130	10	120	70	60	130	None	70 / Fair	
18*	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	
19	36	None	130	0	130	80	80	160	None	100 / Excellent	Ulnar nerve dysaesthesia, DRUJ instability
20	37	None	140	0	140	70	50	120	Valgus, mild	100 / Excellent	
21	24	Moderate	140	10	130	70	80	150	None	70 / Fair	
22	30	Mild	135	0	135	80	60	140	None	85 / Good	Ulnar nerve dysaesthesia
23	25	Mild	140	20	120	90	90	180	None	85 / Good	
24	24	None	135	5	130	90	70	160	None	100 / Excellent	
25	24	Severe	110	30	80	60	60	120	None	50 / Poor	Removed

[1] Valgus instability was graded as none, mild (only tender), moderate or severe.
[2] The Mayo Elbow Performance Score is classified as excellent (>90 points), good (75-89 points), fair (60-74 points) or poor (<60 points).
DRUJ: distal radioulnar joint. * This patient had refused follow-up after surgery.
[#] Data at last follow-up before removal (i.e. revision) 2 years after implantation of the prosthesis.

At final follow-up none of the prostheses showed radiographic signs of loosening. As stated earlier, one (4%) had been removed for frank luxation due to dissociation of the prosthesis (case 25). In 8 the bipolar design compensated for malalignment of the radius on the capitellum (cases 4, 5, 7, 10, 13, 14, 19 and 22). In one it did not and this prosthesis was, as stated before, in a subluxed position (case 15). Seven (29%) showed osteolysis of the proximal radius to some degree (cases 2, 3, 8, 10, 16, 21 and 23). One showed lucency around the stem present and stable since placement of the prosthesis and therefore attributed to suboptimal cementing technique (case 13). Another showed limited lucency at the level of the radial tuberosity (case 8). A third showed lucency at the cement-bone interface around the stem with plenty bone formation at the proximal radius (case 20). Eleven (case 3, 5 thru 10, 12, 13, 15 and 25) showed occurrence or progression of osteopenia of the capitellum. Four showed erosion of the capitellum (cases 3, 15, 23 and 25). Five developed periarticular ossification (cases 8, 9,15, 24 and 25). Eleven had developed grade 1 (case 2, 5 thru 7, 12, 15, 16, 19 and 21 thru 23) and two had developed severe (case 17 and 25) ulnohumeral degeneration. In one of the two cases with severe ulnohumeral erosion the prosthesis was, as stated earlier, in a subluxed position (case 17). Two had stable preexisting mild and 2 had preexisting moderate ulnohumeral degeneration.

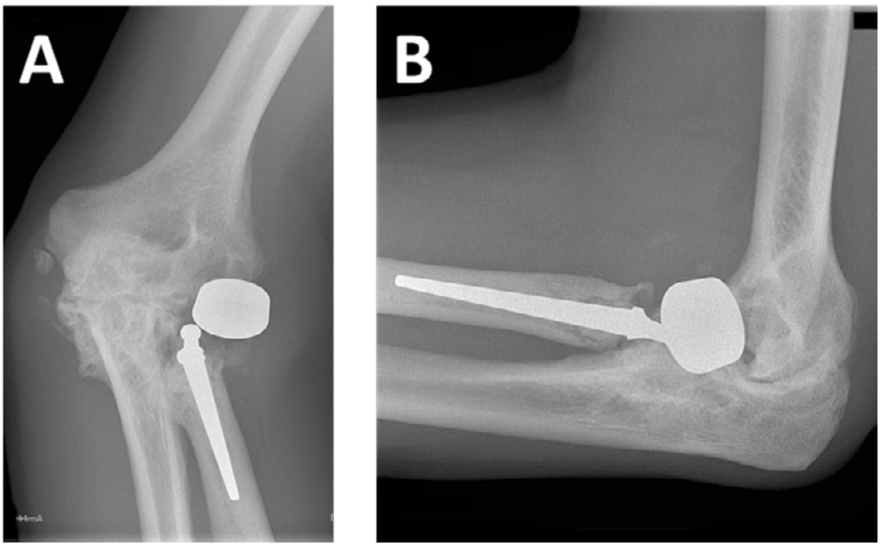

Figure 2: AP [A] and lateral [B] radiographs show dissociation of the prosthesis due to failure of the snap-on articulation between the head and the stem.

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Discussion

Radial head arthroplasty is indicated when the secondary stabilizing function of the radial head is required and reconstruction of the radial head is not feasible[1]. Generally, this is the case with Mason type-3 radial head fractures and more complex fracture dislocations[12]. Initially, only cemented monopolar designs were available. More recently, bipolar designs have been developed. Theoretically, the newer bipolar designs reduce abrasion of the capitellar cartilage and stress at the implant-cement and cement-bone interfaces due to the free rotation between the stem and articular component. Also, radiocapitellar contact pressure may be decreased as compared to monopolar designs due to better alignment of the articular component onto the capitellum. In addition, they are thought to be able to accommodate some degree of malalignment of the radius onto the capitellum. All these advantages still need scientific backing and if bipolar radial head prostheses are associated with superior implant survival and clinical performance than monopolar prostheses also remains to be determined. The current study presents favorable mid-term outcome of a series on 25 patients treated by cemented bipolar radial head arthroplasty for acute fracture of the radial head or failed earlier treatment or posttraumatic sequelae. There was one revision (4%) in 1276 person months of follow-up for dissociation of the prosthesis due to failure of the snap-on mechanism. The bipolar design appeared to be able to accommodate radiocapitellar malalignment in 8 cases (see example in figure 3). None of the stems had come loose. In only one there was lucency around the stem of the prosthesis, but this was attributed to a suboptimal cementing technique.

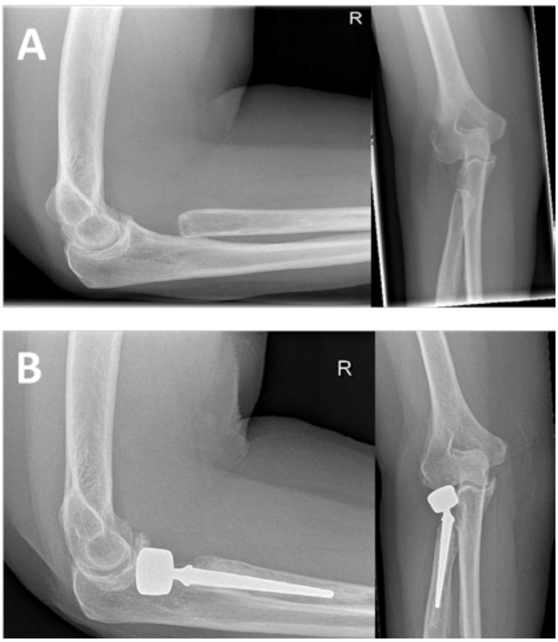

Figure 3: preoperative radiographs of patient with malalignment of the radius following radial head resection [A] and postoperative result after bipolar radial head arthroplasty [B].

Several limitations are recognized. The study is retrospective in nature. There is variation in the presence and nature of associated injuries. Although associated injury will have impact, possibly even profound, on outcome, this effect has not been clarified in the literature to date. Also, due to the variation in nature, severity and treatment of the associated injuries and the fact that some associated injuries go unrecognized and therefore remain untreated, it is extremely difficult, if not impossible, to perform any meaningful analysis stratified for associated injury. There is variation in duration of follow-up between patients. Due to the referral nature of our practice, the majority of cases involved delayed reconstructions. This does however reflect the population in which a bipolar prosthesis is postulated to be beneficial. Some radiographic parameters that were scored (i.e. osteopenia of the capitellum, postoperative degeneration) are difficult to evaluate and subjective. The information does however reflect concerns that are relevant to outcomes of radial head arthroplasty in general.

At end follow-up there had been one (4%) revision for dissociation of the prosthesis and there were 2 (8%) additional radiological failures (subluxations). Revision rates in studies on cemented bipolar radial head arthroplasty have been low so far, but all studies report short- to mid-term follow-up with no long-term results available to date (table 1). Also, radial head prostheses are generally not tracked in national joint registries. However, as is very well illustrated in this case series, the revision rate does not necessarily reflect the true treatment failures. The incidence of prosthetic (sub-)luxations in the current study is similar to the literature. Berschback et al.[8] report 1 (7%) subluxation in 14 patients, Burkhart et al.[10] report 2 (12%) luxations in 17 patients and Brinkman et al.[9] report 2 (18%) revisions for subluxation in 11 patients. Failure of the snap-on mechanism, as was encountered in one case (case 25), has been recognized and reported by O'Driscoll et al.[22]. The authors attributed this failure to polyethylene wear, allowing slippage of the articular component on and off the stem. If reduced stability or frankly uncorrectable radiocapitellar malalignment possibly contributes to levering the articular component of the stem remains open to debate. On the other hand, in a significant number of cases the bipolar design seems to be able to accommodate well for malalignment at the radiocapitellar joint (8 cases, 33%). Naturally, it is not known how a monopolar prosthesis would have performed in these specific cases. There were two radial nerve neuropraxias, both of which fully recovered over time. The osteotomy for the bipolar prosthesis is slightly more distal than for the monopolar prosthesis. This theoretically increases the risk of injury of the deep branch of the radial nerve (ie, posterior interosseous nerve).

Popovic et al. observed progressive radiolucent lines around the stem of the prosthesis in 27 (53%) out of 51 patients[15]. In 11 these remained stable over time and were attributed to suboptimal cementing technique. In 16 these were progressive over time and were attributed to mechanical factors, possibly in conjunction with progressive osteolysis. The authors did, however, not report any revision. Burkhart et al.[10] reported a radiolucent line around the stem in one (6%) out of 17 patients, Rotini et al.[16] in one (5%) out of 19 patients, Dotzis et al.[12] in one (8%) out of 12 patients, Berschback et al.[8] state that they were often observed and Celli et al.[11], Brinkman et al.[9], Smets et al.[17] and Judet et al[13]. do not comment on the occurrence of radiolucent lines around the stem. In the current study we observed a radiolucent line around the stem in one (4%) patient. We do not, at this time, have an explanation between the large discrepancy in incidence of radiolucent lines around the stem between the study by Popovic et al. and the other more recent studies[15]. Popovic et al. reported a moderately high incidence of 31% bone resorption direct under the prosthesis (zones 1 and 7 according to Chanlalit[23]) following bipolar radial head arthroplasty[15]. In the current series a similar incidence (29%) was observed. Rotini et al. also reported a high incidence, although the exact numbers cannot be calculated due to the format the data is presented in[16]. Others reported a lower rate, narratively discussed osteolysis or did not comment on osteolysis[8-13, 17]. Heterotopic ossifications have been observed following bipolar radial head arthroplasty with variable, but occasionally high incidence (range 0-76%), but are mostly asymptomatic[8-12, 15, 16].

Conclusions

The overall mid-term outcome of this series of 25 cemented bipolar radial head arthroplasties can be considered favorable. Complications and less favorable outcomes were encountered and there was one revision, interestingly for dissociation of the prosthesis due to failure of the snap-on mechanism. The bipolar design has shown to be able to compensate for suboptimal radiocapitellar alignment; it can, however, not be clarified if it performed better in this respect than a monopolar prosthesis would have done. Radiographic observations are similar to earlier reports on cemented bipolar radial head arthroplasty. We would suggest considering cemented bipolar radial head prosthesis for unreconstructable fractures of the radial head or posttraumatic sequelae after such fractures in case of concerns about radiocapitellar alignment.

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CHAPTER 10

Radial head arthroplasty: a systematic review

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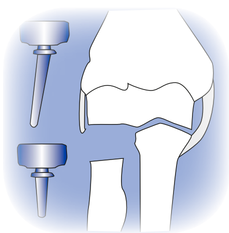

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Abstract

Introduction: Despite the expanding body of literature on radial head arthroplasty, increasing understanding of elbow anatomy, biomechanics and kinetics as well as evolving surgical technique and prosthesis designs there is currently no evidence to support one type of radial head prosthesis over the other.

Purpose: To review the literature and explore the association between prosthesis design variables and timing of surgery and the outcome of modern radial head arthroplasty.

Methods: The search was limited to skeletally mature patients. Major databases were searched from January 1940 to May 2015 to identify studies relating to functional and subjective outcome and radiographic evaluation after radial head arthroplasty.

Results: Thirty articles were included reporting on 727 patients. Regarding implant material, 69% were made of cobalt-chrome, 15% of pyrocarbon, 9% of titanium and 6% of vitallium. Seventy percent were monopolar and 30% were bipolar prostheses. Twenty-one percent were cemented in place, 32% were press-fit, 32% were intentional loose fit and 15% were fixed by an expendable stem. Weighted average follow-up was 45 months. The incidence of revisions ranged among studies from 0-29%. There were 8% revisions in 2714 person-years of follow-up across all 727 patients, yielding a crude overall revision rate of 2.06 per 100 persons-years of follow-up. The revision rate was not significantly affected by prosthesis polarity, material or technique of fixation, nor was it significantly affected by the delay of treatment. There was also not significant effect of prosthesis polarity, material or technique of fixation on postoperative range of motion. The Mayo Elbow Performance Score was only reported for half of the overall patient population, but of those the combined excellent and good results accounted for 85%. Seven percent of the overall patient population underwent secondary surgery other than revision surgery. Twenty three percent were reported to have a complication.

Conclusions: Based on our analysis of the peer reviewed English literature on radial head arthroplasty from 1940 to date there seems to be no evidence to support one type of modern radial head prosthesis over the other. The only exception is formed by the silicone prostheses, which have been shown to be biologically and biomechanically insufficient.

Keywords: elbow; forearm; prosthesis; trauma; upper extremity.

Introduction

The radial head is an important secondary stabilizer of the elbow[1]. This secondary stabilizing function of the radial head is particularly required in many Mason type-3 fractures, due to the high incidence of associated ligamentous injuries seen with those fractures that compromise elbow stability. The same is true for the more complex elbow traumas as terrible triad injuries, complex elbow dislocations and longitudinal radioulnar instability. In these situations it is imperative to replace or reconstruct, and not resect, the radial head, in order to allow healing of the damaged stabilizing soft tissues about the elbow[2].

Since the introduction of radial head prostheses in the literature by Speed et al.[3] in 1941 various prosthetic designs have been available. Those designs varied in material, technique of fixation, modularity and polarity. Despite the quickly rising number of publications on radial head arthroplasty in the recent years, increasing understanding of elbow anatomy, biomechanics and kinetics and evolving surgical technique and prosthetic designs there is currently no evidence to support one type of modern radial head prosthesis over the other. The only exception is formed by the silicone prostheses, which have been shown to be biologically and biomechanically insufficient[4, 5].

The purpose of this systematic review of the literature was to explore the association between prosthetic design variables and timing of surgery and the outcome of modern radial head arthroplasty in order to provide evidence-based clinical recommendations. It was hypothesized that functional outcome is not different for cemented and uncemented placement, unipolar and bipolar prostheses and acute and delayed treatment.

Materials and Methods

Study population

This review was aimed to include human patients with a minimum age of 18 years that were treated by metallic or pyrocarbon prosthetic radial head arthroplasty.

Outcome parameters

Primary outcome measures of interest were:
- Incidence of revision.
- Postoperative ranges of motion.
- Mayo elbow performance score (MEPS).

Secondary outcome measures of interest were:
- Incidence of complications.
- Incidence of secondary surgery.
- Patient reported outcome measures (PROM's). Considered were the disability of the arm, shoulder and hand (DASH) questionnaire, short form (36) health survey (SF-36), American shoulder and elbow score (ASES), patient-rated elbow evaluation (PREE) and Oxford elbow score (OES).

Inclusion and exclusion criteria

Articles written in English and reporting original clinical data reporting on primary radial head arthroplasty using metallic or pyrocarbon prostheses. Articles were included regardless of indication and level of evidence. Only articles with a minimum number of 10 cases and a minimum average follow-up of 2 years were considered. A study was excluded if the type of prosthesis and duration of follow-up were not reported and were not provided by the author upon request.

Search strategy and study selection

A comprehensive literature search was conducted with the assistance of a clinical librarian using the following terms: radius[Mesh], radius fractures[Mesh], arthroplasty, replacement[Mesh], joint prosthesis[Mesh], radial head[tiab], replacement[tiab], arthroplasty[tiab], prosthesis implantation [tiab] and prosthesis[tiab]. The PubMed/Medline and Embase databases were searched using the filters 'English' and 'humans' for the period January 1940 to the date of search and the search was conducted on 27 May 2015. The start date was chosen as the first documentation of a radial head replacement by Speed et al. dates back from 1941[3].

Four authors independently assessed all titles and abstracts and identified eligible articles. Two authors assessed the full text of all eligible studies and did the final inclusion. The lists of references of all eligible publications were manually checked for additional studies potentially meeting the inclusion criteria, but did not yield any additional eligible study. Disagreements were settled by discussion. Based on this strategy 590 articles were identified (figure 1). After screening of title, abstract and the methodology 43 studies were found eligible for inclusion. The full text of all those studies was analysed and applying the inclusion and exclusion criteria 30 studies were finally included. The additional 13 exclusions were for various reasons. Eight reported only pooled data; 5 for radial head arthroplasty and open reduction-internal fixation, 2 for radial head arthroplasty and radial head resection and one for radial head arthroplasty, open reduction-internal fixation and nonoperative treatment. Two reported data on cases that were included in a larger cases series that was presented more recently. Two only reported radiological outcome parameters. In one the type of prosthesis was not mentioned throughout the entire article.

Data analysis

Of only 14 out of 30 studies patient individual data were available. The other 16 studies reported only pooled data. As a consequence, analyses covering all 30 studies had to be performed on the aggregated study level with the data of the individual patients pooled per study. The number of patients per study that underwent revision surgery was expressed for each study in relation to the total number of valid patients in that study and in relation to the total number of person-years of follow-up per study. Revision was defined as removal of the prosthesis, or a part of it, regardless of whether a new radial head or other type of prosthesis was implanted and regardless of indication. The various ranges of motion were expressed as an unweighted average and a weighted average with the number of patients per study group as weights, the latter equalling the mean across the maximally 727 patients. With regards to the MEPS only studies were included in the analyses if the MEPS was used as intended. For the analyses only the interpreted outcome (coded as 1=poor, 2=fair, 3=good and 4=excellent) and not the numerical outcome were used and averaged per study.

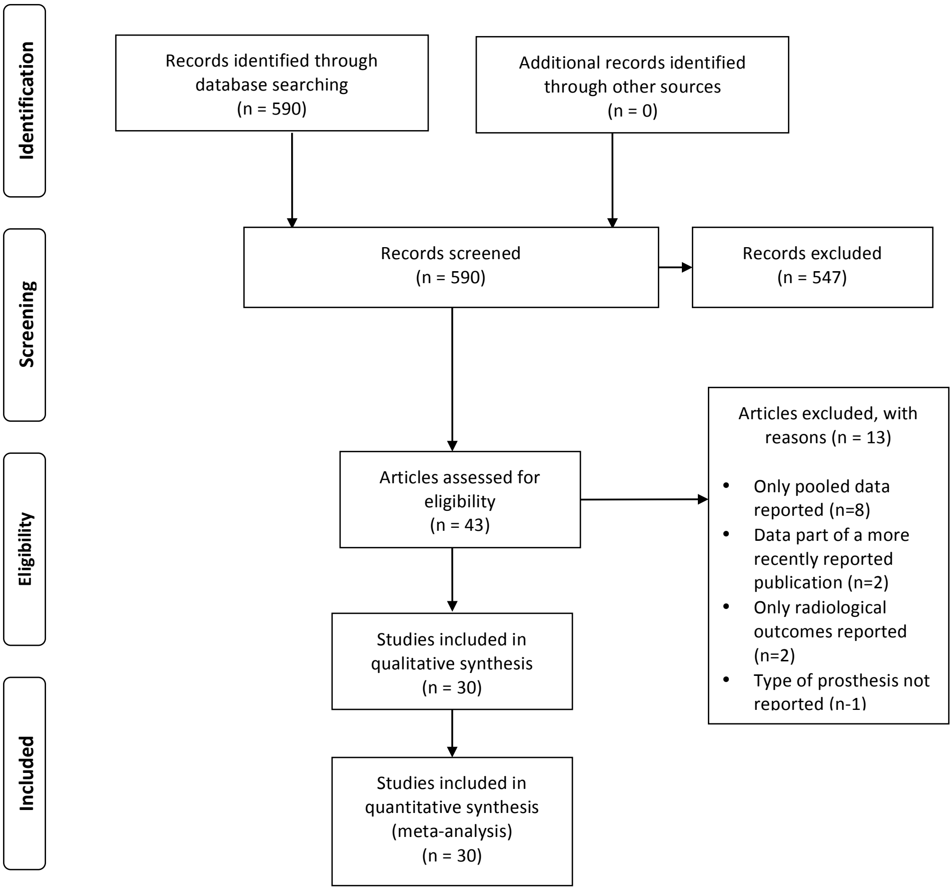

Figure 1: Flow chart of the selection and inclusion of studies.

Complications are narratively reported (table 1). Due to the substantial variability in reportage and nature of the complications this would provide the most information. In addition, the total number of patients with a complication was expressed for each study in relation to the total number of valid patients in that study. We calculated the number of complications from each individual publication and did not routinely use the number that was stated in the publication for analysis; therefore, there may be differences. As radiological complications were considered: symptomatic loosening of the prosthesis, subluxation of the prosthesis and periprosthetic fractures. Radiological findings otherwise were only

Table 1: List of all included studies.

Author	Year	Country	N*	Prosthesis	Material	Type	Fixation	Follow-up (months) (mean, range)	Revisions (%)	Complications (number of complications / number of patients with a complication)
Yan	2015	China	20	Radius Head Comp. (LINK)	Cobalt-Chrome	Monopolar	Loose fit	36 (n/a)	5%	(3/3) 1x malposition (revision), 1x dislocation coronoid fracture, 1x resection HO.
Schetzke	2014	Germany	30	Evolve (Wright Medical)	Cobalt-Chrome	Monopolar	Loose fit	36 (13-60)	17%	(14/unclear) 5x overstuffing (5x revision), 1x infection (revision), 1x ossification, 6x ulnar neuropathy, 1x superficial infection.
Allavena	2014	France	22	Guepar (DePuy Johnson & Johnson)	Cobalt-Chrome	Bipolar	Cemented	50 (n/a)	23%	(16/14) 6x subluxation (1x revision), 1x loosening (revision), 3x lateral elbow pain (3x revision), 2x CRPS, 4x ulnar neuropathy.
Watters	2013	U.S.A.	30	Evolve (Wright Medical)	Cobalt-Chrome	Monopolar	Loose fit	24 (18-53)	10%	(9/9) 3x overstuffing (3x revision), 4x stiffness, 2x nonunion/ malunion coronoid.
Berschback	2013	U.S.A.	27	Katalyst (Integra), Anatomic RHS (Acumed)	Cobalt-Chrome	Bipolar, monopolar	Loose fit, press fit	33 (18-57)	0%	(5/5) 5x resection HO.
El Sallakh	2013	Egypt	12	Anatomic RHS (Acumed)	Cobalt-Chrome	Monopolar	Press fit	42 (22-58)	0%	None
Katthagen	2013	Germany	29	Radial Head (Corin)	Cobalt-Chrome	Monopolar	Press fit	25 (7-54)	3%	(12/11) 1x overstuffing (revision), 6x symptomatic hardware, 3x ulnar neuropathy, 1x CRPS, 1x wound infection.
Sarris	2012	Greece	32	MoPyC (Tornier)	Pyrocarbon	Monopolar	Expandable stem	27 (21-46)	6%	(3/3) 2x dissociation prosthesis (revision), 1x arthrolysis.
Flinkkilä	2012	Finland	31	rHead (Avanta), Anatomic RHS (Acumed)	Cobalt-Chrome	Monopolar, monopolar	Press fit	53 (12-106)	29%	(15/15) 9x loosening (9x revision), 4x resection HO with arthrolysis, 1x radial neuropathy, 1x superficial infection.
Rotini	2012	Italy	31	rHead (SBi)	Cobalt-Chrome	Bipolar, monopolar	Press fit	24 (13-36)	6%	(3/3) 1x loosening (revision), 1x stiffness (revision), 1x persistent wrist pain. Cases hardware removal excluded.
Zunckiewicz	2012	U.S.A.	30	Katalyst (Integra)	Cobalt-Chrome	Bipolar	Loose fit	34 (24-48)	3%	(2/2) 1x overstuffing (revision), 1x instability.
Ricón	2012	Spain	28	MoPyC (Tornier)	Pyrocarbon	Monopolar	Expandable stem	32 (12-62)	11%	(6/6) 3x subluxation (3x revision), 1x peroperative fracture radial neck due to expansion stem prosthesis, 1x instability, 1x ulnar neuropathy.
Lamas	2010	Spain	47	MoPyC (Tornier)	Pyrocarbon	Monopolar	Expandable stem	48 (12-60)	11%	(7/7) 2x dislocation prosthesis (2x revision), 1x stiffness (revision), 1x dissociation prosthesis (revision), 1x fracture stem prosthesis (revision), 2x posterior interosseous nerve palsy.
Chien	2010	Taiwan	13	Evolve (Wright Medical)	Cobalt-Chrome	Monopolar	Loose fit	38 (20-70)	0%	(2/2) 1x stiffness, 1x symptomatic hardware.

Burkhart	2010	Germany	17	Judet CRF (Tornier)	Cobalt-Chrome	Bipolar	Cemented	106 (72-139)	12%	(4/4) 2x dislocation prosthesis (2x revision), 1x perforation shaft, 1x re-fracture ulna.
Celli	2010	Italy	16	Judet CRF (Tornier)	Cobalt-Chrome	Bipolar	Cemented	42 (12-86)	0%	(4/4) 2x ankylosis, 2x synostosis PRUJ.
Shore	2008	Canada	32	Richards (Smith & Nephew), Evolve (Wright Medical)	Titanium, Cobalt-Chrome	Monopolar, monopolar	Press fit & Loose fit	99 (26-166)	0%	(5/5) 3x ulnar neuropathy, 1x posterior interosseous nerve palsy, 1x CRPS.
Popovic	2007	Belgium	51	Judet CRF (Tornier)	Cobalt-Chrome	Bipolar	Cemented	101 (48-156)	0%	(10/10) 1x subluxation, 1x ulnar neuropathy, 4x posterior interosseous nerve palsy, 1x CRPS, 1x synostosis PRUJ, 2x symptomatic radiocapitellar degeneration.
Doornberg	2007	U.S.A.	27	Evolve (Wright Medical)	Cobalt-Chrome	Monopolar	Loose fit	40 (24-55)	7%	(13/unclear) 1x infection (revision), 1x overstuffing (revision), 1x subluxation. 4x stiffness, 5x ulnar neuropathy, 1x symptomatic hardware
Grewal	2006	Canada	26	Evolve (Wright Medical)	Cobalt-Chrome	Monopolar	Loose fit	25 (12-48)	0%	(6/6) 2x stiffness, 2x ulnar neuropathy, 1x posterior interosseous nerve palsy, 1x CRPS.
Chapman	2006	U.S.A.	16	Solar (Stryker Howmedica Osteonics)	Vitallium	Monopolar	Press fit	36 (23-51)	0%	(4/3) 1x stiffness, 1x ulnar neuropathy, 1x symptomatic hardware, 1x arthrolysis with ulnar nerve release.
Dotzis	2006	France	12	Judet CRF (Tornier)	Cobalt-Chrome	Bipolar	Cemented	63 (12-144)	0%	(1/1) 1x stiffness.
Wretenberg	2006	Sweden	18	Radius Head Comp. (LINK)	Cobalt-Chrome	Monopolar	Loose fit	36 (12-84)	28%	(5/5) 5x stiffness (5x revision).
Brinkman	2005	Netherlands	11	Judet CRF (Tornier)	Cobalt-Chrome	Bipolar	Cemented	24 (12-48)	18%	(4/4) 2x subluxation (revision), 2x stiffness.
Ashwood	2004	Australia	16	Evolve (Wright Medical)	Cobalt-Chrome	Monopolar	Loose fit	34 (14-52)	0%	(6/6) 3x ulnar neuropathy, 1x CRPS, 2x superficial infection.
Moro	2001	Canada	25	Richards (Smith & Nephew)	Titanium	Monopolar	Press fit	39 (26-58)	0%	(8/8) 1x posterior interosseous nerve palsy, 2x ulnar neuropathy, 1x CRPS, 1x mild instability, 2x symptomatic hardware, 1x superficial infection.
Harrington	2001	Canada	20	Richards (Smith & Nephew)	Titanium	Monopolar	Press fit	145 (72-348)	20%	(4/4) 4x lateral elbow pain (4x revision).
Smets	2000	Belgium	15	Judet CRF Tornier)	Cobalt-Chrome	Bipolar	Cemented	25 (6-48)	7%	(4/4) 1x stiffness (revision), 1x posterior interosseous nerve, 1x radial neuropathy, 1x synostosis PRUJ.
Judet	1996	France	12	Judet CRF (Tornier)	Cobalt-Chrome	Bipolar	Cemented	45 (24-72)	0%	(2/2) 1x bony impingement, 1x posterior interosseous nerve palsy.
Knight	1993	U.K.	31	Osteonics (Stryker Howmedica)	Vitallium	Monopolar	Press fit	54 (24-96)	6%	(5/4) 2x loosening (2x revision), 2x ulnar neuropathy, 1x synostosis PRUJ.

* Total: number of patients followed-up in the study. n/a: not available. HO = Heterotopic Ossifications. CRPS: complex regional pain syndrome. PRUJ = Proximal Radioulnar Joint.

considered a complication if they required surgical intervention. As a consequence, periarticular ossifications were only considered a complication if resected. The outcome variable secondary surgery was analysed in a similar fashion. Secondary surgery was defined as all surgery about the elbow, including revision surgery, performed after the index surgery. All outcome parameters were analysed for dependence on the prosthesis polarities, materials and techniques of fixation, both jointly as well as separately. In 27 of 30 studies only one combination of prosthetic modularity, material and technique of fixation was used (i.e. only one type of prosthesis). In three studies 2 combinations were used (i.e. two types of prostheses), which we considered as separate groups in the analyses. Therefore, the aggregated pooled data file used for the analyses consisted of 33 study groups rather than 30 studies. All outcome parameters were also analysed according to delay of treatment as dichotomized in three alternative ways: less than or equal to one week versus more than one week, less than or equal to two weeks versus more than 2 weeks and less than or equal to one month versus more than one month. Per study these dichotomized delay of treatment data were summarized as proportion of the number of valid patients. Also age (averaged per study) was used as an explanatory variable.

Statistical analysis

The overall population of all radial head prosthesis was characterized using descriptive statistics on the aggregated level of study group. Unweighted as well as weighted averages across study groups were calculated using the number of patients per study as weights. Special attention was paid to the joint outcome of prosthesis polarity, material and technique of fixation and the operational interrelation between these modularities. Revision data aggregated per study was analysed using generalized linear modelling. The number of revisions per study was assumed to have a negative binomial distribution with the logarithm of the number of person-years as offset. For the effect of explanatory variables on the revision rate a log-link function was used. Rate ratios, the dispersion parameter and mean revision rates per category of the explanatory variables were estimated using the model. The dispersion parameter accounted for the extra-Poisson variability across studies. The various ranges of motion and the MEPS were analysed using weighted linear regression with the number of valid patients per study group as weights. For all analyses a p-value equal to or less than 0.05 was considered significant. Analyses were performed using SPSS 21.0 (IBM Corporation, Armonk, NY, USA) and SAS 9.2 (SAS Institute Inc., Cary, NC, USA).

Results

Population characteristics

Thirty articles were included reporting on 727 patients (Table 1)[6-35]. The number of patients per study ranged from 11 to 51. All studies were case series (Level IV, therapeutic studies). Studies originated in Europe (17 articles), Northern America (9 articles), Asia (2 articles), Australia (1 article) and Northern Africa (1 article). The oldest article was published in 1993 and the most recent in 2015.

Variability among studies in reporting patient and population characteristics was substantial. Data on prosthetic material and modularity was complete, because failure to report these parameters would have resulted in exclusion of the study. The most frequently used prostheses were the Evolve (wright Medical), the Radial Head System (Tornier) and the MoPyC (Tornier), together accounting for 54% of all prostheses (table 2). Regarding implant material 506 (70%) prostheses were made of cobalt-chrome, 107 (15%) of pyrocarbon, 67 (9%) of titanium and 47 (6%) of vitallium. Regarding implant polarity 508 (70%) were monopolar and 219 (30%) were bipolar. Regarding implant fixation 156 (21%) were cemented in place, 230 (32%) were press-fit, 234 (32%) were intentional loose fit and 107 (15%) were fixed by an expandable stem. Only 8 out of the 32 theoretically possible combinations of prosthesis polarity, material and technique of fixation were observed (table 3). This relatively small number of observed combinations complies with the operational interrelationship between these three prosthesis modalities and reflects the true spectrum of available prostheses. In three studies two combinations of prosthesis polarity, material and technique of fixation (i.e. two types of prostheses) were used[10, 29, 32].

Table 2: List with characteristics of all types of radial head prostheses used in the included studies.

Name of prosthesis	Manufacturer	Material	Modularity	Polarity	Fixation	Comment
Anatomic Radial Head System	Acumed	Cobalt-Chrome	Modular	Unipolar	Press-fit	
Evolve Modular Radial Head System	Wright Medical	Titanium	Modular	Unipolar	Loose-fit	
Guepar radial head prosthesis	DePuy, Johnson & Johnson	Cobalt-Chrome	Modular	Bipolar	Cemented	Discontinued
Judet Floating Radial Head (CRF II) (now Radial Head System)	Tornier	Cobalt-Chrome	Modular	Bipolar	Cemented	In text and tables listed as Radial Head System (Tornier) for all occurrences. Currently also available as press-fit.
Katalyst Bipolar Radial Head System	Integra	Cobalt-Chrome	Modular	Bipolar	Loose-fit	
MoPyC radial head	Tornier	Pyrocarbon	Modular	Unipolar	Expandable stem	
Solar radial head	Stryker Howmedica Osteonics	Vitallium	Monoblock	Unipolar	Press-fit	
Radial Head	Corin	Cobalt-Chrome	Monoblock	Unipolar	Press-fit	
Radius Head Component	LINK	Cobalt-Chrome	Monoblock	Unipolar	Loose-fit	
rHead	Avanta	Cobalt-Chrome	Modular	Unipolar	Cemented	Currently Small Bone Innovations (SBi)
rHead	Small Bone Innovations (SBi)	Cobalt-Chrome	Modular	Unipolar	Cemented	
Richards radial head	Smith & Nephew	Titanium	Monoblock	Unipolar	Press-fit	Discontinued

Table 3: Observed combinations of prosthesis polarity, material and technique of fixation.

	Combination of prosthesis polarity, material and technique of fixation	Number of study groups	Studies with 2 combinations	Number of patients
1	Monopolar / cobalt-chrome / press-fit	5	2	97
2	Bipolar / cobalt-chrome / press-fit	1	1	19
3	Monopolar / titanium / press-fit	3	1	67
4	Monopolar / vitallium / press-fit	2	0	47
5	Bipolar / cobalt-chrome ./ cemented	8	0	156
6	Monopolar / cobalt-chrome – intentional loose fit	9	1	190
7	Bipolar / cobalt-chrome / intentional loose fit	2	1	44
8	Monopolar / pyrocarbon / expandable stem	3	0	107
	Total	**33**		**727**

Descriptive summary statistics of the various other independent and dependent variables are presented (table 4). Of each variable two means were calculated across the maximally 33 study groups: an unweighted average and a weighted average with the number of patients per study group as weights, the latter equalling the mean across the maximally 727 patients. These means did not differ much from one another, as reasonably no systematic relationship should exist between the number of patients and the mean of a variable per study and the mean of a variable per study. Other sample statistics than the mean in the total group of patients, such as median, range and standard deviation were not presented, as they do not bear a proper relationship to underlying population parameters since in 16 studies only pooled data were reported. Age at surgery was reported for 667 (92%) of 727 included patients. Weighted average age at surgery was 50 years. Data on delay of treatment was inconsistently and variably reported. It could be determined that either 262 (68%) out of 388 patients for whom the delay of treatment could be inferred from the reported data were operated with a delay of equal to or less than one week, or that 299 (75) out of 398 for whom this could be inferred were operated with a delay of equal to or less than 2 weeks, or that 424 (83%) out of 508 patients for whom this could be inferred were operated with a delay of equal to or less than one month. For many patients information on delay of treatment was not reported: in 47%, 45% and 30% for respectively a delay of equal to or less than one week, a delay of equal to or less than two weeks and delay of equal to or less than one months. Weighted average follow-up was 45 months.

Table 4: Descriptive summary statistics across the aggregated study groups.

	Study groups				Patients	
Independent variable	N	Mean	Minimum	Maximum	N	Mean
Age at surgery (years)	31	48.4	37.0	59.2	667	49.8
Delay of treatment ≤1 week (%)	21	55.6	0.0	100	388	67.5
Delay of treatment ≤2 weeks (%)	21	66.5	0.0	100	398	75.1
Delay of treatment ≤1 months (%)	26	76.4	0.0	100	508	83.5
Follow-up (years)	33	3.6	1.01	8.83	727	3.73
Dependent variable	**N**	**Mean**	**Minimum**	**Maximum**	**N**	**Mean**
Revision surgery (%)	33	7.1	0.0	29.0	727	7.7
Revision surgery (per 100 person-years of follow-up)	33	2.81	0.0	19.83	727	2.1
Postoperative flexion (degrees)	29	130.2	117.0	140.0	609	130.6
Postoperative extension deficit (degrees)	30	15.0	6.0	28.1	625	15.3
Postoperative flexion-extension arc (degrees)	25	115.8	96.4	131.5	523	115.8
Postoperative supination (degrees)	29	72.2	56.8	88.0	610	72.8
Postoperative pronation (degrees)	29	69.7	51.0	84.0	610	69.6
Postoperative pronation-supination arc (degrees)	21	140.3	112.6	168.9	399	141.2
Mayo Elbow Performance Score (coded as 1=poor, 2=fair, 3=good and 4=excellent)*	18	3.37	2.92	3.84	358	3.35

[The mean presented under study groups is an unweighted average and the mean presented under patients is a weighted average with the number of patients per study as weight.]
* For purposes of statistical analysis coded as 1=poor, 2=fair, 3=good and 4=excellent. See text for explanation.

Primary outcome measures

The percentage of patients that underwent revision surgery ranged among studies from 0-29% when expressed in relation to the valid number of patients the studies. The number of revisions per 100 person-years of follow-up ranged from 0 to 20 across studies. In total there were 56 (8%) revisions during 2714 person-years of follow-up across all 727 patients, yielding a crude overall revision rate of 2.06 per 100 person-years of follow-up. Using generalized linear modelling the mean revision rate across all 33 study-groups (i.e. for the entire overall population of 727 patients) based on the negative binomial distribution was 2.53 (95% CI: 1.53 – 4.20) per 100 person-years of follow-up. The simultaneous effect of all 8 combinations of prosthesis polarity, material and technique of fixation was not significant (p=0.92) (table 5). For combinations with a small underlying number of patients the imprecision of the estimates was large, as is reflected by the wide confidence intervals. Even the largest pairwise difference was not significant. Also, the separate prosthesis modalities polarity, material and technique of fixation had no significant effect on revision rate (respective p-values 0.46, 0.69 and 0.98). The revision rate was also not significantly affected by delay of treatment, dichotomized at 1 week (p=0.52), or at 2 weeks (p=0.87), or at 1 month (p=0.77). It has to be noted that delay of treatment was not reported in many studies. Also age was found to have no significant effect on the revision rate (p=0.92).

Table 5: Revision rate (per 100 person-years of follow-up) by combinations of prosthesis polarity, material and technique of fixation as estimated using generalized linear modeling.

Combination of prosthesis polarity, material and technique of fixation	Mean (95% CI)
Monopolar / cobalt-chrome / press-fit	2.74 (0.81 - 9.28)
Bipolar / cobalt-chrome / press-fit	2.63 (0.14 – 51.1)
Monopolar / titanium / press-fit	4.77 (1.16 – 26.4)
Monopolar / vitallium / press-fit	0.91 (0.11 – 7.82)
Bipolar / cobalt-chrome / cemented	2.10 (0.72 – 6.11)
Monopolar / cobalt-chrome / intentional loose fit	2.82 (1.16 – 6.85)
Bipolar / cobalt-chrome / intentional loose fit	0.72 (0.06 – 9.14)
Monopolar / pyrocarbon / expandable stem	3.10 (0.73 – 13.2)
Total	**2.53 (1.53 – 4.20)**

The range of motion variables flexion-extension arc and pronation-supination arc were analysed using weighted linear regression (table 6). Neither on the flexion-extension arc, nor on the pronation-supination arc a significant effect of combination of prosthesis polarity, material and technique of fixation was found (respective p-values 0.76 and 0.19). Also, the flexion-extension arc and the pronation-supination arc were not significantly affected by the separate prosthesis modalities polarity (respective p-values 0.88 and 0.26), material (respective p-values 0.87 and 0.23) and technique of fixation (respective p-values, 0.86 and 0.18). Delay of treatment less than or equal to one week or less than or equal to 2 weeks resulted in a higher pronation-supination arc than longer delays: 130.0 as compared to 157.2 degrees (a difference of 27.2 degrees; 95% CI: 13.1-41.2; p=0.001) for delay less than or equal to one week and 129.1 as compared to 154.2 degrees (a difference of 25.1 degrees 95% CI: 9.2-41.0; p=0.004) for delay equal to or less than 2 weeks. A delay equal to or less than one month versus more than 1 month had no significant effect on pronation-supination arc: 130.8 as compared to 146.3 degrees (a difference of 15.5 degrees (95% CI -5.0 to +36.0; p=0.13). No significant effects of delay of treatment were found on the flexion-extension arc (p-values 0.77, 0.61 and 0.70 for the respective delays of treatment less than or equal to one week, less than or equal to 2 weeks and more than one month). Average MEPS was reported in 18 of the 33 study groups (Table 4). The standard deviation (S.D.) across study groups of the average MEPS was 0.26, allowing small mean differences between groups to reach statistical significance. An overall significant effect of combination of prosthesis polarity, material and technique of fixation on the MEPS was found (p=0.038), meaning that at least one combination differed from the other ones. By testing the difference of each combination with another one (pairwise comparisons) it appeared that the difference between the combinations bipolarity/cobalt-chrome/cemented fixation and monopolarity/pyrocarbon/expandable stem mainly contributed to this overall significance with a p-value of 0.003 (table 7). P-values for the separate effects of the prosthesis modalities on the MEPS were 0.13 for polarity, 0.057 for material and 0.009 for technique of fixation. Although for all four techniques of fixation the coded interpreted outcome was on average between good and excellent, it appeared that within this small range press-fit fixation (mean 3.5) and fixation by an expandable stem (mean 3.7) resulted on average in better outcome scores than cemented fixation (mean 3.1, with respective p-values 0.019 and 0.002). Fixation by an expandable stem (mean 3.7) also scored better than intentional loose fit (mean 3.3, with p=0.024). It has to be noted here that the effect of a separate prosthesis modality is operationally confounded by effects of the other modalities on MEPS.

Table 6: Mean flexion-extension arc and pronation-supination arc by combination of prosthesis polarity, material and technique of fixation as estimated using weighted linear regression analysis.

Combination of prosthesis polarity, material and technique of fixation	Flexion-extension arc (degrees)		Pronation-supination arc (degrees)	
	Mean (95% CI)	P-value	Mean (95% CI)	P-value
Monopolar / cobalt-chrome / press-fit	114.8 (105.3-124.3)	0.76	147.6 (133.1-162.1)	0.19
Bipolar / cobalt-chrome / press-fit	113.9 (92.5-135.4)		112.6 (82.0-143.3)	
Monopolar / titanium / press-fit	119.9 (106.2-133.5)		137.7 (118.2-157.2)	
Monopolar / vitallium / press-fit	115.3 (92.0-138.7)		154.1 (120.6-187.5)	
Bipolar / cobalt-chrome ./ cemented	113.2 (105.3-121.1)		139.9 (125.6-154.1)	
Monopolar / cobalt-chrome / intentional loose fit	112.9 (103.5-122.2)		129.9 (113.9-145.9)	
Bipolar / cobalt-chrome / intentional loose fit	126.5 (112.4-140.6)		135.4 (99.6-171.1)	
Monopolar / pyrocarbon / expandable stem	118.0 (105.9-130.1)		156.7 (139.4-173.9)	
Total	**116.8 (111.5 – 122.1)**		**139.2 (130.7 – 147.8)**	

Table 7: Mean coded interpreted outcome of the Mayo Elbow Performance Score (MEPS)* by combination of prosthesis polarity, material and technique of fixation as estimated using weighted linear regression analysis.

Combination of prosthesis polarity, material and technique of fixation	Mean (95% CI)
Monopolar / cobalt-chrome / press-fit	3.6 (3.1 – 4.0)
Bipolar / cobalt-chrome / press-fit	3.7 (3.2 – 4.0)
Monopolar / titanium / press-fit	No data reported
Monopolar / vitallium / press-fit	3.3 (2.7 – 3.8)
Bipolar / cobalt-chrome / cemented	3.1 (2.9 – 3.3)
Monopolar / cobalt-chrome / intentional loose fit	3.3 (3.1 – 3.5)
Bipolar / cobalt-chrome / intentional loose fit	3.6 (3.0 – 4.0)
Monopolar / pyrocarbon / expandable stem	3.7 (3.4 – 4.0)
Total	**3.5 (3.3 – 3.6)**

* MEPS is coded as 1=poor, 2=fair, 3=good and 4=excellent.

Secondary outcome measures

There was substantial variation between studies in reportage of complications, but also the definition of complication varied among studies. A particular issue was whether or not radiological observations were counted as complication. Therefore it was deemed that comparing incidences was of no value. In the overall patient population there were 182 complications reported in 167 (23%) of 727 patients (table 1).

The incidence of secondary surgery, including revisions, ranged from 0-42% when expressed in relation to the valid number of patients in the studies. Altogether, 107 (15%) out of 727 patients underwent secondary surgery including revision surgery and 51 (7%) out of 727 patients underwent secondary surgery other than revision surgery.

Patient reported outcome measures were scarcely reported. Thirteen articles reported the DASH questionnaire, three reported the SF-36, two reported the ASES, two reported the PREE and none reported the OES.

Discussion

The radial head is an important secondary stabilizer of the elbow[1]. Replacement of the radial head is adamant in injuries in which the extent of ligamentous injury calls for this secondary stabilizing function and it is not possible to reconstruct the radial head. This is the case with Mason type-3 radial head fractures and the more complex elbow traumata. There is currently no evidence to support one type of modern radial head prosthesis over the other. The current study shows that the incidence of revision of radial head arthroplasty regardless of indication varied from 0-29% amongst the included studies. Of all patients, 8% had undergone revision surgery. For the overall study population, the estimated revision rate was 2.5 per 100 person-years of follow-up. There was no significant effect on revision rate, nor was there a significant effect on functional outcome in terms of range of motion by prosthesis polarity, material and technique of fixation. There appeared to be a significant effect of the combination of prosthesis polarity, material and technique of fixation on the MEPS, however, the MEPS was only reported for half of the patients in the overall study population. Twenty-three percent of the overall study population had some complication and 7% underwent secondary surgery other than revision surgery.

Several limitations are recognized. Studies were included regardless of surgical indications. Due to the mixed populations in many studies and limited reportage of associated pathology, it was not possible to perform analyses stratified for indication and/or associated pathology. There was substantial variability amongst studies in the reportage of results. This was particularly true for radiological parameters. Prosthesis polarity, material and technique of fixation are not independent of each other. This resulted in only 8 possible combinations instead of the maximally 32 possible combinations (2 different polarities, 4 different materials and 4 different techniques of fixation) were the prosthetic design parameters to be completely independent. As stated, this reflects the true spectrum of available prostheses. Statistically this means that prosthesis polarity, material and technique of fixation are inextricably operationally confounded with each other. Further, a much larger sample size would be needed to obtain significant effects with sufficient power. Even for the largest pairwise contrast in revision rates between combinations of prosthesis polarity, material and technique of fixation an at least three times larger sample size would be needed.

In the overall population of the current study there were 56 (8%) revisions out of 727 patients, both amongst monopolar (n=44) and bipolar (n=12) prostheses. Thirteen (23%) of those failures were for loosening, 11 (20%) for overstuffing, 10 (18%) for (sub)luxation, 8 (14%) for stiffness, 7 (12%) for lateral elbow pain, 3 (5%) for dissociation of the prosthesis, 2 (4%) for infection, 1 (2%) for malposition and 1 (2%) for fracture of the stem of the prosthesis. One revision for loosening involved a cemented[8] and 12 a press-fit prosthesis[19, 24, 29]. Osteolysis around the stem is described in about 50% of all patients with a press-fit radial head prosthesis[10, 14, 18, 19, 21, 24, 26, 29, 32], with a prevalence of 17-100% in the various studies included in this review. In most cases this osteolysis was deemed asymptomatic. Noteworthy, 9 out of those 12 press-fit failures occurred for in one single case series by Flinkkila et al. and were performed for lateral elbow pain and implant loosening[19]. Although the authors attributed this to poor bony ongrowth, it is not clear why other studies using the same or similar prostheses reported substantial lower incidences of failure. Biomechanical studies suggested that monopolar prostheses better restore elbow stability than bipolar prostheses and it was therefore suggested monopolar prostheses would better resist radiocapitellar subluxation[36, 37]. However, Berschback et al. and Rotini et al. could not confirm this in comparative clinical studies[10, 29]. In the overall population of the current study 5 revisions for (sub)luxation involved a monopolar and 5 a bipolar prosthesis. When replacing the radial head, restoring the length of the radius is important. Overstuffing may result in increased radiocapitellar pressure, which may in turn lead to attrition of the capitellar articular cartilage and pain[38]. On the other hand, failure to restore the length of the radius may result in instability. It has been proposed to use the proximal edge of the lesser sigmoid notch of the ulna with the forearm in neutral rotation as reference for the articulating surface of the prosthesis[39]. It has been postulated that restoring radial length may be easier to accomplish with modular prosthesis. This cannot be confirmed by the current study; of the eleven revisions for overstuffing in the overall population of the current study 10 were modular prostheses and one was a monoblock prosthesis.

There was large variation amongst studies in terms of the quality and quantity in which information and data were reported. Not infrequently important methodological information or important outcome parameters was lacking. This heterogeneity in data hampers sound comparison of studies and renders it impossible to conduct a formal meta-analysis. This problem has also been recognized for total elbow arthroplasty[40]. Obviously, the peer review process is falling short assuring uniformity and quality in data reportage. A discussion about the institution of guidelines for standardized reportage of clinical outcomes seems appropriate. This certainly also holds true for radiological parameters. Radiological findings were reported with too great a variability to allow for a structured analysis and for that reason no radiological outcome parameter was used in this study. However, the nature, evolution and possible correlation with clinical findings is of great interest.

It has been recognized that associated injury about the elbow, forearm or wrist is very likely to affect the outcome after radial head arthroplasty. However, in the current study it became apparent that associated injuries were so scarcely and variably reported that no reliable analysis could realistically be attempted. It is assumed that such associated injuries are often missed during physical examination. MRI studies have shown that 76-96% of elbows that had sustained a radial head fracture may have associated injuries about the elbow[38, 41-43]. Also, if adequate reconstruction or replacement of the radial head is timely performed, many of these injuries may heal without clinical consequences and remain undiagnosed at all.

Based on our analysis of the peer reviewed English literature on radial head arthroplasty from 1940 to date there seems to be no evidence to support one type of modern radial head prosthesis over the other.

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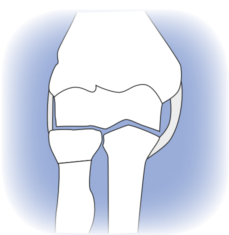
DISCUSSION AND SUMMARY

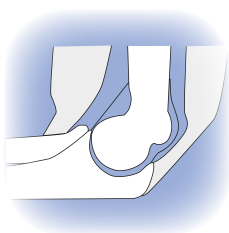
IV

CHAPTER 11

General discussion

Izaäk F. Kodde





This thesis is structured in four parts; **part I** (chapter 1) is a general introduction on function and anatomy of the elbow, **part II** (chapters 2 to 5) focusses on sports related injuries and **part III** (chapters 6 to 10) deals with traumatic injuries. **Part IV** (chapters 11 and 12) is the general discussion, summary and overall conclusion of this thesis.

Part I – Function and anatomy of the elbow

The elbow is one of the most complex joints in the human body. It consists of three distinct joints that allow for flexion and extension of the arm in combination with pronation and supination of the forearm. Stable and painless motion of the elbow is necessary for accurate positioning of the hand in space, which is required for most activities in daily living, but also for performing labor and for sports activities. A full range of stable and painless motion is therefore considered as one of the most important outcome parameters following treatment of elbow injuries. For this reason, it is often the basis of various (patient reported) outcomes scores. The Mayo elbow performance score (MEPS) for instance, is one of the most frequently used outcome scores in elbow surgery and comprises exactly these 4 domains: pain, motion, stability and function of the elbow in daily living[1]. The normal range of motion is variable among individuals and depends age and gender. Back in 1981, Morrey et al. evaluated what amount of motion of the elbow was required to perform 15 activities of daily living[2]. These activities involved motions that are used for personal care and hygiene, but also actions like using a telephone, reading a newspaper, rising up from a chair and opening a door. Their conclusion was that most of these activities can be accomplished with an arc of 100° (30°-130°) of elbow flexion and an arc of 100° (50°-50°) of forearm rotation[2]. More recently, in 2011, Sardelli et al. repeated this study on functional elbow range of motion in daily living. They updated the list of activities with contemporary tasks like using a computer mouse and keyboard, and holding a cellular phone while standing[3]. It was found that using a computer mouse and keyboard requires more pronation (65°) and using a cellular phone requires more flexion (130°) than the previously described activities by Morrey et al[2]. As over 80% of the people in developed countries own a computer, and almost 97% of the world population have a cellular phone subscription at the moment[4], the use of these devices are getting more and more important for the vast majority of the human beings. These numbers indicate the importance of optimal range of motion of the elbow following treatment of elbow pathology, to fulfill the higher demands and expectations of these patients. The pursued outcome of elbow surgery should therefore not only be a stable and painless joint, but also an elbow with optimal range of motion. A special group of patients, that need a different approach in elbow surgery, are high performance athletes. These high demanding group of patients, desire not only a full recovery following treatment, but also a rehabilitation schedule that is as quick and aggressive as reasonable achievable. In order to comply with these demands, many surgical implants have been developed and part of these new designs have been described in part II of this thesis.

The second focus of part 1 was on the anatomy of the elbow. A solid knowledge of elbow anatomy is mandatory for every surgeon to avoid perioperative complications, which might compromise the outcome of elbow surgery. The preoperative plan before any surgical procedure at the elbow should discuss which incision and approach is needed to 1) address the known injuries, but also potential symptomatic associated injuries, and 2) avoid potential complications such as neurologic disorders or formation of heterotopic ossifications (HO). 'Failure to plan your surgery will result in a plan for failure of your surgery.'
Fractures of the radial head are illustrious in the relation of recognized fractures and the occurrence of associated injuries that are difficult to diagnose. The usual approach to the radial head is from lateral through the interval of Kocher, Kaplan or EDC-split (figure 1). The Kocher approach is the most posterior one and uses the interval between the Anconeus and extensor carpi ulnaris (ECU) muscles[5]. The Kaplan (interval between the extensor digitorum communis (EDC) and extensor carpi radialis brevis and longus (ECRBL) muscles[6]) and EDC-split approaches are more anterior and allow for better visualization and repair of fractures of the anterolateral part of the radial head[7]. However, when there is concomitant injury to the lateral collateral ligament (LCL) complex, the extended Kocher approach better facilitates this repair[7]. Whereas the Kocher approach may injure the LCL, a distal extension of the Kaplan approach may damage the posterior interosseous nerve (PIN)[8]. When there is concomitant injury to the ulnar collateral ligament (UCL) a second medial incision can be made. Yet, a single posterior incision allows for adequate access to both the medial and lateral side of the elbow and may be a better alternative in cases of radial head fractures with complex elbow instability[9]. The choice of the approach is finally dictated by preference of the surgeon.

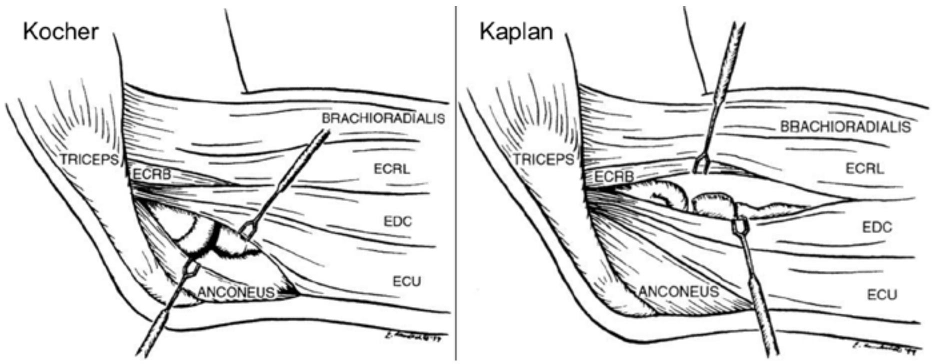


Figure 1: The limited Kocher approach between anconeus and extensor carpi ulnaris and Kaplan approach between extensor digitorum communis and extensor carpi radialis longus and brevis are shown. ECRB = extensor carpi radialis brevis; ECRL = extensor carpi radialis longus; EDC = extensor digitorum communis; ECU = extensor carpi ulnaris. Reproduced with permission of Wolters Kluwer from[10].

Rupture of the distal biceps tendon may go together with damage to the lacertus fibrosis, but concomitant injury to other structures is rare. The approach of the distal biceps tendon should therefore focus on the ability to do a refixation on the native anatomic footprint with the minimum risk on complications. Different approaches to the distal biceps tendon have been described, generally involving either a single anterior incision, or a double incision on the anterior and posterior side of the elbow. Historically, an extensive anterior approach was used, which was frequently complicated by neurologic injuries[11]. Boyd and Anderson therefore described a double incision approach in which the posterior route to the radius was subperiosteal along the ulna[12]. Unfortunately, this approach was associated with more cases of heterotopic ossification (HO) and subsequent loss of motion. The introduction of new implants such as suture anchors, interference screws and cortical buttons, allowed for a less extensive anterior approach. On the other hand, a modification on the double incision approach in which the posterior route to the radius was through the muscles, avoiding the ulna, was developed in order to minimize the risk on HO[13]. All these adjustments to the original surgical techniques seem to diminish to change on complications but enhance the strength of the surgical construct[14].

Overall, one should bear in mind that surgery about the elbow is prone to develop neurologic complications and the formation of HO. It is therefore important to have adequate knowledge of the anatomy and routes of the nerves (including the cutaneous nerves) near the elbow. Proximate nerves should be identified and protected throughout the procedure. Every single time a retractor is placed, the surgeon should remember that it could cause compression or stretch on nearby nerves. To avoid HO, dissection of bone should be limited and bone remnants should be extensively purged. The use of new implants may allow for more limited dissection, but the surgeon should never compromise to the above-mentioned basics because of the implant.

Part II – Sports related injuries

Originally, most research on distal biceps tendon ruptures was conducted in order to improve the surgical technique and construct of the repair[15]. More recently, anatomical and biomechanical studies also focused on the structure and function of the tendon and associated structures. However, the pathophysiology of distal biceps ruptures remains mostly unclear, and the number of studies on this subject is only limited[16, 17]. It has been suggested that causative reasons involve both degenerative and mechanical factors[18]. Regarding the latter; hypertrophic changes of the radial bicipital tuberosity (RBT) may contribute to impingement of the distal biceps tendon between radius and ulna during pronation. In order to investigate this, we performed a study in chapter 2 in which the size of the RBT between patients with a distal biceps tendon rupture and controls was compared. We were unable to verify that the size of the RBT was increased in patients with a distal biceps tendon rupture, compared to controls, on conventional radiographs of the elbow. A reason for this might be the fact that the study was underpowered with 22 case-control pairs. However, a series of 115 case-control pairs is necessary to reach 90% power, a number that outreaches the amount of patients in the most extensive studies to date[19, 20]. In order to provide information on how to diminish the risk on distal biceps tendon ruptures in for instance bodybuilders it is necessary to further investigate this subject. Future studies, however, may rather use data from CT-scans than conventional radiographs, as these give more accurate three-dimensional and volume data of the RBT. Moreover, these scans may be used in simulations of forearm rotations and the variances in distance at the RBT between radius and ulna, as is currently available for simulations of femoroacetabular impingement in the hip[21]. Yet, the CT-scan is no part of the usual work-up of distal biceps tendon ruptures and should therefore be made in the context of an ethical committee approved prospective study. MRI-scans, which are frequently made to confirm the diagnosis of a distal biceps tendon rupture, may be less suitable for these calculations and simulations. Until the day these studies have been performed, the exact pathophysiology of distal biceps tendon ruptures will remain unclear, and the treatment just symptomatic. In case of a very proud appearance of the RBT at standard radiographs with radioulnar impingement during surgery, reduction of the RBT may be performed. Preventive reduction of a normal RBT, however, can lead to decrease in supination strength, as the RBT functions as a mechanical cam[22].

The repair of ruptured distal biceps tendon on the RBT can be performed with use of bone tunnels, suture anchors, interference screws or cortical buttons. The cortical button had the highest failure load compared to the other techniques at cyclic and linear loading in biomechanical studies[23, 24]. In chapter 3 we report on a study we performed in which the clinical outcome for single incision anterior cortical button repair was good, with no complications related to the implant, except for one patient that had symptomatic awareness of the button. Complications were seen in 36% of patients. This led to the question whether the amounts of complications depend on the approach or the type of refixation technique used. All complete distal biceps tendon ruptures need an anterior incision to localize and transpose the (retracted) stump of the distal biceps tendon. A subsequent repair can be performed through the same incision with use of suture anchors, interference screws or cortical buttons. The tendon can also be transposed posteriorly and be repaired through another incision at the posterior side with use of suture anchors or bone tunnels. Whereas the latter was historically associated with radioulnar synostosis formation, our review of the recent literature in chapter 4 showed none of these complications. The double incision approach with bone tunnels repair even showed fewer complications than the anterior approach. We hypothesized that the 'Morrey-modification' of the double incision approach had to do with this[13]. In this approach the radius is exposed through the extensor carpi ulnaris muscle and exposure of the ulna is avoided (figure 2). In addition, the double incision approach may allow for a more anatomic refixation on the RBT footprint compared to the single incision anterior approach[25, 26]. Although current evidence is in favor of the double incision technique, the single incision approach may also lead to excellent results. The anterior approach is considered easier to perform, and therefore more frequently described in the literature in smaller series. The inferior results of the single incision technique could have been confounded by the fact that inexperienced surgeons predominantly use this approach, whereas specialized elbow surgeons more frequently use the double incision technique. In the case of partial ruptures, a single incision posterior approach can be used, thus avoiding all anterior structures and anterior approach associated complications[27]. The approach of the distal biceps tendon should be the one where the surgeon is most familiar with, but results of recent literature ask for reconsideration of the muscle-splitting double incision approach.

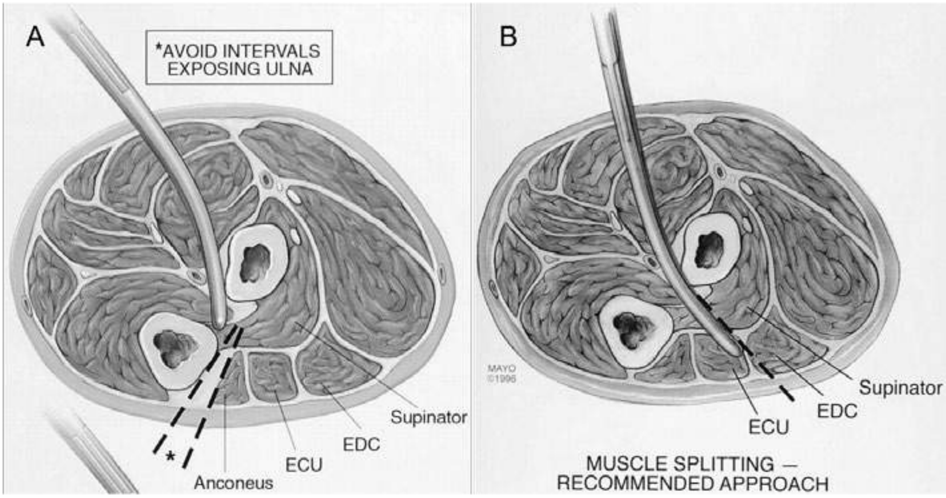


Figure 2: Two diagrams demonstrating the incorrect path [A] and the correct path [B] for exposure of the radial tuberosity through a posterior incision. EDC = extensor digitorum communis; ECU = extensor carpi ulnaris. Reproduced with permission of Rockwater, Inc. from[13].

With regard to the different implants that can be used for distal biceps tendon reconstruction, our review could not show significant differences in clinical outcome. The cortical button was superior to the other implants in biomechanical studies[23, 24]. However, bone tunnels (which used to be the standard procedure) were not inferior to other implants in a biomechanical study by Kettler et al.[23]. They therefore concluded that: 'compared with the newer device-based techniques, the transosseous (bone tunnels) suture technique is still an adequate procedure, especially because the sutures are less expensive than are the suture anchors'[23]. In our review in chapter 4, the bone tunnels technique was associated with fewer complications than the other fixation techniques. Though, we found a strong interrelationship between the bone tunnels fixation and the double incision approach, and we were unable to efficiently disentangle the effects of these variables. The choice of implant should depend on surgical approach and financial based preferences. In athletes the surgeon may prefer a cortical button based on biomechanical studies, although clinical evidence for its superiority is lacking. Heinzelmann et al. combined a cortical button with an interference screw fixation in order to allow for a more aggressive rehabilitation, but they still advised to avoid flexion against resistance for the first 2-3 months, which is comparable with other postoperative rehabilitation protocols[28].

The general treatment strategy for ulnar collateral ligament (UCL) tears is nonoperative for the non-elite athlete and surgical reconstruction for the competitive athlete[29]. In the first, the flexor-pronator mass will keep the elbow stable, but throwing will be limited. Rettig et al. evaluated a conservative treatment program for throwing athletes with a UCL deficiency[30]. The program consisted of two phases: 1) rest and modalities to treat symptoms for 2-3 months, and if painfree, followed by phase 2) muscle strengthening and return to throwing. This program was successful in only 42% of the athletes. The vast majority of literature is therefore on reconstruction techniques of the UCL in athletes. Most studies were from centers in the USA and showed a return to play in 63-92%[31]. In order to investigate European results, we performed a study on 20 European athletes in chapter 5. The results showed a return to sports in 90% of the patients, but 6/20 patients eventually quitted their sports activities, even after a successful comeback. A reason for this phenomenon may be that the athletes in our study did not play at a professional level, and were therefore not financially dependent on a successful return. Based on these results we question whether the results on American athletes can apply one-to-one on European athletes. The orthopedic surgeon that treats European athletes should be ensured of personal or European results, and always be convinced of the expectations and future career plans in athletes. We used triceps fascia as autograft for reconstruction of the UCL. The advantages of this graft are its strength and availability (through the same incision) without donor site morbidity. Although there were no complications on triceps function, the possible affects on triceps strength from the use of triceps fascia autograft in athletes has currently been insufficiently investigated.

Part III – Fractures of the radial head

Fractures of the radial head are frequently considered as benign and isolated, but associated injuries at the elbow occur in up to 92% of cases[32]. Although most of these concomitant injuries are not symptomatic, it is useful to know in which patients these injuries can be expected. We performed a study in which we evaluated the effects of trauma and patient related factors on radial head fractures and associated injuries in chapter 6. We found that symptomatic associated injuries are more common in the elderly. The elderly patient may have lower demands of the elbow in terms of strength and endurance compared to the younger ones, but still need a stable elbow with adequate range of motion. As a consequence, the treatment of elbow trauma in the elderly is challenging. Studies from the USA showed that the number of elbow arthroplasty operations has increased significantly last decade[33]. Moreover, the indication to perform elbow replacement has changed from inflammatory/degenerative to traumatic causes[34]. Both studies from Day et al. and Gay et al. showed that most prosthesis are implanted in the elderly, and more frequently in females compared to males[33, 34]. These numbers are in line with our observations on radial head fractures, and suggest that a poor intrinsic quality of bone (osteoporosis) and soft tissues in the frailty elderly patient lead to more complex elbow fractures requiring more aggressive surgical treatment. Based on these findings, further development of antiresorptives or anabolic treatments to protect against fractures is necessary to offset some of the current trends in elbow replacement in the USA.

With regard to replacement surgery at the elbow in the Netherlands, about 22% of the registered procedures involved radial head arthroplasty in 2014[35]. The differences in surgical technique between total elbow replacement and radial head replacement are numerous. The mean age of patients that underwent total elbow arthroplasty was for instance 64, compared to 51 years for radial head replacement. About 50% of patients received radial head arthroplasty because of an acute fracture, whereas only about 10% of patients with total elbow arthroplasty had an acute fracture. Almost all total elbow prosthesis were cemented and most radial head prosthesis were cementless[35]. These numbers indicate that there are huge differences in patient characteristics, indications and surgical technique between total elbow arthroplasty and radial head arthroplasty. It is therefore important that the radial head prosthesis is analyzed separate in national implant registries. An advantage for the individual surgeon or institution is that indications and surgical technique can be compared with nationwide procedures. In the long term, these register data will also inform about and compare outcome for the various indications, types of implants and surgical techniques for radial head replacement.

Unfortunately, currently the long-term outcome of radial head arthroplasty is predominantly unknown. In our systematic review on metal radial head arthroplasty in chapter 10, we found studies describing the results of 12 different prosthetic designs. The production of two of them was already discontinued. We excluded silicon prosthesis from our review as that kind of implant was popular for a short while, but is currently obsolete because of poor long-term results. With a mean average follow-up of 45 months, the body of literature on the long-term survival of radial head prosthesis is poor. Based on these mid-term results, we found no essential differences among the various types of prosthesis and fixation methods in our review. Even more worrying was the quality of reporting on radial head arthroplasty. Not infrequently important methodological information or important outcome parameters was lacking. This heterogeneity in data hampers sound comparison of studies and thus implants. This problem has also been recognized for total elbow arthroplasty[36]. Obviously, the peer review process is falling short assuring uniformity and quality in data reportage. A discussion about the institution of guidelines for standardized reportage of clinical outcomes seems appropriate. Our studies on press-fit and cemented radial head arthroplasty (chapters 8 and 9, respectively) intended to provide complete, adequate and relevant data on these implants in terms of implants survival and objective clinical, subjective patient-reported and radiological outcome parameters. We suggest this way of reporting for future studies on this subject. The Dutch national implant registry system (LROI) may play an important role in this.

Part IV – General discussion

The management of trauma and sports injuries of the elbow is evolving. Because the elbow is prone to develop posttraumatic stiffness, it is important to allow early active range of motion exercises as soon as possible following injury[37, 38]. Current treatment protocols for radial head fractures are therefore directed to permit direct functional after-treatment of the elbow. This is especially important for athletes, in order to maintain their neuromuscular control. Additionally, athletes wish to return to sports as quickly as possible, as the time of professional practice is only short. Multiple implants have been introduced last decades to facilitate reconstructive surgery of tendons or ligaments and a possibly subsequent rapid recovery. Yet, it remains important to discuss with the athlete before surgery is planned about the wish to resume a sports career, as the dropout, even after successful surgery, may be high, while there is a significant risk on (transient) complications. Rehabilitation is still long after several reconstructive procedures around the elbow despite the use of new fixations devices.

In the cases of fractures, on the other hand, as radial head fractures, the primary reconstruction and rehabilitation should be optimal without doing concessions, also in professional athletes, in order to prevent degenerative changes (with need for arthroplasty) in the long-term[39].

Various implants (cortical buttons, interference screws, radial head prosthesis) have been passed in this thesis. Overall, the objective and subjective outcomes were good, but complications were not infrequently encountered. Moreover, we were unable to find significant differences in outcome between the various implants. In the end, it seems that the type of patient (elderly, athlete etc.), indication to do an operation (what kind of injury/fracture, what kind of (possible) associated injuries) and the surgical technique (approach, repair versus replacement etc.) may be more important on outcome than the type of implant used.

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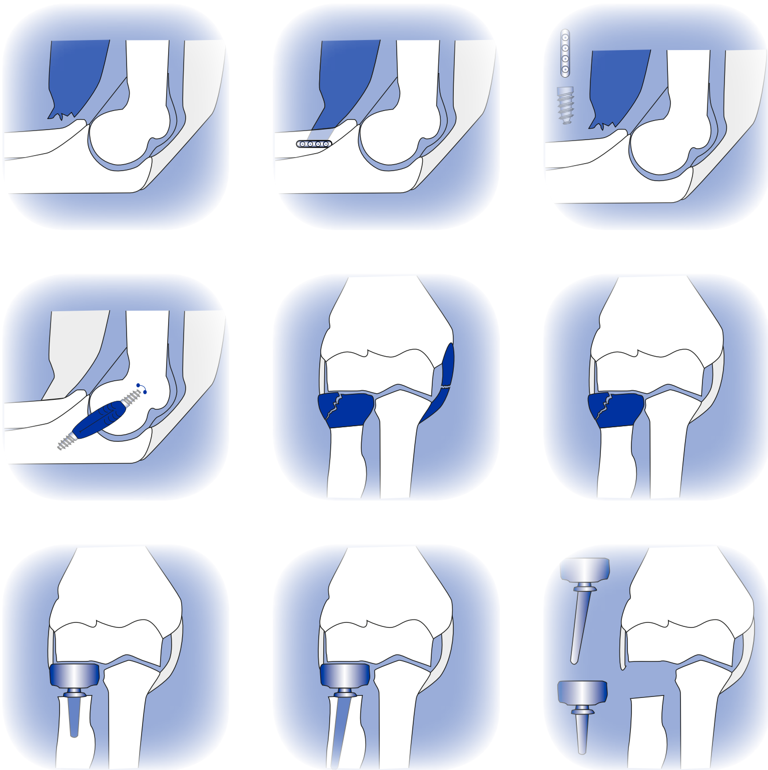
Chapter 12

Summary

TRAUMA AND SPORTS INJURIES OF THE ELBOW

Izaäk F. Kodde



The general aim of this thesis is to assess and enlarge the contemporary knowledge on the pathophysiology and treatment of common traumatic elbow conditions. In **chapter 1**, the basic anatomy and the functional biomechanics of the elbow joint are described in relation to current the management of trauma and sports injuries of the elbow.

The management of distal biceps tendon ruptures has evolved last decades following new insights in local anatomy and the introduction of minimal invasive surgical techniques. However, the underlying pathophysiology remains unclear. In **chapter 2** we evaluated one of the current thoughts, that the height of the radial bicipital tuberosity plays a role in the occurrence of distal biceps ruptures. In a study of 22 patients with a distal biceps tendon rupture, the radial bicipital tuberosity on standardized radiographs was compared with 22 matched controls. We found no significant difference in size of the radial bicipital tuberosity between the groups. The theory of increased impingement of the distal biceps tendon during pronation of the forearm because of hypertrophic changes of the radial bicipital tuberosity couldn't be confirmed.

One of the recently introduced new fixation techniques for distal biceps tendon ruptures is the cortical button technique. The surgical reconstruction of the distal biceps tendon with a cortical button in the same group of 22 patients with a distal biceps tendon rupture was evaluated in **chapter 3.** The results after about two years were good, with a full range of motion, a mean Mayo elbow performance score of 100, mean quickDASH of 10, and full recovery of flexion and supination strength (100% and 97% respectively) compared to the uninjured side. However, there were 36% complications, of which most were transient, and formation of heterotopic ossifications in 23%, which was symptomatic in only one patient.

The results of the cortical button technique were compared with the results of other techniques in **chapter 4**. The approach, method of refixation and outcome of 40 studies on distal biceps tendon rupture repair was systematically reviewed. We found significantly fewer complications after the double-incision approach compared with the single-incision anterior approach and for the bone tunnel fixation compared with the other fixation techniques. As the double-incision approach was used with bone tunnel fixation in 84% of cases, there was a strong interrelationship between these variables, and we were unfortunately not able to efficiently disentangle the effects of these variables. The current results are in contrast with the historical idea that the double-incision approach is associated with more complications (e.g. radioulnar synostosis formation). We therefore advised reconsideration of a muscle-splitting double-incision approach with bone tunnel fixation for the reconstruction of distal biceps tendon ruptures.

Chapter 5 evaluated repair of the ulnar collateral ligament (UCL) or medial collateral ligament (MCL) in 20 European athletes. The reconstruction was performed with a triceps fascia autograft and fixated with bioabsorbable interference screws. After an average 5,5 years follow-up the elbow was stable in all patients. However, 30% had quitted the sport activities they were preoperatively participating in, 10% within one year, and all because of reasons unrelated to the UCL-reconstruction. Consequently, there were 90% excellent results on the Conway scale. The interference screw technique with triceps fascia autograft was concluded to be a simple and safe technique to restore valgus stability in the elbow. The technique and graft should, however, be further evaluated for its use in high-level pitchers or overhead sports performers. The dropout in European athletes, even after successful reconstruction, was high and should be taken into account and be discussed with the athlete in advance of the decision making for UCL surgery.

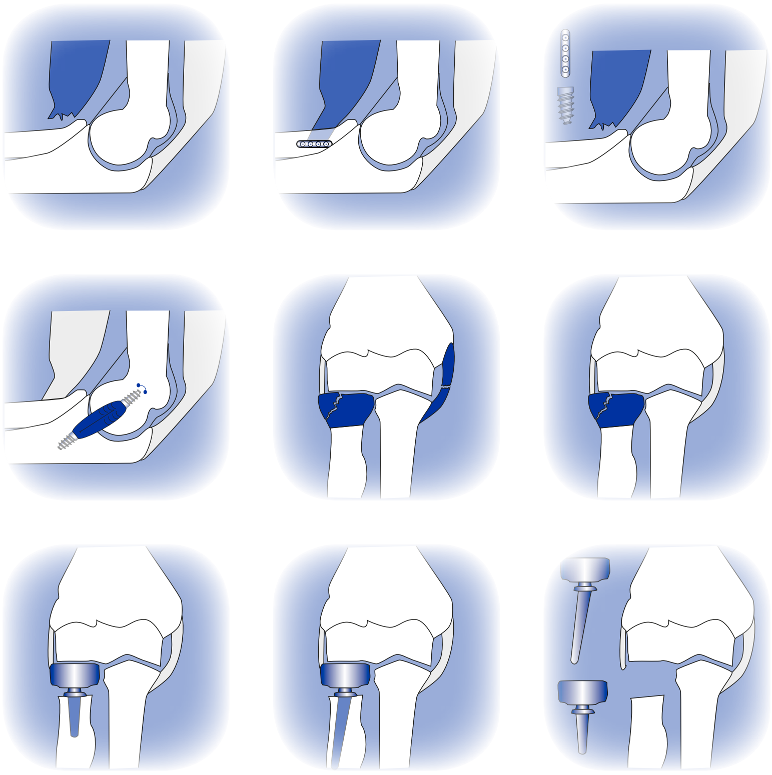
The aim of **chapter 6** was to investigate the effect of trauma and patient related factors on radial head fractures and its associated injuries. A retrospective review of 440 consecutive patients with a radial head fracture was performed and showed symptomatic associated injuries in 11%. The risk for associated injuries was increased with higher patient age and higher complexity of the radial head fracture according to the Mason classification. Trauma mechanism did not have a significant influence on the risk of associated injuries. Complex elbow trauma in patients with a radial head fracture seems therefore to be suspected based on patient characteristics, rather than mechanism of injury. Associated injuries should be actively explored in elderly patients with Mason type-2 or type-3 fractures. The treatment (nonoperative versus open reduction and internal fixation [ORIF]) of Mason type-2 fractures remains subject of debate. **Chapter 7** was a study protocol that described a multi-center international randomized controlled trial in which these treatment modalities will be compared. It is expected that the results of this trial will give an answer on the question what to do with stable partial articular fractures of the radial head. Patient enrollment is currently on its way. Mason type-3 (comminuted) fractures can be treated by ORIF if a stable fixation can be obtained in cases with three or less fracture fragments. More comminuted fractures, and late posttraumatic issues of the radial head require replacement. The first results of press-fit bipolar radial head prosthesis were described in **chapter 8**. The overall mid-term outcome of this series of 30 radial head arthroplasties can be considered favorable. The revision rate was 11%, which compares favorable with the only reported series of monopolar press-fit implants in the literature. Proximal osteolysis around the radial neck was seen in 92%, but asymptomatic in all. Despite the aforementioned revisions, none of the stems had come loose, suggesting the press-fit stem results in sufficient bone ongrowth and adequate fixation. We suggest to consider press-fit bipolar radial head prosthesis for acute comminuted radial head fractures with limited bone loss of the proximal radius. However, in cases with proximal bone loss, or posttraumatic cases with malalignment of the radius, cemented bipolar radial head prosthesis may be a better option. The results cemented bipolar radial head arthroplasties in **chapter 9** has shown that this design was able to compensate for suboptimal radiocapitellar alignment. The overall mid-term outcome of this series of 25 cemented bipolar radial head arthroplasties can be considered favorable, with one (4%) revision and 2 (8%) additional radiological failures. As there were many different radial head implant designs available, the results reported in the literature were systematically reviewed in **chapter 10**. It was noted that radial head arthroplasty was associated with an incidence of revision of 8% with an estimated crude revision rate of 2.06 per 100 person-years of follow-up. There was no significant effect of prosthesis polarity, material and technique of fixation on the revision rate and functional outcome in terms of postoperative range of motion of radial head arthroplasty. Unfortunately, there was substantial variability in reportage of methodology and results amongst studies, with a clear a need for guidelines for standardized reportage of methodology and results.

Hoofdstuk 12

Samenvatting

TRAUMA EN SPORTLETSELS VAN DE ELLEBOOG

Izaäk F. Kodde



Het algemene doel van dit proefschrift was het beoordelen en vergroten van de huidige kennis ten aanzien van de pathofysiologie en behandeling van veel voorkomende traumatische elleboog aandoeningen. In **hoofdstuk 1** werd de basale anatomie en de functionele biomechanica van de elleboog beschreven, in relatie tot de huidige behandelstrategieën voor trauma en sportletsels van de elleboog.

De behandeling van distale bicepspees rupturen is de laatste jaren flink veranderd door nieuwe inzichten in de lokale anatomie en nieuwe minimaal invasieve chirurgische technieken. Ondanks deze veranderingen blijft de onderliggende pathofysiologie van distale bicepspees rupturen onduidelijk. In **hoofdstuk 2** werd één van de huidige theorieën onderzocht, waarbij men er van uit gaat dat de hoogte van de tuberositas radii van invloed is op het ontstaan van rupturen. In een studie met 22 patiënten met een distale bicepspees ruptuur werd de tuberositas radii op standaard röntgenfoto's vergeleken met 22 controle patiënten. De grootte van de tuberositas radii was niet significant verschillend tussen de groepen. De theorie dat er meer impingement van de distale bicepspees zou plaatsvinden tijdens rotaties door hypertrofische veranderingen van de tuberositas radii, kon daarom niet worden bevestigd in deze studie.

Een recent ontwikkelde fixatietechniek voor de bicepspees, is de corticale button techniek. De chirurgische reconstructie van distale bicepspezen met zo een corticale button werd in een groep van 22 patiënten geëvalueerd in **hoofdstuk 3**. De resultaten 2 jaar na operatie waren goed; met een volledige beweeglijkheid van de elleboog, een gemiddelde Mayo elbow performance score van 100, gemiddelde quickDASH van 10, en een volledig herstel van kracht (100% flexie kracht, 97% supinatie kracht) vergeleken met de contralaterale zijde. Er waren echter complicaties in 36% van de patiënten, waarvan het merendeel slechts tijdelijk van aard. Heterotope ossificaties werden bij 23% gezien, maar was slechts symptomatisch in 1 patiënt. De resultaten van de corticale button techniek, werden vergeleken met de resultaten van andere technieken om de distale bicepspees te herstellen in **hoofdstuk 4.** De benadering, methode van fixatie en uitkomsten van 40 studies werden systematisch bekeken. Er waren significant minder complicaties na de dubbele-incisie benadering met bot-tunnel fixatie, vergeleken met de andere fixatie technieken. Omdat de dubbele-incisie benadering werd toegepast met bot-tunnel fixatie in 84% van de gevallen, was er een sterke relatie tussen deze variabelen, en waren wij helaas niet in staat om de effecten van deze losse variabelen te onderscheiden. De huidige resultaten verschillen met de historische perceptie dat de dubbele-incisie benadering tot meer complicaties (bijvoorbeeld radioulnaire synostosis formatie) zou leiden. Wij adviseerden daarom om het toepassen van de muscle-splitting dubbele-incisie benadering met bot-tunnel fixatie te heroverwegen voor de behandeling van distale bicepspees rupturen.

Het herstel van het mediale collaterale ligament (MCL) in de elleboog in 20 Europese sporters werd geëvalueerd in **hoofdstuk 5**. De herstelprocedure werd uitgevoerd door middel van het fixeren van een stuk triceps fascie met oplosbare interferentieschroeven. Na een gemiddelde follow-up van 5,5 jaar was de elleboog in alle patiënten stabiel. Dertig procent was echter gestopt met de sportactiviteiten, 10% zelfs in het eerste jaar na de reconstructie, vanwege redenen die los stonden van de operatie. Er was dus een 90% excellent resultaat op de Conway scale, en de techniek met triceps fascie en oplosbare interferentieschroeven was betrouwbaar en veilig om de stabiliteit in de elleboog te herstellen. De techniek en graft moeten echter verder worden geëvalueerd voor gebruik in professionele bovenhandse topsporters. Zelfs na een succesvolle reconstructie, stopte een aanzienlijk deel van de Europese sporters met sporten. Dit gegeven dient besproken te worden met een sporter alvorens wordt besloten tot een operatieve reconstructie van het MCL.

Het doel van **hoofdstuk 6** was om te bekijken wat het effect van traumamechanisme en patiënt-factoren is op het voorkomen van radiuskopfracturen en geassocieerde letsels. Een retrospectieve studie met 440 patiënten met een radiuskopfractuur, liet in 11% symptomatische geassocieerde letsels zien. Het risico op geassocieerde letsels was hoger voor oudere patiënten en werd ook meer gezien bij complexere fracturen volgens de Mason classificatie. Het traumamechanisme had geen significant effect op geassocieerde letsels. Het lijkt daarom dat de arts complexere elleboogletsels moet vermoeden op basis van patiënt-factoren, in plaats van het traumamechanisme. Men moet bedacht zijn op geassocieerde letsels in oudere patiënten met een Mason type-2 of type-3 fractuur van de radiuskop. Daar waar het duidelijk is dat Mason type-1 fracturen conservatief behandeld dienen te worden, daar is de optimale behandeling (conservatief versus operatief) van Mason type-2 fracturen nog onduidelijk. Het studieprotocol voor een internationale multicenter gerandomiseerde trial waarin non-operatief wordt vergeleken met open repositie interne fixatie (ORIF) voor Mason type-2 fracturen, werd beschreven in **hoofdstuk 7**. Het is de verwachting dat de resultaten van deze studie eindelijk antwoord zullen geven op de vraag wat te doen met stabiele partieel articulaire radiuskopfracturen. De inclusie van patiënten is reeds gestart. Communitieve (Mason type-3) fracturen van de radiuskop kunnen middels ORIF behandeld worden indien er drie of minder fragmenten zijn. Meer communitieve fracturen en posttraumatische afwijkingen van de radiuskop vereisen een radiuskopprothese. De eerste resultaten van 30 bipolaire press-fit radiuskopprotheses werden beschreven in **hoofdstuk 8**. De resultaten in deze serie werden als gunstig beschouwd. Het revisie percentage van 11% in de middellange termijn was gunstig vergeleken met de resultaten van series monopolaire press-fit radiuskopprotheses in de literatuur. Botresorptie rondom de nek van de radius werd in 92% van de gevallen gezien, maar was niet symptomatisch. Ondanks de eerder genoemde revisies, was geen van de protheses los gaan zitten, wat suggereert dat de press-fit prothese voldoende vastgroeit. Wij adviseerden om een press-fit radiuskopprothese te overwegen in de behandeling van acute communitieve fracturen met beperkt botverlies van de proximale radius. Als er echter sprake is van proximaal botverlies, of een slechte uitlijning van de radius ten opzichte van het capitellum, dan kan een gecementeerde bipolaire prothese een betere behandeloptie zijn. De resultaten van een serie met 25 gecementeerde bipolaire radiuskopprothesen in **hoofdstuk 9** liet namelijk zien dat dit implantaat in staat was suboptimale radiocapitellaire uitlijning te compenseren. De middellange-termijn resultaten waren gunstig met slechts één (4%) revisie en twee (8%)

additionele radiologische gebreken. Aangezien er veel verschillende radiuskopprothese designs op de markt zijn, werden de resultaten van al deze implantaten systematisch vergeleken in **hoofdstuk 10**. In het algemeen was radiuskopprothesiologie geassocieerd met een revisiepercentage van 8% met een geschat revisieaantal van 2.06 per 100 persoonsjaren follow-up. Er was geen significant effect van prothese polariteit, materiaal of fixatietechniek op het revisieaantal of postoperatieve beweeglijkheid van de elleboog. Helaas was er een grote variabiliteit in de kwaliteit van rapporteren van de diverse studies, die goed vergelijken van de literatuur moeilijk maakt. Er zijn duidelijk richtlijnen voor het gestandaardiseerd rapporteren van methodiek en resultaten in elleboogprothesiologie noodzakelijk.

APPENDICES

PhD PORTFOLIO

Name PhD student:	Izaäk Frederik Kodde	
PhD period:	January 2011 – May 2016	
Name PhD supervisor:	prof. dr. C.N. van Dijk	
Name PhD cosupervisor:	prof. dr. D. Eygendaal	
1. PhD training		
	Year	**Workload (ECTS)**
General courses		
- Epidemiologie	2015	0.5
Specific courses		
- Arthroplasty & Arthroscopy of the elbow	2011	0.5
- AO trauma course – principles in operative fracture management	2012	1
- Advanced Trauma Life Support Refresher Course	2014	0.5
- AO trauma course – Advanced Principles of Fracture Management	2014	1
- AO trauma course – Approaches and fracture care in practice	2015	0.5
Seminars, workshops and master classes		
-		
Presentations		
- Traumadagen	2011	0.5
- Brussels Hand Symposium	2012	0.5
- NOV voorjaarsvergadering	2012	0.5
- AAVAB wetenschapsdag Amphia ziekenhuis	2012	0.5
- SECEC annual congress	2012	0.5
- Traumadagen	2013	0.5
- Slotervaartziekenhuis wetenschapsmiddag	2014	0.5
- SECEC annual congress	2014	0.5
- AAVAB wetenschapsdag Amphia ziekenhuis	2015	0.5
- SECEC annual congress	2015	0.5

2. Teaching		
	Year	Workload (Hours/ECTS)
Lecturing		
- residents	2012-2016	2
Tutoring, Mentoring		
- medical students	2012-2016	1
Supervising		
- medical students	2012-2016	2

3. Parameters of Esteem	
	Year
Grants	
- AO start-up grant	2013
- AO best research grant	2015
Awards and Prizes	
- AO best research grant	2015

4. Publications	
	Year
Peer reviewed	
- see Bibliography	2006-2016
Other	
- see Bibliography	2011-2015

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Scientific Publications

2006 'Metabolic and genetic regulation of cardiac energy substrate preference'
I.F. Kodde; J. van der Stok; R.T. Smolenski; J.W. de Jong
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DOI: 10.1016/j.cbpa.2006.09.014

2011 'Laterale elleboogsklachten; een overzicht van locale pathologie'
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2012 'Preservation of infected aortic grafts with intra-abdominal abscesses by percutaneous drainage and specific antibiotic therapy.'
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Vascular Disease Management 2012:9(11):E189-E192

2012 'Long-term results after ulnar collateral ligament reconstruction of the elbow in European athletes with interference screw technique and triceps fascia autograft.'
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J Shoulder Elbow Surgery; DOI: 10.1016/j.jse.2012.07.010

2013 'Surgical treatment of post-traumatic elbow stiffness: a systematic review'
I.F. Kodde; J. van Rijn; M.P.J. van den Bekerom; D. Eygendaal
J Shoulder Elbow Surgery; DOI: 10.1016/j.jse.2012.11.010

2013 'Best approach for the repair of distal biceps tendon ruptures'
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2013 'Semiconstrained total elbow arthroplasty for post-traumatic arthritis of deformities of the elbow: a prospective study.'
I.F. Kodde; R.P. van Riet; D. Eygendaal
J Hand Surg Am; DOI: 10.1016/j.jhsa.2013.03.051

2013 'Reconstruction of distal biceps tendon ruptures with a cortical button'
I.F. Kodde; M.P.J. van den Bekerom; D. Eygendaal
Knee Surg Sports Traumatol arthrosc; DOI: 10.1007/s00167-013-2571-3

2013 ‘Subxiphoid pericardial window to exclude occult cardiac injury after penetrating thoracoabdominal trauma’
M. Hommes; A.J. Nicol; J van der Stok; I.F. Kodde; P.H. Navsaria
Br J Surg; DOI: 10.1002/bjs.9241

2014 ‘A randomized controlled trial of nonoperative treatment versus open re duction and internal fixation for stable, displaced, partial articular fractures of the radial head: the RAMBO trial.’
I.F. Kodde; W. Bruinsma; R.J. de Muinck Keizer; P. Kloen; A.L. Lindenbhovius; J.P. Vroemen; R. Haverlag; M.P. van den Bekerom; H.W. Bolhuis; P.H. Bullens; S.A. Meylaerts; P. van der Zwaal; P.E. Steller; M. Hageman; D.C. Ring; D. den Hartog; E.R. Hammacher; G.J. King; G.S. Athwal; K.J. Faber; D. Drosdowech; R. Grewal; J.C. Goslings; N.W. Schep; D. Eygendaal
BMC Musculoskelet Disord; DOI: 10.1186/1471-2474-15-147

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2015 ‘The effect of trauma and patient related factors on radial head fractures and associated injuries in 440 patients.’
I.F. Kodde; L. Kaas; N. van Es; P.G.H. Mulder; C.N. van Dijk; D. Eygendaal
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2015 ‘Hip arthroscopy in obese, a successful combination?’
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The Open Orthop J; DOI: 10.2174/1874325001610010001

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2014 'Arthroscopic techniques in the elbow'
I.F. Kodde; F.T.G. Rahusen; D. Eygendaal
EFORT: Surgical Orthopaedics and Traumatology.
DOI: 10.1007/978-3-642-34746-7_67

2014 'Preclinical Training Strategies'
G.J.M. Tuijthof; I.F. Kodde; G.M.M.J. Kerkhoffs
ESSKA: Effective Training of Arthroscopic Skills;
DOI: 10.1007/978-3-662-44943-1_10

2015 'Repair of distal biceps tendon rupture'
I.F. Kodde; D. Eygendaal
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Podium presentations

2012 'Total elbow arthroplasty for posttraumatic deformities of the elbow'
I.F. Kodde; D. Eygendaal
Brussels Hand Symposium, Brussel, 28 jan 2012

2012 'MCL reconstructie van de elleboog in Nederlandse atleten'
I.F. Kodde; F.T.G. Rahusen; D. Eygendaal
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2012 'Needling voor tendinitis calcarea van de schouder'
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2012 'Ulnar Collateral Ligament reconstruction of the elbow in European athletes'
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2012 'MCL reconstructie van de elleboog in Nederlandse atleten'
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Poster presentations

2010 'results of Needling as treatment for tendinitis calcarea of the rotator cuff'
AAVAB wetenschapsmiddag Amphia ziekenhuis, Breda, 19 nov 2010

2011 'Totale elleboog prothese bij posttraumatische afwijkingen van de elleboog'
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2015 'Press-fit bipolar radial head arthroplasty, mid-term results of thirty cases'
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2015 'Cemented bipolar radial head arthroplasty, mid-term follow-up of t wenty-five cases'
SECEC 2015 congress meeting, Milano, 16-19 sep 2015

2015 'Hip arthroscopy in obese; a successful combination'
BHS-SIDA meeting, Milano, 26-27 nov 2015

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Curriculum vitae

Izaäk Frederik (Sjaak) Kodde, was born in Krimpen aan de Lek, on May 18, 1984. After graduating from high school (VWO, Comenius College, Capelle aan den IJssel) in 2002, he studied technical business administration for one year. The next year he started studying medicine at Erasmus University in Rotterdam, and had a short internship abroad at Harefield Heart Science Centre, Imperial College London (UK) where he discovered his interest in scientific research. He especially enjoyed the times of his internships in Tilburg, after which he visited Cape Town (South Africa) for clinical internships and research at the Trauma Unit of Groote Schuur Hospital (prof. dr. Andrew Nicol). During these 7 months in Africa his enthusiasm for trauma and orthopedics was born. In 2009 he started as surgical resident in Breda (dr. Lijckle van der Laan) and made the first plans for this thesis with prof. dr. Denise Eygendaal. In 2012 he was accepted for his residency in orthopedic surgery by his supervisor prof. dr. C. Niek van Dijk. Parts of his training in orthopedic surgery were performed at the orthopedic departments of Academic Medical Center Amsterdam (prof. dr. C. Niek van Dijk), Slotervaart Hospital (dr. Harm van der Vis) and Amphia Hospital (prof. dr. Denise Eygendaal). He will finish his training at the Academic Medical Center Amsterdam in 2018.

This thesis deals with current issues in the management of trauma and sports injuries of the elbow. Common sports injuries of the elbow involve ruptures of the distal biceps tendon and the ulnar collateral ligament. Various surgical techniques in their treatment are discussed. The radial head is most frequently fractured after trauma of the elbow and may require operative fixation or replacement by prosthesis. Different kinds of radial head prosthesis are critically evaluated and compared.