The name for the **elbow** in Latin is **cubitus**. **Capitulum** and its synonym **Capitellum**- Both are diminutives of the Latin word *caput*, meaning head, and so mean a little head. If you have difficulty remembering whether the radius articulates at the capitulum or the trochlea, it may help to note that the head of the radius articulates at this little head. They go at one another "head to head". The stem caput is pretty obviously the source of the English word capital = most important. A capital offense is one for which the punishment was once decapitation or a serious crime for which you might lose your head. The "**funny bone**" is not a bone but the ulnar nerve, a vulnerable and sensitive nerve lying close to the surface near the point of the elbow. Hitting it causes a tingling pain or sensation that may be felt all the way to the fingers. **Olecranon** - is of Greek origin. *Olene* = elbow and *kranion* is head. Hence, the head of the elbow. Our word cranium has the same root. **Ulna** is the latin word for elbow. It comes from the older Greek word *olene* meaning elbow. **Trochlea** - A *trochlea* is a pulley (Latin).

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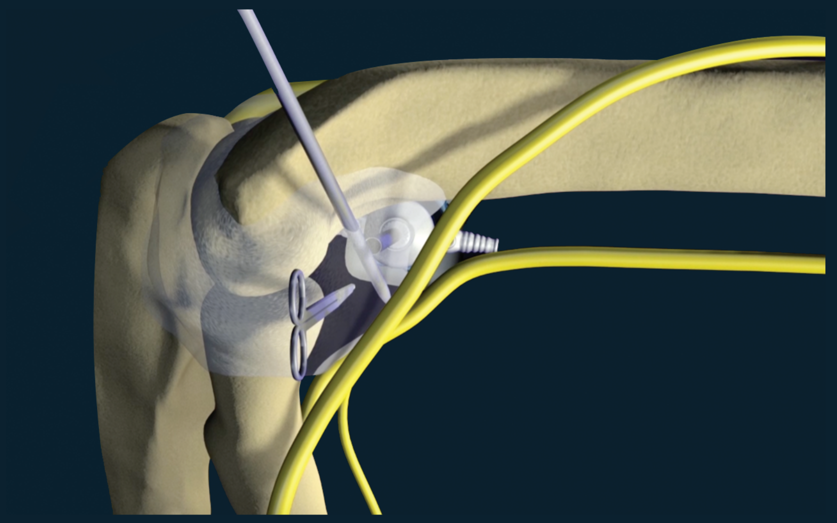
Sequelae Of Injuries Of The Lateral Compartment Of The Elbow: ...

Amir R. Kachooei

2021

Sequelae Of Injuries Of The Lateral Compartment Of The Elbow: Assesment And Possible Solutions



Amir R. Kachooei

Sequelae Of Injuries Of The Lateral Compartment Of The Elbow Assesment And Possible Solutions

ACADEMISCH PROEFSCHRIFT

ter verkrijging van de graad van doctor
aan de Universiteit van Amsterdam
op gezag van de Rector Magnificus
prof. dr. ir. K.I.J. Maex
ten overstaan van een door het College voor Promoties ingestelde commissie,
in het openbaar te verdedigen
op maandag 29 maart 2021, te 14.00 uur

door Amir Reza Kachooei
geboren te Mashad

Promotiecommissie

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Faculteit der Geneeskunde

Sequelae Of Injuries Of The Lateral Compartment Of The Elbow Assesment And Possible Solutions

Gevolgen Van Verwondingen Van Het Laterale Compartiment Van De Elleboog Beoordeling En Mogelijke Oplossingen

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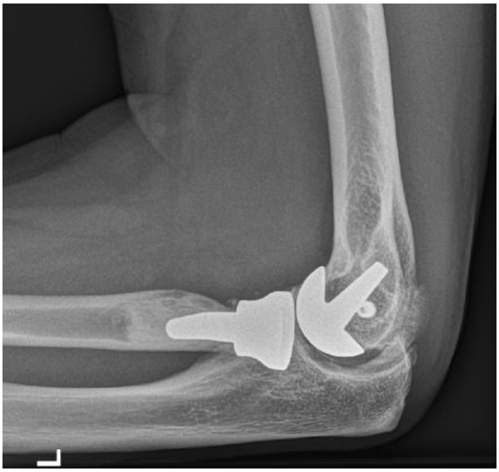

CONTENTS Page

PART I

INTRODUCTION

Chapter 1

General Introduction and outline of the thesis

OVERVIEW OF THE PATHOLOGY

Mason in his paper in 1954 stated that "The elbow joint tolerates trauma very badly. Even a minor injury can be responsible for some residual loss of range of movement". The elbow is a three-compartment joint including radiocapitellar, ulnohumeral, and radioulnar articulations. The ulnohumeral moves as a hinge in a unilateral direction from extension to flexion and the radioulnar articulation plays only in the forearm rotation. The radiocapitellar articulation also glides and rotates over the capitellum during flexion-extension and supination-pronation, which may have a substantial effect on elbow motion and thus function.

Anatomy

The radiocapitellar joint resembles the patellofemoral articulation with dense cancellous bone directed longitudinally in the radial head as it is in the patella. This may explain longitudinal fissures in the radial head when it fractures. Maximum contact between the radial head and capitellum is when the elbow flexed to 130 degrees with the forearm in mid-pronation. The radial head articulates with the lesser sigmoid notch of the ulna over 320 degrees of its circumference although the arc of forearm supination-pronation is almost 160 degrees. The radial head fits almost tightly inside the notch with the annular ligament surrounding the rest of the head circumference (1). Thus, 40 degrees of the radial head, which is called the "safe zone", does not have any contact with the lesser sigmoid notch.

The radius and ulna are linked via the interosseous membrane (IOM) along the middle of the forearm with the distal and proximal radioulnar ligaments linking the two bones at the ends creating three sites of connection. The middle portion of the IOM, the so-called Central Band (CB) or the interosseous ligament (IOL), is ligamentous and plays the principle role in load transfers along the forearm. The direction of the IOL from distal ulna to proximal radius prevents proximal migration of the radius when it is loaded axially from the wrist. However, after resection of the radial head, the IOL is responsible for 71% of forearm stiffness while 90% of axial load is transmitted through the IOL. Having said that, in the absence of the radial head, the IOL may become attenuated and fails over time if partially injured.

Disruption of the interosseous ligament (IOL) is difficult to diagnose intraoperatively. It is usually accompanied with radial head fractures during a forceful axial load during which a more severe fracture is associated with higher chance of injury (2). But even a Mason type 1 may be accompanied by the IOL injury.

Epidemiology

Radial head fractures seem the most common injury of the elbow with reported incidence of 30-44% of elbow injuries, and 1.5-4 % of fractures in adults (1, 3, 4). The incidence of radial head and neck fractures is 30-55 per 100,000 population per year (5, 6). Radial head fractures account for 70% of the incidence while neck fractures account for the rest of 30% (7). High energy mechanism is responsible for most of the radial head fractures in men which is mostly seen at a mean age of 37 years. However, falling mechanism corresponds to most of the radial head fractures in women with a mean age of 52 years. As a whole, there seems no difference in the age distribution nor the sex, but the only attributing factor remains the mechanism of injury (8). The most common fracture type is Mason type 1 accounting for 74-82% of radial head fractures followed by type 2 in 14-16%, type 3 in 2.7-7% and type 4 (radial head fracture as part of a complex injury) in 1.1-3 % of the patients (4, 7).

Acute longitudinal radioulnar dissociation (ALRUD) is a condition commonly known as Essex-Lopresti injury, and is defined with distal radioulnar joint dissociation, interosseous ligament injury, and radial head fracture. The incidence of ALRUD was reported as low as 1% of radial head fractures which was considered a rare injury (9, 10). Using radiographs of the wrist found radial shortening of 2 mm or more in 9% of patients sustaining a radial head fracture with which a more severe fracture was correlated with greater shortening (11). Another study found the wrist pain in 25% of the patients six weeks after a radial head fracture out of which only 9% showed shortening of >2mm (11). Based on the functional outcomes, >4mm shortening is considered clinically relevant and <4mm can be managed conservatively (12).

Radial Head Fracture Classification

Although radial head fractures are still classified by the eponym of Mason, it seems that the first radial head fracture was reported in 1834 by Berard who discovered the radial head fracture by accident while doing an autopsy (13). Wilhelm Conrad Röntgen, the German physicist, discovered X-rays in 1895 for which he won the Noble Prize in 1901. Photographic images produced by X-ray radiation were called skiagram (Greek word meaning shadow) or roentgenogram. Following the discovery of X-rays, radial head fractures were diagnosed more frequently, and physicians started to report their experience with various fracture patterns, which was the start of classifying radial head fractures.

Probably the first classification was introduced by Cutler in 1926 using 50 patients to classify the head fractures into 3 and neck fractures into 1 group (14). Gaston et al. in 1949 classified the adult radial head fractures in 113 cases into 3 types and separated types 2 and 3 based on retained anterior capsule integrity in type 2 and capsule disruption with dislocation in type 3 (15). He concluded that radial head excision within 12 hours or even 6 hours after injury reduces substantially the risk of myositis ossificans in compare to patients operated after 2-3 weeks. Mason in 1954 presented his classification based on the follow-up of 100 cases. In the summary of his paper, he concluded that "*when in doubt, resect*" (1). Johnston in 1962 added type 4 to Mason's classification defined as radial head fractures with dislocation. However, he disagreed with Mason's statement regarding type 2 fractures and stated that "if in doubt, treat conservatively" (3). Broberg and Morrey in 1987 reported the results of radial head fractures as part of the elbow fracture-dislocation referring to Johnston's type 4 classification. They added >2 mm displacement and 30% head involvement to differentiate between types I and II. In contrast to the early excision, they recommended determining treatment by the fracture type irrespective of dislocation because the best results were seen with nonoperative treatment of types 1 and 2, and early complete excision of type 3 (16). Hotchkiss in 1997 presented treatment strategy based on motion block and advised for internal fixation because of the evolving devices for saving the head. He suggested head preserving by rigid internal fixation in the "safe zone" when possible and excision when grossly comminuted (17). He advised for saving the head to prevent radius proximal migration, which was previously reported by Curr and Coe (1946) in one case and Essex-Lopresti (1951) in 2 cases associated with comminuted radial head fracture. However, McDougall and White in 1957 related distal radioulnar subluxation to head excision rather that happening at the time of injury (3). Mechanical block as suggested by Hotchkiss, was introduced as the treatment plan of Adler and Shaftan in 1964. They suggested starting early motion even in the presence of a comminuted fracture, and excise the head only if the mechanical block hinders motion after 8 weeks of nonoperative treatment (18).

Van Riet and Morrey presented a classification in 2006 to not only describe the radial head fracture type in isolation but also describes the associated injuries (19). That being said, they used the traditional Mason classification followed by the abbreviation of the articular injury such as olecranon (o), coronoid (c), distal radioulnar joint/interosseous ligament (d), lateral collateral ligament (l), and medial collateral ligament (m). For instance, the term of *Type III lm* indicates a radial head fracture with accompanying injury to both MCL and LCL after an elbow dislocation. Another predictor of a complex injury was found to be the loss of cortical contact between the fractured fragment and the rest of the head which was strongly associated with a complex elbow injury especially in a Mason Type II fracture (20). This type was classified as *stable* and *unstable* based on the cortical contact. The last classification so far was presented in 2015 by Kodde et al by categorizing the amount of energy transferred during trauma as low energy trauma (LET) and high energy trauma (HET). Low energy trauma indicates fall from standing while HET indicates falling from height, sports trauma, or motor vehicle accidents. They showed that the mechanism of radial head fractures is LET in 60%, while HET is the more common mechanism in young men. Moreover, the associated injuries were not different between LET and HET (21).

Biomechanics and Stability

The axial force distribution ratio across the radiocapitellar/ulnohumeral joint is measured about 58%: 42 % in neutral, 54%:46% in pronation, and 57%:43% in supination when the elbow is tested in extension (22). Other than the axial load within the radiocapitellar joint, the radial head bears 18% of the loads which is transferred transversely via the proximal radioulnar joint (23).

The medial ulnar collateral ligament (MUCL) is known as the primary and the radial head as the secondary stabilizers against valgus (24, 25). The radial head is responsible for almost 30% of valgus stability and in the absence of the radial head, the force may reach to 9 times body weight on the MUCL (24). It often becomes insufficient in throwing athletes due to frequent valgus loads.

The Lateral ulnar collateral ligament (LUCL) is an important constraint against posterolateral and varus instability, which might injure during traumatic events with or without a radial head fracture. The LUCL and the supinator crest on the lateral proximal ulna play an important role in restraining posterolateral subluxation of the radial head and forced elbow external rotation by working as a hammock (26).

Counterintuitively, Jensen et al showed that the radial head is an important stabilizer in forced varus and forced external rotation. This may be due to the important role of the LUCL in external rotation and varus stabilization. The annular ligament, as an integrate part of the LCUL, becomes lax after radial head excision leading to possible elbow instability during forced varus and external rotation, while stability in forced valgus is independent of radial head presence and is substantially dependent on a healthy MCL (27). The effect of the radial head on the tension of the LUCL has been emphasized by repairing the LUCL with higher tension after radial head excision which could restore varus stability (28).

Force transmission is greatest in the radiocapitellar joint when elbow flexion is 0-30 degrees and it consistently decreases by increasing elbow flexion. Moreover, this force is the greatest with forearm pronation than supination (29). Forearm rotation also alters with elbow flexion-extension as the maximum pronation occurs in extension, but the maximum supination occurs in elbow flexion. Moreover, tension on the interosseous ligament increases as well as the contact force across the DRUJ and PRUJ increases with elbow extension (30).

In 1951, Essex-Lopresti described the injury pattern including radial head fracture, IOM rupture, and distal radioulnar joint (DRUJ) dissociation after an axial traumatic event resulting in forearm both bone instability. Further reports showed that this condition results in proximal migration of the radius with subsequent complications to the elbow and wrist. Following research has increased our understanding about this complex injury to be more vigilant about accompanying ligament injuries once a radial head fracture is seen on a radiograph. This is also one of the absolute contraindications of radial head resection when suspected.

To diagnose the IOL injury, ultrasound and magnetic resonance imaging are suggested, but they are not part of a routine assessment. However, preo-perative wrist radiographs might show positive ulnar variance suggestive of the IOL injury. Two techniques have been introduced to test the IOL sufficiency intraoperatively, including “radius pull test” and “radius joystick test”. Smith et al introduced radius pull test in 2002 to use a longitudinal traction on the radius after radial head resection. Displacement of >3 mm relative to ulna was suggestive of the IOL injury while displacement of >6 mm was suggestive of both the IOL and DRUJ injury. Radius joystick test was introduced by Soubeyrand et al in 2011 showing that lateral displacement of radius is more pronounced after radial head resection and in the presence of IOL insufficiency. Having said that, we aimed to test both techniques in terms of interobserver and intraobserver reliability [Chapter 1]. Because the interobserver reliability of both tests was based on the surgeons’ feeling of displacement, we introduced a technique in measuring displacement after radial head excision to test the integrity of IOL in cadavers. In this study, we also aimed to find the best position for performing the joystick technique with less error [Chapter 2].

Radiocapitellar Osteoarthritis (OA)

There are multiple factors making the radiocapitellar joint prone to OA. In a cadaver study, it was shown that aging starts from the radiocapitellar joint (31). In a traumatic event with a radial head fracture, the capitellum cartilage might be lacerated which makes the capitellum prone to OA progression. On the other hand, malunion of the radial head fracture might theoretically result in step-off causing wear of the capitellum cartilage, which subsequently ends to a painful arthritis. To study the rate, reason, and solution for this condition following a radial head fracture, we decided to study factors associated with radiocapitellar OA by studying the follow-up X-rays of patients with an isolated radial head fracture [Chapter 3]. We also studied the outcomes of concomitant fractures of the radial head and capitellum, the so-called kissing lesion [Chapter 4].

TREATMENT OPTIONS

Nonoperative treatment

The choice of treatment is offered after classifying a radial head fracture and the concomitant injuries. It is generally accepted to treat type I and stable type II fractures nonoperatively. This has to be confirmed by checking no block in motion. Hematoma aspiration is a safe procedure to relief pain. Nonoperative treatment consists of 48 hours of rest in a sling while avoiding cast immobilization. Early start of motion is encouraged by the patient which can be supported by physical therapy if needed (32).

Akesson et al. reported their long term results of nonoperative treatments after a mean of 19 years in 49 patients with moderately displaced type II fracture. Only 6 patients were treated with late excision, while 40 patients remained asymptomatic. Although the prevalence of arthritis was significantly higher in the injured elbows in compare to the uninjured side (82% vs. 21%), functional outcome was considerably favorable and unrelated to the radiographic findings (33).

Although surgery is suggested if block in motion is encountered, a true block is rare and difficult to interpret due to pain. Elbow can be examined after drainage of hematoma and infiltration of local anesthetic, but it is not highly reliable. Surgery ranges from excision to ORIF and arthroplasty.

Radial head excision

Excision can be done only if there are no associated injuries; however, multiple studies have shown a high rate of concomitant ligament injuries. This rate was reported as high as 50-71% with displaced fractures and 75-100% with comminuted radial head fractures (34-36). Loss of cortical contact between the radial head fragments is an important indicator of a more complex elbow injury with an odds ratio of 21 (20). Moreover, injury to the forearm interosseous ligament (IOL) has to be ruled out before excising the head. The role of preoperative ultrasound and MRI in detecting the IOL injury is debatable (2, 37). Intraoperative examination includes longitudinal pull test and lateral joystick test (38, 39). However, the drawback of these test is inaccuracy in diagnosing partial ruptures. That being said, excision is not advocated as the first option if resources are available. In some developing countries with limited resources, very good results comparable to arthroplasty was reported where the authors repaired the MCL and medial capsule routinely if the radial head was to excise after a terrible triad injury (40). The report of Antuna on 26 patients younger than 40 years is one of the long term studies on radial head excision after an isolated type II or III radial head fracture with a mean follow-up of 25 years. They reported no pain in 81%, good to excellent results in 92%, wrist pain in 3 patients, functional range of motion in almost all patients, and elbow arthritis in 16 patients (mild in 17 and moderate in 9). However, there was no correlation between radiographic findings and functional outcomes (41).

Open reduction internal fixation (ORIF)

Years after Mason and others suggested 'preserve or excise', authors suggested the importance of preserving the native head. ORIF was performed initially for partial fractures involving only one fragment with satisfactory results which is a characteristic of introductory studies. With additional experiments and expanded indications of ORIF for more comminuted fractures, the results declined and were not as good as the isolated fractures whereas the rate of failures and reoperations increased resulting in a shift toward arthroplasty. Further studies showed that arthroplasty might have advantages for more complex fractures of the elbow. Although fixation with newer implants and techniques was promising, studies have shown that arthroplasty has more favorable outcomes than ORIF in more complex injuries (42). ORIF should be considered only if fewer than 3 fragments are present and if a stable fixation can be achieved by using screw, plate, and bone graft.

ORIF is mostly linked to a Mason type II fracture. In a stable and isolated type II fractures, decision has to be made between nonoperative and ORIF. Of note, surgery increases the chance of complications as well as reoperations which has to be discussed with the patient (43). A type II fracture as part of a complex injury is more challenging and decision has to be made between ORIF and arthroplasty because fixation of the fragments is often tenuous and the risk of failure and nonunion is high. The size and number of the fragments, metaphyseal comminution, loss of fragments, and deformity of fragments are some other factors that make ORIF less predictable unless a stable and reliable fixation can be achieved.

When a radial head fracture as part of a complex injury is not amenable to secure fixation, radial head replacement with a prosthesis is suggested to stabilize the elbow.

Radial Head Arthroplasty

The first report of radial head arthroplasty was by Speed in 1941. He used the Vitallium implants (an alloy consisted of 65% cobalt, 30% chromium, 5% molybdenium) in 3 patients over the stump of the radius to avoid bone regrowth and heterotopic ossification as well as preventing valgus instability after excision of the radial head (44). In 1951, Carr and Howard reported increased stability with excellent results following radial head replacement in 12 patients (45), which was the year that Essex-Lopresti explained longitudinal instability although he did not use a prosthesis. Cherry in 1953 reported the use of acrylic prosthesis (a chemical compound of poly methyl methacrylate which is a transparent plastic material) to prevent proximal migration of the radial shaft; however, the prosthesis was not durable (46, 47). Alfred Swanson (1923-2016), an American Hand Surgeon, pioneered in the concept of using flexible silicone for the small joints. He inserted the first silicone implant for finger in 1964, after which Swanson Silastic radial head prosthesis became commercially available in 1969. Better pain relief and improved functional results were reported in 1974 after early replacement (48-50) but was abandoned later because of silicone synovitis, prosthesis fracture, and inability to resist axial loads due to flexibility (51, 52). The first report of complications was published in 1979, which further lead to a high rate of prosthesis removal and thus the popularity of silicone radial head prosthesis diminished (50). During this time that silastic prosthesis was popularized for being used commonly in the US, Canadians were using metal prosthesis all along. Harrington published the results of 17 patients operated in Toronto during 1966 and 1979 including 15 metal and 2 silastic prosthesis. They found 14 good and excellent results and 3 fair and poor results while there was no difference between metal and silastic prostheses (53, 54).

Metallic prosthesis made of cobalt-chromium as well as other materials including pyrocarbon (55, 56), titanium (57) and even polymethyl methacrylate (58) were used in producing the modern generation of radial head prostheses. Other variables in choosing a prosthesis are the stem length (short or long stem), head design (monoblock versus bipolar), and type of fixation (intentionally loose fit, press-fit, cemented) (59). It is speculated that an intentionally loose fit stem rotates within the medullary canal accommodating the anatomy, which resolves concerns about the exclusive complications related to the bipolar design such as component dislodgement and osteolysis due to polyethylene wear (60).

Chanlalit et al classified stress shielding after radial head prosthesis to 3 stages (61). They found 63% stress shielding with rigidly-fixed implants regardless of the design. Stress shielding was detectable after an average of 11 months which was started uniformly from the outer periosteal cortex. Martin Fuentes et al reported that the cortical resorption around radial neck was independently associated with reoperation (62). Other study on Pyrocarbon radial head prosthesis found cortical resorption in 92% of the patients which was stable after 1 year and they did not any failure in stem fixation despite cortical resorption (63).

Although some advocate on a specific design, the choice of radial head prosthesis remains mostly dependent to surgeon's preference and availability in the region.

In comparison to the native radial head, contact area decreases and contact stress increases after replacing the head with a prosthesis. Forces with axisymmetric (circular) head is not sensitive to rotation or degrees of elbow flexion, but with nonaxisymmetric (elliptical) head, forces become closer to the native head if inserted in the best orientation. In an inappropriate orientation, forces across the radiocapitellar increases significantly showing its sensitivity to proper orientation during surgery (64). On the other hand, the kinematics of the native and a custom-made well-oriented head were identical with every elbow position/rotation suggesting that an anatomic radial head can reproduce elbow biomechanics. However, 90 degrees rotating this custom-made prosthesis altered forces across the radiocapitellar joint suggesting that the radial head shape might have an influence on degenerative changes of the radiocapitellar joint (65).

Aims and Goals of the Thesis

1. To identify the behavior and the outcomes of both operative and nonoperative treatments after a radial head fracture.
2. To identify the role of the associated injuries with a radial head fracture and their biomechanical implication.
3. To assess the long-term outcomes of partial elbow arthroplasty including radial head and radiocapitellar arthroplasty.
4. To assess the role of prosthesis design and material in the prognosis of radial head arthroplasty.

Outline and Hypothesis of the Thesis

This thesis is structured in two sections, each including 4 chapters. In ***section I***, we focused on the assessment of the post-traumatic pathology, associated injuries with a radial head fracture, and the role of nonoperative treatment after a radial head fracture.

Chapter 1: To study the intraobserver and interobserver reliability of the diagnosis of interosseous ligament (IOL) rupture in a cadaver model.

Chapter 2: To introduce a technique for the diagnosis of interosseous ligament (IOL) disruption based on lateral displacement of the radius after radial head resection and to determine the cutoff value of the lateral displacement for the diagnosis of disruption, the best elbow position for testing, and the diagnostic performance of the technique in different positions.

Chapter 3: To study if patients that have a second radiograph 2 or more years after nonoperative treatment of an isolated radial head fracture have radiocapitellar osteoarthritis (RC OA).

Chapter 4: to investigate if radial head fracture type is associated with a concomitant fracture of the capitellum.

In ***section II***, we focused on the role of radial head arthroplasty. This section discusses about the mid- and long-term outcomes, the rate of prosthesis removal, the survival of the arthroplasty, and the role of prosthesis design in the outcome of a radial head arthroplasty.

Chapter 5: to determine the overall incidence of radial head prosthesis removal or revision. Our secondary objectives addressed the incidence of removal or revision based on the type of prosthesis fixation (cemented, uncemented smooth stem, uncemented press-fit), material (metal, titanium, pyrocarbon), and design (short vs long stem and monopolar vs bipolar), and the reasons for prosthetic removal or revision.

Chapter 6: This study tests the hypothesis that there are no factors associated with removal or revision of a radial head prosthesis. A secondary analysis addressed the time to removal or revision.

Chapter 7: To assess the short-term to midterm functional and radiographic results of elbows after RC PA. Our secondary aim was to assess the survival of the RC PA.

Chapter 8: To assess the outcomes of using antibiotic-impregnated polymethy-lmethacrylate (PMMA) bone cement to make a patient specific radial head

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PART II

Assessment of Post-traumatic Pathology

Chapter 2

Intraoperative Physical Examination for Diagnosis of Interosseous Ligament Rupture-Cadaveric Study.
Kachooei AR, Rivlin M, Wu F, Faghfouri A, Eberlin KR, Ring D.
J Hand Surg Am. 2015 Sep;40(9):1785-90.e1.

ABSTRACT

PURPOSE

To study the intraobserver and interobserver reliability of the diagnosis of interosseous ligament (IOL) rupture in a cadaver model.

METHODS

On 12 fresh frozen cadavers, radial heads were cut using an identical incision and osteotomy. After randomization, the soft tissues of the limbs were divided into 4 groups: both IOL and triangular fibrocartilage (TFCC) intact; IOL disruption but TFCC intact; both IOL and TFCC divided; and IOL intact but TFCC divided. All incisions had identical suturing. After standard instruction and demonstration of radius pull-push and radius lateral pull tests, 10 physician evaluators with different levels of experience examined the cadaver limbs in a standardized way (elbow at 90° with the forearm held in both supination and pronation) and were asked to classify them into one of the 4 groups. Next, the same examiners were asked to re-examine the limbs after randomly changing the order of examination.

RESULTS

The interobserver reliability of agreement for the diagnosis of IOL injury (groups 2 and 3) was fair in both rounds of examination and the intraobserver reliability was moderate. The intra- and interobserver reliabilities of agreement for the 4 groups of injuries among the examiners were fair in both rounds of examination. The sensitivity, specificity, accuracy, positive, and negative predictive values were all around 70%. The likelihood of a positive test corresponding with the presence of IOL rupture (positive likelihood ratio) was 2.2. The likelihood of a negative test correctly diagnosing an intact IOL was 0.40.

CONCLUSIONS

In cadavers, intraoperative tests had fair reliability and 70% accuracy for the diagnosis of IOL rupture using the push-pull and lateral pull maneuvers. The level of experience did not have any effect on the correct diagnosis of intact versus disrupted IOL.

INTRODUCTION

The triangular fibrocartilage complex (TFCC), radiocapitellar contact, and interosseous ligament (IOL) contribute to radioulnar longitudinal stability (1, 2). There are circumstances that might influence the management of an acute, displaced fracture of the radial head without dislocation of the elbow including malalignment restricting forearm rotation, lateral and medial collateral ligament tear, clicking, impingement, and disruption of the IOL, which is less common but also important to diagnose (3). Problems with forearm rotation are more common, but injury to the IOL causes greater impairment with the resultant forearm deformity hindering motion of the elbow, forearm, and wrist and causing pain.

An IOL disruption can be difficult to diagnose and is often recognized late. Radiological methods for assessing the integrity of the IOL such as MRI and ultrasonography are imperfect and not routinely available or used (4-6). A popular alternative for displaced fractures of the radial head treated operatively is to test the integrity of the IOL using intraoperative physical examination maneuvers. Two techniques of examination were introduced to help diagnosing the IOL rupture intra-operatively and to predict the level of instability. Smith et al described the “radius pull test” in which longitudinal traction on the radius is expected to cause displacement of the radius with respect to the ulna greater than 3 mm after cutting the IOL and greater than 6 mm after cutting both the IOL and TFCC (7). Soubeyrand et al described “radius joystick test” and showed that the lateral displacement of proximal radius remarkably increased after IOL division while the forearm was in full pronation (8).

This study tested the inter- and intra-observer reliability and diagnostic performance characteristics of simulated intraoperative diagnosis of IOL rupture using both techniques.

METHODS

Cadaver preparation

In this study, we used 12 fresh frozen cadavers (5 men and 6 women) with a mean age of 72 years (range 62 to 92 years) at the time of death. We had one pair of limbs from a 62-year-old man. We thawed the cadavers at room temperature 24 hours prior to preparation and kept them in a refrigerator during a 3-day study examination. No prior scars or gross deformities were found on inspection of the cadavers.

A single surgeon prepared the cadavers using an identical incision starting from lateral epicondyle to distal radioulnar joint (DRUJ) dorsally. The radial head, IOL, and DRUJ were exposed identically in all cadavers. The radial head was exposed through a split in the common digital extensor muscles. We cut the annular ligament and excised the radial head 1.5 cm distal to the joint line while protecting the insertion of biceps. The IOL was exposed by developing an interval between the extensor carpi radialis brevis (ECRB) and the extensor digitorum communis (EDC). We sharply detached the central band and distal and proximal oblique bundles of the IOL from the radius. The DRUJ was exposed by extending the same interval toward the wrist with retracting the retinaculum and 4th compartment off the DRUJ while exposing the distal oblique bundle. In case of difficulty with exposing the DRUJ, a separate approach in between extensor carpi ulnaris (ECU) and extensor digiti quinti (EDQ) was carried out. We transected the TFCC by detaching the dorsal and volar distal radioulnar ligaments from the radius and the entire attachment of the TFCC to the distal ulna.

We prepared 12 cadavers in 4 groups of 3 cadavers each: group 1, radial head resection alone; group 2, radial head resection and IOL cut; group 3, radial head resection, and TFCC and IOL cut; group 4, radial head resection and TFCC cut.

After preparation, the incisions were sutured leaving the proximal part (the radial head) visible for testing. Cadavers were randomly assigned a number from 1 to 12 and placed in a row on an examination table. We asked 10 physician evaluators of varying levels of experience including 2 faculty hand surgeons, 2 hand surgery fellows, 2 general orthopedic surgeons, 2 orthopedic residents, and 2 non-specialist medical doctors to examine the cadavers and record their diagnosis and the group of injury.

Examination

Examiners were instructed regarding how to examine the cadavers and how to interpret the results based on the original instructions with no prior experience. The tests were also demonstrated. Most of the examiners were examining IOL integrity for the first time. The proximal radius stump was held with a clamp. We used 2 tests to diagnose IOL rupture: the radius pull-push test and the radius joystick (lateral pull) test. The radius pull test is performed by pulling the radius longitudinally on the hand and wrist to assess proximal and distal migration of the radius with respect to the capitellum. The radius joystick test is performed by exerting lateral traction on the proximal radius in which the lateral movement would be obviously increased if IOL is ruptured.

After standard instruction and demonstration of radius pull-push and radius lateral pull tests, 10 physician evaluators examined the cadaver limbs in a standardized way (elbow at 90 degrees with the forearm held in both supination and pronation). When all tests were completed, examiners were asked to group them into one of the 4 groups of both IOL and TFCC intact, IOL divided but TFCC intact, both IOL and TFCC divided, or TFCC divided but IOL intact. Next, the same examiners were asked to re-examine the limbs after randomly changing the order of examination in the same session.

Statistical analysis

We calculated intra- and inter-observer reliability of the diagnosis of IOL rupture using the Fleiss kappa (an agreement measure for categorical ratings). Kappa values are interpreted as slight agreement with κ: 0.01-0.20, fair agreement with κ: 0.21-0.40, moderate agreement with κ: 0.41-0.60, substantial agreement with κ: 0.61-0.80, and almost perfect agreement with κ: 0.81-1.00. Our primary analysis classified the groups 1 and 4 as the diagnosis of intact IOL and groups 2 and 3 as the diagnosis of IOL disruption. Secondarily, we analyzed the data with all 4 groups separated.

We also calculated the diagnostic performance characteristics (sensitivity, specificity, positive and negative predictive value, and accuracy) for the diagnosis of IOL rupture. We calculated the likelihood ratio (LR), which shows how much the test improves the likelihood of making a correct diagnosis. Positive LR>10 and negative LR<0.1 indicate that the test is very useful, 5<positive LR<10 and 0.2>negative LR>0.1 indicate that the test is often useful, 2<positive LR<4.9 and 0.50>negative LR>0.21 indicate that the test is sometimes useful, and 1<positive LR<1.9 and 1>negative LR>0.51 indicate that the test is rarely useful.

We assigned the numbers from 1 to 5 to the level of experience as follows: 1 to the non-specialist medical doctors, 2 to the orthopedic residents, 3 to the general orthopedic surgeons, 4 to the orthopedic hand fellows, and 5 to the faculty hand surgeons. We assessed the correlation between the level of experience and the number of errors each individual had using the Spearman correlation.

In order to find the power of the study, we performed a post hoc power analysis using the sensitivity measured in our study in respect to the sensitivity introduced in the previous report of joystick test (8). Considering type I error to be 0.05 with the sample size of 12 cadavers, the post hoc analysis was done using the exact binomial test.

RESULTS

The inter-observer reliability of agreement for the diagnosis of IOL injury (groups 2 and 3) was fair in both rounds of examination (κ: 0.35 and 0.29) [Table 1], and the intra-observer reliability was moderate (κ: 0.44). [Table 2]

The inter-observer reliability of agreement for the 4 groups of injuries among the examiners was fair in both rounds of examination (κ: 0.25). [Table 3] The intra-observer reliability was fair as well (κ: 0.37). [Table 2]

The sensitivity, specificity, accuracy, positive, and negative predictive values were all around 70%. The likelihood of a positive test corresponding with the presence of the IOL rupture (positive likelihood ratio) was 2.2. The likelihood of the IOL rupture with a negative test (negative likelihood ratio) was 0.40. (On line Appendix).

Table 1. Inter-observer reliability: Ten (10) raters assigned 12 cadavers to 2 groups of intact and disrupted Intra-osseous ligament (IOL) in two separate round of examination

	First exam		Second exam		Correct injury type
	Intact IOL (Types 1 & 4)	Disrupted IOL (Types 2 & 3)	Intact IOL (Types 1 & 4)	Disrupted IOL (Types 2 & 3)	
Cadaver1	5	5	7	3	Intact IOL
Cadaver2	5	5	8	2	Intact IOL
Cadaver3	1	9	3	7	Disrupted IOL
Cadaver4	1	9	2	8	Disrupted IOL
Cadaver5	5	5	3	7	Disrupted IOL
Cadaver6	8	2	8	2	Intact IOL
Cadaver7	0	10	0	10	Disrupted IOL
Cadaver8	3	7	3	7	Intact IOL
Cadaver9	2	8	1	9	Disrupted IOL
Cadaver10	9	1	5	5	Intact IOL
Cadaver11	7	3	4	6	Disrupted IOL
Cadaver12	10	0	10	0	Intact IOL
Agreement	47%	53%	45%	55%	
Fleiss Kappa	0.345		0.289		
***P* value**	<0.001		<0.001		

Table 2. Intra-observer reliability

	Agreement with 4 groups		Agreement with IOL rupture	
Examiner	**Kappa**	**P value**	**Kappa**	**P value**
E1	0.51	<0.01	0.47	0.10
E2	0.31	0.04	0.50	0.05
E3	0.33	0.12	0.63	0.03
E4	0.45	<0.01	0.29	0.16
E5	0.43	<0.01	0.66	0.02
E6	0.35	0.02	0.50	0.08
E7	0.31	0.05	0.27	0.31
E8	0.28	0.10	0.17	0.56
E9	0.31	0.06	0.21	0.41
E10	0.33	0.04	0.66	0.02
Average	0.37		0.44	

Table 3. Inter-observer reliability: Ten (10) raters assigned 12 cadavers to a total of 4 types of injuries in two separate round of examination

	First exam				Second exam				Correct injury type
	Type 1	Type 2	Type 3	Type 4	Type 1	Type 2	Type 3	Type 4	
Cadaver1	4	5	0	1	3	3	0	4	type 4
Cadaver2	5	5	0	0	7	2	0	1	type 1
Cadaver3	1	5	4	0	2	5	2	1	type2
Cadaver4	0	6	3	1	1	2	6	1	type 3
Cadaver5	4	4	1	1	2	1	6	1	type 2
Cadaver6	6	1	1	2	6	2	0	2	type 4
Cadaver7	0	1	9	0	0	1	9	0	type 3
Cadaver8	3	6	1	0	2	7	0	1	type 1
Cadaver9	0	1	7	2	1	1	8	0	type 3
Cadaver10	8	1	0	1	5	5	0	0	type 1
Cadaver11	7	3	0	0	3	6	0	1	type 2
Cadaver12	8	0	0	2	8	0	0	2	type 4
Agreement	38%	32%	22%	8%	33%	29%	26%	12%	
Fleiss Kappa	0.245				0.253				
P value	<0.001				<0.001				

Characteristics of the combination of radius lateral pull test and radius pull-push test

	First exam	Second exam
$PPV = \frac{TP}{TP + FP}$	$\frac{44}{44+20} = 69$	$\frac{47}{47+19} = 71$
$NPV = \frac{TN}{TN + FN}$	$\frac{40}{40+16} = 71$	$\frac{41}{41+13} = 76$
$Specificity = \frac{TN}{FP + TN}$	$\frac{40}{40+20} = 67$	$\frac{41}{41+19} = 68$
$Sensitivity = \frac{TP}{TP + FN}$	$\frac{44}{44+16} = 73$	$\frac{47}{47+13} = 78$
$Accuracy = \frac{TP + TN}{\text{Total Population}}$	$\frac{44+40}{120} = 70$	$\frac{47+41}{120} = 73$
$LR+ = \frac{\text{Sensitivity}}{1 - \text{Specificity}}$	2.2	2.4
$LR- = \frac{1 - \text{Sensitivity}}{\text{Specificity}}$	0.4	0.32

PPV=Positive Predictive Value, NPV=Negative Predictive Value, LR+ = Positive Likelihood Ratio, LR- =Negative Likelihood Ratio, TN=True Negative, TP=True Positive, FN=False Negative, FP=False Positive

By observing the number of errors in the diagnosis of intact versus divided IOL the level of experience did not have any effect on correct diagnosis. [Table 4]

Using the calculated sensitivity of 73% in our study in contrast to 100% sensitivity in the previous report, the power of our study was 0.90. Fleiss Kappa for testing the reliability was also significant showing that we had enough

Table 4. The effect of experience on correct diagnosis of intact versus disrupted IOL

		Assigned level of experience	Number of errors out of 12 cadavers			
			Test	***P value****	**Retest**	***P value****
Examiner1	Orthopedic Resident-1	2	3		2	
Examiner2	Medical Doctor-1	1	4		5	
Examiner3	Hand Surgeon-1	5	4		2	
Examiner4	Orthopedic Resident-2	2	4		3	
Examiner5	Orthopedic Surgeon-1	3	1	*0.86*	3	*0.13*
Examiner6	Hand Surgeon-2	5	3		2	
Examiner7	Hand Fellow-1	4	5		3	
Examiner8	Medical Doctor-2	1	3		5	
Examiner9	Orthopedic Surgeon-2	3	5		2	
Examiner10	Hand Fellow-2	4	3		5	

* Spearman's correlation between the level of experience and the number of errors during test and retest

power to accept the results.

To test whether paired limbs affected the results as dependent samples, we performed the analysis with 11 cadavers once after omitting one of the pair and again after omitting the other one. Fleiss kappa was 0.22 and 0.25, respectively, with *P* values<0.001. There was no substantial change in kappa showing that created injuries can be accounted as independent samples.

DISCUSSION

This study tested the inter- and intra-observer reliability and diagnostic performance characteristics for diagnosis of forearm IOL injury using intraoperative physical examination techniques including pull-push and lateral pull tests.

Several limitations affect the interpretation of these data. Cadavers do not have the same muscle tension as live humans. The age of the cadavers at the time of death was higher than the age that IOL injury commonly occurs. The examiners were relatively inexperienced, but the confidence level for diagnosis of the IOL rupture was roughly the same for every examiner. The small sample size, the method of TFCC destabilization, and repeating of the testing on a same day may have affected the results of our study. Furthermore, IOL injury is uncommon, and no one has extensive experience with intraoperative physical examination.

The results of our study showed fair inter-observer and moderate intra-observer reliability for diagnosis of the IOL injury using clinical examination. Diagnostic performance characteristics (specificity, sensitivity, positive and negative predictive values, and accuracy) were all around 70% in both rounds of examination. The positive and negative likelihood ratios suggest that the tests are sometimes useful. The second round of examination showed small improvement in the results, but the difference was not remarkable. Most of the examiners expressed low level of confidence in terms of deciding whether the IOL was divided or not. Based on analysis on the number of errors each examiner had and the distribution of errors across the specimens, the level of experience did not have an effect on the correct diagnosis of intact versus disrupted IOL.

Anatomic and biomechanical studies have shown the importance of the IOL in linking the radius to the ulna (3, 9). The results of these studies establish the rationale behind the radius pull test to check the longitudinal stability of the radius by visually observing the amount of displacement (7). The radius joystick test is based on the observation that lateral displacement of the radius increases after disruption of the restraints (8). The initial study of this test found 100% sensitivity, 88% specificity, 90% positive predictive value, and 100% negative predictive value. In the original description, the joystick test was done in full pronation where the IOL was supposed to reach to the maximum stiffness (8). However, a recent biomechanical study showed that the IOL is lax during pronation while mid-IOL and distal IOL tension are maximum in neutral and supination, respectively (11). Moreover, Hotchkiss et al measured the highest IOL stiffness in supination and the lowest IOL stiffness in pronation (2). The length of the IOL bundles does not change with different positions of the forearm (12). Although these reports are suggestive of stiffness in supination, the differences we found regarding the ability of lateral joystick test may be because of the way they prepared the cadavers (2 groups of IOL intact versus divided), the way the authors instructed the examiners, and the number and level of experience of the examiners they had.

The likelihood ratios suggest that these tests are imperfect but often useful is spite of the fact that the inter-observer reliability of the tests was fair. These tests may perform better when used in conjunction with other diagnostic modalities including imaging and direct visualization of the radius movement with respect to the other structures rather than relying only on the sense of movement, which may be less reliable.

Clinical diagnosis of the IOL rupture seems to be evolving with the introduction of new examination techniques. However, making a correct diagnosis is still difficult, and clinical findings should be interpreted with caution. The introduced tests may not be reliable enough to be applied exclusively for decision-making, and we still need to use the imaging studies to improve diagnosis. Because there is a limited experience in examining this structure in any level of hand surgery experience, we can also assume that there is a learning curve, which requires multiple physical examinations together with imaging confirmation.

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Chapter 3

Intraoperative Technique for Evaluation of the Interosseous Ligament of the Forearm.
Kachooei AR, Rivlin M, Shojaie B, van Dijk CN, Mudgal C.
J Hand Surg Am. 2015 Dec;40(12):2372-6.e1.

ABSTRACT

PURPOSE

To introduce a technique for the diagnosis of interosseous ligament (IOL) disruption based on lateral displacement of the radius after radial head resection and to determine the cutoff value of the lateral displacement for the diagnosis of disruption, the best elbow position for testing, and the diagnostic performance of the technique in different positions.

METHODS

We used 10 fresh-frozen cadavers. After resection of the radial head, a Steinman pin was placed into the radius medullary canal and used to mark the pin location on the capitellum. We applied 1 kg force to pull the proximal radius laterally and measured the displacement in full supination, neutral, and full pronation of the forearm with the elbow in extension and then in 90° flexion. All measurements were performed once with the IOL intact and again with it cut. To assess diagnostic efficacy, receiver operating characteristics curves were constructed. To determine the quality of the technique, we measured the area under the receiver operating characteristics curve for each position. We also determined the cutoff value to obtain the highest sensitivity and specificity.

RESULTS

The area under the curve of the test in extension-supination and flexion-supination showed that these positions were excellent for the diagnosis of IOL disruption. The cutoff value of 5.5 mm lateral displacement in extension-supination had 100% sensitivity and 90% specificity. In flexion-supination, the cutoff value of 9 mm had 100% sensitivity and 90% specificity for the diagnosis of IOL disruption.

CONCLUSIONS

This maneuver was reliable and accurate in cadavers with complete IOL disruption. It is likely that in an intraoperative setting, these results will be reproducible.

INTRODUCTION

Forearm instability may be more pronounced when disruption of radial head and neck is accompanied by interosseous ligament (IOL) disruption. The chance of an IOL injury is correlated with the severity of the radial head fracture (1), however, even low energy (Mason I) injuries may be associated with IOL injury (2). After radial head resection, the IOL is responsible for axial load bearing up to 71% of the forearm (3, 4). This may lead to attenuation of a partially injured IOL, which may eventually lead to instability (3).

IOL disruption can be difficult to diagnose and is often initially missed. IOL disruption can be diagnosed by MRI (5) and ultrasonography (6), but their application is difficult in an acute setting. Often there are no symptoms localizing IOL injury and thus clinical suspicion is paramount (1). Radius pull test (longitudinal pull) (7) and radius joystick test (lateral pull) (8) can assess the presence or absence of radioulnar dissociation at the time of surgery. However, these tests are highly dependent on the examiner’s experience and are usually judged on a subjective sense of movement, which has been shown to be unreliable in predicting the injury even if attending hand surgeons do it (9). Moreover, the positioning while examining is not well described. For these reasons, we think that an objective method would be more reliable and reproducible to quantify the movement independent of the examiner’s experience. This information might aid in the decision between radial head resection and prosthetic implantation (10, 11). Although most surgeons likely would prefer arthroplasty to resection in the setting of an unreconstructable radial head fracture, radial head resection may still be offered to selected patients (12). In these situations, accurate diagnosis of concomitant IOL disruption is of paramount importance in preventing forearm instability following a radial head resection.

In this study, we aimed to introduce a technique for the diagnosis of IOL disruption using the amount of lateral displacement of the radius after radial head resection. A further purpose of this study was to determine the best elbow position to test the IOL and to determine the diagnostic performance of the technique in different positions.

METHODS

In this study, we used 10 fresh frozen cadaver upper limbs (4 male, 6 female, mean age at time of death 63 years, range 53-82). Cadavers were thawed 24 hours prior to preparation. Cadavers were free of scars or gross deformity.

One surgeon carried out identical dorsal extended incisions on all cadavers from lateral epicondyle to the Lister tubercle approaching the IOL and the radial head between the extensor carpi radialis brevis and the extensor digitorum communis muscles. After cutting the annular ligament, the radial head was excised 1.5 cm distal to the joint line and proximal to the bicipital tubercle to simulate the comminuted radial head fractures requiring excision and possible replacement. Prior to performing any measurement, the IOL was completely exposed. This ensured that the cadavers were free of occult deformities, fractures, or limitations of motion. Furthermore, this ensured a uniform exposure and setup prior to and after the IOL sectioning and limited the variability in muscle stripping.

After removing the radial head, we placed a Steinman pin into the radius medullary canal by grabbing the radial neck with a bone clamp and pulling the radius posterolaterally with elbow in full flexion. We placed the sharp tip facing the capitellum. We marked the pin location on the capitellum using a sharp tip surgical marker in resting position both in 90 degrees flexion and full extension of the elbow and neutral rotation of the forearm while the lateral side of the elbow was facing upward and the palm of the hand was resting fully on the table. [Figure 1] We applied 1 kg (2.2 lbs.) force using a tension meter to pull the proximal radius stump laterally with respect to the radiocapitellar joint (upward while the arm was resting on the table) by passing a number 5.0 suture thread around the neck of the radius. [Figures 1] An assistant was also monitoring the position of the arm during force application to prevent any displacement from the purely directed lateral force. We measured the displacement between the tip of the intramedullary pin and the marked point on the capitellum using a caliper while an assistant was holding the cadaver arm. We applied the force only in one direction (lateral in respect to the elbow) and thus only measured the displacement in one axis. This amount of force was chosen because it could be replicated by pulling the radius laterally until the elbow was nearly elevated off of the operation table while the arm was resting on it. This could also be done in an operative setting with a small incision when approaching the radial head and neck. We measured the displacement in full supination, neutral, and full pronation with full elbow extension and again at 90 degrees of flexion. We used a caliper because of its precision to less than 1 mm. All measurements were performed first with the IOL intact and then cutting it. The degree of lateral displacement was measured in millimeters and tabulated. One surgeon, not blinded to the state of the IOL, consistently took the measurements, which were not repeated.

Continuous data were reported as means and standard deviation after testing the normality using a 1-sample Kolmogorov-Smirnov test. Categorical data were presented as absolute values and percentages. We conducted a

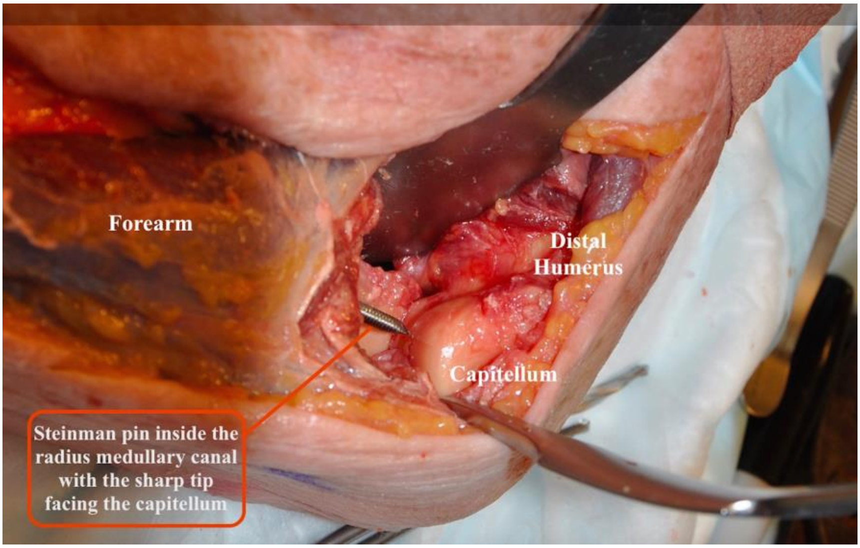

Figure 1. A Steinman pin was inserted into the radius medullary canal with the sharp tip facing the capitellum.

paired t-test to compare the measured displacements before and after sectioning of the IOL.

To assess the diagnostic efficacy of this technique for the diagnosis of IOL disruption, receiver operating characteristics (ROC) curves were constructed for each position of examination. To determine the quality of the technique, we measured the area under the ROC curve (AUC) for each position with a significance test for it. AUC of 0.90-1.0 is considered as an excellent test, 0.8-0.89 as good, 0.70-0.79 as fair, 0.60-0.69 as poor, and 0.50-0.59 as failed. Accordingly, we determined the cutoff value to obtain the highest possible sensitivity and specificity in the diagnosis of IOL disruption.

RESULTS

With the IOL intact, lateral displacement in extension-supination was less than 6 mm and in flexion-supination was less than 10 mm. With the IOL sectioned, displacement was more than 6 mm in extension-supination and more than 10 mm in flexion-supination. [Table 1; online appendix] The difference in displacement before and after IOL disruption was statistically significant in almost all positions; however, the greatest change was noted in supination regardless of elbow flexion or extension. [Table 2]

Table 1. Measured values of proximal radius lateral displacement after radial head resection in 10 cadavers *(measurements are in millimeters)*

	Mean (SD)	Min-Max
IOL intact *(mm.)*		
Full Extension		
Supination	2.9 (2.2)	0-6
Neutral	14 (5.2)	6-23
Pronation	13 (5.0)	2-19
90 Flexion		
Supination	4.7 (3.1)	0-10
Neutral	15 (3.2)	11-19
Pronation	12 (3.6)	6-17
IOL disruption *(mm.)*		
Full Extension		
Supination	13 (4.9)	6-20
Neutral	20 (8.0)	12-41
Pronation	17 (8.4)	5-34
90 Flexion		
Supination	17 (6.0)	10-28
Neutral	20 (5.2)	11-29
Pronation	20 (6.8)	10-31

IOL= Inter-osseous ligament, SD=Standard deviation, Min=Minimum, Max=Maximum

Table 2. Pairwise comparison of the mean displacement before and after IOL disruption *(mean differences and SDs are in millimeters)*

	Mean difference (SD) [mm.]	*P value**
Extension-Supination	10.0 (4.1)	<0.001
Extension-Neutral	6.0 (5.5)	0.008
Extension-Pronation	4.1 (7.8)	0.13
Flexion-Supination	12.0 (6.4)	<0.001
Flexion-Neutral	5.1 (5.0)	0.011
Flexion-Pronation	8.7 (5.5)	0.001

IOL= Inter-osseous ligament, SD=standard deviation
* Paired t-test

The AUC of the test in extension-supination and flexion-supination were 0.990 and 0.995 respectively showing that these positions were excellent for the diagnosis of the IOL disruption. The AUC of the test in flexion-neutral and flexion-pronation showed that these positions were good. [Table 3; Figure 2]

Accounting for the highest sensitivity in the diagnosis of IOL disruption, the cutoff value of 5.5 mm lateral displacement in extension-supination had 100% sensitivity and 90% specificity. In flexion-supination, the cutoff value of 9 mm had 100% sensitivity and 90% specificity in the diagnosis of IOL disruption. [Table 4]

DISCUSSION

Determining the cutoff value was a trade-off between specificity and sensitivity. By choosing the larger numbers, the specificity increased while sensitivity decreased. By choosing the smaller number, the sensitivity increased at the expense of specificity. Therefore, we picked the number as a cutoff to achieve the highest possible sensitivity

Table 3. Measuring the area under the receiver operating characteristic (ROC) curve to determine the most accurate examination position for diagnosis of the IOL disruption

Examination position	Area under curve	95% CI	*P value*
Extension-Supination	0.99	0.96-1.0	<0.001
Extension-Neutral	0.75	0.53-0.97	0.059
Extension-Pronation	0.62	0.36-0.88	0.36
Flexion-Supination	1.00	0.98-1.0	<0.001
Flexion-Neutral	0.82	0.62-1.0	0.016
Flexion-Pronation	0.87	0.70-1.0	0.006

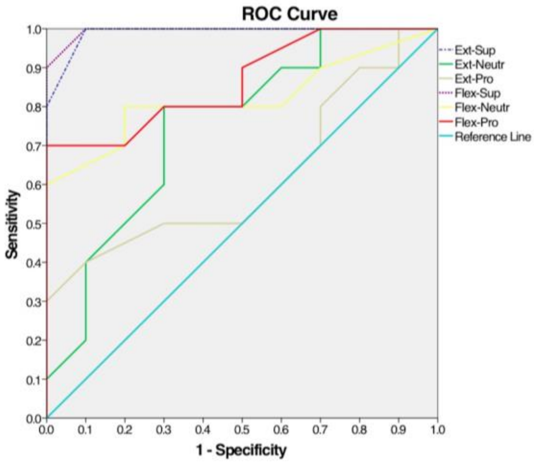

Figure 2. The ROC curves for different positions of the elbow shows that flexion-supination and extension-supination had the highest area under the curve (AUC).

Table 4. Determination of the cutoff

Examination position	Cutoff value (mm)*	Sensitivity	Specificity
Extension-Supination	5.5	100	90
	7.5	80	100
Flexion-Supination	9	100	90
	10.5	90	100

* IOL disruption is present if lateral displacement is greater than or equal to

and specificity. Using the cutoff values, for instance, 4 mm displacement in extension-supination had 90% specificity meaning that there was a 10% chance of being false negative. Conversely, a displacement of 7 mm in extension-supination was 100% sensitive showing that there was 0% chance of being a false positive. In a clinical setting by accepting this cutoff, displacements larger than 5.5 mm need special consideration while smaller displacements likely imply an intact IOL. We used a caliper for the measurements, however in a clinical setting, we can use a ruler instead that can measure down to 1mm.

Although not common, some failure of surgeries for traumatic elbow fracture-dislocations is because of failure to recognize early an IOL disruption. Trousdale et al reported that 20% of patients with delayed diagnosis of IOL injury and subsequent treatment had satisfactory outcomes (13). This raises the importance of early diagnosis and treatment of this type of injury (14, 15). In cases with high index of suspicion, imaging modalities are valuable to aid in pre-surgical planning. However, simple and accurate intra-operative evaluation should be performed as standard practice given the above results for any case that may require radial head resection.

In a cadaver study, Smith et al described the radius pull test to assess the amount the longitudinal radius displacement (7). They showed that longitudinal displacement of more than 3 mm was associated with disrupted IOL and displacement of more than 6 mm was associated with both IOL and triangular fibrocartilage disruption. Furthermore, Soubeyrand et al dres-cribed the joystick radius test as a subjective intra-operative screening test (8). According to their instructions, the test should be performed in maximal pronation while radius is pulled laterally creating a pivot around the distal radioulnar joint. They considered full pronation as the most stable position and the test negative if no displacement occurred with the pull. In contrast, our results showed that supination was the most reliable position for the diagnosis of the IOL disruption. This finding has also been confirmed in a biomechanical study showing larger compressive stiffness – load/displacement (N/mm) – with supination rather than neutral and pronation (16). Given the maximum stiffness of the IOL in supination, we can assume that lateral displacement would be more pronounced in supination if IOL was disrupted.

Our measurements were done on cadavers with no muscle tone. This is a limitation of cadaveric experiments, and the results may be altered *in vivo*. Moreover, other bony and ligamentous injuries may be associated with the IOL injury. However, our study describes a standardized way of evaluating the competence of the interosseous complex irrespective of other confounding injuries. Despite of the variability in measured values among cadavers, the directions of values were all consistent in all positions before and after IOL disruption. We caution against overzealous lateral loading of the radius as there is a risk of traction on the posterior interosseous nerve; however, reports support the maneuver's safety (8). The test may also be difficult to perform if the annular ligament is partially intact. This would clearly alter the surgeon's ability to displace the radial neck laterally. We only tested this technique on complete IOL disruption; however, partial rupture of the IOL may allow less displacement. Another limitation of our study is that intra and inter-observer reproducibility is unknown.

Using the above measurement technique in forearm supination and 90 degrees of flexion, it may be possible to accurately evaluate the IOL intra-operatively. This maneuver was shown to be reliable and accurate in cadavers with complete IOL disruption. However, its efficacy in partial injuries merits future studies on a larger number of cadavers.

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Chapter 4

Evaluation of Radiocapitellar Arthritis in Patients with a Second Radiograph at Least 2 Years after Nonoperative Treatment of an Isolated Radial Head Fracture.
Kachooei AR, Ring D.
Arch Bone Jt Surg. 2017 Nov;5(6):375-379.

ABSTRACT

BACKGROUND

To study if patients that have a second radiograph 2 or more years after nonoperative treatment of an isolated radial head fracture have radiocapitellar osteoarthritis (RC OA).

METHODS

We used the database of 3 academic hospitals in one health system from 1988 to 2013 to find patients with isolated radial head fractures (no associated ligament injury or fracture) that had a second elbow radiograph after more than 2 years from the initial injury. Of 887 patients with isolated radial head fractures, 54 (6%) had an accessible second radiograph for reasons of a second injury (57%), pain (30%), or follow-up visit (13%). Two orthopedic surgeons independently classified the radial head fractures on the initial radiographs using the Broberg and Morrey modified Mason classification, and assessed the development of RC OA on the final radiograph using a binary system (yes/no).

RESULTS

Four out of 54 (7.5%) patients had RC OA, one with isolated RC arthrosis that seemed related to capitellar cartilage injury, and 3 that presented with pain and had global OA (likely primary osteoarthritis).

CONCLUSION

With the caveat that some percentage of patients may have left our health system during the study period, about 1 in 887 patients (0.1%) returns with isolated radiocapitellar arthritis after an isolated radial head fracture, and this may relate to capitellar injury rather than attrition. Patients with isolated radial head fractures can consider post-traumatic radiocapitellar arthritis a negligible risk.

INTRODUCTION

Radial head fractures are common and radiocapitellar osteoarthritis (RC OA) rarely brings patients to the doctor. Broberg and Morrey modified Mason's classification of isolated partial articular fractures by adding thresholds of 30% of the articular surface and 2 mm displacement. While a 2 mm step off was linked to arthrosis in some joints, the same relationship does not appear to hold true in the elbow. In fact, the concern with displacement is that there will be hindrance of forearm rotation, not arthritis of the radiocapitellar or proximal radioulnar joints (1). A cadaver study testing found that 3 mm of displacement hindered forearm rotation in 7 of 9 cadavers (2). In another study of nonoperatively treated Mason type II fractures, patients with displacement less than 2 mm had no difference in functional outcome measures, range of motion, and subsequent RC OA compared to with patients with more than 2 mm displacement (3).

If slight deformity does not result in RC OA we can downgrade that issue in treatment considerations. This study addressed the primary null hypothesis that there are no factors associated with RC OA after non-operative treatment of isolated radial head fractures. Secondarily, we aimed to study the time to the diagnosis of RC OA.

METHODS

Patients

In a retrospective study, we used the database of 3 academic medical centers to find patients with the diagnosis of radial head fracture from 1988 to 2013 using International Classification of Diseases, 9th Revision, Clinical Modification (ICD-9-CM) diagnosis code of 813.05. We included patients older than 16 years of age, with an isolated radial head fracture treated nonoperatively, and with an accessible follow-up elbow radiograph of more than 2 years after the initial injury. We excluded patients with concomitant elbow fracture or fracture-dislocation, and patients with prior elbow trauma or osteoarthritis. Of 4306 elbow injuries with radial head fractures, 887 patients had isolated radial head fracture, out of which 54 patients had a follow-up elbow radiograph after more than 2 years from the initial injury. We excluded patients with concomitant injuries and patients treated operatively (radial head prosthesis, open reduction and internal fixation, and head resection) leaving 54 patients with 54 isolated radial head fractures treated nonoperatively.

We reviewed the medical record to gather demographic data and injury characteristics. The reason for the later radiograph was recorded and grouped as subsequent injury, persistent pain, and research visits.

Radiographic assessment

Anteroposterior and lateral radiographic views of the elbow at the time of injury and at the final follow-up visit were captured. Radial head fractures were classified on the initial radiographs using the Broberg and Morrey modified Mason classification: type I (fracture fragment less than 30% of the head and less than 2 mm displacement), type II (fracture fragment more than 30% of the head and more than 2 mm displacement), and type III (comminuted fracture involving the whole head). Further, development of radiocapitellar osteoarthritis (RC OA) was assessed on the final radiograph. Because isolated RC OA is not a common finding on radiographs and it is usually mild, we used a binary rating to group the patients based on whether RC OA was developed (yes/no). Two orthopedic surgeons reviewed the radiographs independently (ARK and DR) to classify the radial head fracture type as well as to rate the RC OA. A consensus was made after discussion if there was any disagreement between raters regarding the type of the fracture or the existence of RC OA. Only 4 (7.5%) developed RC OA all of which were Mason type I radial head fracture.

Data analysis

Categorical and continuous data were presented as absolute numbers with percentages and mean with standard deviation, respectively. Considering RC OA as an outcome variable, we used Chi Square or Fisher's exact test for categorical data and independent student's t-test for continuous data to assess the related factors in the development of RC OA. [Table 1]

Table 1. Demographic and fracture characteristics of the patients with radial head fracture alone after nonoperative treatment

	RC OA after nonoperative treatment	
	No (N=50)	**Yes (N=4)**
Age, mean (SD)	52 (13)[a]	50 (16)[b]
Follow up, mean (SD)	6.2 (3.6)[c]	9.6 (4.7)[d]
Sex, no. (%)		
Male	17 (85)	3 (15)
Female	33 (97)	1 (3)
Race, no. (%)		
White	43 (91)	4 (9)
Non-white	7 (100)	0
Side, no. (%)		
Right	25 (93)	2 (7)
Left	25 (93)	2 (7)
Dislocation, no. (%)		
Yes	3 (100)	0
No	47 (92)	4 (8)
Follow up, no. (%)		
Recent trauma	31 (97)	1 (3)
Pain	16 (84)	3 (16)
Follow up	3 (100)	0
Mason type, no. (%)		
I	43 (91)	4 (9)
II	6 (100)	0
III	1 (100)	0

RC OA Radiocapitellar osteoarthritis; SD Standard deviation;
[a] Age Min-Max=21-81 years;
[b] Age Min-Max=36-73 years
[c] Follow up Min-Max=2.1-18 years;
[d] Follow up Min-Max=3.4-15 years

RESULTS

The only factor related to the development of RC OA was the time elapsed since injury with 3 of 4 presented after 10 years. [Tables 2 and 3] Three of 4 patients—all evaluated for pain many years after fracture--had also developed some degrees of ulnohumeral osteoarthritis. [Table 3, Figures 1-4]

Table 2. Assessment of the related factors in the developmenet of RC OA

	P value
Mason type (I, II, III)	*0.73*
Time to follow-up (<5 y, 5-10 y, >10 y)	*0.036*
Dislocation	*0.61*
Race	*0.42*
Age	*0.56*
Side	*0.95*
Sex	*0.10*

RC OA radiocapitellar osteoarthritis

DISCUSSION

Our objective was to assess the relation between the radial head fracture type and the incidence of RC OA after nonoperative treatment of an isolated radial head fracture. Isolated arthrosis of the RC joint is uncommon after isolated radial head fractures.

There are some limitations with retrospective studies including loss of follow up, and inaccurate medical records. Our sample was too small to be representative of the whole isolated radial head fractures and the number of RC OA was too small to let us make a strong inferences; however, our results are internally acceptable for the same population. The subset of patients we studied was not representative of the average patient with radial head fracture. We studied patients that returned, most of whom had recent trauma and less than 1/3 had symptoms, likely for reasons unrelated to the original fracture.

There was only one patient with isolated RC arthrosis, which looked like a

Table 3. Patients with the finding of radiocapitellar osteoarthritis in the follow-up radiographs

Patient	Sex	Race	Age	Side	Reason of follow-up	Treatment	Dislocation	Mason type	Time to follow-up (year)	Other findings
1	Male	White	42	Left	Pain	Nonoperative	No	1	3	UH OA
2	Female	White	48	Right	Pain	Nonoperative	No	1	10	UH OA
3	Male	White	73	Right	Pain	Nonoperative	No	1	10	UH OA
4	Male	White	36	Left	Trauma	Nonoperative	No	1	15	

UH OA: ulnohumeral osteoarthritis

Figure 1. Anteroposterior elbow view of a 45-year-old male 3 years after the initial injury shows slight deformed head with radiocapitellar and ulnohumeral arthrosis.

Figure 2. Anteroposterior elbow view of a 58-year-old male 10 years after the initial injury shows slight deformed head with radiocapitellar and ulnohumeral arthrosis.

Figure 3. Anteroposterior elbow view of a 83-year-old male 10 years after the initial injury shows slight deformed head with radiocapitellar and ulnohumeral arthrosis.

Figure 4. Anteroposterior elbow view of a 51-year-old male 15 years after the initial injury shows radiocapitellar arthrosis.

capitellar cartilage injury. Three other patients had RC OA as part of a global OA (ulnohumeral, PRUS, and RC). All four patients had type I radial head fractures. The patients with global arthrosis might have primary osteoarthritis incidentally or perhaps there was more of an elbow injury than apparent on the radiographs and this is post-traumatic OA, although that seems less likely. The prevalence of OA (7.5%) in our population is likely related to the fact that most patients had a second radiograph of their elbow mostly due to pain.

In the process of aging, degenerative changes start from the radiocapitellar articulation (4, 5). Primary osteoarthritis, fractures involving the lateral elbow compartment, and persistent elbow instabilities might also result is RC OA (6, 7). RC OA is uncommon after radial head fractures even if it heals with deformity. It seems that the radial head fracture type and the degree of deformity after healing was unrelated to the development of RC OA.

CONCLUSION

In conclusion, 6% of patients with isolated radial head fractures returned for a second radiograph more than 2 years after injury. Only 7.5% had radiocapitellar arthrosis and 3 of the 4 patients had ulnohumeral arthrosis, likely primary. With the caveat that some percentage of patients may have left our health system during the study period, about 1 in 887 patients (0.1%) returns with isolated radiocapitellar arthritis after an isolated radial head fracture, and this may relate to capitellar injury rather than attrition. Patients with isolated radial head fractures can consider post-traumatic radiocapitellar arthritis a negligible risk, but additional study is warranted.

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Chapter 5

Outcomes of Concomitant Fractures of the Radial Head and Capitellum: The "Kissing Lesion".
Claessen FM, Kachooei AR, Verheij KK, Kolovich GP, Mudgal CS.
J Hand Microsurg. 2016 Aug;8(2):100-5.

ABSTRACT

BACKGROUND

Radial head compression against the capitellum may cause concomitant fracture of the capitellum. The purpose of this study was to investigate if radial head fracture type is associated with a concomitant fracture of the capitellum.

PATIENTS AND METHODS

Data were identified from five area hospitals. We retrieved records of patients older than 18 years of age who underwent treatment for concomitant capitellum fracture and radial head fracture between January 2002 and January 2013. Patients with olecranon fractures or trochlea fractures were excluded.

RESULTS

A total of 10 patients with a radial head fracture and a concomitant capitellum fracture were included. Based on the operative reports, nine radial head fractures were classified as Hotchkiss modification of the Mason classification type II, and one was classified as type I. Based on the available radiographs and computed tomography, three capitellum fractures were type I, and seven were type II according to the Grantham classification.

CONCLUSION

Surgeons have to be alert to capitellar damage in case of a Hotchkiss type II radial head fracture.

INTRODUCTION

Radial head fractures are among the most common fractures of the adult elbow and occur with a variety of associated injuries (1-3). Radial head and capitellum fractures both result from an axial load onto an extended elbow with the forearm in pronation (1, 2). Radial head compression against the capitellum in this position may cause concomitant fracture of the capitellum (2). Capitellar fractures comprise 2% of overall elbow fractures and are frequently missed on radiographs (4). A concomitant radial head and capitellum fracture is a rare event and only a few reports have been described. We have called this concomitant occurrence a 'kissing lesion'. Caputo et al. first demonstrated that Mason type II radial head fractures are most commonly associated with fractures of the capitellum (5). Nalbantoglu et al. also reported that more severe radial head fractures increase the risk of capitellum fracture (6).

It remains uncertain as to whether radial head fracture type is correlated with the presence of a kissing lesion. Treatment of these fractures may be complicated compared to an isolated radial head fracture. The capitellum is at risk because of possible impingement on the radial head (6). A missed capitellum fracture can lead to complications, such as avascular necrosis, loss of elbow function, malunion and nonunion (7-10). We therefore aim to investigate if radial head fracture type can predict a kissing lesion. We secondarily aim to evaluate which capitellar fracture type is most commonly found in kissing lesions. We hypothesize that radial head fracture type is not associated with the presence of a kissing lesion, and capitellar fracture type is not associated with the presence of a kissing lesion.

PATIENTS AND METHODS

Study design and participants

After institutional review board (IRB) approval of this retrospective study, we used Current Procedural Terminology (CPT) codes to identify patients with concomitant radial head and capitellum fractures (Appendix 1). Medical data of patients with one of these CPT codes were retrieved through the institutional Research Patient Data Repository (RPDR). This is a centralized clinical data registry, covering patients over 5 hospitals.

We included patients 18 years of age or above who underwent treatment for capitellum fracture and radial head fracture between January 2002 and 2014. After reviewing the radiographs manually, 11 patients could be included in our study. Patients with olecranon or trochlea fractures were excluded.

Outcome measures and explanatory variables

In this study, we evaluated the demographic and fracture characteristics from the medical records including the age at the time of operative treatment, sex, race, capitellum fracture type, radial head fracture type, and side of injury. We followed patients prospectively to assess the, range of flexion, extension, pronation, supination, and completed the Disabilities of the Arm, Shoulder, and Hand (DASH), and Mayo elbow performance index questionnaires. The radial head fractures were classified according to the Hotchkiss Modification of the Mason Classification comprising type I as non-displaced or mildly displaced fractures of the radial head or neck, type II as displaced (>2mm) fractures of the head or neck (angulated), and type III as severely comminuted fracture of the radial head and neck (11). Capitellum fractures were graded according to the classification of

Grantham et al (9) comprising grade I when a thin osteochondral portion is fractured, grade II when a larger capitellum fragment displaces antero-superiorly, and grade III when the capitellar fragment is comminuted.

RESULTS

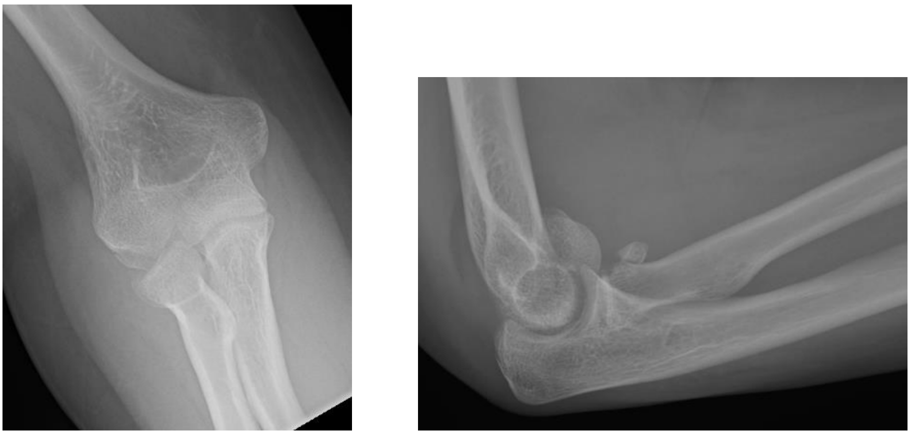
A total of ten patients with a radial head fracture and a concomitant capitellum fracture were included in this study (0.2% of radial head fractures). These ten patients were operated on by three different surgeons, who each took care of five, four and one patient respectively.

The mean age of the patients was 35 years (range: 19-51) at the time of injury (Table 1). Of the ten patients included, six were male and four were female.

The mechanism of injury in all patients was falling on an outstretched arm. In six patients, the left elbow was affected. Based on the operative reports and radiographs, the data was assessed by a research fellow and checked by an orthopaedic surgeon specialized in hand and upper extremity surgery. They then classified nine radial head fractures as type II and one as type I. Furthermore, three capitellum fractures were graded as

Table 1. Characteristics included cases

Case no	Age	Gender	Side	Type radial head fractuur	Type capitellum fractuur	Treatment	Type and number screws capitellum	Direction screws capitellum	Type and number screws radial head	Direction screws radial head	Follow-up (months)	Arc of motion	Extension/ flexion	Pronation/ supination
1	40	F	L	II	II	Excision radial head fragment Screw fixation	3 headless	Anterior-Posterior			2	120	20-140	85/85
2	25	F	R	II	II	Screw fixation	2 headed cannulated	Posterior-anterior	1 headless screw	Posterior-anterior	6	135	0-135	90/86
3	36	M	R	II	II	Screw fixation	2 Herbert	Anterior-Posterior	1 Herbert	Anterior-Posterior	4	135	0-135	90/90
4	51	M	L	II	II	Screw fixation	2 Herbert	Anterior-Posterior	2		2			
5	37	F	L	I	I	Excision radial head fragments and loose capitellum fragments								
6	45	M	L	II	II	Screw fixation	5	2 lateral-medial 1 anterior-posterior 2 caudaal-craniaal			72	130	10-140	90/85
7	34	M	L	II	II	Screw fixation	2 Herbert	Anterior-posterior	2	Anterior-posterior	22	130	0-130	90/90
8	26	M	R	II	II	Screw fixation	2 headless	Lateral-medial	1 headless	Lateral-medial	2	135	0-135	
9	41	M	R	II	.	.	.							
10	43	F	R	II	I	Screw fixation	2	Anterior-Posterior	2 headless	Lateral-medial	5		30-140	90/90

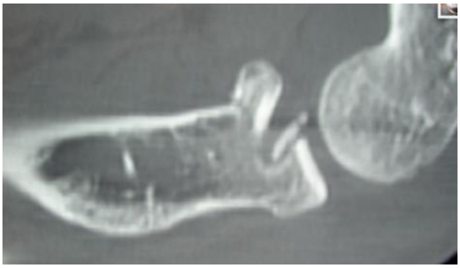


(A) (B)

Figure 1 (A and B). Anteroposterior and lateral views of the elbow showing type II radial head fracture with concomitant type I capitellum fracture.

(A) (B)

Figure 2 (A and B). Anteroposterior and lateral views of the elbow showing type II radial head fracture with concomitant type II capitellum fracture



CT scan examples of concomitant fractures of the radial head and capitellum. The capitellar fracture fragment is trapped within the radial head fracture.

type I, and seven were graded as type II (Figure 1-2). Besides the radial head fracture with a concomitant capitellum fracture, three of these patients sustained a lateral column distal humerus fracture as well. No additional description of bony and/or ligamentous injuries diagnosed intra-operatively, was documented in the operative notes.

All ten patients had surgical repair. Eight patients had open reduction and screw fixation alone, one patient had a capitellar screw fixation combined with excision of the radial head fragment and one patient had both fracture fragments excised. Devices used for fixation included K-wires, Herbert screws, mini-fragment screws and headed or headless cannulated screws.

Preoperative radiographs were available in seven patients. All preoperative radiographs were performed in our included hospitals. In five of those seven patients (71%), complete loss of cortical contact of the radial head fragment was seen (Table 1). In three patients fracture classification was determined by operative reports and postoperative radiographs, because no preoperative radiographs were available.

The mean follow-up was nine months (range: 2-22 months). Due to the varying times of follow-up appointments, we were unable to conclusively demonstrate or identify a time to fracture union. Postoperative range of motion could be assessed in eight of ten patients. The average arc of flexion-extension was 128° (range: 110-135). A flexion contracture was found in three patients (mean: 17 degrees, range: 10-20 degrees). The range of supination-pronation was almost full in comparison to the contralateral side in all patients. No patients required any subsequent procedures. All fractures healed uneventfully and we did not observe any evidence of AVN of the capitellar fragments or post-traumatic arthritis. Due to the retrospective nature of our study, we were unable to apply any scoring systems or outcomes tools to our outcomes data.

DISCUSSION

The articular cartilage covers the concave surface of the radial head as well as an arc of approximately 280 degrees around the radial head rim (12). Fractures of the radial head usually occur because of an axial load transmitted through the radiocapitellar joint as 90% of the force across the elbow is transmitted through the radial head (14). The greater the force being exerted to the radial head, the more likely the capitellum to be damaged.

The radial head functions as an important stabilizer to valgus stress, axial stress, and postero- lateral rotational forces (12, 15). Good long-term outcome (i.e. range of motion, no clinical symptoms) has been reported for non-operative treatment of 2-5 mm displaced Mason type 2 radial head fractures (16). However, the amount of displacement is not correlated to the instability of the radial head (17). Therefore, there appear to be no amount of displacement that can predict if operative treatment leads to better outcomes in Mason type 2 radial head fractures (16).

Displaced radial head fractures caused by high-energy trauma have a high prevalence of associated fractures or ligamentous injuries (17-21). The number of associated injuries is strongly correlated with the severity of the radial head fracture (17, 19). Unstable fractures can lead to loss of radiocapitellar contact and chronic elbow instability (18). Treatment of radial head fracture can be complicated if a concomitant capitellum fracture occurs. The capitellum is at risk for impinging on the radial head, and a missed capitellum fracture can lead to avascular necrosis, elbow instability, elbow stiffness, degenerative changes, chronic pain, malunion, and nonunion (7-10, 22). Therefore, operative restoration of the radiocapitellar surface and the lateral column buttress is essential to optimize outcomes (6, 18, 21, 23, 24). [Table 2]

Diagnostic challenges include the small size of the fracture fragments as well as overlapping of the radial head and capitellum fracture in plain radiographs. To avoid a missed diagnosis and proper planning prior to surgery, computed tomography (CT) scanning should be performed in both fractures of radial head and capitellum fractures to assess the radiocapitellar joint. This also continues to the intraoperative evaluation of the capitellum in order to assess the concomitant cartilage or osteochondral lesions.

In our retrospective study of 11 patients with kissing lesions, 10 radial head fractures were classified as type II of Hotchkiss Modification of the Mason Classification, and 1 was classified

Table 2. Studies presenting the kissing lesion

Author	Year	Number of Patients	Mean age (Y)	Follow-up (month)	Treatment of Capitellum	Treatment of Radial head	Pain free	Flexion	Extension	Pronation	Supination
Ward W	1988	7	31	29.4	3 ORIF, 4 Excision	2 ORIF, 4 head excision, 1 Conseravtive	6	137	(-15)	87	84
Nalbantoglu U	2008	10	33	No Follow-up	2 ORIF, 8 Excision	10 ORIF	.	.	.	.	.
Caputo A	2006	10	33	11	10 Excision	10 ORIF	10	142	(-5)	78	80
Our study	2016	10	35	9	9 ORIF, 1 excision	8 ORIF, 2 excision	.	Arc 128		Full	Full

as type I. Based on the available radiographs, 3 of the capitellum fractures were type I, and 7 were type II according to the Grantham classification. The occurrence of a higher Mason type radial head fracture with a concomitant capitellum fracture is consistent with earlier studies (4-6).

Rineer showed that among Mason type 2 fractures, a complete loss of cortical contact of any fragment is strongly predictive of an associated elbow fracture, although complete loss of cortical contact of the radial head fragment was only found in 4 of 8 preoperative radiographs (19). A possible explanation could be the underestimation of the prevalence of complex injuries in the study of Rineer et al (19).

In one case in our study the anterior quadrant of the radial head was removed but the remainder of the radial head remained intact and the elbow was stable. Excision of radial head fragments should be avoided in unstable elbows (25) if the surface of the radial head fragments is greater than 25% because of the risk of painful clicking or symptomatic elbow instability (26-28). Moreover, higher stress at the ulnotrochlear articulation after radial head excision leads to secondary arthritis in the majority of the cases (26).

The strengths of this study are the large cohort compared to earlier studies and the availability of the follow-up period for 9 of the 11 patients. This study should be interpreted in light of several limitations. Because of the retrospective nature of this study, some data are missing or could be inaccurate. Previous studies used the Mason's classification for radial head fractures while we used the Hotchkiss Modification of the Mason Classification instead (4-6).

In conclusion, in our series 10 of 11 patients had a Hotchkiss type II radial head fracture. It appears that higher grades of radial head fracture are more likely to be associated with a concomitant capitellar fragment. Our data is consistent with other pre-existing data in this regard. The treating surgeon must therefore have a high index of suspicion for a concomitant capitellar injury when treating a type II or III fracture of the radial head.

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PART III

Partial Arthroplasty for Post-Traumatic Injuries

Chapter 6

The Rate of Radial Head Prosthesis Removal or Revision: A Systematic Review and Meta-Analysis.
Kachooei AR, Baradaran A, Ebrahimzadeh MH, van Dijk CN, Chen N.
J Hand Surg Am. 2018 Jan;43(1):39-53.e1.

ABSTRACT

BACKGROUND

We conducted a meta-analysis and systematic review with the primary objective to determine the overall incidence of radial head prosthesis removal or revision. Our secondary objectives addressed the incidence of removal or revision based on the type of prosthesis fixation (cemented, uncemented smooth stem, uncemented press-fit), material (metal, Vitallium, titanium, pyrocarbon), and design (short vs long stem and monopolar vs bipolar), and the reasons for prosthetic removal or revision.

METHODS

We included 30 studies with a total of 1,017 patients out of whom 77 prostheses were removed and 45 prostheses were revised.

RESULTS

The pooled rate of radial head prosthesis removal or revision was 10.0% (95% confidence interval, 7.3%-13.6%) with a mean follow-up of 38 months. Subgroup analysis showed that the incidence of removal/revision was lowest with the cemented fixation, longer-stem, Vitallium material, and bipolar prosthesis. More than half of the prostheses were removed/revised for excision of the heterotopic ossification (47%) and for the treatment of stiffness and limitation of motion (42%). Other reasons recorded were pain (19%), loosening (16%), overstuffing (13%), instability (12%), infection (8%), and prosthesis disassembly (4%).

CONCLUSION

The current data show that the highest incidence of removal/revision occurred within 2 years after implantation. There was no major difference in the incidence of removal/revision among different designs and materials. Implant removal was often performed as part of a procedure to manage elbow stiffness and heterotopic ossification at the surgeon's preference, not necessarily because the implant was malfunctioning. It appears that most radial head arthroplasties have an acceptable and comparable mid-term longevity; however, it is unclear whether long-term longevity will differ between devices.

INTRODUCTION

A radial head arthroplasty is recommended if a radial head fracture occurs in conjunction with elbow or forearm instability, and the radial head fracture is not repairable (1). Radial head arthroplasties may be either monopolar or bipolar, and may have fixed stems or smooth stems (2). The overall survival of radial head arthroplasty, regardless of the individual characteristics, is unknown. In addition, it is not clear if arthroplasty removal or revision is related to arthroplasty design, injury pattern, or time from initial injury (3).

We conducted a meta-analysis and systematic review with the primary objective to determine the overall incidence of radial head prosthesis removal or revision. Our secondary objectives addressed the incidence of removal or revision based on the type of prosthesis fixation (cemented, uncemented smooth stem, uncemented pressfit), material (metal, vitallium, titanium, pyrocarbon), and design (short vs. long stem, and monopolar vs. bipolar), and the reasons for prosthetic removal or revision.

METHODS

This systematic review and meta-analysis was based on Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (4). This study did not indicate the clinical outcomes after radial head prosthesis removal/revision rather we attempted to only answer the study questions.

We searched for all published clinical studies on the radial head prosthesis for acute treatment of fractures of the radial head in the following databases: MEDLINE, MEDLINE preprints, SCOPUS, EMBASE, and the Cochrane Central Register of Controlled Trials (CENTRAL). The literature search was performed on March 4th, 2015 using the search strings available in the appendix 1. We also hand searched the bibliographies referenced in the studies identified in the computer search.

Eligibility Criteria

Any study reporting clinical information on radial head prosthesis replacement for radial head fractures was considered potentially relevant and selected for primary review. There were no limitations for time period, language, and time to follow-up. The level of evidence was classified according to the definition given by the Oxford Centre for Evidence-based Medicine (5). All levels of evidence that was assigned by the authors were included. All prospective, randomized, controlled studies (Levels I and II) and all prospective or retrospective studies with or without control groups (Levels III and IV) were accepted to be included in our study if they reported the incidences of radial head prosthesis removal or revision. Because most of the included studies were case series, we used Newcastle-Ottawa Quality Assessment Scale to assess the methodologic quality of the papers. All participants had to be >18 years of age. We included studies reporting the number and proportion of radial head prosthesis removal/revision for any reason. We excluded studies reporting the results of silicone arthroplasty and also excluded 1 study reporting the results of a hand-made polymethylmethacrylate radial head in an attempt to minimize the heterogeneity of the pooled data and to better reflect the current thinking regarding implant design and material. We excluded case reports and papers reporting results after prosthesis removal or failure without documentation of the clinical results of arthroplasty.

Study Selection

In stage 1, we searched for all relevant articles electronically. A total of 323 clinical studies on the radial head prosthesis replacement for radial head fractures were identified. In stage 2, abstracts of all 323 studies were checked manually in a primary screening by two independent reviewers. Discrepancies in the review process were resolved by the senior authors. Sixty-seven articles met the preliminary inclusion criteria. In stage 3, the two reviewers evaluated the full texts to extract the data and manually find other relevant articles in the reference list of the included papers. When there were shared data in articles, only the latest article was included. We excluded 8 articles about the silicone radial head prosthesis, 1 article about the handmade polymethylmethacrylate radial head, 16 articles reporting late radial head implantation after failure of a prior prosthesis or ORIF, and 15 articles because of shared data or inadequate reporting. Further we found 3 more studies through hand searching of the relevant references. After further exclusion via reviewing the full texts, 30 articles fulfilled all inclusion and exclusion criteria. In stage 4, two reviewers checked the data independently in a standardized fashion. Any conflicts were mediated by senior author review. Furthermore, the eligible articles were reviewed for quality assessment using Newcastle-Ottawa Quality Assessment Scale, and included in the systematic review and the meta-analysis. We did not consider a minimum level of quality to not exclude any study. [Figure 1]

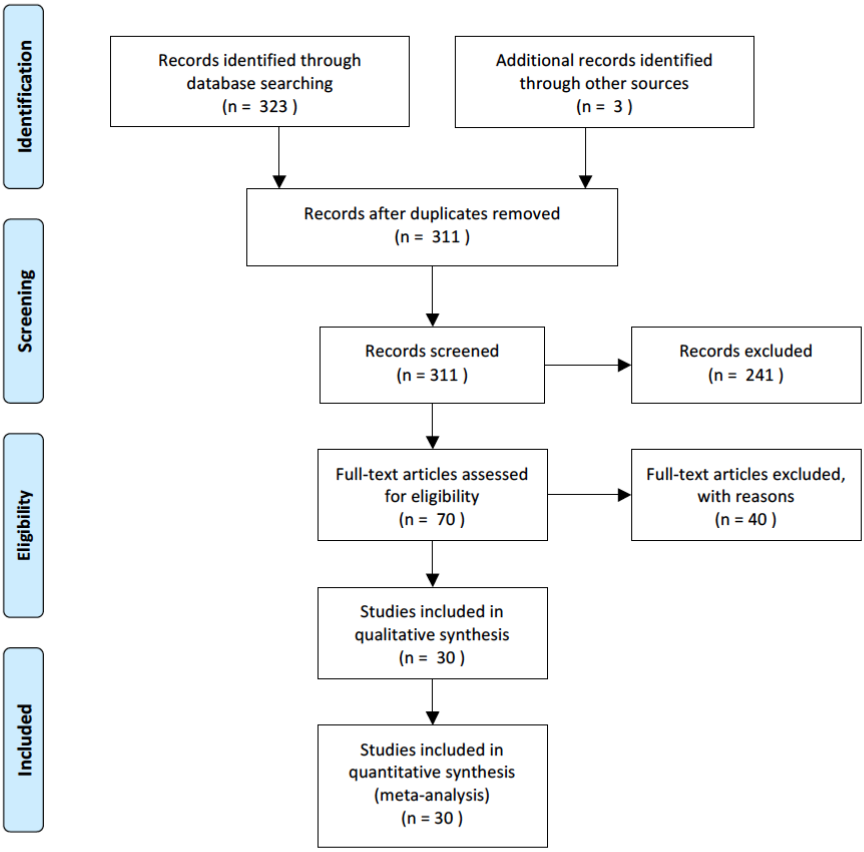


Figure 1. PRISMA flow diagram.

Outcome Measures

The primary outcome was the incidence of radial head prosthesis removal or revision after implantation for a fracture. Revision was defined as removing the old radial head prosthesis for any reason and replacing with a new one. The incidence of removal and revision were analyzed separately by creating a forest plot. Further, the incidence of removal or revision was analyzed after pooling the number of removals or revisions in each study.

Subgroup analysis was performed to determine if the prosthesis design had a relationship with removal or revision of radial head prostheses. These included the type of fixation (cemented vs. uncemented pressfit vs. smooth stem), stem length (short vs. long stem), head mobility (monobloc vs. bipolar), and the material (metal vs. titanium vs. vitallium vs. pyrocarbon). Subgroup assignment was based on the device description in the original paper.

Statistical analysis

This analysis took study effects into account, and a random-effects model was used for statistical analysis to calculate the risk ratio and 95% confidence interval. The null hypothesis (the true effect size is zero) was rejected if *P* value<0.05.

When doing a meta-analysis, we need to see if the effects found in the individual studies are similar enough that one can be confident that a combined estimate will be a meaningful description of the set of studies. The individual estimates of treatment effect can vary by chance. The question is whether there is more variation than would be expected by chance alone. This excessive variation is called heterogeneity. To address the proportion of sampling error versus the true effect, we assessed the heterogeneity using Q statistics, and the degree of freedom to compute the *P* value which addresses the null hypothesis that the dispersion of the effect size was because of the random sampling error. We rejected the null hypothesis if $P<0.05$ suggesting that the true effects varied. We also used the Q statistics to compute the I^2, which shows what proportion of dispersion in the effect sizes was because of true difference in the effect. If I^2 equals zero, this suggests that all dispersion in the effect sizes can be attributed to the random sampling error. I^2 describes the percentage of total variation across studies that are due to heterogeneity rather than chance. Negative values of I^2 are put equal to zero so that I^2 lies between 0% and 100%. A value of 0% indicates no observed heterogeneity, and larger values show increasing heterogeneity. Following rule-of-thumb, we considered I^2 >40% as substantial heterogeneity.

Publication bias

We checked the publication bias by constructing a funnel plot to visually check for asymmetry.

Quality control

We used the Newcastle-Ottawa Quality Assessment Scale to score the quality of the included studies (6). This scale is a convenient tool that has been used in meta-analysis studies to score the quality of observational studies including case-control and cohort (7,8).

RESULTS

Study characteristics

We included 30 studies for data extraction. In total, the study cohort included 1,017 patients out of whom 77 prostheses were removed and 45 prostheses were revised at a mean follow-up of 38 months. The mean age of the patients was 32 years at the time of implantation. [Table 1]

Four studies reported the pooled results

Table 1. Extracted data from 30 included studies

Study No.	First Author	Year	Study Design	Number of Patients	Number of Removal	Number of Revision	Prosthesis	Head	Fixation	Material	Stem Length	Age (yrs.)	Follow up (mon.)
1	Ha AS	2012	Retrospective	258	24	38	Mixed					46	12.8
2	Flinkkilä T	2012	Retrospective	42	9	0	Avanta & Acumed	Monopolar	UP	Metal	Short	56	50
3	Katthagen JC	2013	Retrospective	31	1	0	Corin	Monopolar	UP	Metal	Long	60	25
4	Lim YJ	2008	Retrospective	7	0	0	Vitallium	Monopolar	C	Vitallium	Short	53.3	29.7
5	Sarris IK	2012	Retrospective	32	2	0	MoPyC	Monopolar	UP	Pyrocarbon	Long	54	27
6	Watters TS	2014	Retrospective	30	0	3	Evolve	Monopolar	UL	Metal	Short		
7	Birkedal JP	2004	Retrospective	22	4	0	Evolve	Monopolar	UL	Metal	Short		
8	Gabrion A	2005	Retrospective	10	1	0	Judet	Bipolar	C	Metal	Long	48.2	31.7
9	Grewal R	2006	RC	26	0	0	Evolve	Monopolar	UL	Metal	Short	54	24.5
10	Celli A	2010	Retrospective	16	0	0	Judet	Bipolar	C	Metal	Long	46.1	41.7
11	Chemama B	2009	Retrospective	4	1	0	Mixed					39.5	46
12	Contreras-Joya M	2015	Retrospective	82	11	0	Mixed					41.6	18
13	Egol KA	2007	Retrospective	15	1	1	Wright & Stryker	Monopolar	UL	Metal	Short		27
14	Forthman C	2007	Retrospective	25	2	0	Evolve	Monopolar	UL	Metal	Short	48	32
15	Holmenschlager F	2002	Retrospective	16	0	0	Judet	Bipolar	C	Metal	Long		19
16	Dotzis A	2006	Retrospective	14	0	0	Judet	Bipolar	C	Metal	Long	44.8	63.6
17	Issac RT	2015	Prospective	10	0	0	.	Monopolar	UP	Metal	Long	33.5	14
18	Moro JK	2001	Retrospective	25	0	0	S & N	Monopolar	UP	Titanium	Long	54	39
19	Winter M	2009	Retrospective	13	1	2	Mixed					40	25
20	Ring D	2008	Retrospective	27	2	0	Evolve	Monopolar	UL	Metal	Short		47
21	Zhao J	2007	Retrospective	10	0	0	.	Monopolar	C	Titanium	Long	38	23.7
22	Ricon FJ	2012	Retrospective	28	3	0	MoPyC	Monopolar	UP	Pyrocarbon	Long	54	32
23	Popovic N	2000	RC	11	0	0	Judet	Bipolar	C	Metal	Long	52.7	32
24	Muhm M	2011	RC	39	2	0	Evolve	Monopolar	UL	Metal	Short	59	44.4
25	Knight DJ	1993	RC	36	2	0	Vitallium	Monopolar	UL	Vitallium	Short	53	54
26	Doornberg J	2007	Retrospective	37	2	0	Evolve	Monopolar	UL	Metal	Short	52	40
27	Popovic N	2007	Retrospective	55	0	0	Judet	Bipolar	C	Metal	Long	51	100.8
28	Harrington IJ	2000	Retrospective	44	4	0	S & N	Monopolar	UP	Titanium	Long	46	145.2
29	Moghaddam A	2008	Retrospective	30	0	1	Evolve	Monopolar	UL	Metal	Short	49	29
30	Wretenberg P	2006	RC	22	5	0	Link	Monopolar	UP	Metal	Long	52	44.4

RC: Retrospective Cohort study, S & N: Smith and Nephew, UP: Uncemented Pressfit, UL: Uncemented Loose, C: cemented

of multiple prostheses designs (9-12), while 8 papers used exclusively the Evolve prosthesis (Wright Medical Technology, Arlington, Tennessee) (13-20), 6 papers used the Judet prosthesis (Tornier SAS, Saint-Ismier, France) (21-26), 1 paper used the Link prosthesis (Waldemar Link, GmbH & Co, Hamburg, Germany) (27), 2 papers used the Smith & Nephew prosthesis (Smith & Nephew, Inc., Memphis, TN) (28,29), 2 papers used a Vitallium prosthesis (Howmedica, Osteonics, London, UK) (30,31), 2 papers used Pyrocarbon (MoPyC) radial head prosthesis (Bioprofile Laboratory, Grenoble, France) (32,33), 1 paper used the Corin prosthesis (Corin Group PLC, Cirencester, UK) (34), 1 paper used Wright and Stryker prostheses (Stryker Corp., Allendale, New Jersey) (35), and 1 paper used Avanta rHeads (Avanta Orthopedics, San Diego, California) and Acumed Anatomical Radial Heads (Acumed, Hillsboro, Oregon) (36). Moreover, 2 papers did not mention the make of the prosthesis with one using an uncemented, pressfit monobloc prosthesis (37) and another using a cemented titanium monobloc prosthesis (38). Vitallium is an alloy comprised of cobalt, chromium, and molybdenum with resistance to corrosion. Of the 2 studies, one used the Vitallium prosthesis with cement (31) and one used uncemented loose fixation with a smooth stem (30). MoPyC radial head prosthesis is composed of a pyrocarbon head with mechanical characteristics close to that of bone while the stem and neck are made of titanium.

Test of heterogeneity

We performed statistical testing for heterogeneity to determine if the incidence of radial head prosthesis removal/revision was the same in all studies. Cochran Q result rejected the null hypothesis that there is no heterogeneity between studies (Q=55.5; degree of freedom=29; P=0.003). Moreover, I^2 revealed that almost half (46%) of the variation across the studies was because of heterogeneity rather than sampling error and chance. Considering the presence of heterogeneity, we used random-effects model to conduct the meta-analysis.

Quality Assessment

The mean Newcastle-Ottawa Scale score for 6 cohort studies was 5.8 out of 9. The mean score for 25 retrospective studies was 8.0 out of 9, with the higher scores showing better quality. **[Tables 2 and 3]**

Incidence of radial head prosthesis removal/revision

After pooling the number of removal and revision in each study, based on the random-effects model with inclusion of 30 studies, the incidence of radial head prosthesis removal or revision was 10.0 % (95%CI: 7.3%-13.6%) [Figure 2]. Because each study is given weight based on the sample size, the overall removal or revision would not be equal to the sum of the incidences of removal and revision.

Incidence of radial head prosthesis removal

Based on the random-effects model after inclusion of 30 studies, the incidence of radial head prosthesis removal was 9.8% (95%CI: 8.0%-12.1%) [Figure 3] Cochran Q statistics did not show heterogeneity between studies for the removal outcome with only 17% heterogeneity due to true difference in the effect (Q=36; P=0.21; I^2=16.8).

Incidence of radial head prosthesis revision

Based on the random-effects model after inclusion of 30 studies, the incidence of radial head prosthesis revision was 3.8% (95%CI: 2.3%-6.1%) [Figure 4]. Cochran Q statistics rejected

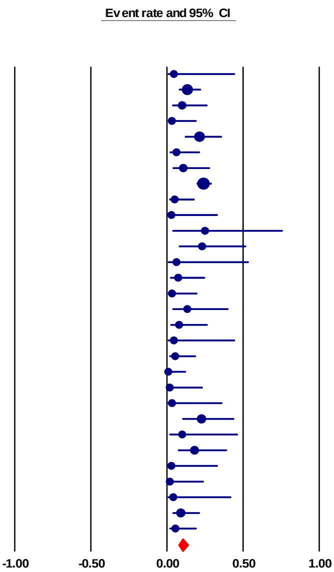
Table 2. Quality Assessment of the Studies Using Newcastle-Ottawa Scale for Cohort Studies

Study Number	First Author	Representativeness of the exposed cohort	Selection of the nonexposed cohort	Ascertainment of exposure	Outcome not present at start of study	Comparability	Assessment of outcome	Follow-up length	Follow-up adequacy	Total
9	Grewal R	*				*	*	*	*	5
17	Issac RT	*	*		*	*	*		*	6
23	Popovic N	*				*	*	*	*	5
24	Muhm M	*		*	*	*	*	*		6
25	Knight DJ	*		*		*	*	*	*	6
30	Wretenberg P	*		*	*	*	*	*	*	7

Table 3. Quality Assessment of the Studies Using Newcastle-Ottawa Scale for Case-Control Studies

Study Number	First Author	Case definition adequate	Representativeness of cases	Selection of controls	Definition of controls	Comparability	Ascertainment of exposure	Same ascertainment method	Nonresponse rate	Total
1	Ha AS	*	*	*	*	*	*	*	*	8
2	Flinkkilä T	*	*	*	*	*	*	*	*	7
3	Katthagen JC	*	*	*	*	**	*	*	*	9
4	Lim YJ	*	*	*	*	**	*	*	*	9
5	Sarris IK	*	*	*	*	**	*	*	*	9
6	Watters TS	*	*	*	*	*	*	*	*	8
7	Birkedal JP	*	*	*	*	*	*	*	*	8
8	Gabrion A	*	*	*	*	**	*	*	*	9
10	Celli A	*	*	*	*	*	*	*	*	8
11	Chemama B	*		*	*	*	*	*	*	7
12	Contreras-Joya M	*		*	*	*	*	*	*	7
13	Egol KA	*		*	*	*	*	*	*	7
14	Forthman C	*	*	*	*	**	*	*	*	9
15	Holmenschlager F	*	*	*	*	**		*	*	8
16	Dotzis A	*	*	*	*	**		*	*	8
18	Moro JK	*	*	*	*	**		*	*	8
19	Winter M	*	*	*	*		*	*	*	7
20	Ring D	*	*	*	*	**	*	*	*	9
21	Zhao J	*		*	*			*	*	5
22	Ricon FJ	*	*	*	*	**	*	*	*	9
26	Doornberg J	*	*	*	*	**	*	*	*	9
27	Popovic N	*		*	*	*		*	*	7
28	Harrington IJ	*	*	*	*	**	*	*	*	9
29	Moghaddam A	*	*	*	*	**	*	*	*	9

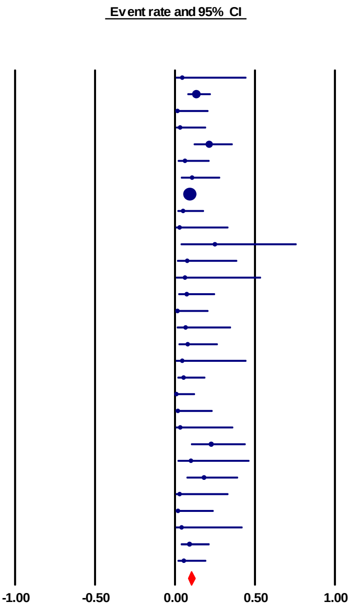
Study name	Subgroup within study	Event rate	Lower limit	Upper limit	Total
Issac RT 2015	Removal/Revision	0.045	0.003	0.448	0 / 10
Contreras M 2015	Removal/Revision	0.134	0.076	0.226	11 / 82
Watters TS 2014	Removal/Revision	0.100	0.033	0.268	3 / 30
Katthagen JC 2013	Removal/Revision	0.032	0.005	0.196	1 / 31
Flinkkila T 2012	Removal/Revision	0.214	0.115	0.363	9 / 42
Sarris IK 2012	Removal/Revision	0.063	0.016	0.218	2 / 32
Ricon FJ 2012	Removal/Revision	0.107	0.035	0.284	3 / 28
Ha AS 2012	Removal/Revision	0.240	0.192	0.296	62 / 258
Muhm M 2011	Removal/Revision	0.051	0.013	0.183	2 / 39
Celli A 2010	Removal/Revision	0.029	0.002	0.336	0 / 16
Chemama B 2009	Removal/Revision	0.250	0.034	0.762	1 / 4
Winter M 2009	Removal/Revision	0.231	0.076	0.522	3 / 13
Lim Y J2008	Removal/Revision	0.063	0.004	0.539	0 / 7
Ring D 2008	Removal/Revision	0.074	0.019	0.252	2 / 27
Moghaddam A 2008	Removal/Revision	0.033	0.005	0.202	1 / 30
Egol KA 2007	Removal/Revision	0.133	0.034	0.405	2 / 15
Forthman C 2007	Removal/Revision	0.080	0.020	0.269	2 / 25
Zhao J 2007	Removal/Revision	0.045	0.003	0.448	0 / 10
Doornberg J 2007	Removal/Revision	0.054	0.014	0.192	2 / 37
Popovic N 2007	Removal/Revision	0.009	0.001	0.127	0 / 55
Grewal R 2006	Removal/Revision	0.019	0.001	0.236	0 / 26
Dotzis A 2006	Removal/Revision	0.033	0.002	0.366	0 / 14
Wretenberg P 2006	Removal/Revision	0.227	0.098	0.444	5 / 22
Gabrion A 2005	Removal/Revision	0.100	0.014	0.467	1 / 10
Birkedal JP 2004	Removal/Revision	0.182	0.070	0.396	4 / 22
Holmenschlager F 2002	Removal/Revision	0.029	0.002	0.336	0 / 16
Moro JK 2001	Removal/Revision	0.019	0.001	0.244	0 / 25
Popovic N 2000	Removal/Revision	0.042	0.003	0.425	0 / 11
Harrington IJ 2000	Removal/Revision	0.091	0.035	0.218	4 / 44
Knight DJ 1993	Removal/Revision	0.056	0.014	0.197	2 / 36
		0.100	0.073	0.136	



Forest plot of the incidence of radial head prosthesis removal or revision using random effect model

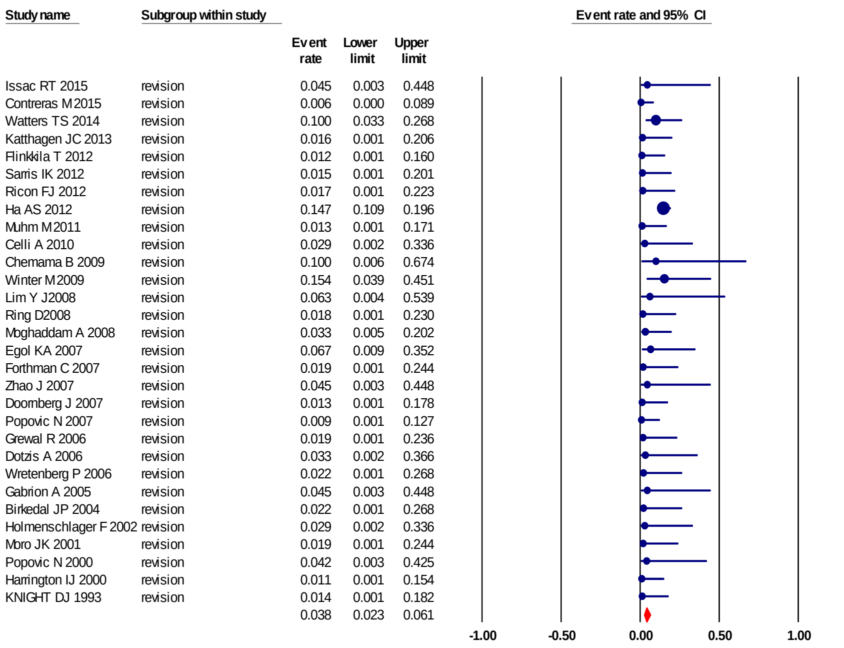
Figure 2. forest plot of radial head prosthesis removal and revision using random effect model.

Study name	Subgroup within study	Event rate	Lower limit	Upper limit
Issac RT 2015	removal	0.045	0.003	0.448
Contreras M 2015	removal	0.134	0.076	0.226
Watters TS 2014	removal	0.016	0.001	0.211
Katthagen JC 2013	removal	0.032	0.005	0.196
Flinkkila T 2012	removal	0.214	0.115	0.363
Sarris IK 2012	removal	0.063	0.016	0.218
Ricon FJ 2012	removal	0.107	0.035	0.284
Ha AS 2012	removal	0.093	0.063	0.135
Muhm M 2011	removal	0.051	0.013	0.183
Celli A 2010	removal	0.029	0.002	0.336
Chemama B 2009	removal	0.250	0.034	0.762
Winter M 2009	removal	0.077	0.011	0.391
Lim Y J2008	removal	0.063	0.004	0.539
Ring D 2008	removal	0.074	0.019	0.252
Moghaddam A 2008	removal	0.016	0.001	0.211
Egol KA 2007	removal	0.067	0.009	0.352
Forthman C 2007	removal	0.080	0.020	0.269
Zhao J 2007	removal	0.045	0.003	0.448
Doornberg J 2007	removal	0.054	0.014	0.192
Popovic N 2007	removal	0.009	0.001	0.127
Grewal R 2006	removal	0.019	0.001	0.236
Dotzis A 2006	removal	0.033	0.002	0.366
Wretenberg P 2006	removal	0.227	0.098	0.444
Gabrion A 2005	removal	0.100	0.014	0.467
Birkedal JP 2004	removal	0.182	0.070	0.396
Holmenschlager F 2002	removal	0.029	0.002	0.336
Moro JK 2001	removal	0.019	0.001	0.244
Popovic N 2000	removal	0.042	0.003	0.425
Harrington IJ 2000	removal	0.091	0.035	0.218
KNIGHT DJ 1993	removal	0.056	0.014	0.197
		0.098	0.080	0.121



Forest plot of the incidence of radial head prosthesis removal using random effect model

Figure 3. forest plot of radial head prosthesis removal using random effect model.



Forest plot of the incidence of radial head prosthesis revision using random effect model

Figure 4. forest plot of radial head prosthesis revision using random effect model.

the null hypothesis showing 36% heterogeneity between studies for the revision outcome (Q=46.6; *P*=0.027; I^2=35.6).

Prosthesis removal based on the type of fixation

Based on the random-effects model for 8 studies with cemented, 10 studies with uncemented smooth stem, and 8 studies with uncemented pressfit fixations, the incidence of radial head prosthesis removal/revision was 4.0% (95%CI: 1.6%-9.8%), 8.2% (95%CI: 5.4%-12.3%), and 11.3% (95%CI: 6.6%-18.6%), respectively [Figure 5].

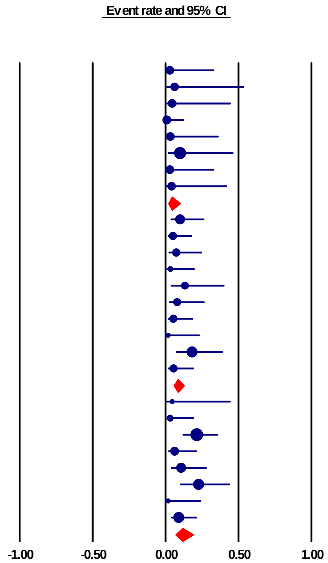
Prosthesis removal based on the stem length

Based on the random-effects model for 14 studies with long stem and 12 studies with short stem prostheses, the incidence of radial head prosthesis removal/revision was 8.3% (95%CI: 5.4%-12.5%) for the long stem prostheses and 9.9% (95%CI: 6.6%-14.5%) for the short stem prostheses [Figure 6].

Prosthesis removal based on the material

Based on the random-effects model for different materials including 19 studies of metal, 3 studies of titanium, 2 studies of pyrocarbon, and 2 studies of vitallium radial head prosthesis, the incidence of radial head prosthesis removal/revision was 9.1% (95%CI: 6.1%-13.2%) for metal prostheses, 7.2% (95%CI: 3.0%-16.3%) for titanium prostheses, 8.6% (95%CI: 3.6%-19.1%) for pyrocarbon prosthesis, 5.7% (95%CI: 1.7%-17.8%) for vitallium prosthesis [Figure 7].

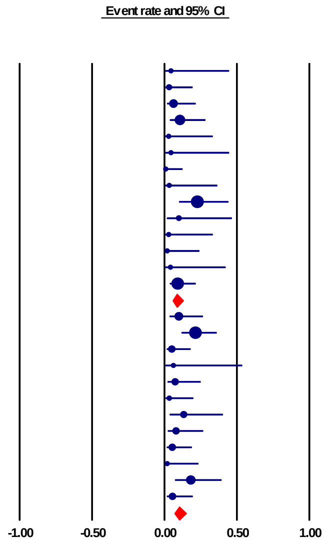
Group by Fixation	Study name	Subgroup within study	Event rate	Lower limit	Upper limit	Total
Cemented	Celli A 2010	Removal/Revision	0.029	0.002	0.336	0 / 16
Cemented	Lim Y J2008	Removal/Revision	0.063	0.004	0.539	0 / 7
Cemented	Zhao J 2007	Removal/Revision	0.045	0.003	0.448	0 / 10
Cemented	Popovic N 2007	Removal/Revision	0.009	0.001	0.127	0 / 55
Cemented	Dotzis A 2006	Removal/Revision	0.033	0.002	0.366	0 / 14
Cemented	Gabrion A 2005	Removal/Revision	0.100	0.014	0.467	1 / 10
Cemented	Holmenschlager F 2002	Removal/Revision	0.029	0.002	0.336	0 / 16
Cemented	Popovic N 2000	Removal/Revision	0.042	0.003	0.425	0 / 11
Cemented			0.040	0.016	0.098	
Uncemented loose	Watters TS 2014	Removal/Revision	0.100	0.033	0.268	3 / 30
Uncemented loose	Muhm M2011	Removal/Revision	0.051	0.013	0.183	2 / 39
Uncemented loose	Ring D 2008	Removal/Revision	0.074	0.019	0.252	2 / 27
Uncemented loose	Moghaddam A 2008	Removal/Revision	0.033	0.005	0.202	1 / 30
Uncemented loose	Egol KA 2007	Removal/Revision	0.133	0.034	0.405	2 / 15
Uncemented loose	Forthman C 2007	Removal/Revision	0.080	0.020	0.269	2 / 25
Uncemented loose	Doornberg J 2007	Removal/Revision	0.054	0.014	0.192	2 / 37
Uncemented loose	Grewal R 2006	Removal/Revision	0.019	0.001	0.236	0 / 26
Uncemented loose	Birkedal JP 2004	Removal/Revision	0.182	0.070	0.396	4 / 22
Uncemented loose	Knight DJ 1993	Removal/Revision	0.056	0.014	0.197	2 / 36
Uncemented loose			0.082	0.054	0.123	
Uncemented pressfit	Issac RT 2015	Removal/Revision	0.045	0.003	0.448	0 / 10
Uncemented pressfit	Katthagen JC 2013	Removal/Revision	0.032	0.005	0.196	1 / 31
Uncemented pressfit	Flinkkila T 2012	Removal/Revision	0.214	0.115	0.363	9 / 42
Uncemented pressfit	Sarris IK 2012	Removal/Revision	0.063	0.016	0.218	2 / 32
Uncemented pressfit	Ricon FJ 2012	Removal/Revision	0.107	0.035	0.284	3 / 28
Uncemented pressfit	Wretenberg P 2006	Removal/Revision	0.227	0.098	0.444	5 / 22
Uncemented pressfit	Moro JK 2001	Removal/Revision	0.019	0.001	0.244	0 / 25
Uncemented pressfit	Harrington IJ 2000	Removal/Revision	0.091	0.035	0.218	4 / 44
Uncemented pressfit			0.113	0.066	0.186	



Forest plot of the incidence of radial head prosthesis removal/revision based on the type of fixation using random effect model

Figure 5. forest plot of radial head prosthesis removal/revision rate based on the type of fixation using random effect model.

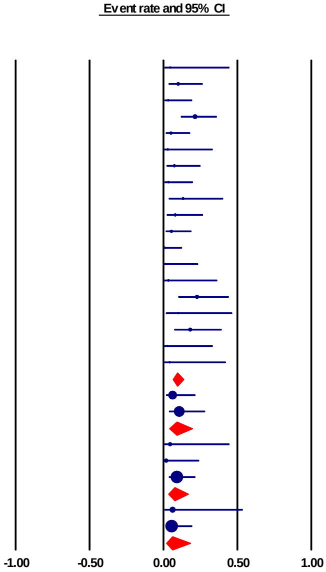
Group by Stem	Study name	Subgroup within study	Event rate	Lower limit	Upper limit	Total
Long	Issac RT 2015	Removal/Revision	0.045	0.003	0.448	0 / 10
Long	Katthagen JC 2013	Removal/Revision	0.032	0.005	0.196	1 / 31
Long	Sarris IK 2012	Removal/Revision	0.063	0.016	0.218	2 / 32
Long	Ricon FJ 2012	Removal/Revision	0.107	0.035	0.284	3 / 28
Long	Celli A 2010	Removal/Revision	0.029	0.002	0.336	0 / 16
Long	Zhao J 2007	Removal/Revision	0.045	0.003	0.448	0 / 10
Long	Popovic N 2007	Removal/Revision	0.009	0.001	0.127	0 / 55
Long	Dotzis A 2006	Removal/Revision	0.033	0.002	0.366	0 / 14
Long	Wretenberg P 2006	Removal/Revision	0.227	0.098	0.444	5 / 22
Long	Gabrion A 2005	Removal/Revision	0.100	0.014	0.467	1 / 10
Long	Holmenschlager F 2002	Removal/Revision	0.029	0.002	0.336	0 / 16
Long	Moro JK 2001	Removal/Revision	0.019	0.001	0.244	0 / 25
Long	Popovic N 2000	Removal/Revision	0.042	0.003	0.425	0 / 11
Long	Harrington IJ 2000	Removal/Revision	0.091	0.035	0.218	4 / 44
Long			0.083	0.054	0.125	
Short	Watters TS 2014	Removal/Revision	0.100	0.033	0.268	3 / 30
Short	Flinkkila T 2012	Removal/Revision	0.214	0.115	0.363	9 / 42
Short	Muhm M2011	Removal/Revision	0.051	0.013	0.183	2 / 39
Short	Lim Y J2008	Removal/Revision	0.063	0.004	0.539	0 / 7
Short	Ring D 2008	Removal/Revision	0.074	0.019	0.252	2 / 27
Short	Moghaddam A 2008	Removal/Revision	0.033	0.005	0.202	1 / 30
Short	Egol KA 2007	Removal/Revision	0.133	0.034	0.405	2 / 15
Short	Forthman C 2007	Removal/Revision	0.080	0.020	0.269	2 / 25
Short	Doornberg J 2007	Removal/Revision	0.054	0.014	0.192	2 / 37
Short	Grewal R 2006	Removal/Revision	0.019	0.001	0.236	0 / 26
Short	Birkedal JP 2004	Removal/Revision	0.182	0.070	0.396	4 / 22
Short	Knight DJ 1993	Removal/Revision	0.056	0.014	0.197	2 / 36
Short			0.099	0.066	0.145	



Forest plot of the incidence of radial head prosthesis removal/revision based on the stem length using random effect model

Figure 6. forest plot of radial head prosthesis removal/revision rate based on the stem length using random effect model.

Group by Material	Study name	Subgroup within study	Event rate	Lower limit	Upper limit	Total
Metal	Issac RT 2015	Removal/Revision	0.045	0.003	0.448	0 / 10
Metal	Watters TS 2014	Removal/Revision	0.100	0.033	0.268	3 / 30
Metal	Katthagen JC 2013	Removal/Revision	0.032	0.005	0.196	1 / 31
Metal	Flinkkila T 2012	Removal/Revision	0.214	0.115	0.363	9 / 42
Metal	Muhm M 2011	Removal/Revision	0.051	0.013	0.183	2 / 39
Metal	Celli A 2010	Removal/Revision	0.029	0.002	0.336	0 / 16
Metal	Ring D 2008	Removal/Revision	0.074	0.019	0.252	2 / 27
Metal	Moghaddam A 2008	Removal/Revision	0.033	0.005	0.202	1 / 30
Metal	Egol KA 2007	Removal/Revision	0.133	0.034	0.405	2 / 15
Metal	Forthman C 2007	Removal/Revision	0.080	0.020	0.269	2 / 25
Metal	Doornberg J 2007	Removal/Revision	0.054	0.014	0.192	2 / 37
Metal	Popovic N 2007	Removal/Revision	0.009	0.001	0.127	0 / 55
Metal	Grewal R 2006	Removal/Revision	0.019	0.001	0.236	0 / 26
Metal	Dotzis A 2006	Removal/Revision	0.033	0.002	0.366	0 / 14
Metal	Wretenberg P 2006	Removal/Revision	0.227	0.098	0.444	5 / 22
Metal	Gabrion A 2005	Removal/Revision	0.100	0.014	0.467	1 / 10
Metal	Birkedal JP 2004	Removal/Revision	0.182	0.070	0.396	4 / 22
Metal	Holmenschlager F 2002	Removal/Revision	0.029	0.002	0.336	0 / 16
Metal	Popovic N 2000	Removal/Revision	0.042	0.003	0.425	0 / 11
Metal			0.091	0.061	0.132	
Pyrocarbon	Sarris IK 2012	Removal/Revision	0.063	0.016	0.218	2 / 32
Pyrocarbon	Ricon FJ 2012	Removal/Revision	0.107	0.035	0.284	3 / 28
Pyrocarbon			0.086	0.036	0.191	
Titanium	Zhao J 2007	Removal/Revision	0.045	0.003	0.448	0 / 10
Titanium	Moro JK 2001	Removal/Revision	0.019	0.001	0.244	0 / 25
Titanium	Harrington IJ 2000	Removal/Revision	0.091	0.035	0.218	4 / 44
Titanium			0.072	0.030	0.163	
Vitallium	Lim Y J2008	Removal/Revision	0.063	0.004	0.539	0 / 7
Vitallium	Knight DJ 1993	Removal/Revision	0.056	0.014	0.197	2 / 36
Vitallium			0.057	0.017	0.178	



Forest plot of the incidence of radial head prosthesis removal or revision based on the material using random effect model

Figure 7. forest plot of radial head prosthesis removal/revision rate based on the material using random effect model.

Prosthesis removal based on the prosthesis head mobility

Based on the random-effects model for 20 studies with monopolar head and 6 studies with bipolar head, the incidence of radial head removal/revision was 10.0% (95%CI: 7.3%-13.4%) for monopolar and 3.7% (95%CI: 1.3%-10.1%) for bipolar radial head prostheses [Figure 8].

The reason of prosthesis removal or revision

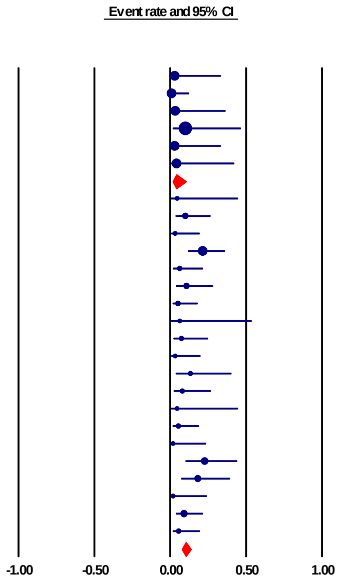
The reasons of radial head prosthesis removal or revision were mentioned as either subjective (e.g. pain) or objective (e.g. loosening). Based on the recorded reasons, prostheses were removed or revised for the treatment of heterotopic ossification in 36 cases (47%), for the treatment of stiffness and limitation of motion in 32 cases (42%), overstuffing in 10 cases (13%), loosening in 12 cases (16%), prosthesis disassembly in 3 cases (4%), infection in 6 cases (7.8%), instability in 9 cases (12%), and pain in 15 cases (19%) [Table 4].

Reasons for revision were overstuffing and persistent subluxation or dislocation immediately after implantation. [39]. The leading reason of RHP removal was to excise the heterotopic ossification and to release the elbow stiffness both of which account for more than 50% of the removal/revisions [Table 4].

Publication bias

We constructed a funnel plot to assess the publication bias. In the absence of publication bias, we would expect the studies to be symmetrically about the combined effect size. The observed asymmetry in our funnel plot suggests the likelihood of some publication bias [Figure 9]. This is mostly true when

Group by Head	Study name	Subgroup within study	Event rate	Lower limit	Upper limit	Total
Bipolar	Celli A 2010	Removal/Revision	0.029	0.002	0.336	0 / 16
Bipolar	Popovic N 2007	Removal/Revision	0.009	0.001	0.127	0 / 55
Bipolar	Dotzis A 2006	Removal/Revision	0.033	0.002	0.366	0 / 14
Bipolar	Gabrion A 2005	Removal/Revision	0.100	0.014	0.467	1 / 10
Bipolar	Holmenschlager F 2002	Removal/Revision	0.029	0.002	0.336	0 / 16
Bipolar	Popovic N 2000	Removal/Revision	0.042	0.003	0.425	0 / 11
Bipolar			0.037	0.013	0.101	
Monobloc	Issac RT 2015	Removal/Revision	0.045	0.003	0.448	0 / 10
Monobloc	Watters TS 2014	Removal/Revision	0.100	0.033	0.268	3 / 30
Monobloc	Katthagen JC 2013	Removal/Revision	0.032	0.005	0.196	1 / 31
Monobloc	Flinkkila T 2012	Removal/Revision	0.214	0.115	0.363	9 / 42
Monobloc	Sarris IK 2012	Removal/Revision	0.063	0.016	0.218	2 / 32
Monobloc	Ricon FJ 2012	Removal/Revision	0.107	0.035	0.284	3 / 28
Monobloc	Muhm M 2011	Removal/Revision	0.051	0.013	0.183	2 / 39
Monobloc	Lim Y J 2008	Removal/Revision	0.063	0.004	0.539	0 / 7
Monobloc	Ring D 2008	Removal/Revision	0.074	0.019	0.252	2 / 27
Monobloc	Moghaddam A 2008	Removal/Revision	0.033	0.005	0.202	1 / 30
Monobloc	Egol KA 2007	Removal/Revision	0.133	0.034	0.405	2 / 15
Monobloc	Forthman C 2007	Removal/Revision	0.080	0.020	0.269	2 / 25
Monobloc	Zhao J 2007	Removal/Revision	0.045	0.003	0.448	0 / 10
Monobloc	Doornberg J 2007	Removal/Revision	0.054	0.014	0.192	2 / 37
Monobloc	Grewal R 2006	Removal/Revision	0.019	0.001	0.236	0 / 26
Monobloc	Wretenberg P 2006	Removal/Revision	0.227	0.098	0.444	5 / 22
Monobloc	Birkedal JP 2004	Removal/Revision	0.182	0.070	0.396	4 / 22
Monobloc	Moro JK 2001	Removal/Revision	0.019	0.001	0.244	0 / 25
Monobloc	Harrington IJ 2000	Removal/Revision	0.091	0.035	0.218	4 / 44
Monobloc	Knight DJ 1993	Removal/Revision	0.056	0.014	0.197	2 / 36
Monobloc			0.100	0.073	0.134	



Forest plot of the incidence of radial head prosthesis removal/revision based on head mobility using random effect model

Figure 8. forest plot of radial head prosthesis removal/revision rate based on the head mobility using random effect model.

Table 4. The subjective and objective reasons of radial head prosthesis removal or revision

Study Number	First Author	Year	Reason for Removal or Revision	Time from Surgery to Removal
1	Ha AS	2012	Heterotopic ossification (33 out of 62 removal or revision); stiffness, decreased range of motion, or pain from thickened synovium or joint capsule (27/62); and infection (2/62).	
2	Flinkkilä T	2012	9 removed for loosening	
3	Katthagen JC	2013	1 removed for overstuffing and elbow stiffness.	
5	Sarris IK	2012	2 removed for stem–neck dissociation	5 weeks
6	Watters TS	2014	3 revisions for overstuffing	
7	Birkedal JP	2004	4 removed for reduced motion and pain	
8	Gabrion A	2005	1 removed for instability	
11	Chemama B	2009	1 removed for severe pain on the lateral column	6 months
12	Contreras-Joya M	2015	5 removed for pain in pronosupination, 4 removed for capitellar injuries, 1 removed for dislocation, and 1 removed for infection	
13	Egol KA	2007	1 removed for loosening, 1 revised	36 months
14	Forthman C	2007	2 removed for recurrent instability	
19	Winter M	2009	1 revision for overstufiing, 1 revision for radial head disassembling, 1 removed for late infection in the patient that had a prior revision for prosthesis disassembly	
20	Ring D	2008	1 removed for elbow contracture release, 1 removed for infection	
22	Ricon FJ	2012	3 removed for radiohumeral subluxation	
24	Muhm M	2011	1 removed for pain, 1 removed for ROM limitation and radioulnar synostosis	3 and 11 months
25	Knight DJ	1993	1 removed for loosening, 1 removed for loosening and radioulnar synostosis	
26	Doornberg J	2007	1 removed for heterotopic ossification, 1 removed for infection	Both before 1 year
28	Harrington IJ	2000	4 removed for pain	
29	Moghaddam A	2008	1 revision for subluxation	
30	Wretenberg P	2006	5 removed for limited ROM (overstuffuing)	Mean 2.1 (0.5-4) yrs

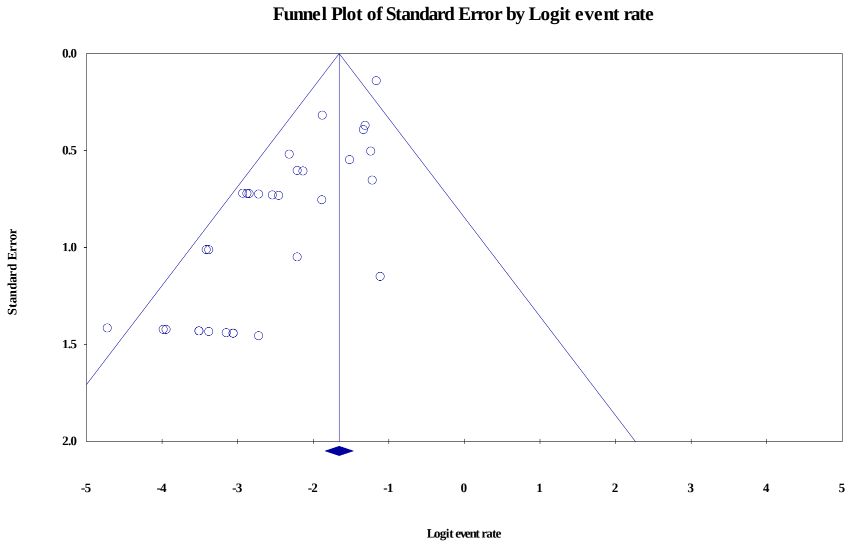


Figure 9. funnel plot of standard error by event rate.

analysis includes clinical trials to find bias in publishing null results. However, in the context of our research, this means that including better-powered studies might have lead to low-bias meta-analysis. In fact, the publication bias section and the idea of having a funnel plot is a technique to highlight any statistically probable error in the review, aiming to elevate the validity of the whole conclusion drawn.

DISCUSSION

In this systematic review, we studied the overall incidence of radial head prosthesis (RHP) removal or revision and the incidence of removal/revision based on the characteristics of individual prostheses to determine if the type of fixation, material, stem length, and head mobility had any effect on the incidence of removal/revision. The overall incidence of removal and revision was 10%. Overlapping confidence intervals implied that there was no major difference in the incidence of removal/revision among different designs.

These results should be interpreted in the light of the limitations of the study. Most of the studies were small case series and retrospective with short to mid-term follow-up. The fracture or fracture-dislocation patterns were heterogeneous. We were unable to find any trial comparing the outcomes of different prostheses. Some studies reported the pooled results of multiple types of prostheses with no explicit distinction between prosthetic designs. Furthermore, reasons of removal are subjective. However, the strength and the value of this study is the large number of studies, the large number of medical centers and surgeons, and the variety of prosthesis designs included.

Although follow-up ranged from 12.8 to 145 months, most removals or revisions occurred within the first year after implantation (18,19,27,40,41). The chance of removal/revision over time might be higher, but we were unable to capture this data from these small series with short to mid-term follow-up. We were unable to test the correlation between the reason and the time of removal/revision because only 7 papers had reported the mean time from surgery to removal/revision. The majority of early removals seem to be related to heterotopic ossification, infection, joint stiffness, and persistent subluxation while late removals – although less common – were mostly related to osteolysis, loosening, and capitellar cartilage wear (2,36,42). Implant removal was often performed as part of a procedure to manage elbow stiffness and heterotopic ossification at the surgeon's preference not necessarily because the implant was malfunctioning. The reason that the long stem and cemented implants may have had a lower revision and removal rate may relate to the difficulties with removing this implant design.

Some studies demonstrated that asymptomatic radiolucencies around the stem are common (19,28,30); however, it is unclear whether these radiolucencies remain stable over time or progress, or if progression of radiolucencies is related to prosthetic design. In addition, management of progressive lucencies varies among authors (36,42). van Riet et al reported loosening as the leading reason of removal in 29 out of 45 patients who underwent removal or revision surgery 42. In contrast, Popovic et al reported no revision or removal after a cemented fixed-stem despite radiographic findings of periprosthetic lucencies in 27 patients (25). There is some evidence that radiolucenies around a loose fitting monopolar stem remain stable after 2 years 17. The answer to whether these prostheses need to be removed is unclear and studies showed that the decision to remove a radial head prosthesis was dependent on the surgeon's discretion (3).

There were no differences in the incidence of prosthesis removal among various designs. Removal/ revision of pressfit arthroplasty was performed for osteolysis, subcapital bone resorption, and radiographic lucency around the stem (36). Removal/ revision of bipolar arthroplasty was primarily due to component dissociation (39,43,44). In most revision cases, the arthroplasty was revised to a long stem, cemented bipolar arthroplasty. The conclusion that the implant with lowest removal/revision incidence is a cemented, long-stem, Vitallium, and bipolar prosthesis might reflect the fact that it was harder to remove, which indirectly reflects surgeon's reluctance to try. Also the decision to remove/revise a device might depend more on the surgeon's preference rather than a problem with the prosthesis (3).

The current data shows that the highest rate of removal/revision occurred within two year after implantation. Moreover, there seems to be differences in the reasons of removal/revision between different designs. It appears that most radial head arthroplasties have an acceptable mid-term longevity; however, it is unclear whether long-term longevity will differ between devices.

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Chapter 7

Factors associated with removal of a radial head prosthesis placed for acute trauma.
Kachooei AR, Claessen FM, Chase SM, Verheij KK, van Dijk CN, Ring D.
Injury. 2016 Jun;47(6):1253-7.

ABSTRACT

BACKGROUND

This study tests the hypothesis that there are no factors associated with removal or revision of a radial head prosthesis. A secondary analysis addressed the time to removal or revision.

METHODS

We reviewed the database of two large hospitals from 2000 to 2014 and identified 278 patients that had radial head replacement after an acute fracture or fracture dislocation of the elbow: 19 had removal and 3 had revision of the radial head implant within the study period. Explanatory variables including demographics, the type of injury, prosthesis type, surgeon, medical centre, and associated injuries were evaluated. Survival analysis using Kaplan-Meier curves evaluated time to removal/revision.

RESULTS

After adjustment for potential confounders using Cox regression multivariable analysis, hospital was the only factor independently associated with removal or revision (Hazard ratio=2.4, Confidence interval: 1.03-5.8, P value=0.043). The highest proportion of removal/revision was during the first year after implantation and decreased by half each year over the second to fourth years. The most common reason for removal of the prosthesis was to facilitate removal of heterotopic ossification (the majority with proximal radioulnar synostosis) rather than technical error or problems with the prostheses.

CONCLUSION

These findings suggest that the decision to remove a radial head prosthesis may depend more on surgeon or hospital preferences than on objective problems with the prosthesis. Until clarified by additional study, removal of a prosthesis should not be considered an objective outcome in research. In addition, patients offered removal of a radial head prosthesis, might get the opinion of more than one surgeon at more than one hospital before deciding whether or not to proceed.

Introduction

Restoration of radiocapitellar contact helps prevent subluxation or dislocation after a fracture-dislocation of the elbow or forearm (1-3). When fixation of a fracture of the radial head is tenuous, there are missing or irreparable fragments, or the potential for nonunion or malunion is high (more than 3 fragments), radiocapitellar contact can be restored by removing the radial head and replacing it with a prosthesis (4-9). Prosthetic replacement of the radial head may have more in common with silicone rubber replacement of the metacarpophalangeal joints of the hand than with prosthetic replacement of the knee, hip or shoulder (10). A radial head prosthesis is used to help stabilize the elbow while the collateral ligaments heal (2, 11). Once the ligaments are healed it is safe to remove the prosthesis as subluxation or dislocation of the elbow would be very unusual (2). The elbow does well in the long-term after excision of the radial head without prosthetic replacement for a displaced fracture or fracture-dislocation (12).

Intentionally loose prostheses have good results more than 10 years after implantation and it is not clear that radiographic signs of loosening or changes on the capitellum correlate with discomfort (8, 13-15). It is not clear that having a metal radial head prosthesis in place is of any benefit to the elbow once the ligaments are healed. In fact, it is possible that the prosthesis can do more harm than good over the long term. A prosthesis that is too large can cause wear of the capitellum and subluxation of the ulnohumeral joint (8, 9, 16). Bipolar prostheses lead to osteolysis due to wear debris (1, 9, 17). Press fit prostheses are associated with gradual loss of bone at the neck and can unintentionally loosen—but it is not clear if either of these issues causes symptoms (18).

Because there are many types of prostheses and differences in opinion about the role a prosthesis might play over the long term, removal of a prosthesis might be highly variable. We have a sense that the decision to remove a prosthesis may be surgeon-specific and unrelated to patient, injury, or technical factors. In any case, patients and surgeons would benefit from an awareness of factors associated with removal of a radial head prosthesis. Considering the pre and peri-operative factors, this study tests the hypothesis that there are no factors associated with removal/revision of radial head prostheses. Secondary analysis addressed the survival of the radial head prosthesis, the time to removal/revision, and the reasons for removal/revision of the radial head prosthesis.

Methods

Study population

In this institutional review board approved study, we used the institutional databases from 2 level I trauma centers from May 2000 to December 2013 to retrospectively identify patients that had radial head replacement for fracture of the radial head or neck using CPT procedure codes. Indications for radial head replacement were Mason type 2 or 3 radial head fractures with or without elbow dislocation. Six patients with radial head replacement done for malunion or nonunion were excluded leaving 278 patients having radial head replacement within 3 months of an acute injury. Of 278 included patients, 19 had removal and 3 had revision of the radial head implant within the study period.

The surgery for the radial head replacement was set as the start time. The date of reoperation for radial head removal/revision, the date of last follow-up visit, and the time elapsed from the first surgery to removal was recorded.

Explanatory variables used in the analysis included age, sex, race, side, surgeon that put the prosthesis in, medical center, prosthesis type, type of injury, associated injuries, presence of dislocation, and implant type (loose smooth spacer vs. other). Surgeons that put the prosthesis in and took the prosthesis out were categorized in 2 groups including hand surgeons and trauma surgeons. Prostheses were categorized as either loose smooth spacer prostheses (Evolve, Wright Medical technology Inc., Arlington, TN, USA) accounting for 234 prostheses or other types of prosthesis (press fit monoblock and cemented bipolar) accounting for 44 of 278 prostheses. The surgeon's rationale for removing the prosthesis and the other explanatory variables were recorded from the medical record.

Statistical analysis

We conducted a survival analysis starting at the time of first surgery for radial head replacement with removal/ revision as an endpoint. Survival analysis was performed using the Kaplan-Meier method. We used point censoring using the date of the last follow-up visit.

Categorical data were presented as absolute values and percentages. Continuous data were reported as means ± standard deviation after testing the normality. Using log-rank test, we analyzed the effect of potential explanatory variables on the survival of the radial head prosthesis. Variables with $P<0.10$ were inserted into a Cox multivariable regression analysis to yield the hazard ratio of independent variables on the radial head prosthesis removal/revision.

Results

Twenty-two out of 278 (8%) patients with the mean age of 49±13 (range, 23 to 64 years) had removal or revision of the radial head implant at one of our hospitals during the study period. [Table 1]

In bivariate analysis the only pre and peri-operative factors associated with removal/revision were the hospital and the injured arm (right more common than left). [Table 2]

After adjustment for the explanatory variables in multivariable analysis, only the hospital was independently associated with removal/revision of the radial head prosthesis (Hazard ratio=2.4, Confidence interval: 1.03-5.8, *P* value=0.043). [Table 3]

The proportional hazard assumption was not met for 'hospital' showing that the hazard ratio increased over time at 'hospital-2' ($P=0.047$).

The highest proportion of removal was during the first year after implantation (11 patients, 50%) and decreased each year by half over the following second to fourth years. [Figure 1]

Postoperative factors associated with removal/revision included infection, instability, and continued pain at the elbow with pronation/supination. The most common reason for removal of the prosthesis was to facilitate removal of heterotopic ossification (the majority with proximal radioulnar synostosis) [Table 4]

suggesting that the act of prosthesis removal had little to do with problems with the implant, but rather the physician and the patient decided to remove the prosthesis to provide better access to heterotopic bone (while other surgeons did not feel they needed to remove the prosthesis for similar surgeries). Demographic and injury features were not related to removal/revision of the radial head prosthesis.

Hand surgeons and trauma surgeons were equally likely to implant a prosthesis but most removals/revisions were performed by hand surgeons (21 of 22). [Table 5]

Table 1. Characteristics of the patients underwent removal or revision of the radial head prosthesis

Patient	Age	Sex	Race	Side of injury	Type of injury	Associated injuries	Implanting surgeon	Removing surgeon	Prosthesis type	Subjective reason of removal	Objective reason of removal	Secondary surgery	Months to removal or revision
1	58	Female	White	Right	Monteggia	Coronoid fx, ulna shaft fx, LCL rupture	Hand Surgeon	Hand Surgeon	Wright	Limited ROM	HO	Removed	1
2	60	Female	White	Left	Olecranon Fx-Dx		Hand Surgeon	Hand Surgeon	Wright	Pain	Instability of the PRUJ/ radiocapitellar articulations	Removed	1
3	36	Male	Other	Left	Radial head Fx w/o Dx		Hand Surgeon	Hand Surgeon	Wright	Limited ROM	HO	Removed	3
4	23	Male	White	Right	Olecranon Fx-Dx	Proximal ulna fx, LCL rupture	Trauma Surgeon	Hand Surgeon	Wright	Pain	Instability of the head/ulnar malalignment	Revision	3
5	54	Female	White	Right	Terrible triad	Coronoid fx, LCL rupture	Hand Surgeon	Hand Surgeon	Wright	Pain	Loosening	Revision	3
6	59	Female	Other	Right	Radial head Fx w/o Dx		Trauma Surgeon	Hand Surgeon	Wright	Limited ROM	HO	Removed	6
7	37	Male	Other	Right	Terrible triad	Coronoid fx, LCL rupture	Trauma Surgeon	Hand Surgeon	Wright	Limited ROM	HO	Revision	6
8	64	Male	White	Right	Terrible triad	Coronoid fx, olecranon fx, LCL rupture	Hand Surgeon	Hand Surgeon	Wright		Infection	Removed	6
9	27	Male	Other	Right	Terrible triad	Coronoid fx, LCL rupture	Hand Surgeon	Hand Surgeon	Wright	Limited ROM	HO	Removed	8
10	55	Female	Other	Right	Monteggia	Olecranon fx, corocoid fx, LCL rupture	Trauma Surgeon	Hand Surgeon	Wright	Pain	Loosening	Removed	11
11	26	Male	White	Right	Olecranon Fx-Dx	Olecranon fx, distal humerus fx	Hand Surgeon	Hand Surgeon	Wright	Limited ROM	HO	Removed	11
12	60	Female	White	Right	Radial head Fx w/o Dx		Hand Surgeon	Hand Surgeon	Biomet	Pain	Loosening	Removed	14
13	54	Female	White	Left	Radial head Fx without Dx		Hand Surgeon	Hand Surgeon	Biomet	Limited ROM	HO	Removed	15
14	48	Male	White	Right	Radial head Fx w/o Dx	Olecranon fx	Hand Surgeon	Hand Surgeon	Biomet		Infection	Removed	19
15	44	Male	White	Left	Terrible triad	Coronoid fx, LCL rupture	Hand Surgeon	Hand Surgeon	Biomet	Pain	HO	Removed	20
16	50	Female	White	Right	Olecranon Fx-Dx	LCL rupture	Hand Surgeon	Hand Surgeon	Wright	Pain	Capitellar wear	Removed	21
17	57	Female	White	Left	Terrible triad	Coronoid fx, LCL rupture	Hand Surgeon	Hand Surgeon	Wright	Limited ROM	HO	Removed	21
18	57	Male	White	Left	Terrible triad	Olecranon fx	Trauma Surgeon	Trauma	Wright	Pain	Capitellar wear	Removed	32
19	49	Female	White	Left	Terrible triad	Coronoid fx, LCL rupture, olecranon fx	Trauma Surgeon	Hand Surgeon	Wright	Pain	Capitellar wear	Removed	35
20	62	Female	White	Left	Terrible triad	Distal radius fx, Distal humerus fx, coronoid fx, LCL rupture	Trauma Surgeon	Hand Surgeon	Wright	Pain	Capitellar wear	Removed	46
21	62	Male	White	Right	Terrible triad	Coronoid fx, LCL rupture	Hand Surgeon	Hand Surgeon	Biomet	Pain	Loosening	Removed	68
22	49	Male	White	Right	Olecranon Fx-Dx	Olecranon fx	Trauma Surgeon	Hand Surgeon	Wright	Pain	Capitellar wear	Removed	135

More than half of the prostheses were removed by the surgeon that initially implanted the prosthesis (13 of 22).

Discussion

We found that about 8% of patients had removal/revision of the prosthesis, usually within the first year, more often at one hospital than the other (Hazard ratio: 2.4), and most commonly to help remove heterotopic bone, which is not related to technical error or problems with the prosthesis. Implants placed by trauma surgeons were often removed by hand surgeons. Eleven of the 22 (50%) prostheses were removed within the first year of surgery.

The observation that radial head prostheses are more likely to be removed or revised in one hospital than another and by hand surgeons than trauma surgeons suggests that differences in surgeon preferences or surgical techniques and training might influence

Table 2. Characteristics of patients with radial head implant arthroplasty (N=278)

	Radial head prosthesis removal		*P* value*
	No (n=256, 92%)	Yes (n=22, 8%)	
Age, mean (SD)	51 (17)	49 (13)	*0.62*
Hospitals, no (%)			
Hospital 1	194 (76)	11 (50)	*0.03*
Hospital 2	62 (24)	11 (50)	
Initial Surgeon Subspecialty			
Trauma Surgeon	98 (38)	8 (36)	*0.55*
Hand Surgeon	158 (62)	14 (64)	
Sex, no (%)			
Male	131 (51)	11 (50)	*0.94*
Female	125 (49)	11 (50)	
Race, no (%)			
White	202 (79)	17 (77)	*0.23*
Other	54 (21)	5 (23)	
Side, no (%)			
Right	98 (38)	14 (64)	*0.09*
Left	157 (62)	8 (36)	
Type of injury, no (%)			
Olecranon Fx-Dx/Monteggia	37 (14)	7 (32)	*0.25*
Terrible triad/Radial head Fx with elbow dislocation	135 (53)	10 (45)	
Radial head fracture w/o dislocation	76 (30)	5 (23)	
Essex-Lopresti	8 (3)	0	
Dislocation, no (%)			
Yes	172 (67)	17 (77)	*0.82*
No	84 (33)	5 (23)	
Concurrent surgeries, no (%)			
ORIF distal humerus	8 (3)	2 (9)	*0.40*
ORIF ulna	56 (22)	7 (32)	
ORIF olecranon	25 (10)	4 (18)	
ORIF coronoid	73 (28)	6 (27)	
LCL repair	120 (47)	11 (50)	
Implant, no (%)			
Wright	217 (85)	17 (77)	0.54
Other #	39 (15)	5 (23)	

* Log-rank test

Other prostheses included Biomet, Synthesis, Tournier, and Avanta

Table 3. Cox regression analysis of predictors of radial head prosthesis removal

	Hazard ratio	95% CI	*P*-value
Side	2	0.82-4.9	*0.13*
Hospital	2.4	1.03-5.8	*0.043*

CI= Confidence Interval

implant removal. This may reflect differences of opinion rather than expertise. The factors associated with removal of the implant in this study suggest that the decision to remove a radial head prosthesis may be subjective. The pre-operative features of the patient and the injury were not predictive of the probable future removal. In prior studies, factors associated with removal or revision of a radial head prosthesis included silastic compared to metallic implants (16, 19) and younger age (45 versus 52 years on average) (16). In a study of bipolar prostheses, 6 of 22 were revised due to subluxation or dislocation of the elbow, 3 were removed for lateral elbow pain with radiographic and intraoperative findings consistent with a prosthesis that was too long causing wear of the capitellum, and one was removed because of pain associated with lucency around the stem (20).

Revision of the prosthesis after healing

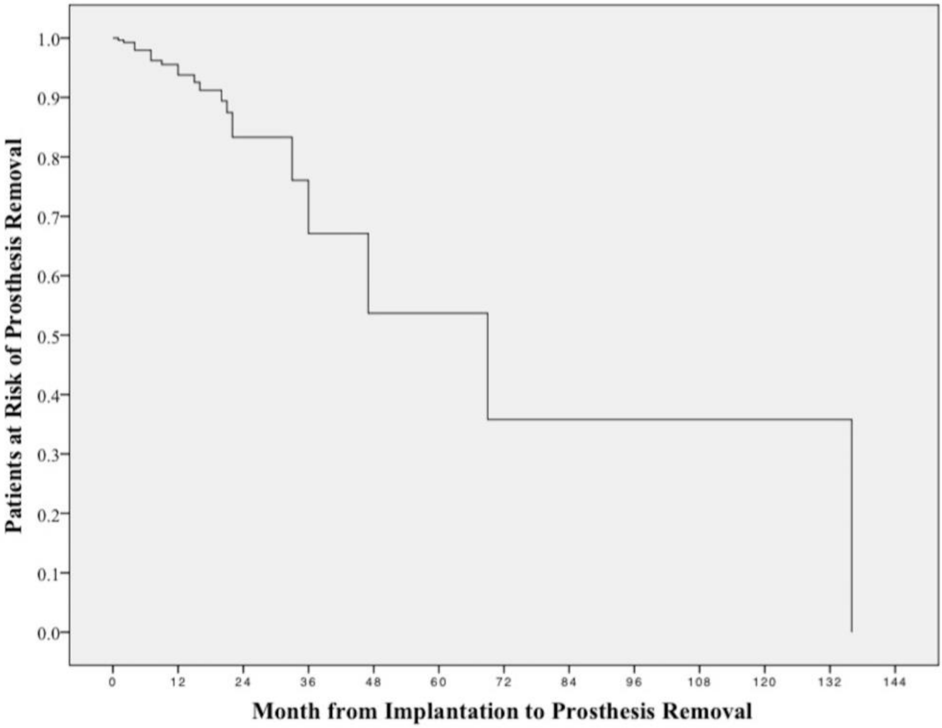

Figure 1. Kaplan-Meier curve shows the survival of the radial head implant with the majority of them being removed over the first years after implantation.

Table 4. Reasons for radial head prosthesis removal (22 pts)

Reason	No (%)
Loosening	4 (15)
Infection	2 (7)
Instability	2 (12)
HO (synosthosis)	9 (35)
Painful radiocapitellar wear	5 (23)

of the ligaments is of questionable value, but removal might help increase the range of motion when there is heterotopic ossification or a prosthesis that is too large and might help alleviate pain, particularly if the prosthesis is too large (21). It is not clear whether a correctly sized prosthesis provides any benefit or harm over the long term. A better understanding of the factors associated with radial head prosthesis removal might contribute to better surgical techniques and decreased surgeon-to-surgeon variation in implant removal.

The strength of this study includes the large cohort of patients with a primary radial head implant surgery. However, this study should also be interpreted with its limitations in mind. First, the data is from 2 centers and most of the prostheses were intentionally loose smooth spacer prostheses, so this data might not be representative of the average center or radial head prosthesis. Second, some patients may have had prosthesis removal outside of our system, so the true removal rate is likely slightly higher. Third, with only 22 removals or revisions there is a risk of overfitting with the multivariable model and we were not able to consider all issues resulting in removal or revision. Lastly, this study design is retrospective, which makes it inherently more susceptible to data loss and bias.

Table 5. Percentage of implants placed and removed/revised by each category of surgeons

Total cases=278	Total replacement by Trauma surgeons	106
	Total replacement by Hand surgeons	172
Total removal=22	Replaced by Trauma surgeons	8
	Replaced by Hand surgeons	14
	Removal by Trauma surgeons	1
	Removal by Hand surgeons	21
	Removal by the same surgeon	13
	Removal by a different surgeon	9

Conclusion

Demographic and injury features, and the type of implant did not influence the proportion of radial head prosthesis removal/revision. The observed differences by hospital might reflect differences in the preferences of the surgeons or differences in surgical techniques and training. Until clarified by additional study, removal of a prosthesis should not be considered an objective outcome in research. In addition, patients offered removal of a radial head prosthesis might get the opinion of more than one surgeon at more than one hospital before deciding whether or not to proceed.

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Chapter 8

Radiocapitellar prosthetic arthroplasty: short-term to midterm results of 19 elbows.
Kachooei AR, Heesakkers NAM, Heijink A, The B, Eygendaal D.
J Shoulder Elbow Surg. 2018 Apr;27(4):726-732.

ABSTRACT

BACKGROUND

Few studies have discussed the short-term results of radiocapitellar (RC) prosthetic arthroplasty (PA). In this study, we assessed the short-term to midterm functional and radiographic results of elbows after RC PA. Our secondary aim was to assess the survival of the RC PA.

METHODS

We included 19 elbows in 18 patients with a mean follow-up of 35 months (range, 12-88 months). Patients were examined for instability and range of motion and were assessed using Mayo Elbow Performance Index and Oxford Elbow Score at any subsequent visits. RC PA was the primary treatment in 16 elbows, and 3 were revision radial head arthroplasty with concomitant capitellar resurfacing.

RESULTS

Range of motion, pain, and functional scores improved significantly from the preoperative to the final follow-up visit. Categoric grouping of the final Mayo Elbow Performance Index outcome scores showed 9 excellent, 5 good, 3 fair, 0 poor, and 2 missing data. However, stability of the elbow remained unchanged. There was no pain in 11 patients, mild pain in 5, and moderate pain in 3. Radiographic assessment showed no significant progress in ulnohumeral arthritis, although 3 elbows showed osteoarthritis progression to a higher grade. There were no major complications, including infection, revision, disassembly of the components, or conversion to total elbow arthroplasty. Survival of the RC PA was 100%.

CONCLUSION

Elbow arthritis seems to become stationary after RC PA. Symptomatic RC osteoarthritis would probably benefit from RC PA regardless of the etiology.

Introduction

Radiocapitellar prosthetic arthroplasty involves a radial head arthroplasty with a polyethylene-articulating surface together with metallic capitellar resurfacing arthroplasty. It has been used for the treatment of symptomatic radiocapitellar osteoarthritis. Isolated arthrosis of the radiocapitellar joint is the end result of different conditions, which may require prosthetic arthroplasty to alleviate pain, restore near-normal kinematics, and stabilize the lateral column especially when valgus or longitudinal instability exists (6). The incidence of symptomatic isolated radiocapitellar osteoarthritis is very low after an isolated radial head fracture (under review). However, rare conditions such as osteonecrosis of the capitellum and injuries to both radial head and capitellum (kissing lesion) might end up to radiocapitellar osteoarthritis (3).

Five studies including a total of 36 patients with a follow-up range of 6-50 months have reported only short-term results after radiocapitellar prosthetic arthroplasty (RC PA) (1, 4-6, 8, 11). We have also published the short-term results of our experience with 6 elbows in 2014 (6). The body of literature on the outcomes of RC PA is small and inconclusive because of small number of patients and a short follow-up.

In this study, we primarily aimed to assess the short to mid-term functional and radiographic results of 19 elbows after RC PA including those previously reported cases. Our secondary aim was to assess the survival of the RC PA.

Methods

In a retrospective cohort study, we found 30 consecutive elbows in 29 patients between 2007 and 2016 that had been replaced by a radiocapitellar arthroplasty at a level 1 academic hospital. All surgeries were performed by the senior author (D.E.). IRB approval was waived by our institution's medical ethical committee. Patients were examined for instability and range of motion, and were assessed using Mayo Elbow Performance Index (MEPI) and Oxford Elbow Score (OES) at any subsequent visits. We retrospectively reviewed the charts and collected the clinical and radiographic data of the patients with RC PA. The data and radiographs of the last follow-up visit were used for analysis. Some patients had longer follow-up with radiographic assessment only, which were available in their records.

Patients with less than 12-month follow-up were excluded leaving 19 elbows in 18 patients for analysis [Table 1]. The indication for surgery was isolated symptomatic radiocapitellar degenerative arthritis that was refractory to nonoperative treatment. Isolated

Table 1. Demographic data of the patients (N=19 elbows, 18 patients)

Age, mean (SD)	53 (11)
Sex, no. (%)	
Male	8 (42)
Female	11 (58)
Side, no. (%)	
Right	13 (68)
Left	4 (21)
Bilateral	1 (11)
Type of surgery, no. (%)	
Primary	16 (84)
Revision	3 (16)
Type of prosthesis, no. (%)	
LRE	15 (79)
UERC	3 (16)
Others*	1 (5)
Type of fixation, no. (%)	
Cemented	3 (16)
Uncemented	15 (79)
Capitellum cemented/Radial head uncemented	1 (5)
Indication, no. (%)	
Arthritis	15 (79)
Osteonecrosis of the capitellum	1 (5)
RHP with capitellum erosion	3 (16)
Follow-up (month), mean (SD)	35 (13)

*Radial head Tornier + custom made capitellum
LRE Lateral Resurfacing Elbow system
UERC Uni-Elbow Radio Capitellum system
RHP Radial ehad prosthesis

radiocapitellar degenerative arthritis was defined as pain over the radiocapitellar joint with palpation, inability to perform activities of daily living due to this pain, and radiographic signs of degenerative arthritis of the radiocapitellar joint. Limited motion and some extent of valgus instability were also present in most of the patients. Mild degenerative arthritis of the ulnohumeral joint was not a contraindication for radiocapitellar prosthetic arthroplasty.

Clinical assessment included preoperative and final postoperative range of motion, pain, instability, and ability to perform the activities of daily living. We also assessed function using Mayo elbow performance index (MEPI) and Oxford elbow score (OES). MEPI was graded as excellent for score of 95-100, good for score of 80-94, fair for score of 60-79, and poor for score of ≤60 [Table 2].

We reviewed preoperative and final postoperative radiographs to assess changes. Degenerative changes of the ulnohumeral joint was graded as none, mild, moderate, and severe as described by Broberg and Morrey (2). Osteoarthritis grading was also categorized as none/mild versus moderate/severe as described by Lindenhovius et al, which showed higher interobserver reliability (9). Ulnohumeral angle was measured on the anteroposterior view of the elbow. Osteopenia of the capitellum was assessed on the anteroposterior view of the elbow and was categorized as 'yes' or 'no'. Signs of component loosening including lucency and component displacement, heterotopic bone formation, radial head or neck resorbing, were also assessed [Table 3]. Conversion to total elbow arthroplasty was considered a failure in survival.

Sixteen patients were primarily treated by radiocapitellar prosthetic arthroplasty, while three were treated with revision radial head arthroplasty and concomitant capitellar resurfacing arthroplasty. In all of the 3 revision elbows, radial head prosthesis was only revised to match the primary arthroplasty of the capitellum, meaing that a radial head prosthesis was revised to a radiocapitellar prosthetic arthroplasty. The Lateral Resurfacing Elbow system (LRE; Biomet, Warsaw, IN, USA), a press-fit hydroxyapatite coated surface replacement system, which retains the native radial head and proximal radioulnar joint, was used in 15 patients. It is monoblock and is available in 4 sizes of small, medium, large, extra large placed without cement. The Uni-Elbow Radio Capitellum (UERC) system (Small Bone innovations, Morrisville, PA, USA), in which the fixation is different and excision of the native radial head is required, was used in 3 patients.

Table 2. Comparing function and stability before and after surgery

	All elbows (no=19)			LRE prosthesis (no=15)		Non-LRE Prostheses (no=4)	
	Pre-op	**Post-op**	***P* value**	**Pre-op**	**Post-op**	**Pre-op**	**Post-op**
ROM, mean (SD)							
Flexion	121 (10)	131 (9.8)	*0.051*	120 (11)	130 (9.3)	123 (5)	136 (11)
Flexion contracture	24 (14)	13 (13)	*0.065*	25 (13)	12 (13)	20 (18)	16 (14)
Arc	97 (21)	119 (29)	*0.027*	95 (21)	118 (20)	103 (22)	121 (20)
Pronation	63 (8)	70 (16)	*0.002*	63 (9.0)	69 (19)	60 (5.0)	73 (5.0)
Supination	59 (14)	69 (20)	*0.041*	58 (16)	66 (22)	60 (5.0)	80 (5.0)
Arc	121 (19)	139 (34)	*0.003*	122 (21)	136 (38)	120 (5.0)	153 (5.0)
Valgus instability, no. (%)							
None	6 (32)	9 (47)	*0.41*	6 (40)	7 (47)	0	2 (50)
Grade 1	12 (63)	10 (53)		9 (60)	8 (53)	3 (75)	2 (50)
Grade 2	1 (5)	0		0	0	1 (25)	0
MEPI , mean (SD)	46 (14)	90 (12)	*<0.001*	39 (9.0)	90 (11)	62 (10)	88 (17)
OES, mean (SD)	21 (9)	84 (69)	*0.024*	24 (13)	86 (77)	20 (7.5)	76 (31)

It includes a modular radial head and monoblock capitellum component in 2 sizes of small and large for both right and left sides. Of these 3 patients with UERC, one was a primary radiocapitellar arthroplasty, while 2 were revision arthroplasties in that a bipolar press fit radial head prosthesis was revised to a bipolar cemented long stem in one elbow, and a loose fit monoblock radial head was revised to a short stem monoblock radial head in another patient. One of the three patients that were operated in a revision setting received a custom radiocapitellar prosthesis (Techmedica, Camarillo, CA, USA). Results of the systems were separated based on LRE (15 elbows) versus non-LRE (4 elbows) systems [Table 2 and 3]. The average time to follow-up visit was 35 months (range, 12 to 88 months). The average radiographic follow-up was 53 months (range, 19 to 93 months) [Figure 1-4].

Table 3. Radiographic assessment of the radopcapitellar arthroplasty at the final follow up visit

	All elbows (no=19)			LRE prosthesis (no=15)		Non-LRE prostheses (no=4)	
	Pre-op	**Post-op**	***P* value**	**Pre-op**	**Post-op**	**Pre-op**	**Post-op**
Carrying angle, mean (SD)	158 (3.1)	162 (4.5)	*0.002*	157 (3.3)	162 (4.8)	160 (2.0)	162 (3.7)
Ulnohumeral arthritis, no. (%)							
None	7 (37)	5 (26)		3 (20)	2 (13)	4 (100)	3 (75)
Grade 1	8 (42)	8 (42)	*0.102*	8 (53)	8 (53)	0	0
Grade 2	4 (21)	6 (32)		4 (27)	5 (34)	0	1 (25)
Capitellum osteopenia, no. (%)							
No	12 (63)	6 (32)	*0.014*	10 (66)	5 (34)	2 (50)	1 (25)
Yes	7 (37)	13 (68)		5 (34)	10 (66)	2 (50)	3 (75)
Other complicaions		No. (%)			No. (%)		No. (%)
Heterotopic ossification		1 (5.3)			0		1 (5.3)
Capitelar component displacement		1 (5.3)			1 (5.3)		0
Radial head or neck resorption		3 (16)			1 (5.3)		2 (11)
disassembly		0			0		0
Loosening		0			0		0
Conversion to TEA		0			0		0

Figure 1. Anteroposterior and lateral elbow views of a 56- year old female with primary degenerative arthritis of the left radiocapitellar joint.

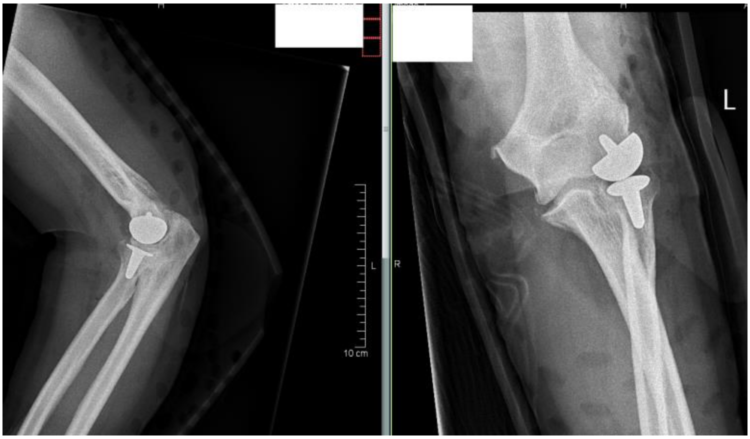

Figure 2: Anteroposterior and lateral elbow views of the same patient one day after radiocapitellar prosthetic arthroplasty using the Lateral Resurfacing Elbow system (LRE; Biomet, Warsaw, IN, USA).

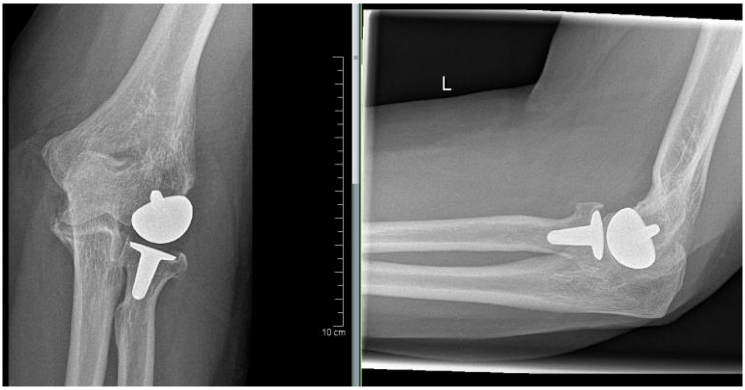

Figure 3. Anteroposterior and lateral elbow views of the same patient at a 12-month follow-up.

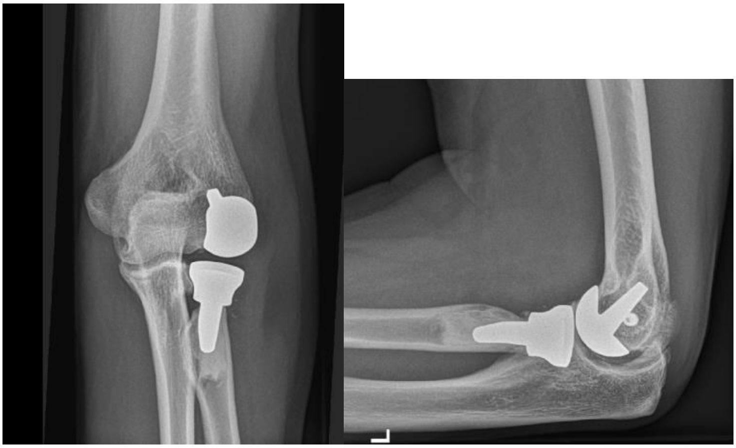

Figure 4 A-B. Anteroposterior and lateral elbow views after radiocapitellar prosthetic arthroplasty using Uni-Elbow Radio Capitellum (UERC) system (Small Bone innovations, Morrisville, PA, USA)

Heijink et al have previously reported on the short-term results of 6 patients out of 15 with LRE system, which we also included to report the mid-term follow-up results and survival of the prosthesis. One of these primary RC PA was done with LRE system in a patient with a separated and widely displaced capitellum after sustaining osteonecrosis of the capitellum [Table 4].

Statistical analysis

Categorical data is reported in numbers and percentages while continuous variables are reported as mean and standard deviation. Paired t-test was used to compare changes from preoperative to final postoperative.

Table 4. Radiographic assessment of the radopcapitellar arthroplasty in the original 6 patients with a mean follow up of 67 months (range, 24-93 months)

	Pre-op	Post-op
ROM, mean (SD)		
Flexion	124 (5.0)	128 (6.0)
Flexion contracture	26 (13)	18 (11)
Arc	98 (17)	110 (7.0)
Pronation	72 (7.5)	70 (9.0)
Supination	61 (25)	73 (10)
Arc	133 (29)	143 (16)
Instability, no. (%)		
None	5	5
Grade 1	1#	1^
Grade 2	0	0
MEPI , mean (SD)	41 (7.4)	93 (8.2)
OES, mean (SD)	.	121 (111)
Carrying angle, mean (SD)	159 (3.0)	162 (3.0)
Ulnohumeral arthritis, no. (%)		
None	2 (33)	1 (17)
Grade 1	3 (50)	3 (50)
Grade 2	1 (17)	2 (33)
Capitellum osteopenia*, no. (%)		
No	4 (67)	2 (33)
Yes	1 (17)	3 (50)
Other complicaions	No. (%)	
Heterotopic ossification	0	
Capitelar component displacement*	1 (5.3)	
Radial head or neck resorption	1 (5.3)	
disassembly	0	
Loosening	0	
Conversion to TEA	0	

Grade 1 valgus instability with no postop instability
^ Grade 1 varus instability postoperatively with no prior instability
* One patient with prior capitellar osteonecrosis underwent radiocapitellar arthroplasty

Result

Range of motion improved significantly from the pre-op to the final follow-up visit [Table 2]. Moreover, functional scores including MEPI and OES improved significantly at the final follow-up in compare to the pre-op status. Categorical grouping of the final MEPI scores showed 9 excellent, 5 good, 3 fair, no poor outcome, and 2 missing data. The missing data belonged to the recent patients, who failed to complete the MEPI, but the other functional and radiographic measures were recorded. However, stability of the elbow remained unchanged (*P* value=0.41) [Table 2 and 4]. There was a significant improvement in pain at the final follow-up visit with no pain in 11 patients, mild pain in 5, and moderate in 3 (*P* value=0.004). All patients reported to be able to perform the activities of daily living independently at the final follow-up visit whereas 7 reported inability in doing hair, 4 in doing shoes, 1 in hygiene, 3 in feeding, and 3 in putting on a shirt during the pre-op period.

Radiographic assessment showed a significant change in carrying angle although the mean difference was not large enough to be clinically significant (mean pre-op angle: 158 degrees; mean post-op angle: 162 degrees). Progression of ulnohumeral arthritis was not significant after radiocapitellar prosthesis replacement (*P* value=0.102) although 3 elbows showed further progression of OA to a higher grade. Heterotopic bone formation existed in most of the patients prior to surgery but new bone formation was found only in 1 patient. The capitellar component was displaced in one patient – the one with capitellar osteonecrosis that was lacking a bony support for the capitellar component. Asymptomatic radial head or neck resorbing was evident in 3 patients, one after revision of the radial head arthoplasty, one with Uni-Elbow Radio Capitellum system, and one with LRE system. Asymptomatic radiolucency of 1 mm was found in only one patient around the radial head component. Because it was asymptomatic, this was not considered a sign of loosening [Table 3 and 4].

Other complications including dis-assembly and conversion to total elbow arthroplasty were not found in any of the patients. Survival of the prosthesis during the follow-up of 35 months (min-max: 12-88 months) was 100% with no signs of loosening.

Discussion

We reviewed the short to mid term results after radiocapitellar prosthetic arthroplasty in 18 patients with the primary aim to assess their functional outcome and secondarily the radiographic changes after prosthetic arthroplasty. RC PA after an isolated radiocapitellar arthritis showed satisfactory results.

The number of patients and the length of follow-up are the limitation in advocating this type of surgery. Also, surgeries and visits were done by a single surgeon that might have resulted in a biased interpretation of the clinical examination. This is a single center study, which might be different in the hand of the other surgeons. Overall cohort is not homogenous in terms of indications and the type of prosthesis systems; however, the results were comparable.

Our results showed that the functional outcomes improved after RC PA surgery. This included moderate to severe pain before surgery that improved to none or mild in most cases at the latest follow-up visit. Patients also reported diminished pain with the pain items of the MEPI and OES questionnaires. The residual pain can be attributed to the residual ulnohumeral arthritis, which apparently did not show further progression after RC PA. It can be expected that improved carrying angle and stability have probably halted the progression of ulnohumeral arthritis as well as improving the range of motion. Thus, a moderate to severe radiocapitellar arthritis with none or mild ulnohumeral arthritis regardless of the etiology would probably benefit from RC PA. Although 3 elbows showed progression of the ulnohumeral OA, the non-significant *P* value might be due to small number of the samples. But, still most of the elbows did not show any progression toward a higher OA grades in a short to mid-term follow-up.

Kepler et al reported a 12-month follow-up of a patient who underwent a Uni-Elbow Radio Capitellar prosthetic arthroplasty following a capitellum fracture nonunion. At the latest follow-up visit, the patient had a painless elbow with 20-130 degrees of flexion and full rotation, with no signs of radiographic loosening (8). Pooley reported that they have used the LRE system in 22 elbows since 2005 of whom he only reported the outcome of 5 elbows in 2010 with a follow-up ranging from 9 to 18 months. Range of flexion-extension improved from 37-125 preoperatively to 18-140 degrees, and MEPI improved from 48 to 88 with 2 excellent, 2 good, and 1 fair outcome postoperatively. Moreover the survival of the prosthesis was 100% to the latest follow-up [11]. In a multicenter prospective study from 2006 to 2010, 19 elbows underwent LRE system replacement of whom 17 were available for the mean follow-up of 22.6 months (range: 6-47 months). The MEPI improved from 50 to 85 with 12 excellent, 2 good, and 3 fair or poor outcomes postoperatively. In addition, elbow flexion-extension and supination-pronation improved from 37-100 and 52-53 degrees preoperatively to 25-125 and 75-70 degrees postoperatively. The survival of the prosthesis was 100%, however, the outcome in the first 2 patients were not satisfactory because of implant malpositioning in excessive horizontal direction, and 1 patient had a poor outcome because of overstuffing. Overall, 3 patients in their series required elbow arthrolysis and neurolysis of the ulnar nerve (4). Bigazzi et al reported their experience with Uni-Elbow Radio Capitellum system in 7 patients during 2011 to 2013 with a mean follow-up of 40 months (range: 12-50 months) after traumatic degeneration of the lateral elbow compartment. At the latest follow up examination, there were 5 excellent and 2 good outcomes according to categorical grading of the MEPI. Also arc of flexion-extension and supination-pronation improved from 24 and 8 degrees preoperatively to 116 and 94 degrees postoperatively. Survival of the RC PA was 100% although one patient required elbow arthrolysis to remove the extensive HO. No other complications were observed other than asymptomatic loosening of the radial component in 2 patients (1).

The existing literature is limited to the described studies including 8 patients with UERC and 22 patients with LRE system. In our series, we also reported the results of 15 LRE and 3 UERC systems. Although the patient population and indications were heterogenous throughout the studies, all reported a substantial reduction in pain and improved function and range of motion with 100% survival rate in a short to mid term follow-up. Major complications were few including reoperation for elbow artholysis or ulnar nerve neurolysis. The effect of the amount of radial head resection on the radio-capitellar and radioulnar articulation, which is different between the 2 systems, is still unclear. Moreover, subsequent capitellum osteopenia remains a concern as whether it is the result of alteration in radiocapitellar load transfer, component malposition, understuffing of the prosthesis, or simply an illusion because of the difference in contrast between the bones surrounding a highly radiopaque metal component. Apparently, RC PA is advisable for radiocapitelar arthritis when a concomitant valgus or longitudinal instability exists. Thus, it is not clear whether revision of the radial head prosthesis to a RC PA would add any extra benefit other than a simple removal of the radial head prosthesis when ligaments are intact or healed (7, 10).

Conclusion

Marked improvement in pain, function, and motion is in support of the considered indications. Moreover, overall elbow arthritis seems to become stationary after RC PA. Symptomatic radiocapitellar arthritis would probably benefit from RC PA regardless of the etiology. However, consequences such as osteopenia and osteolysis as well as the difference between different systems and materials will remain open for future research.

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Chapter 9

Short to Mid-Term Results of Patient-Specific Polymethylmethacrylate Radial Head Prosthesis in Complex Radial Head Fractures Using 3-Dimentional Mold System.
Kachooei AR, Meidanshahi M, Sedigh A, Zohoori M, Ebrahimzadeh MH, Eygendaal D.
Injury. 2020 (Under review)

ABSTRACT

BACKGROUND

In this prospective cohort study, we followed up patient with radial head fracture treated with patient-specific polymethylmethacrylate (PMMA) radial head prosthesis (RHP) using 3-dimentional (3D) printing technique.

METHODS

We used computed tomography (CT) scan of both elbows to reconstruct the bones in Mimics software and used the uninjured radial head to mirror and reconstruct the fractured head as well as the stem considering offset and tilt relative to the head. By using molds, the RHP was made with PMMA intraoperatively. To avoid overlongthening, a customized cutting guide was designed by referencing from the intact capitellum. Lateral collateral ligament was repaired in all patients while the medial collateral ligament was not approached in any. Patients were followed for a mean of 18 months (13-20 months).

RESULTS

Radial head fracture was replaced with a customized prosthesis in 10 patients while 9 were only available. Mean grip strength was 86% of the unaffected side. Mean arc of extension-flexion was 125 degrees on the operated side and 145 degrees on the unaffected side. Moreover, mean arc of supination-pronation was 162 degrees on the operated side and 168 degrees on the unaffected side. Five out of 9 patients (56%) were still complaining of slight vague wrist pain with activity. One patient complained of proximal forearm pain who was the only patient with signs of loosening on radiographic exam. Based on Mayo Elbow Performance Index (MEPI), there were 4 excellent, 4 good and 1 fair results. Moreover, the mean DASH score was 11 out of 100 (0-37) showing minimal disability while the patient can cope with most living activities. No patient ever complained of ulnar nerve symptoms requiring intervention.

CONCLUSION

When resources are limited or not available, PMMA RHP can be used safely as an alternative to metal prostheses to restore valgus and axial stability of the forearm. The use of 3D printing optimized the design and surgical technique of the radial head arthroplasty, and we need further studies to assess the long term follow-ups.

INTRODUCTION

Traditionally the radial head was excised when there was doubt about sufficient fixation of its fractures (1). However, researches showed that excision might not be a good idea in many instances and surgeons are advocated to either preserve or replace the radial head to maintain higher stability and strength (2, 3). Radial head arthroplasty (RHA) has been shown to be superior to internal fixation in modified Mason type 3 and 4 radial head fractures in the short term (4). Also, the rate of removal or revision of a RHA due to a complication is very low accounting for less than 5% of the replacements, which is in favor of replacing in contrast to the expected instability and loss of strength after excision (5-8).

In developing countries especially countries under wide sanction where there is a shortage of manufactured prostheses with costly medical services, trend has been toward excision (9). A series has shown very good results with hand-made polymethacrylate spacer after radial head excision with no complications due to using this material (10). Knowing that the radial head prosthesis acts as a spacer while the ligaments heal, we came up with the idea of producing a customized radial head prosthesis by applying 3-dimensional (3D) printing technique. By using this technique, we were able to design anatomic and patient-specific radial head prosthesis made out of polymethylmethacrylate (PMMA), which reduced the cost to 10% of the available metal prostheses.

In this prospective cohort, we followed our patients and we aim to report our results after a minimum of one year follow up in patients with modified Mason type 2, and 3 in whom the radial head was replaced by a customized PMMA radial head prosthesis using 3D printing technique.

MATERIALS AND METHODS

In this prospective study approved by the Internal Review Board of the university, we followed the patients who underwent radial head replacement using patient-specific radial head prosthesis (RHP) made of polymethylmethacrylate (PMMA). We included patients with Mason type 2 and 3 radial head fractures referred during May 2017 to June 2018. The indication for radial head replacement was obvious limited motion. Patients were followed for minimum of 12 months and we did not plan to remove any prosthesis until the final follow up.

Customized PMMA radial head prosthesis

We used computed tomography (CT) scan of both elbows to reconstruct the bones in Mimics software and used the uninjured radial head to reconstruct the fractured head with the following method. On the CT model of the injured side, we determined the level of bone cut on the radial neck based on the fracture extension in the coronal and sagittal planes. The same height was determined on the radial neck of the uninjured side to separate the head in the software. To create stem for the prosthesis, we used the diameter of internal canal of the proximal radius and determined the length from the neck to the biceps tuberosity on the injured model. Stem design was done on the uninjured CT to apply the offset in relation to the head. Then the head and stem model were mirrored to create the head geometry on the fractured side [Figure 1].

The designed prosthesis was 3D-printed with the Food and Drug Administration (FDA) approved Polylactic Acid (PLA). Using the obtained model, we then made a two-piece medical silicon mold to make the prosthesis intraoperatively. We used standard PMMA that is available for use with knee and hip prostheses.

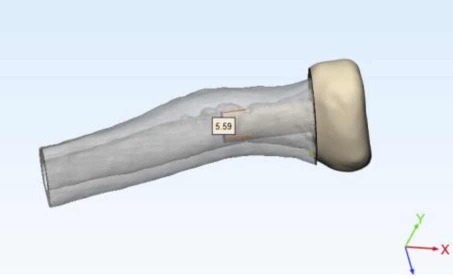

Figure 1. The radial head prosthesis was designed by mirroring the intact radial head. Stem was designed using the internal canal diameter which was a mean of 6 mm, and stem offset and tilt was determined along the canal toward the biceps tuberosity with a mean of 10 degrees tilt relative to the head.

Intraoperatively, we poured the dough of PMMA in the sterilized mold. We used a 1.2 mm K-wire within the stem with a length 2 mm longer than the length of the stem to increase the stiffness at the head-stem junction and also be used as a radiographic marker [Figure 2].

Because the height was predetermined in the software, we had to determine the cut level on the neck after removing the fragments of fractured radial head. We designed a customized cutting guide and 3D-printed it to get reference from the capitellum as measured previously [Figure 3]. We reamed the medullary

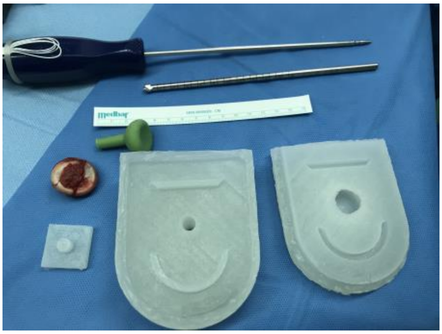

Figure 2. Molds were made out of medical silicone and was sterilized using plasma. A printed radial head was used as a trial, a reamer size of 6.5 was used to ream the canal up on to the biceps tuberosity, and a 3.5 mm suture anchor was used to repair the lateral collateral ligament.

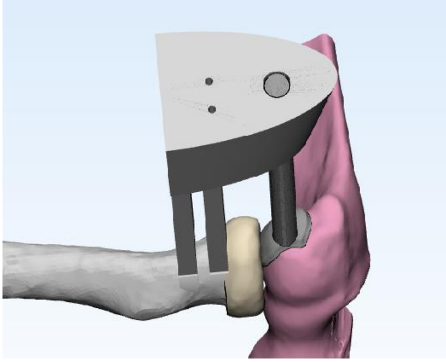

Figure 3. The cutting guide was designed with reference from the intact capitellum to determine the head height and avoiding overlengthening of the radial head prosthesis. The cutting guide was fixed on the radius by using two 1 mm K-wires through the holes and then the cut was made above the wires.

canal of the radius using incremental reamers used for anterior cruciate ligament (ACL) reconstruction. We reamed the canal 0.5 size larger than the stem diameter because the prosthesis was meant to fit loose in the canal.

Surgical technique

We used the lateral skin incision for all of the patients in our series. We then approached the radial head through the middle of extensor digitorum communis (trans EDC) and extended the dissection up over the lateral column when needed. When coronoid fracture was present, lasso technique was used to repair the anterior capsule to the bone via anteroposterior holes in the ulna using a #1 Fiberwire suture and it was tied over the dorsal ulna. Customized PMMA radial head was replaced as described above, and the lateral collateral ligament was repaired in all patients using a 3.5 mm suture anchor with a valgus force on the elbow in 30 degrees of flexion. Medial collateral ligament was not repaired in any patient. Some patients had capitellum chondral lesion at the time of index surgery showing a kissing lesion on both the radial head and

Figure 4. Capitellum erosion due to the initial traumatic event which was seen at the time of index surgery. This shows a kissing lesion including radial head fracture and capitellum chondral lesion. Progress toward radiocapitellar osteoarthritis can be attributed to these lesions rather than the type of prosthesis.

capitellum [Figure 4].

Post-op period

Elbows were immobilized in a long arm splint for the first 2 days after which active and active assisted elbow motion at home was instructed and patients were also sent for physical therapy depending on their progress. Patients were also instructed to avoid varus load on elbow but encouraged to do overhead exercises. Patients were also instructed to keep their forearm in a sling during nights and at rest during the days for one month after surgery.

RESULTS

Patient population

Radial head fracture was replaced with a customized prosthesis in 10 patients. One patient did not even return to remove the sutures and was lost to follow-up. We were able to invite the other 9 patients for radiographic and physical examination with a mean follow-up of 18 months (13-20 months) [Table 1].

Average time from injury to surgery was 33 days (5-90 days) and the mean age at the time of surgery was 30 years. There were 5 radial head fracture-dislocations, 3 terrible triads, and 1 patient with an old Essex-Lopresti injury.

Table 1. Demographic data of patients with cement radial head prosthesis

Patient	Side	Time to surgery	Time to F/U (month)	Age	Sex	Injury type	Coronoid repair	LUCL repair	MUCL repair	PT Sessions (no.)	Secondary surgery
1	R	1 month	20	24	F	RH fx-dx	.	Yes	.	10	No
2	R	3 months	20	31	M	RH fx-dx	.	Yes	.	30	No
3	L	7 days	20	28	M	RH fx-dx	.	Yes	.	20	No
4	L	9 days	19	29	F	TT	Yes	Yes	.	10	No
5	L	3 months	18	50	M	TT	.	Yes	.	10	No
6	L	1 month	18	25	M	RH fx-dx	.	Yes	.	90	No
7	R	4 years	17	25	F	Essex Lopresti	.	Yes*	Yes*	30	Radial head broken removal after 2 months/MUCL reconstruction and DRUJ reconstruction after 8 months
8	R	7 days	16	25	M	RH fx-dx	.	Yes	.	20	Radioulnar synostosis excision after 16 months
9	L	5 days	13	36	M	TT	Yes	Yes	.	20	Manipulation under anesthesia after 4 months
Average		33 days	18	30						27	

R=right; L=left; F/U=follow up; F=female; M=male; LuCL=lateral ulnar collateral ligament; MUCL=medial ulnar collateral ligament; PT=physiotherapy, TT=terrible triad

RH fx-dx=radial head fracture-dislocation; PRP=platelet rich plasma; CSI=corticosteroid injection; HA=hyaloronic acid; DRUJ=distal radioulnar joint

* ligament reconstruction was done using tibialis anterior allograft.

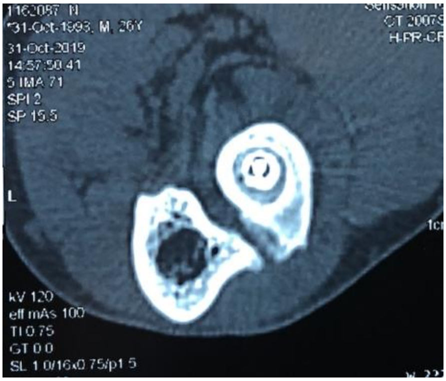

Figure 5. Proximal radioulnar synostosis that was removed 16 months after index surgery in patient 8. Prosthesis stem is seen within the radial canal which is meant to fit loose. No endosteal erosion is seen after 16 months.

Lateral collateral ligament was repaired in all patients after replacing the radial head, while medial collateral ligament was not approached in any patient as the MCL tends to have a high natural potency for healing. [Table 1]

Physical examination

The mean grip force on the operated side was 86% of the unaffected side. Mean arc of extension to flexion was 125 degrees on the operated side and 145 degrees on the unaffected side. Moreover, mean arc of supination to pronation was 162 degrees on the operated side and 168 degrees on the unaffected side. One patient with 15 degrees of extension deficit only complained of limited extension (Patient 2). One patient had limited rotation due to radioulnar synostosis that underwent synostosis excision 16 months after index surgery and gained satisfactory rotation (patient 8) [Figure 5]. No other patient complained of limited motion and functional impairment due to limited motion [Table 2].

Five out of 9 patients (56%) still were complaining of slight vague wrist pain with activity. Based on Mayo Elbow Performance Index (MEPI), there were 4 excellent, 4 good and 1 fair results after a mean follow-up of 18 months. Fair result in this patient was due to moderate pain with activities which was scored 8/10 on visual analogue score (VAS). Moreover, the mean DASH score was 11 out of 100 (0-37) showing minimal disability while the patient can cope with most living activities and no treatment is required [Table 2].

No patient ever complained of ulnar nerve symptoms requiring any intervention. We did not have any patient with infection, neither superficial nor deep.

Radiographic examination

Loose stem with neck resorption was visible in radiographic exam of patient 1. She was complaining of a weak sensation in the forearm and slight vague radiating pain along the dorsal forearm with no pain in the elbow although her range of motion was full [Figure 6]. She was a heavy worker and carpet weaver eliciting pain after long hours of working [Table 3].

One patient with synostosis required excision surgery with retaining the prosthesis in place (patient 8). As a second look on the radiocapitellar joint 16 months after surgery, capitellum cartilage seemed fine with no obvious lesion [Figure 7]. One patient with painful medial HO required surgery to

Table 2. Final follow-up examination of patients with cement radial head prosthesis (mean follow-up=18 months)

Patient	Grip (kg)		Extension		Flexion		Supination		Pronation		VAS rest (0-10)	VAS activity (0-10)	MEPI Score (0-100)	DASH Score (0-100)	HO	Vague Wrist pain	Proximal forearm pain
	Affected	Non-affected	Affected	Non-affected	Affected	Non-affected	Affected	Non-affected	Affected	Non-affected							
1	18	22	15	0	135	135	90	90	90	90	0	6	85	15	.	Y	y
2	47	56	15	0	130	140	70	85	70	70	2	3	85	13	.	.	.
3	19	26	5	-5	135	135	80	80	80	80	0	0	100	0	.	Y	.
4	24	26	-10	-10	150	150	100	100	100	100	0	0	100	0	.	.	.
5	35	33	0	0	130	135	80	80	85	85	0	0	100	0	.	.	.
6	42	48	15	-10	130	150	85	90	65	65	0	0	100	4	.	Y	.
7	21	28	0	-10	130	130	80	80	80	80	0	2	80	37	.	Y	.
8	37	42	10	-10	130	140	70	90	70	90	0	1	85	22	Y	.	.
9	36	44	12	-10	120	140	80	80	80	80	0	8	70	12	.	Y	.
Average	31	36	7	-6	132	139	82	86	80	82	0	2	89	11	1	5	1

VAS=visual analogue score; MEPI=Mayo Elbow Performance Index; DASH=Disabilities of Arm Shoulder Hand; HO=Heterotopic Ossification

Figure 6. Patient 1 with pain along the dorsal forearm started one year after the index surgery. On radiographic exam, collar bone resorption and stem loosening are obvious. Endosteal scalloping and sclerosis at the base of the stem – so-called vase sign – is present. Late-onset low grade infection has to be considered.

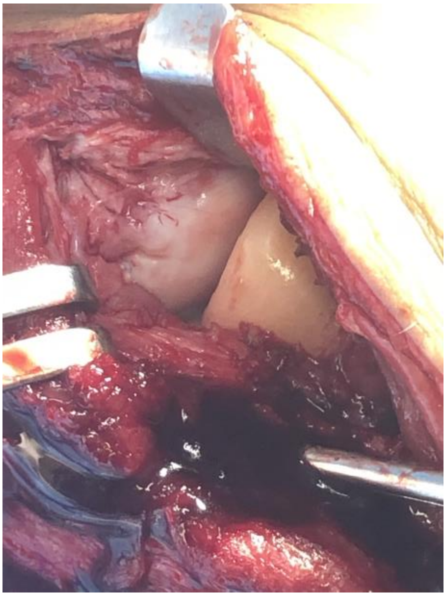

Figure 7. Patient 8 was planned to remove the proximal radioulnar synostosis 16 months after index surgery. Second look at the prosthesis-capitellum interface showed existing of healthy cartilage with no or little cartilage defect or degenerative changes.

Table 3. Radiographic findings during and at the last follow up.

Patient	Ulnohumeral arthritis	Capitellum arthritis	Capitellum osteopenia	Radial head fracture	Radial neck resorption	Loosening	Revision arthroplasty	Medial HO	Anterior HO	Synostosis
1	.	.	Yes	.	Yes	Yes	.	.	.	.
2	.	.	.	.	.	.	.	.	.	.
3	Yes	.	Yes	.	.	.	.	Yes	Yes	.
4	.	.	Yes	*Yes #*	.	.	.	Yes	.	.
5	.	.	.	.	.	.	.	.	.	.
6	.	.	.	.	.	.	.	Yes	Yes	.
7	.	.	Yes	*Yes #*	.	.	.	*Yes**	.	.
8	.	.	.	.	.	.	.	.	.	*Yes***
9	.	.	.	.	.	.	.	.	.	.
Total	1	0	4	2	1	1	0	3	2	1

HO=heterotopic ossification
* required surgery for recalcitrant medial elbow pain; ** required surgery for limited rotation;
# did not require surgery and fracture was found incidentally in the follow up radiographs. Patients did not have any complaint relating to the fractured prosthesis

excise the HO with MCL reconstruction (patient 7) [Figure 8 A-C].

Radial head broke in patient 7 which was an error in the surgical technique where we used longer neck in an old essex-lopresti injury to presumably restore the radius and ulna association [Figure 8 A-C]. Radial head had been excised 4 years ago for a fracture by another provider and she was referred due to continuous elbow and wrist pain. This surgical error caused ulnohumeral varus and opening of the lateral ulnohumeral joint with increased compression force over the prosthesis which broke it during physical therapy. There was no complaint related to the broken prosthesis, but this patient underwent subsequent surgery to excise painful medial HO, and to reconstruct

MCL and distal radioulnar joint ligaments due to pain and instability in the wrist [Table 3].

The Radial head also broke at the head/neck junction in another patient which we found accidentally on follow-up radiographic exam. The patient had no complaint and scored 0 on DASH and 100 on MEPI (patient 4). Therefore, no further intervention was done.

Capitellum osteopenia, and medial and anterior HO were not related to any complaint and were only visible on radiographs [Figure 9 A-D].

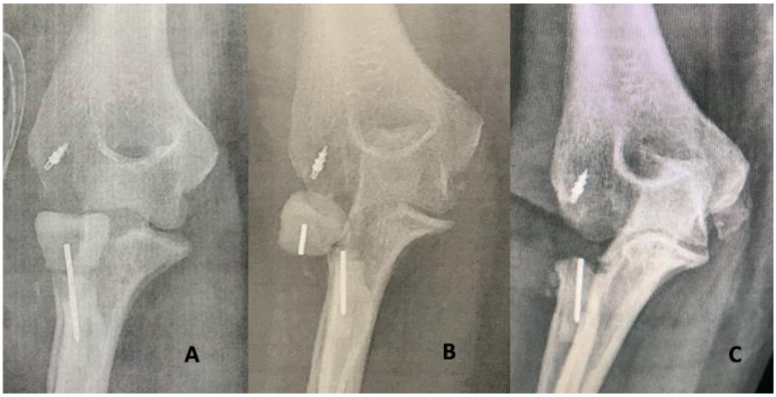

Figure 8. Radial head was excised in an Essex-Lopresti injury 4 years ago in patient 7. Because of pain and instability of the elbow, we planned to replace the head and reconstruct the lateral collateral ligament (LCL). (A) Due to surgical error and radius subsidence, we were not able to restore radius length, which caused overlengthening of the prosthesis and ulnotrochlear subluxation. (B) This resulted in prosthesis head-neck junction break while the patient was doing physical therapy. (C) Although the broken head was removed, the patient continued complaining of medial elbow and wrist pain with newly appeared medial heterotopic ossification (HO).

Figure 9. (A) Patient 6 with radial head fracture-dislocation. (B) Lateral view and (C) anteroposterior view and of the elbow at the final follow up after 18 months with asymptomatic medial HO. (D) On examination, range of motion was comparable with the contralateral side.

DISCUSSION

We operated on 10 patients to replace the radial head fracture with a customized cement radial head prosthesis (RHP) because of limited access to the currently available metal prostheses. We assessed the short to mid-term results of the patients for clinical and radiographic changes while the RHP was retained. Clinical and radiographic examination showed good to excellent results in the patients.

Limitation to our study was the small number of patients because this was a pilot study on the short to mid-term results. Also, there was heterogeneity of patients in terms of demographic data although the type of injury in most patients was terrible triad or radial head fracture-dislocation. Longer follow-up is needed to assess for loosening of the implant or erosion of the capitellum or progress to posttraumatic osteoarthritis.

Bone cement showed promising results in terms of not progressing toward elbow osteoarthritis or bone resorption, and probably can be used safely as a spacer. By not press-fitting the stem and allowing rotation of the stem inside the canal at extremes of forearm rotation, it resembles a bipolar prosthesis while the disadvantage of component dissociation in conventional bipolar RHP was eliminated (5). Moreover, this allows to compensate for radiocapitellar malalignment (11, 12). We used short stem and designed it up to the biceps tuberosity. This allows reaming the canal along the forearm rotational axis [Figure 10] and prevent the technical failure of malrotation, often seen in long stemmed prosthesis. Ferreeira et al also showed that filling the diameter of the canal is probably more important than filling the length of the canal (13). There was no risk of oversizing because it was a custom-made device copying patient's exact anatomy. By this, we may be able

Figure 10. Using short stem with predefined tilt relative to the head stays parallel to the forearm rotational axis which passes from the radial head in the elbow toward ulnar head in the wrist.

to prevent chronic attenuation of the LCL complex. We also avoided overlengthening by using customized cutting guides to cut the radial neck by referencing from the capitellum. This was also checked by forceless and spontaneous reduction of the radiocapitellum after inserting the prosthesis. It should be noted that repairing important elements including coronoid and LCL play an important role in stability and final outcome while the radial head, as a secondary stabilizer, play the role as a spacer helping improve stability. Annular ligament was also repaired or reapproximated when possible.

The idea of making RHP out of bone cement came from a study done in Argentina in 2010 where they used handmade polymethacrylate radial head spacer in complex radial head fracture-dislocations. Although it was not precisely made, there were 14 excellent, 14 good, 8 fair, and 2 poor results after a mean follow-up of 54 months, and only 8 out 38 accepted to remove the spacer. We therefore, decided to improve the design by using CT scans to make the customized RHP. The rate of RHP removal was shown in a meta-analysis to be 9.9% (95% CI: 7.7%-12.6%) including different materials and mades with no significant difference among them (5). This study showed that most RHP were removed in the first year and the rate of removal declined over time, and mostly were removed to release elbow stiffness and to excise synostosis (5, 14). It seems that the materials used in the radial head prostheses were not a determinant in the functional outcome but the extent of injury and surgical technique in repairing the ligamentous elements are of importance in achieving an acceptable outcome (15).

One patient in our series was complaining of proximal forearm pain started 1 year after the index surgery. On radiographic exam, she showed proximal radius canal widening and sub-collar bone resorption indicating loosening. O'Driscoll and Herald also showed that proximal forearm pain was eliminated after removal of a radiographically loose stem and they related this pain as an indicator of loosening requiring prosthesis removal (16). However; there is also a possibility of low grade infection causing late onset signs and symptoms after 1 year.

CONCLUSION

When resources are limited or not available, PMMA RHP can be used safely as an alternative to metal prostheses to restore valgus and axial stability of the forearm. The use of 3D printing optimized the design and surgical technique of the radial head arthroplasty, and we need further studies to assess the long term follow-ups. This is a very promising technique in countries with limited resources, countries under sanctions, and for patients with limited insurance coverage.

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PART IV

General Discussion and Summary

Chapter 10

General Discussion and Conclusions

Decision Making for The Treatment of a Radial Head Fracture

Multiple factors may affect the decision between operative and nonoperative treatment of a radial head fracture. Considering the fracture pattern and the related osseous and ligamentous injuries, the radial head fracture can be categorized as 1) an isolated stable fracture, or 2) unstable fracture as part of a more complex injury. When there is no or little displacement between the fracture fragments, the periosteum remains intact and the chance of displacement is rare. In contrast, lack of bony contact between the fragments with mobile and displaced fragments indicates an unstable fracture pattern which raise vigilance in detecting other associated injuries (1).

The goal of treatment of isolated stable fractures is to restore motion. Instability of the elbow and arthrosis of the elbow compartments are unlikely with a stable elbow (2). Even in the presence of a radiographic arthrosis, the patient often remains asymptomatic. The only concern with this type of injury is capsular contracture with possible limitation in the end-range movement although the functional range of motion is almost always regained. True motion block is very unlikely and nonoperative treatment with capsular stretching is the mainstay of treatment (3).

In contrast, the goal of treatment of unstable radial head fractures is to restore the alignment and stability of the forearm and the elbow. Restoration of the radiocapitellar contact is important in both elbow stability and elbow alignment while other concomitant injuries may need to be addressed accordingly. The ultimate goal of surgery of an unstable radial head fracture is to prevent subluxation and dislocation of the elbow for which decision has to made between excision, repair, or replacement of the head depending on the associated injuries as well as the available resources.

Management of Stable Radial Head Fractures

Clinical implications

A large amount of the radial head fractures is nondisplaced. This includes 1) an occult fracture presenting with tenderness over the head which is often not visible on standard radiographs, 2) modified Mason type I described as nondisplaced, 3) and most of modified

Mason type II fractures described as >30% of the circumference or >2 mm displacement although there is a moderate reliability to assess on standard radiographs (4).

The mechanism of these fractures is impaction and the contact between the fragments is preserved. The associated injuries, if any, are subtle and responsive to non-operative treatment. The only indication for surgery is a true motion block which is rare and difficult to detect in an acute setting. Aspiration of hematoma and injection of lidocaine may relieve pain. Late examination is another way to examine when the pain subsides. However, there is little evidence that the two methods are reliable enough to distinguish between reluctance to move and true motion block. Moreover, there is insufficient evidence about effectiveness and safety of joint aspiration (5). Other finding during examination is crepitus which has not shown to be correlated with further impairment.

This type of injury is responsible to nonoperative treatment measures with good to excellent outcomes, full restoration of the forearm rotation, and no or minimal restriction of full extension. Arthrosis in the long-term is rare. Only small proportion of type II fractures may require late surgery.

Herbertsson et al reported full motion, no objective impairment, no arthrosis, and only occasional pain in 3 elbows out of 32 with nonoperative management of a displaced type I radial head fracture after a mean of 21 years (6). Akesson et al reported favorable outcomes with no subjective impairment in 40 out of 49 patients with 2-5 mm displacement in a two-fragment fracture after a mean of 19 years. Only 8 patients reported occasional pain and 1 patient reported daily pain. Motion was slightly restricted in flexion, extension, and supination. Of these, 6 underwent late excision with no clear reason (7). In a prospective study of Mason type I and II fractures, patients were followed for 1 year. Only 2 out of 187 elbows underwent surgical intervention with the rest achieving good or excellent outcomes with nonoperative treatment (8).

Immobilization versus early mobilization

The duration of immobilization does not seem to affect the outcomes of nonoperative treatment. In randomized clinical trial, immediate immobilization was compared with a 5-day immobilization. At one week, the immediate mobilization group reported less pain and better function, but after 4 weeks both groups were comparable for pain, range of motion, and function (9). In another randomized study, patients were allocated into three groups of immediate mobilization, 48-hour sling before mobilization, and casting for 7 days before mobilization. The first two groups showed superior results in compare to cast immobilization. Patients in the immediate mobilization groups reported more pain in the first 3 days. Patients in the 48-hour sling group showed better function, strength, and range of motion of all. Therefore, a delay of 48 hour before starting movement might be advantageous although it is suggested to individualize mobilization based on the characteristics of the fracture and the patient (10). A randomized trial divided the patients with Mason type I and II fractures into three groups of immobilization in a cast in 90 degrees of flexion for 2 weeks, in a cast in extension for 2 weeks versus immediate mobilization in a sling without joint aspiration. The results showed no significant difference between casting in extension and sling mobilization. The worst results were seen in flexion casting while the best results were found in extension casting. Extension deficit was seen in 17 out of 81 patients while flexion deficit was only seen in 2 patients (11).

Management of Unstable Radial Head Fractures

Clinical implications

With a high energy trauma (HET) including falling from height, sports trauma, or motor vehicle accidents, a high index of suspicion is essential to look for the associated injuries. Extensive swelling and ecchymosis of the elbow indicates a complex injury. Bruising and tenderness over the medial compartment requires assessment of the MCL complex. Moreover, tenderness over the wrist may be indicative of DRUJ and IOL injury which requires bilateral wrist radiographic assessment to measure the radial shortening. Although >2 mm shortening relative to the contralateral side was shown to be correlated with the IOL injury, it is concluded that >4 mm is clinically relevant requiring operative intervention while <4 mm is amenable to nonoperative treatment (3, 12).

Nonoperative management

In selected cases, nonoperative management might be effective provided that the patient accepts the drawbacks of requiring a delayed surgery (13). This can be offered to patients with 1) concentric elbow after reduction, 2) no block in motion due to a radial head fracture, 3) a small coronoid fracture (<50%), 4) elbow remains stable when extended to about 30 degrees.

Radial head excision

In the presence of the associated injuries and elbow instability, radial head excision is not suggested because restoration of the radiocapitellar contact plays a role in elbow stability. Elbow may remain stable after either early or delayed excision of the head in an isolated radial head fracture and elbow dislocation but there is a high risk of re-dislocation if a coronoid fracture is present that is why it is called a terrible triad (14, 15). If a radial head excision is considered, IOL injury has to be ruled out by > 3mm displacement with the pull-push test or > 6 mm displacement with the lateral pull test in the supination-extension position and > 9mm displacement in the supination-flexion position (16). A recent study comparing excision versus radial head arthroplasty concluded that the MCL and the posteromedial capsule can be repaired in replace of a radial head arthroplasty which provided comparable results in terrible triad injuries (17). Another study comparing excision versus internal fixation of the comminuted Mason type III (mixed cases of isolated and associated injuries) found better range of motion, grip strength, and functional outcomes after internal fixation (18).

Internal fixation

The initial reports of internal fixation of the partial radial head fractures were very good. However, further expanding the indications showed more complications including nonunion, device failure, and poorer outcomes with internal fixation of more complex radial head fractures. It is not clear whether the initial good results could also be achieved with nonoperative or even excision of the head. Thus, internal fixation should be offered in selected patients where there is little or no metaphyseal bone loss with reparable head fragments.

Radial head prosthetic arthroplasty

The indication to use a prosthesis is elbow instability in the absence of the radial head. Prosthetic replacement seems to work better than internal fixation with less complications in an unstable multi-fragment radial head fracture. A randomized trial comparing a monoblock prosthesis versus ORIF found 91% good to excellent results with prosthesis versus 65% with ORIF as well as less complications with prosthesis (14% versus 48%) in comparison to ORIF (19). Another randomized trial comparing bipolar prosthesis versus ORIF found superior results with prosthesis when managing Mason type III fractures (20). Moreover, an Essex-Lopresti injury is an indication for prosthetic replacement because the chance of failure is high with ORIF due to axial instability (21).

Multiple studies comparing various designs and materials found little superiority of any design. We studied the durability and survival of all available radial head brands with different designs and materials, where we found little difference between different designs [Chapter 5]. Although hypothetically applying the head geometry may play a role in better restoration of function and motion, there is little or no difference between symmetric versus asymmetric heads, loose-fit versus press-fit stem fitting, monoblock versus bipolar, and metal versus pyrocarbon, titanium, and even polymethymethacrilate bone cement (22-24). To improve our understanding about interpretation and management of pain and stiffness following a radial head replacement, we decided to study the reasons for failure of a prosthesis**.** In this study we found that most of the reasons of prosthesis removal were irrelevant to the prosthesis itself and removal was significantly correlated with the surgeon’s decision [Chapter 6]. In rare cases after nonoperative treatment of the radial head fracture, radiocapitellar arthrosis may progress for which a late surgery might be offered to manage the painful elbow. We further studied the outcomes of concomitant replacement of the radial head and the capitellum using different designs of radiocapitellar prosthetic arthroplasty, where we could not establish any difference between the designs while the outcomes were comparable to early radial head replacement [Chapter 7]. Therefore, the choice of the prosthesis depends on the surgeon’s preference and availability in the region.

In resource limited countries, alternatives have been used in replace of a routine radial head prosthesis. The prosthesis has to remain in place until the ligaments heal and stabilize the elbow after which removal of the prosthesis does not seem to affect the stability. Following the evidence, the prosthesis seems to work more as a spacer to provide axial stability of the radius, valgus stability of the elbow following radiocapitellar contact, varus stability of the elbow by providing tension on the LCL, and to prevent convergence of the radius and the ulna. As an alternative to the metal radial head prosthesis, a study on the hand-made polymethacrylate (PMMA) spacer in unstable elbows showed 28 patients with good or excellent results, 8 fair and 2 poor results. Spacer was removed in 8 out of 38 patients after a mean of 54 months (25). Following the use of 3D printing technology in medicine, we designed the patient-specific radial head prosthesis and the molds by using the contralateral elbow CT scans. The prosthesis was made of the PMMA after hardening in the mold, which provided a cheap alternative to the standard prostheses and comparable functional outcomes after a mean of 18 months [Chapter 8]. We assume that the technique may be applied in resource-limited areas although its persuasive cost and the ease of use may expand its application.

General Conclusions

1. The majority of the radial head fractures are stable fractures and responsive to nonoperative treatments. A small number of the patients may remain symptomatic for which late surgery has shown very good results with either radial head excision or replacement. The surgeon has to be mindful about the concomitant injury to the capitellum which may lead to a painful elbow.
2. The risk of radiocapitellar arthritis after a radial head fracture is rare accounting for 0.5% of the fractures which is negligible. The degree of fracture displacement does not seem to influence the incidence of arthritis, but a more generalized elbow arthritis in the ulnohumeral joint is suggestive of that the severity of the initial trauma and the associated injuries are more prognostic.
3. A symptomatic radiocapitellar arthritis would benefit from radiocapitellar prosthetic arthroplasty irrespective of the etiology. Moreover, general elbow arthritis seems to become stationary after radiocapitellar prosthetic replacement.
4. The rate of prosthesis removal or revision for any reason is very low accounting for 10% of the replacements with most being removed within the first 2 years after implantation. There is no substantial difference in the longevity of different designs and different materials. This suggests the very good mid- to long-term outcomes of the radial head arthroplasty irrespective of the design.
5. The majority of the reasons of prosthesis removal are unrelated to the prosthesis itself, which includes excision of the radioulnar synostosis and release of elbow stiffness. Moreover, it might be the surgeon's perception of the symptoms to offer removal or revision of the prosthesis rather than an objective problem with the prosthesis.
6. When resources are limited, polymer-thylmethacrylate (PMMA) can be used to make a spacer, which showed to be a safe and effective alternative to restore elbow stability. The use of 3D printing technology may optimize the design.

Clinical Implications and Future Perspectives

The management considerations of the radial head fracture depend on the elbow stability. With the majority of injuries, the elbow remains stable with which the nonoperative management of the radial head fracture results in good to excellent functional outcomes. Even the symptomatic elbows would benefit from late surgery to excise the head, which supports the effectiveness of initial nonoperative management.

With injuries leading to elbow instability, head preservation surgery is preferred with superior results after radial head arthroplasty in comparison to the internal fixation. It seems that the prosthesis design does not affect the outcomes of elbow surgery. However, more long-term studies are required. The implications of arthroplasty on the capitellar cartilage, capitellar osteopenia, lesser sigmoid notch, and proximal radius bone resorption is not clear. Moreover, long-term studies are of paramount to assess the alterations in head geometry after nonoperative treatment on the capitellum cartilage and the lesser sigmoid notch.

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Chapter 11

Summary (English)

PART I - INTRODUCTION

Radial head fractures seem the most common injury of the elbow with reported incidence of 30-44% of elbow injuries. ***Chapter I*** discusses anatomy, epidemiology, classification of the radial head fractures, associated injuries and the diagnostic tests. In this chapter, general consideration regarding nonoperative and operative treatments and their indication with the historical background is presented.

PART II - Assessment of Posttraumatic Pathology

In ***PART II***, we focused on the assessment of the post-traumatic pathology, associated injuries with a radial head fracture including the IOL injury, and the role of nonoperative treatment after a radial head fracture. Two techniques have been introduced to test the associated injury to the IOL intraoperatively, including "radius pull test" and "radius joystick test". In ***Chapter 2*** we studied the intraobserver and interobserver reliability of the diagnosis of interosseous ligament (IOL) rupture in a cadaver model. Head replacement is mandatory if the IOL injury is documented. The introduced lateral pull technique is a qualitative method based on the surgeon's perception of excessive displacement. To quantify the amount of displacement, we introduced a technique in ***Chapter 3*** for the diagnosis of interosseous ligament (IOL) disruption based on lateral displacement of the radius after radial head resection and we determined the cutoff value of the lateral displacement for the diagnosis of disruption, the best elbow position for testing, and the diagnostic performance of the technique in different positions.

Malunion of the radial head fracture might theoretically result in step-off causing wear of the capitellum cartilage, which subsequently ends to a painful arthritis. To study the rate, reason, and solution for this condition following a radial head fracture, we decided to study factors associated with radiocapitellar OA in ***Chapter 4*** by studying the follow-up X-rays of the patients with an isolated radial head fracture who have undergone nonoperative treatment. Some radial head fractures are accompanied with a capitellum fracture which might exacerbate the condition which is so-called a kissing lesion. In ***Chapter 5***, we studied the treatment options and outcomes of patients with associated fractures of the capitellum.

PART III - Partial Arthroplasty for Posttraumatic Injuries

In ***PART III***, we focused on the role of radial head arthroplasty. This section discusses about the mid- and long-term outcomes, the rate of prosthesis removal,

the survival of the arthroplasty, and the role of prosthesis design in the outcome of a radial head arthroplasty. We first studied the literature and determined the overall incidence of radial head prosthesis removal or revision in a systematic review in ***Chapter 6***. Our secondary objectives addressed the incidence of removal or revision based on the type of prosthesis fixation (cemented, uncemented smooth stem, uncemented press-fit), material (metal, titanium, pyrocarbon), and design (short vs long stem and monopolar vs bipolar), and the reasons for prosthetic removal or revision. Knowing the survival and the reason to remove a prosthesis helps understand if the design or material has any role in the survival of the radial head prosthesis. This study showed that there was no substantial difference in the rate of removal between the designs and different materials. We then studied our patients' outcomes in ***Chapter 7*** regarding the rate and reason of prosthesis removal this study tests the hypothesis that there are no factors associated with removal or revision of a radial head prosthesis. A secondary analysis addressed the time to removal or revision. This study showed that the decision to remove a prosthesis is associated with specific surgeon, but the prosthesis design was not independently associated with prosthesis removal. Rarely, radial head fractures and the associated injuries to the capitellum cartilage may lead to a painful radiocapitellar arthritis for which a radiocapitellar prosthetic arthroplasty (RC PA) may be a solution. However, there is scarce data regarding mid-term outcomes of RC PA. In ***Chapter 8,*** we assessed the short-term to midterm functional and radiographic results of elbows after RC PA. Our secondary aim was to assess the survival of the RC PA. In resource limited regions, a metal radial head prosthesis might not be readily available or either be covered by the insurance. A cost effective method has been introduced by using polymethylmethacrylate (PMMA) bone cement to make a hand-made prosthesis which worked as an spacer with good results. We took the advantage of this material by applying 3D reconstruction of the contralateral radial head to precisely produce a PMMA radial head by mirroring the contralateral head. In ***Chapter 9*** we reported the outcomes of using antibiotic-impregnated polymethy-lmethacrylate (PMMA) bone cement to make a patient specific radial head. The results were comparable to the routine prostheses over a 18 month follow-up.

PART IV – General Discussion

Based on the literature and the current studies, the treatment plan is discussed in ***Chapter 10*** which helps make a decision and manage the radial head fractures and the associated injuries in a proper manner.

Chapter 12

Samenvatting

DEEL I - INLEIDING

Een radiuskopfractuur is de meest voorkomende fractuur rond de elleboog, met een gerapporteerde incidentie van 30-44% van alle elleboogletsels.

In hoofdstuk I van dit proefschrift wordt de anatomie, epidemiologie en classificatie van radius kopfracturen beschreven, alsmede de bijkomende letsels en de diagnostische tests hiervan. Vervolgens worden de overwegingen benoemd om een operatieve interventie te indiceren.

DEEL II - Beoordeling Van Posttraumatische Pathologie

In deel II hebben we ons gericht op de beoordeling van de bijkomende letsels bij een radiuskopfractuur en posttraumatische pathologie. Hierbij is onder andere gekeken naar letsels van de membrana interossei (MI).

Er zijn twee technieken voorgesteld om het begeleidend letsel van de MI peroperatief vast te stellen.

De eerste is de zogenaamde "radius pull test" en de 2^{e} is de "radius joystick test". In Hoofdstuk 2 bestudeerden we de intraobserver en interobserver betrouwbaarheid om een MI ruptuur vast te stellen in een kadavermodel. Als er sprake is van een MI letsel, lijkt reconstructie of vervangen van het caput radii belangrijk.

In Hoofdstuk 3 introduceren we een nieuwe techniek om insufficiëntie van het MI vast te stellen op basis van laterale verplaatsing van de radius, na een radiuskopresectie in kadavers.

Malunion van een radiuskopfractuur kan resulteren in versnelde slijtage van het capitellum. In sommige gevallen gaat dit gepaard met een pijnlijke (posttraumatische) artrose. In hoofdstuk 4 hebben we de factoren bepaald die mogelijk verband houden met radio-capitellaire artrose na een radiuskop fractuur. Hiertoe zijn röntgenfoto's geanalyseerd van patiënten met een geïsoleerde radiuskopfractuur, die een niet-operatieve behandeling hebben ondergaan. In hoofdstuk 5 hebben we de behandelopties voor en resultaten van patiënten met een radiuskopfractuur, die tevens een fractuur van het capitellum hadden, bestudeerd.

DEEL III - Partiele Arthroplastiek Van De Elleboog Voor Posttraumatische Aandoeningen

In DEEL III hebben we ons gericht op de rol van de arthroplastiek van de radiuskop.

In dit hoofdstuk worden de middellange termijn resultaten besproken van de radiuskopprothese. Hierbij is gekeken naar de survival van het implantaat als mede naar de invloed van het design van de prothese op de survival. In hoofdstuk 6 is een systematic review gedaan naar de incidentie van het verwijderen of reviseren van radiuskopprotheses.

Het is van belang de survival van een radiuskopprothese te kennen en te weten of deze afhankelijk is van de fixatie methode (gecementeerd, ongecementeerd of ‘intential loose fit’), materiaal (cobaltchroom, titanium, pyrocarbon), de lengte van de steel en type articulatie (monopolair versus bipolair). Deze studie toonde aan dat er geen substantieel verschil was in survival tussen verschillende designs, fixatie methodes en gebruikte materialen. Vervolgens presenteren we de uitkomsten van onze patiënten met een radiuskopprothese in hoofdstuk 7 waarin gekeken is naar de survival van het implantaat en reden tot explantatie. Deze studie toonde aan dat de beslissing om een prothese te verwijderen verband houdt met de werkwijze en voorkeuren van de behandelend chirurg.

Soms leiden fracturen van de radius kop of het capitellum tot een symptomatische artrose waarvoor een radiocapitellaire prothese (RCP) een oplossing kan zijn. De gegevens over de resultaten van RCP op middellange termijn zijn schaars. In Hoofdstuk 8 hebben we de korte en middellange functionele en radiologische resultaten na een RCP beoordeeld.

In bepaalde regio's zijn metalen radiuskopprotheses niet beschikbaar of worden deze niet gedekt door de zorgverzekering. Een kosten-effectieve methode is geïntroduceerd door gebruik te maken van polymethyl-methacrylaat (PMMA) botcement om een handgemaakte radiuskopprothese te maken die als een ‘spacer’ werkt, met hoopvolle eerste resultaten. In hoofdstuk 9 rapporteerden we de resultaten van het gebruik van met antibiotica geïmpregneerd polymethylmethacrylaat (PMMA) botcement om een patiëntspecifieke radiuskop te maken middels een mal op basis van een 3D-reconstructie van de contralaterale radiuskop. De resultaten waren vergelijkbaar met de standaard radiuskopprothesen gedurende een follow-up van 18 maanden.

DEEL IV - Algemene Bespreking

De uitkomsten van de studies in dit proefschrift worden gespiegeld aan de vigerende literatuur. Er wordt een voorstel gedaan voor het in kaart brengen van acute radiuskopfracturen en bijkomende letsels, teneinde een optimaal behandelplan op te stellen.

PART V

Appendix

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Last update: September 2020

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Google Scholar: https://scholar.google.com/citations?user=4FUreP4AAAAJ&hl=en

Education and Experience:

1994-1998	High school	Diploma	Imam Reza High School, Mashhad, Iran
1998-2004	Medical School & Internship	MD	Mashhad University of Medical Sciences, Mashhad, Iran
2007-2011	Orthopedic Residency	MD	Mashhad University of Medical Sciences, Mashhad, Iran
2013-2016	Hand and Upper Extremity Research Fellow	Post Doc	Massachusetts General Hospital, Harvard Medical School, Boston, USA
2016-2017	International Research Fellow		Rothman Institute Hand Service, Philadelphia, USA
2014-2016	Research Fellow		Ara Nazarian's Orthopedic Lab Collaboration, Beth Israel Deaconess Medical Center, Boston, USA
2014-now	PhD Candidate	PhD	Academic Medical Center, Amsterdam, The Netherlands
2018	Hand Fellowship		Iran University of Medical Sciences, Tehran, Iran
2017	USMLE Step 1	Passed 229	
2018	USMLE Step 2 CK	Passed 242	
2018	USMLE Step 2 CS	Passed	
2018	ECFMG Certified	USMLE	United States Medical Licensing Exam
2019	USMLE Step 3	Passed 231	
2020-2021	Clinical Foot & Ankle Fellowship		Rothman Institute, Thomas Jefferson University, Philadelphia, USA
2021-2022	Clinical Hand Fellowship		Rothman Institute, Thomas Jefferson University, Philadelphia, USA

Academic Appointments

2018-now	Board Member	Educational Committee, Iranian Orthopedic Association
2018-2019	Director	Medical Students Orthopedic Program, Mashhad University of Medical Sciences
2017-now	Affiliated Faculty	Research Division Rothman Institute Hand Service
2017-now	Orthopedic Consultant	National Forensic Medicine Organization
2015-now	Deputy Director	Orthopedic Research Center
2012-now	Orthopedic Consultant	Mashhad Medical Council
2012	Founder	Joint Care Clinic, Hemophilia Center
2012-now	Director	English Website, Orthopedics Department
2011-now	Assistant Professor of Orthopedic Surgery	Mashhad University of Medical Sciences, Mashhad, Iran
2011-now	Board Member	Orthopedic Resaerch Center
2011-now	Orthopedic Consultant	Sarvar Hemophilia Center

Achievements

1998	Rank 59 (Regional); Rank 113 (in the Nation) (Among more than 442,000 high school graduates)	University Entrance Exam	Iran
2007	Rank 29 (in the Nation) (Among more than 15,000 General physicians)	Residency Entrance Exam	Iran
2010	Awarded as Top Resident (Local) (Among 24 orthopedic residents)	Orthopedic Residency Program	Mashhad, Iran
2011	Rank 1 (Local) (Among 24 orthopedic residents)	Pre-Board Orthopedic Exam	Mashhad, Iran
2011	Rank 1 (in the Nation) (Among more than 170 board eligible orthopedic surgeons)	Board Exam	Iran
2012	Rank 1 (In the Nation) (Among 9 orthopedic surgeon participants)	Hand Fellowship Entrance Exam	Iran

Patents

Date	Title	Country	Patent no.
2020	Apparatus for Anatomic Three Dimensional Scanning and Automated Three Dimensional Cast and Splint Design	USA	63001945
2019	3D Printed Anatomical Model	USA	62/799,884
2018	Elbow Exoskeleton Utilizing A Combination Of Electrical Stimulation And Near-Infrared Spectroscopy,	USA	62/670,724
2018	Mechanical Elbow Locomotor	Iran	96101
2018	Customized 3D printed radial head prosthesis	Iran	97044
2015	System and Method for an External Hip Fixator	USA	PCT/US2015/041926
2014	Orthopedic Dual Sliding Compression Plate (ODSCP)	USA	US00D717434S
2013	Weight-bearing Percentage Sensor (WPS)	Iran	79026
2011	Orthopedic Dual Sliding Compression Plate (ODSCP)	Iran	68572

Awards

2018	Top Innovative Design for the Radial Head Prosthesis, Start-up Demo
2018	Elected Top Researcher in Orthopedic Surgery
2018	Top Technology Promoter, Mashhad University of Medical Sciences
2017	Second Top Paper, 25th Meeting of the Iranian Orthopedic Association
2016	3rd Top Technology Promoter, Mashhad University of Medical Sciences
2016	Elected Top Resercher in Orthopedic Surgery
2016	Collaboration in an awarded grant: AO North America
2016	Collaboration in an awarded grant: Orthopaedic Research and Education Foundation (OREF)
2016	Poster chosen to be highlighted for the (Hand and Wrist) Guided Poster Tour, AAOS, Orlando
2015	Top reviewer at Harvard Medical School, Publons
2014	ABJS Journal Promotion, Dean of the Medical School
2013	ODSCP innovation, Ministry of Health
2012	Founder, Hemophilia Joint Care Clinic
2011	Gold Medal & Diploma, "Geneva Invention" Exhibition
2011	Diploma for ODSCP, Romanian Ministry of Education, Research, Youth and Sport
2011	1st Rank, Ministry of Health Award, National Orthopedic Board Exam
2011	1st Rank, University Award, Pre-Board Examination of Orthopedics
2010	Top Orthopedic Resident

Grants

2015	$9,250	Co-investigator, AO Trauma North America
2015	$5,000	Co-investigator, OREF

Traveling grants

2014	AO Fellowship, Boston, USA
2012	Elective Orthopedic Surgery (EOS) 'Excellence' Training Program, Spain

Volunteer Jobs:

- Hemophilia Patient Care, Joint Care Clinic
- Board of Directors, Epidermolysis Bullosa (EB) Society

Publications (Books)

2019	**Amir Kachooei**, Tendon Transfers for Low Ulnar Nerve Palsy In: "Hand Surgery: tricks of the trade", Editor: Pedro Bredjikilian MD, Thieme Publisher
2017	Ebrahimzadeh MH, **Kachooei AR**. Principles and techniques of articular and Periarticular injection (persian).2nd ed.
2017	Ebrahimzadeh MH**, Kachooei AR**. Knee excerise in osteoarthritis (persian). 2nd ed.
2012	**E**brahimzadeh MH, **Kachooei AR**. Principles and techniques of articular and Periarticular injection (persian).1st ed.
2013	Ebrahimzadeh MH, **Kachooei AR**. Knee excerise in osteoarthritis (persian). 1st ed. 2013.
2004	**Kiernan JA.** Barr's the human nervous system: an anatomical viewpoint.7th ed. Cooperation in translation of the book in neurology, English to Persian.

Publication (Peer-reviewed papers)

2020 Javadi Hedayatabad J, **Kachooei AR**, Taher Chaharjouy N, Vaziri N, Mehrad-Majd H, Emadzadeh M, Abolghasemian M, Ebrahimzadeh MH. The Effect of Ozone (O3) versus Hyaluronic Acid on Pain and Function in Patients with Knee Osteoarthritis: A Systematic Review and Meta-Analysis. Arch Bone Jt Surg. 2020 May;8(3):343-354.

2020 Javadi I, Sargazi R, Daryaee MR, **Kachooei AR**. Influencing Factors on COVID-19 Infection Despite Protective Measures Among Orthopedic Residents: Air Ventilation and Contact Duration. Arch Bone Jt Surg. 2020 Apr;8(Suppl 1):310-312.

2020 Sedigh A, **Kachooei AR**, Beredjiklian PK, Vaccaro AR, Rivlin M. Safety and Efficacy of Casting during COVID-19 Pandemic: A Comparison of the Mechanical Properties of Polymers Used for 3D Printing to Conventional Materials Used for the Generation of Orthopaedic Orthoses. Arch Bone Jt Surg. 2020 Apr;8(Suppl 1):281-285.

2020 Baradaran A, Ebrahimzadeh MH, Baradaran A, **Kachooei AR**. Prevalence of Comorbidities in COVID-19 Patients: A Systematic Review and Meta-Analysis. Arch Bone Jt Surg. 2020 Apr;8(Suppl 1):247-255.

2020 Abolghasemian M, Ebrahimzadeh MH, Enayatollahi M, Honarmand K, **Kachooei AR,** Mehdipoor S, Mortazavi MJ, Mousavian A, Parsa A, Akasheh G, Bagheri F, Ebrahimpour A, Fakoor M, Moradi R, Razi M. Iranian Orthopedic Association (IOA) Response Guidance to COVID-19 Pandemic April 2020. Arch Bone Jt Surg. 2020 Apr;8(Suppl 1):209-217.

2020 Shariyate MJ, **Kachooei AR.** Association of New Coronavirus Disease with Fragility Hip and Lower Limb Fractures in Elderly Patients. Arch Bone Jt Surg. 2020 Apr;8(Suppl1):297-301.

2020 **Kachooei AR**, Heidari A, Divband G, Zandinezhad ME, Mousavian A, Farhangi H, Aminzadeh B, Zarifian A, Bagheri F, Badiei Z. Rhenium-188 radiosynovectomy for chronic haemophilic synovitis: Evaluation of its safety and efficacy in haemophilic patients. Haemophilia. 2020 Jan;26(1):142-150.

2019 Esmaeilzadeh J, Hesaraki S, Ebrahimzadeh MH, Asghari GH, **Kachooei AR**. Creep behavior of Biodegradable Triple-component Nanocomposites Based on PLA/PCL/bioactive Glass for ACL Interference Screws. Arch Bone Jt Surg. 2019 Nov;7(6):531-537.

2019 von Keudell A, **Kachooei A,** Mohamadi A, Mortensen SJ, Okajima S, Egan J, Weaver M, Dyer GSM, Nazarian A. Biomechanical properties of an intramedullary suture anchor fixation compared to tension band wiring in osteoporotic olecranon fractures- A cadaveric study. J Orthop. 2019 Aug 7;17:144-149.

2019 Said J, Frizzell K, Heimur J, **Kachooei A**, Beredjiklian P, Rivlin M. Visualization During Endoscopic Versus Open Cubital Tunnel Decompression: A Cadaveric Study.J Hand Surg Am. 2019 Aug;44(8):697.e1-697.e6. doi: 10.1016/j.jhsa.2018.10.004.

2019 Lans J, Alvarez J, **Kachooei AR**, Ozkan S, Jupiter JB. Dorsal Lunate Facet Fracture Reduction Using a Bone Reduction Forceps. J Wrist Surg. 2019 Apr;8(2):118-123. doi: 10.1055/s-0038-1673407.

2019 Tulipan JE, **Kachooei AR**, Shearin J, Braun Y, Wang ML, Rivlin M. Ultrasound Evaluation for Incomplete Carpal Tunnel Release. Hand (N Y). 2019 Mar 12:1558944719832040. doi: 10.1177/1558944719832040

2019 Deml C, Baradaran A, Chen N, Nasr M, **Kachooei AR**. Fowler Central Slip Tenotomy or Spiral Oblique Retinacular Ligament Reconstruction? A Cadaveric Biomechanical Study in Swan-Neck Deformity. Hand (N Y). 2019 Mar 8:1558944719834643. doi: 10.1177/1558944719834643.

2019 Ebrahimzadeh A, **Kachooei AR**. Reality Does Not Recognize Borders. Arch Bone Jt Surg. 2019 Jan;7(1):2.

2019 Jimenez ML, Hioe SD, **Kachooei AR**, Shearin JW, Jones CM, Rivlin M.Single-Bundle vs Double-Bundle (Anatomical) Reconstruction of the Thumb Ulnar Collateral Ligament: Biomechanical Study. Hand (N Y). 2019 Jul;14(4):483-486. doi: 10.1177/1558944717744338.

2018 Baradaran A, Baradaran A, Ebrahimzadeh MH, Kachooei AR, Rivlin M, Beredjiklian P. Comparison of Custom-made Versus Prefabricated Thumb Splinting for Carpometacarpal Arthrosis: A Systematic Review and Meta-analysis.Arch Bone Jt Surg. 2018 Nov;6(6):478-485. Review.

2018 Stephen Hioe, Christopher Jones, Megan Jimenez, **Amir R. Kachooei**, Michael Rivlin. The Effect of Distal Pole Scaphoid Resection on Wrist Biomechanics. HAND. 2018

2018 Wu F, **Kachooei AR (Corresponding author)**, Ebrahimzadeh MH, Bagheri F, Hakimi E, Shojaie B, Nazarian A. Bilateral Arm-Abduction Shoulder Radiography to Determine the Involvement of the Scapulothoracic Motion in Frozen Shoulder.Arch Bone Jt Surg. 2018 May;6(3):225-232.

2018 Ghale-Noie ZN, Hassani M, **Kachooei AR**, Kerachian MA. High Serum Alpha-2-Macroglobulin Level in Patients with Osteonecrosis of the Femoral Head. Arch Bone Jt Surg. 2018 May;6(3): 219-224.

2018 Hassankhani GG, Moradi A, Birjandinejad A, Vahedi E, **Kachooei AR**, Ebrahimzadeh MH. Translation and Validation of the Persian Version the Boston Carpal Tunnel Syndrome Questionnaire. Arch Bone Jt Surg. 2018 Jan;6(1):71-77.

2018 **Kachooei AR,** Heesakkers NAM, Heijink A, The B, Eygendaal D. Radiocapitellar prosthetic arthroplasty: short-term to midterm results of 19 elbows. J Shoulder Elbow Surg. 2018 Apr;27(4):726-732. doi: 10.1016/j.jse.2017.12.013.

2018 Rivlin M, **Kachooei AR**, Wang ML, Ilyas AM. Electrodiagnostic Grade and Carpal Tunnel Release Outcomes: A Prospective Analysis. J Hand Surg Am. 2018 Jan 31. pii: S0363-5023(16)31148-0. doi: 10.1016/j.jhsa.2017.12.002.

2018 **Kachooei AR,** Baradaran A, Ebrahimzadeh MH, van Dijk CN, Chen N. The Rate of Radial Head Prosthesis Removal or Revision: A Systematic Review and Meta-Analysis. J Hand Surg Am. 2018 Jan;43(1):39-53.e1. doi: 10.1016/j.jhsa.2017.08.031.

2017 **Kachooei AR,** Ring D. Evaluation of radiocapitellar arthritis in patients with a second radiograph at least 2 years after nonoperative treatment of an isolated radial head fracture. Arch Bone Jt Surg. 2017. 5(6). 375-379

2017 Shariati MJ, **Kachooei AR,** Ebrahimzadeh MH. Massive Emphysema and Pneumothorax Following Shoulder Arthroscopy under General Anaesthesia: A Case Report. Arch Bone Jt Surg. 2017. 5(6). 459-463

2017 **Kachooei AR**, Ring D. Persistent Medial Subluxation of the Ulna with Radiotrochlear Articulation. Arch Bone Jt Surg. 2017 Jul;5(4):263-268.

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2017 Ebrahimzadeh MH, **Kachooei AR**. Crash in Publication Ethics in 2016 in a Glance: Avoid Paper Retraction. Arch Bone Jt Surg. 2017 Jan;5(1):1.

2017 Orbay JL, Ring D, **Kachooei AR (Corrsponding author)**, Santiago-Figueroa J, Bolano L, Pirela-Cruz M, Hausman M, Papandrea RF. Multicenter trial of an internal joint stabilizer for the elbow. J Shoulder Elbow Surg. 2017 Jan;26(1):125-132. doi: 10.1016/j.jse.2016.09.023

2016 Moradi A, Menendez ME, **Kachooei AR**, Isakov A, Ring D. Update of the Quick DASH Questionnaire to Account for Modern Technology. Hand (N Y). 2016 Dec;11(4):403-409. doi: 10.1177/1558944715628006.

2016 Claessen FM, Heesters BA, Chan JJ, **Kachooei AR**, Ring D. A Meta-Analysis of the Effect of Corticosteroid Injection for Enthesopathy of the Extensor Carpi Radialis Brevis Origin. J Hand Surg Am. 2016 Oct;41(10):988-998.e2. doi: 10.1016/j.jhsa.2016.07.097.

2016 Ebrahimzadeh MH, Vahedi E, Baradaran A, Birjandinejad A, Seyyed-Hoseinian SH, Bagheri F, **Kachooei AR**. Psychometric Properties of the Persian Version of the Simple Shoulder Test (SST) Questionnaire.Arch Bone Jt Surg. 2016 Oct;4(4):387-392

2016 Soheila Refahi, Amir Reza Kachooei, Majid Farsadpour, Ramin Shahrayeni, Maryam Goudarzian , Yasamin Molavi Taleghani, Samira Foji, Parastoo Amiri, Akram Malekkahi, Mozhdeh Salari, Marjan Vejdani. Is Prescription Of Knee MRI According To Standard Clinical Guideline? Acta Medica Mediterranea, 2016, 32: 1207

2016 Claessen FM**, Kachooei AR**, Verheij KK, Kolovich GP, Mudgal CS. Outcomes of Concomitant Fractures of the Radial Head and Capitellum: The "Kissing Lesion". J Hand Microsurg. 2016 Aug;8(2):100-5. doi: 10.1055/s-0036-1585430. Epub 2016 Jul 15.

2016 Sabzevari S, Ebrahimpour A, Roudi MK, **Kachooei AR (Corresponding author).** High Tibial Osteotomy: A Systematic Review and Current Concept.Arch Bone Jt Surg. 2016 Jun;4(3):204-12.

2016 Rivlin M, Eberlin KR, **Kachooei AR**, Hosseini A, Zivaljevic N5, Li G, Mudgal C.. Side-to-Side Versus Pulvertaft Extensor Tenorrhaphy-A Biomechanical Study. J Hand Surg Am. 2016 Aug 18. pii: S0363-5023(16)30418-X. doi: 10.1016/j.jhsa.2016.07.106.

2016 Femke M. A. P. Claessen, **Amir R. Kachooei (Co-first authors)** · Gregory P. Kolovich ·Geert A. Buijze · Luke S. Oh · Michel P. J. van den Bekerom · Job N. Doornberg. Portal placement in elbow arthroscopy by novice surgeons: cadaver study. Knee Surg Sports Traumatol Arthrosc. 2016 Jun 28 DOI 10.1007/s00167-016-4186-y

2016 **Kachooei AR**, Mellema JJ, Tarabochia MA, Chen N, van Dijk CN, Ring D. Involvement of the lesser sigmoid notch in elbow fracture dislocations. J Shoulder Elbow Surg. 2016 May 24. pii: S1058-2746(16)00121-X. doi: 10.1016/j.jse.2016.02.013

2016 Baradaran A, Ebrahimzadeh MH, Birjandinejad A, **Kachooei AR (Corresponding author)**. Cross-Cultural Adaptation, Validation, and Reliability Testing of the Modified Oswestry Disability Questionnaire in Persian Population with Low Back Pain. Asian Spine J. 2016 Apr;10(2):215-9. doi: 10.4184/asj.2016.10.2.215.

2016 **Kachooei AR**, Talaei-Khoei M, Faghfouri A, Ring D. Factors associated with operative treatment of enthesopathy of the extensor carpi radialis brevis origin. J Shoulder Elbow Surg. 2016 Apr;25(4):666-670. doi: 10.1016/j.jse.2015.12.019.

2016 **Kachooei AR**, Claessen FM, Chase SM, Verheij KK, van Dijk CN, Ring D. Factors associated with removal of a radial head prosthesis placed for acute trauma. Injury. 2016 Mar 3. pii: S0020-1383(16)30022-5. doi: 10.1016/j.injury.2016.02.023.

2016 **Kachooei AR**, Tarabochia M, Jupiter JB. Distal Radius Volar Rim Fracture Fixation Using DePuy-Synthes Volar Rim Plate.J Wrist Surg. 2016 Mar;5(1):2-8. doi: 10.1055/s-0035-1570740.

2016 Von Keudell A, **Kachooei AR (Co-first author)**, Moradi A, Jupiter JB. Outcome of surgical fixation of lateral column distal humerus fractures. J Orthop Trauma. 2016 May;30(5):245-50. doi: 10.1097/BOT.0000000000000496.

2015 Ebrahimzadeh MH, Moradi A, Vahedi E, **Kachooei AR**. Mid-term clinical outcome of radial shortening for kienbock disease. J Res Med Sci. 2015 Feb;20(2):146-9.

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2015 Ebrahimzadeh MH, Birjandinejad A, **Kachooei AR (Corresponding author).** Cross-Cultural Adaptation, Validation, and Reliability of the Michigan Hand Outcomes Questionnaire among Persian Population. Hand Surg. 2015; 20(1):25-31. doi: 10.1142/S0218810415500033

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2015 Ebrahimzadeh MH, Birjandinejad A, Mardani-Kivi M, Razi S, **Kachooei AR (Corresponding author)**. Oxford Shoulder Score: A Cross-Cultural Adaptation and Validation Study of the Persian Version in Iran. Iranian Journal of Medical Sciences. 2015; 40(5):404-410

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2014 Mohammad Taghi Peyvandi,Mahdi Mazloumi, Mohammad Garadaghi,Ali Parsa, Hassan Bahrami Nassab, Amir Reza Kachooei, Ali Reza Hootkani. Clinical trial on femoral head osteonecrosis: simple core decompression vs. core decompression and fibular allo-graft placement. J Am Sci 2014;10(1s):74-77]. (ISSN: 1545-1003).

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2013 Rahimi H, **Kachooei AR**, Hallaj moghaddam M, Gharedaghi M, Mirkazemi M, Shahpari O, Hassani M, Moradi A, Asadian M. A Modified Triple Pelvic Osteotomy for the Treatmentof Hip Hypoplasia. Arch Bone Jt Surg. 2013; 1(1): 31-34. PMCID: PMC4151405

2013 Ebrahimzadeh MH, Mashhadinejad H, Moradi A, **Kachooei AR**. Carpal Tunnel Release in Diabetic and Non-DiabeticPatients. Arch Bone Jt Surg. 2013 September; 1(1): 23-27. PMCID: PMC4151404

2013 Bahari-Kashani M, **Kachooei AR**, Ebrahimi H, Peivandi MT, Amel-Farzad S, Bekhradianpoor N, Azami M, Fatehi A, Bahari-Kashani G. Comparative study of peroneal tenosynovitis as the complication of intra-articular calcaneal fracture in surgically and non-surgically treated patients. Iran Red Cres Med J. 2013; 15(10):e11378.

2013 Gharehdaghi M, Khooei A, Moradi A, Rahimi SH, **Kachooei AR**, Seyf P, Ebrahimi H, Sabzevari S, Ganji S, Ghaboulian N, Ziaei S, Asadian M.. 103 case to case compare of Core Needle biopsy results with open biopsy one in skeletal tumor. Life Sci J .2013;10(9s):245-250

2013 Omidi-Kashani F, Samini F, Hasankhani EG, **Kachooei AR**, Toosi KZ, Golhasani-Keshtan F. Does percutaneous kyphoplasty have better functional outcome than vertebroplasty in single level osteoporotic compression fractures? A comparative prospective study. J Osteoporos. 2013;2013:690329. doi: 10.1155/2013/690329. Epub 2013 Jul 18.

2013 **Kachooei AR,** Peivandi MT, Ebrahimzadeh MH, Razi S, Mahdavian-Naghashzargar R, Noori M, Habibzade-Shojaie SR, Hajitaghi H. Outcome assessment in the treatment of A2-OTA type fractures of the distal radius by short arm cast versus long arm cast. Annals of Biological Research.2013; 4 (5):247-251

2013 Ebrahimzadeh MH, **Kachooei AR (corresponding author)**, Soroush MR, Hasankhani EG, Razi S, Birjandinejad A. Long-term clinical outcomes of war-related hip disarticulation and transpelvic amputation. J Bone Joint Surg Am. 2013 Aug 21;95(16):e1141-6. doi: 10.2106/JBJS.L.01160.

2013 Samani SS, **Kachooei AR (corresponding author),** Ebrahimzadeh MH, Omidi-Kashhani F, Mahdavian-Naghashzargar R, Razi S. Application of Orthopedic Dual Sliding Compression Plate(ODSCP) in high medial tibial open wedge osteotomies. Iran Red Cres Med J. 2013 Apr;15(4):335-9. DOI:10.5812/ircmj.8371

2013 Makhmalbaf H**, Kachooei AR (corresponding author),** Mazloumi SM, Ebrahimzadeh MH, Omidi-Kashani F, Seyf P, Shiravani-Bakhtiari R, Bekhradianpoor N, Ebrahimi H. Bilateral one-half spica cast after open reduction and pelvic osteotomy in the Developmental Dislocation of the Hip. Iran Red Crescent Med J. 2013 Dec;15(12):e13366. doi: 10.5812/ircmj.13366. Epub 2013 Dec 5. PMID: 24693391

2011 Peivandi MT, **Kachooei AR**, Nazemian Z. New method to remove a broken guide pin in the hip joint. Orthopedics. 2011 Oct 5;34(10):e685-7. doi: 10.3928/01477447-20110826-25.

2011 Peivandi MT, **Kachooei AR,** Mahvelati ES, Mostafavian SZ, Ebrahimzadeh MH, Razi A. Comparison of Short and Long Arm Cast in Treating Stable Distal Radius Fractures in Adults. IJOS (Persian). 2011(summer); 9(3):121-5.

2010 **Kachooei AR,** Razi Sh, Mahdavian R, Makhmalbaf H. Results of posterior cruciate ligament avulsion fixation. IJOS (Persian).2010; 8:121-5.

2008 Peivandi MT, **Kachooei AR,** Amel-Farzad S. traumatic hip dislocation in an infant. Iran Red Crescent Med J.2008 oct;10(4):338-340.

2006 Peivandi MT, **Kachooei AR,** Amel-Farzad S. traumatic hip dislocation in an infant.IJOS (Persian). 2006 (winter);5:114-116.

2014	A Birjandinejad, MT Peivandi, AR Kachooei, A Razi, S Amelfarzad, F Omidi-Kashani. Necessity of MRI in Acute and Mild knee Problem. SAUSSUREA
2015	Appropriateness of Knee MRI Prescriptions in a Hospital of Birjand, 2014. International Journal of Scientific Reports

Publications (non peer-reviewed)

2014	**Kachooei AR.** Frozen shoulder: A common cause of shoulder pain. Journal of Mashhad Medical Council (JMMC). 1393 (2014); 18(2):105. (Persian) http://jmmc.mums.ac.ir/article_4218_592.html
2009	**Kachooei AR.** Fever. Navid-No.2009;44:17-21 (Persian) http://www.mums.ac.ir/research/fa/navid44.
2005	**Kachooi AR**, Razi Sh. Evaluation of increasing rate of brucellosis incidence in Avareshk in 2003-2005. Navid-No. 2005;10(29):17-20. (Persian)

Oral Presentations:

2019	Sep 5-7	74th Annual Meeting of the American Society for Surgery of the Hand (ASSH) Paper: Finite Element Method (FEM) Analysis of the Effect of the Plate Length and the Number of Screws in the Fixation of a Type A2 Distal Humerus Fracture	Las Vegas, USA
2019	June 17-21	14th IFSSH & 11th IFSHT Triennial Congress with combined FESSH Congress Paper: Factors associated with operative treatment of enthesopathy of the extensor carpi radialis brevis origin	Berlin, Germany
2019	June 17-21	14th IFSSH & 11th IFSHT Triennial Congress with combined FESSH Congress Paper: Intraoperative Technique for Evaluation of the Interosseous Ligament of the Forearm	Berlin, Germany
2019	June 17-21	14th IFSSH & 11th IFSHT Triennial Congress with combined FESSH Congress Paper: Radiocapitellar prosthetic arthroplasty: short-term to midterm results of 19 elbows	Berlin, Germany
2019	June 17-21	14th IFSSH & 11th IFSHT Triennial Congress with combined FESSH Congress Paper: Involvement of the lesser sigmoid notch in elbow fracture dislocations	Berlin, Germany
2019	June 17-21	14th IFSSH & 11th IFSHT Triennial Congress with combined FESSH Congress Paper: Factors associated with removal of a radial head prosthesis placed for acute trauma	Berlin, Germany

2018	Oct 22-26	26th Annual Meeting of Iranian Orthopedic Association Paper: The effect of Distal Pole Scaphoid Resection on Wrist Biomechanics	Tehran, Iran
2018	Oct 22-26	26th Annual Meeting of Iranian Orthopedic Association Paper: Electrodiagnostic Grade and Carpal Tunnel Release Outcomes	Tehran, Iran
2018	Oct 22-26	26th Annual Meeting of Iranian Orthopedic Association Paper: Single bundle versus Double Bundle Reconstruction of the Thumb Ulnar Collateral Ligament: Biomechanical Study	Tehran, Iran
2018	Oct 22-26	26th Annual Meeting of Iranian Orthopedic Association Paper: Side to side versus Pulvertaft Extensor Tenorrhaphy: Biomechanical Study	Tehran, Iran
2018	Oct 22-26	26th Annual Meeting of Iranian Orthopedic Association Paper: Visualization during Endoscopic vs. Open Cubital Tunnel Decompression: A Cadaveric Study	Tehran, Iran
2018	Oct 22-26	26th Annual Meeting of Iranian Orthopedic Association Paper: Rhenium 188 Radiosynovectomy for Chronic Hemophilic Arthropathy	Tehran, Iran
2018	Oct 22-26	26th Annual Meeting of Iranian Orthopedic Association Invited: Epidemiology and causes of brachial plexus injuries in Iran compared to world statistics	Tehran, Iran
2018	8-May	Iranian Association of Surgeons Invited: "Mallet finger"	Tehran, Iran
2018	March 6-10	AAOS Paper: Ultrasound-guided Basal Joint Injection: Does Experience Matter?	New Orleans, USA
2018	1-Mar	Iranian Association of Surgeons, Khorasan Branch Invited: "Pelvis tumor case presentation"	Mashhad, Iran
2018	16-Feb	5th Biennial International Congress of ISKAST Paper: One Stage Surgical Treatment for Concomitant Rotator Cuff Tears with Shoulder Stiffness has Comparable Results with Isolated Rotator Cuff Tears: A Systematic Review	Kish, Iran
2018	16-Feb	5th Biennial International Congress of ISKAST Invited: "Arthroscopic Treatment of Tennis Elbow"	Kish, Iran
2018	Jan 10-12	22nd Annual Orthopedic Congress of Shahid Beheshti University of Medical Sciences Invited: "Elbow Trauma: Panel Discussion"	Tehran, Iran

2017	Nov 20-24	25th Annual Meeting of Iranian Orthopedic Association Paper: Portal placement in elbow arthroscopy by novice surgeons: cadaver study	Tehran, Iran
2017	Nov 20-24	25th Annual Meeting of Iranian Orthopedic Association Paper: Multicenter trial of an Internal Joint Stabilizer for the Elbow	Tehran, Iran
2017	Nov 20-24	25th Annual Meeting of Iranian Orthopedic Association Paper: A Meta-Analysis of the Effect of Corticosteroid Injection for Enthesopathy of the Extensor Carpi Radialis Brevis Origin	Tehran, Iran
2017	Nov 20-24	25th Annual Meeting of Iranian Orthopedic Association Paper: Involvement of the Lesser Sigmoid Notch in Elbow Fracture Dislocations	Tehran, Iran
2017	Nov 20-24	25th Annual Meeting of Iranian Orthopedic Association Paper: Factors Associated with Operative Treatment of Enthesopathy of the Extensor Carpi Radialis Brevis Origin	Tehran, Iran
2017	Nov 20-24	25th Annual Meeting of Iranian Orthopedic Association Paper: Outcome of Surgical Fixation of Lateral Column Distal Humerus Fractures	Tehran, Iran
2017	Nov 20-24	25th Annual Meeting of Iranian Orthopedic Association Paper: Distal Radius Volar Rim Fracture Fixation Using DePuy-Synthes Volar Rim Plate.	Tehran, Iran
2017	June 4-8	11th Biennial ISAKOS Congress Paper: Outcomes Following Surgical Treatment for Rotator Cuff Tears with Adhesive Capsulitis are Equivalent to Surgical Treatment for Rotator Cuff Tears Alone: A Systematic Review"	Shanghai, China
2017	Feb 2-3	21st Annual Orthopedic Congress of Shahid Beheshti University of Medical Sciences "Surgery for Scaphoid Nonunion"	Tehran, Iran
2016	Dec 7-10	Orthopaedic Summit 2016 Evolving Techniques Paper: Single Bundle vs. Double Bundle (Anatomical) Reconstruction of the Thumb Ulnar Collateral Ligament - Biomechanical Study"	Las Vegas, Nevada
2016	Dec 6-9	Iranian Association of Surgeons, Khorasan Branch "Elbow arthroscopy: arthrofibrosis release	Mashhad, Iran
2016	Oct 24-28	IFSSH 50th anniversary Paper: Involvement of the Lesser Sigmoid Notch in Elbow Fracture Dislocations"	Buenos-Aires, Argentina

2016	Oct 24-28	IFSSH 50th anniversary Paper: The Rate of Radial Head Prosthesis Removal or Revision: A Systematic Review and Meta-Analysis"	Buenos-Aires, Argentina
2016	Sep 26-30	24th Annual Meeting of the Iranian Orthopedic Association Paper: The Rate of Radial Head Prosthesis Removal or Revision: A Systematic Review and Meta-Analysis	Tehran, Iran
2016	30-Sep-16	71st Annual Meeting of the American Society for Surgery of the Hand Paper: Electrodiagnostic Severity and Carpal Tunnel Release Outcomes: A Prospective Analysis"	Austin, TX, USA
2016	Sep 26-30	24th Annual Meeting of the Iranian Orthopedic Association Paper: The Rate of Radial Head Prosthesis Removal or Revision: A Systematic Review and Meta-Analysis	Tehran, Iran
2016	Aug 17th	Dr. Sheikh Hospital Radiosynovectomy in Hemophilia	Mashhad, Iran
2016	Aug 25th	Iranian Society for Surgery of the Hand "Radial Head Fractures"	Sari, Iran
2016	May 26-27	EbneSina Orthopedic Seminar " arthroscopic release in elbow stiffness"	Hamedan, Iran .
2016	May 26-27	EbneSina Orthopedic Seminar "Portals in elbow arthroscopy"	Hamedan, Iran .
2016	Jan 13-16	American Association of Hand Surgery (AAHS) Paper: Factors Associated with Removal of a Radial Head Prosthesis Placed for Acute Trauma"	Scottsdale, Arizona .
2016	Jan 13-16	American Association of Hand Surgery (AAHS) Paper: The Influence of Dominant Limb Involvement on DASH and QuickDASH"	Scottsdale, Arizona .
2015	Dec 4th	43rd annual meeting of New England Hand Society Paper: Factors Associated with Operative Treatment of Enthesopathy of the Extensor Carpi Radialis Brevis Origin"	Sturbridge, MA, USA .
2015	Jun 5th	5th Harvard Orthopedic Trauma Research Day Paper: Intra-operative evaluation of the inter-osseous membrane (IOM) of the forearm"	Boston, MA, USA .

2015	May 29th	26th Annual Smith's Day Paper: Factors associated with removal of the radial head prosthesis inserted for acute fracture"	Boston, MA, USA .
2015	Jan 29-30	Live Microvascular Surgery for Extremities "Principles of Microsurgery"	Mashhad, Iran .
2015	Jan 21-24	American Association of Hand Surgery (AAHS) Paper: Side-to-side vs. Pulvertaft Extensor Tendon Repair; Biomechanical Study"	Bahamas, USA .
2015	Sep 10-12	70th American Society for Surgery of the Hand (ASSH) Paper: Factors associated with re-operation after surgery for scaphoid nonunion"	Seattle, WA .
2014	Nov 24-28	3rd International Khorasan Congress for Surgeons (IKCS) "Wrist Arthroscopy"	Mashhad, Iran .
2014	Oct 15-18	Orthopedic Trauma Association (OTA) Paper: Clinical trial in the treatment of A2-OTA type fractures of the distal radius by casting"	Tampa, Florida, USA .
2014	Oct 13-17	22nd Annual meeting of the Iranian Orthopedic Association Paper: Intra-operative evaluation of the interosseous membrane (IOM) of the forearm"	Tehran, Iran .
2014	Jun 20th	4th annual Harvard Orthopedic Trauma Research Day Paper: Outcome of surgical fixation of lateral column distal humerus fractures."	Boston, MA, USA .
2014	May 30th	25th Annual Smith's Day "Mallet fracture: single pin fixation technique"	Boston, MA, USA .
2013	Dec 6th	41st annual meeting of New England Hand Society Paper: Variation in operative treatment for de Quervain's Tendinopathy"	Sturbridge, MA, USA .
2012	Oct 15-19	20th Annual meeting of the Iranian Orthopedic Association Paper: Comparison of short and long arm cast in treating stable distal radius fractures in adults"	Tehran, Iran .
2012	Nov 7-9	The 3rd International Congress of Endoscopic and Minimally Invasive Surgery "Principles of Arthroscopy"	Mashhad, Iran .

2011	Dec 15th	15th annual congress of Iranian society of physical medicine, rehabilitation and electrodiagnosis Paper: 26 year Long term clinical follow up of Iranian veterans with hip disarticulation and hemipelvis amputation"	Tehran, Iran .
2009	Dec 9th	Mashhad University of Medical Sciences "The necessity of MRI in acute and mild knee trauma"	Mashhad, Iran .
2005	Dec 24th	Ghaem Hospital Paper: Results of posterior cruciate ligament avulsion fixation"	Mashhad, Iran .
2002	Sep	Academy of young researchers "Fever and the fever curves"	Tabriz, Iran .
2001	Dec 1st	Mashhad University of Medical Sciences "Crimean-Congo Hemorrhagic Fever (CCHF)"	Mashhad, Iran

Poster Presentations

2019	June 17-21	Berlin, Germany	14th IFSSH & 11th IFSHT Triennial Congress with combined FESSH Congress Persistent Medial Subluxation of the Ulna with Radiotrochlear Articulation
2018	Oct 22-26	Tehran, Iran	26th Annual Meeting of Iranian Orthopedic Association Evaluation of Radiocapitellar Arthritis in Patients with a Second Radiograph at least 2 Years after Nonoperative Treatment of an Isolated Radial Head Fracture
2018	Oct 22-26	Tehran, Iran	26th Annual Meeting of Iranian Orthopedic Association Radiocapitellar Prosthetic Arthroplasty: Short term to midterm Results of 19 Elbows
2018	Oct 22-26	Tehran, Iran	26th Annual Meeting of Iranian Orthopedic Association Comparison of Custom made versus Prefabricated Thumb Splinting for Carpometacarpal Arthrosis: A Systematic Review and Metaanalysis
2018	Oct 22-26	Tehran, Iran	26th Annual Meeting of Iranian Orthopedic Association Bilateral Arm Abduction Shoulder Radiography to Determine the Involvement of the Scapulothoracic Motion in Frozen Shoulder
2018	Oct 22-26	Tehran, Iran	26th Annual Meeting of Iranian Orthopedic Association The Role of CPM versus no-CPM in the Treatment of Frozen Shoulder: A Systematic Review and Metaanalysis

2018 — Oct 22-26 — Tehran, Iran — 26th Annual Meeting of Iranian Orthopedic Association
Dorsal Lunate Facet Fracture Reduction using a Bone Clamp

2017 — March 19-22 — San Diego, California — ORS 2017 Annual Meeting
"Equivalent Outcomes Are Observed For Surgical Treatment Following Rotator Cuff Tears With Adhesive Capsulitis Versus Rotator Cuff Tears Without Adhesive Capsulitis: A Systematic Review"

2017 — March 19-22 — San Diego, California — ORS 2017 Annual Meeting
Bilateral Arm-Abduction Shoulder Radiography to Determine the Involvement of the Scapulothoracic
Motion in Frozen Shoulder

2017 — March 19-22 — San Diego, California — ORS 2017 Annual Meeting
Biomechanical Properties Of A New Intramedullary Suture Anchor Fixation Compared To Tension Band Wiring In Osteoporotic Olecranon Fractures

2017 — March 14-18 — San Diego, California — AAOS American Academy of Orthopedic Surgeons
Electrodiagnostic Severity and Carpal Tunnel Release Outcomes: A Prospective Analysis

2016 — September 26-30 — Tehran, Iran — 24th Iranian orthoped surgeon Congress
Evaluation of Radiocapitellar Arthritis in Patients with a Second Radiograph at least 2 years after Nonoperative Treatment of an Isolated Radial Head Fracture

2016 — September 26-30 — Tehran, Iran — 24th Iranian orthoped surgeon Congress
Evaluation of Radiocapitellar Arthritis in Patients with a Second Radiograph at least 2 years after Nonoperative Treatment of an Isolated Radial Head Fracture

2016 — September 26-30 — Tehran, Iran — 24th Iranian orthoped surgeon Congress
Factors associated with operative treatment of enthesopathy of the extensor carpi radialis brevis origin

2016 — September 26-30 — Tehran, Iran — 24th Iranian orthoped surgeon Congress
Application of Orthopedic Dual Sliding Compression Plate (ODSCP) in High Medial Tibial Open Wedge Osteotomies

2016 — September 26-30 — Tehran, Iran — 24th Iranian orthoped surgeon Congress
Involvement of the lesser sigmoid notch in elbow fracture dislocations

2016 — September 14-16 — Bologna, Italy — European Orthopaedic Research Society 24th Annual Meeting
Application of Orthopedic Dual Sliding Compression Plate (ODSCP) in High Medial Tibial Open Wedge Osteotomies

2016 — March 1-5 — Orlando, Florida — American Association of Orthopedic Surgeons (AAOS)
Outcome Assessment after Aptis Distal Radioulnar Joint (DRUJ) Implant Arthroplasty

2016	January 13-16	Scottsdale, Arizona	American Association of Hand Surgery (AAHS)
	Outcomes of concomitant fractures of the radial head and capitellum: The kissing lesion		
2016	January 13-16	Scottsdale, Arizona	American Association of Hand Surgery (AAHS)
	Outcome Assessment after Aptis Distal Radioulnar Joint (DRUJ) Implant Arthroplasty		
2016	January 13-16	Scottsdale, Arizona	American Association of Hand Surgery (AAHS)
	Factors Associated with Operative Treatment of Enthesopathy of the Extensor Carpi Radialis Brevis Origin		
2015	September 10-12	Seattle, WA	70th American Society for Surgery of the Hand (ASSH)
	"The Influence of Dominant Limb Involvement on DASH and QuickDASH"		
2015	September 10-12	Seattle, WA	70th American Society for Surgery of the Hand (ASSH)
	"Outcome Assessment after Aptis Distal Radioulnar Joint (DRUJ) Implant Arthroplasty"		
2015	September 10-12	Seattle, WA	70th American Society for Surgery of the Hand (ASSH)
	"Factors Associated with Removal of a Radial Head Prosthesis Placed for Acute Trauma"		
2015	September 10-12	Seattle, WA	70th American Society for Surgery of the Hand (ASSH)
	"Intra-operative evaluation of the inter-osseous membrane (IOM) of the forearm"		
2015	September 10-12	Seattle, WA	70th American Society for Surgery of the Hand (ASSH)
	"Intraoperative Physical Examination for Diagnosis of Inter-Osseous Ligament (IOL) Rupture - Cadaveric Study"		
2015	September 10-12	Seattle, WA	70th American Society for Surgery of the Hand (ASSH)
	Side-to-side versus Pulvertaft extensor tendinorrhaphy		
2015	September 10-12	Seattle, WA	70th American Society for Surgery of the Hand (ASSH)
	Outcome of concomitant fractures of the radial head and the capitellum: The 'Kissing lesion'		
2015	February 21-24	Bahamas, USA	American Association of Hand Surgeons (AAHS) annual meeting
	"Intra-operative Evaluation of the Inter-osseous Ligament (IOL)"		
2015	March 28-31	Las Vegas, USA	Orthopedic Research Society (ORS) annual meeting
	"Side-to-side Versus Pulvertaft Extensor Tendon Repair - Biomechanical Study"		
2015	January 14-17	Tehran, Iran	1st National Congress on Trauma
	"Long-term clinical outcomes of war-related hip disarticulation and transpelvic amputation."		

2014	October 3-5	Bari, Italy	8th Bari International Conference on hemophilia
	"Influencing factors on the functional level of haemophilic patients assessed by fish."		
2014	October 3-5	Bari, Italy	8th Bari International Conference on hemophilia
	"Vicious cycle of multiple invasive treatments in a hemophilic inhibitor positive child with resistant knee flexion contracture. A case report."		
2014	September 18-20	Boston, USA	69th American Society for Surgery of the Hand (ASSH)
	"Long-Term Clinical Outcome of Radial Shortening on Kienbock's Disease."		
2014	October 13-17	Tehran, Iran	22nd Annual meeting of the Iranian Orthopedic Association
	"Variation in operative treatment for de Quervain's Tendinopathy"		
2013	April 18-21	Chicago, U.S.A.	"13th international muskuloskeletal congress for hemophilia"
	"factors influencing functional independence score in hemophilia"		
2012	May 2-5	Geneva, Switzerland	"15th European Society of Sports Traumatology knee Surgery and Arthroscopy (ESSKA) congress"
	"Results of posterior cruciate ligament avulsion fixation"		
2011	February 24-	Mashhad, Iran	Mashhad University of Medical Sciences
	"Results of posterior cruciate ligament avulsion fixation"		

Training Programs

2018	Multi-ligament and Osteotomy Course (Arthrex Arthrolab)	Munich, Germany
2017	Shoulder and Elbow Arthroscopy (Amphia Hospital)	Breda, Netherlands
2016	Ligament reconstruction procedures (Rothman Institute)	Philadelphia
2015	Ultrasound-guided minimally invasive treatment of tendinopathies (FAST procedure) (Rothman Institute)	Philadelphia
2015	Endoscopic Carpal and Cubital Tunnel Release (Rothman Institute)	Philadelphia
2015	Wrist and Elbow Arthroscopy (Rothman Institute)	Philadelphia
2014	AO Fellowship (Massachusetts General Hospital)	Boston
2014	Elbow Arthroscopy (Smith & Nephew)	Boston
2012	Elective Orthopaedic Surgery 'Excellence' Training Program on haemophilic patients (La Paz Hospital)	Madrid, Spain
2012	Hip Arthroplasty Fellowship (Stolzalpe Hospital)	Stolzalpe, Austria
2012	AO Trauma Course- advances in operative fracture management	Dizin, Iran
2011	AO Trauma Course- advances in operative fracture management	Shiraz, Iran
2011	Infant Hip Sonography (by Reinhard Graf)	Mashhad, Iran

Memberships

2016	Current	Scientific board of 3rd national and 2nd International Stem cells and Regenerative Medicine Congress
2016	Current	Research Committee, Iranian Hand Society
2016	Current	Athens Institute for Education and Research
2015	Current	American Association of Orthopedic Surgeons (AAOS)
2015	Current	World Association of Medical Editors (WAME), www.wame.org
2015	Current	Researchers Institute
2012	2014	European Society of Sports Traumatology Knee surgery and Arthroscopy (ESSKA)
2012	Current	Supreme Council, Orthopaedic Research Center, Mashhad University of Medical Sciences
2012	Current	Stem Cell Committee, Mashhad University of Medical Sciences
2011	2015	AO TRAUMA (www.aotrauma.org)
2011	Current	Iranian Orthopedic Association
1999	2005	Top Student Committee 'Kanoon Daneshjooyane Momtaz', Mashhad University of Medical Sciences
1998	2005	Academy of Young Researchers 'Bashgahe Danesh Pajohane Javan', Azad University
1998	2005	Student Research Committee, Mashhad University of Medical Sciences

Appointments at Meetings:

2020	11-14 February	Co-chair	6th Iranian Society for Knee Surgery Arthroscopy Sports Traumatology (ISKAST)	Kish. Iran
2018	22-24 November	Course Director	2nd Annual Hand Elbow Shoulder Meeting	Mashhad, Iran
2017	12-13 October	Course Director	1st Annual Hand Elbow Shoulder Meeting	Mashhad, Iran
2015	29-30 February	Course Director	Live Microvascular Surgery for Extremities	Mashhad, Iran
2014	May	Scientific Committee	Stem Cell in Clinical Application	Mashhad, Iran
2012	7-9 Nov	Executive Director	3rd international congress of endoscopic and minimally invasive surgery	Mashhad, Iran
2012	August	Scientific Committee	Stem Cell in Clinical Application	Mashhad, Iran

Editorial Activities

Role	Journal
Editorial Board	Austin Pain & relief
Editorial Board	Luz Y Saber
Managing Editor	Archives of Bone and Joint Surgery
Editorial Board	Archives of Bone and Joint Surgery
Associate Editor	Advances in Human Biology
Reviewer	BMC Musculoskeletal disorders
Reviewer	BMJ case reports (British Medical Journal)
Reviewer	Iranian Red Crescent Medical Journal
Reviewer	Health and Quality of Life Outcomes (HQLO) Journal
Reviewer	Medical Journal of Mashhad University of Medical Sciences
Reviewer	Razavi International Journal of Medicine
Reviewer	African Journal of Microbiology Research
Reviewer	Case Reports in Orthopedics
Reviewer	Archives of Trauma Research
Reviewer	The 19th World Multi-Conference on Systemics, Cybernetics and Informatics: WMSCI 2015, July 12-15, 2015 – Orlando, Florida, USA
Reviewer	Patents, Mashhad University of Medical Sciences
Reviewer	McMaster Online Rating of Evidence (MORE)
Reviewer	Disability and Rehabilization
Reviewer	PLOS ONE Journal.
Reviewer	Stem Cells and Translational Medicine
Reviewer	Journal of International Medical Research (JIMR)

Teaching Experiences:

2011 – now: Orthopedic course for Medical students of Mashhad University of Medical Sciences
2011 – now: Orthopedic Surgery for Orthopedic Residents of Mashhad University of Medical Sciences
2011 – now: Orthopedic course for Midwifery students of Mashhad University of Medical Sciences
2011 – now: Orthopedic course for Operating Nurses of Mashhad University of Medical Sciences
2005: "Research Traning Workshop" for medical students of Mashhad University of Medical Sciences, 2005

Theses

2015	First Advisor	Ehsan Salimi	Medical Student	Influencing factors on the functional level of haemophilic patients assessed by FISH
2015	First Advisor	Ehsan Hakimi	Medical Student	Bilateral Arm-Abduction Shoulder Radiography to Determine the Involvement of the Scapulothoracic Motion in Frozen Shoulder
2016	First Advisor	Shima Esmaelpanah	Medical Student	Association between laboratory findings and plantar fasciitis

2016	First Advisor	Moslem Fallah	Orthopedic Resident	Clinical outcome of ACL reconstruction using hamstring tendon autograft versus tibialis tendon allograft
2017	Consultant	Azadeh Seyd Mohammad Khani	Medical Student	A comparative study of the outcomes of lumbar discectomy surgery in obese and non-obese patients
2017	Second Advisor	Afshin Noferesti	Medical Student	Does prior local cortisone injection affects improvement after carpal tunnel release
2018	First Advisor	Vahid Shahabinejad	Medical Student	Outcome study of total knee arthroplasty in hemophilia patients
2018	First Advisor	Ahmad Reza Zarifian	Medical Student	Biomechanical Effect of the Length of Fixation for Distal Humerus Fracture using Finite Element Analysis
2018	First Advisor	Arash Heidari	Orthopedic Resident	Rheniume-188 radiosynovectomy for chronic hemophilic arthropathy and synovitis
2018	Consultant	Hamideh Azizi	Master of OT/PT	The efficacy of continuous passive motion device on pain and functional range of motion in patients with frozen shoulder
2018	Consultant	Zahra Morovati	Master of OT/PT	Determining the effect of pain protection on Pain, Range of motion and hand strength in elderly people with osteoarthritis
2018	Consultant	Maryam Daghiani	Master of OT/PT	Comparison of Physiotherapy and Corticosteroid injection on Pain, functional ability and Quality of life in patient with impingement syndrome
2019	First Advisor	Hosein Ghorbani	Medical Student	Comparison of Custom-made versus Prefabricated Thumb Splinting for Carpometacarpal Arthrosis: A Systematic Review and Meta-analysis
2019	First Advisor	Fatemeh Far Homam	Medical Student	Patient Loyalty: Associated factors in remaining loyal and to recommend a physician to friends and families
2019	First Advisor	Ehsan Asghari	Medical Student	How long does it take for pain to recur after cortisone injection for eECRB, and De Quervain?
2019	Consultant	Mahdi Alimohammadi	Orthopedic Resident	The effect of Laterjet Procedure on Surface Area and Intra-Articular Stress Distribution :A Simulation Study Using 3D Finite Element Method
2019	Consultant	Amir Hosein Zabihi	Medical Student	Examination of the reliability and validity of theForgotten Joint Score-12 questionnaire (FJS-12)
2019	Consultant	Abdullatif Rezwani	Medical Student	Evaluation of functional outcomes and short-term complications in hip arthroplasty following advanced osteonecrosis due to medications and supplements
2020	Consultant	Mahsa Zaferanieh	Master of OT/PT	Clinical trial comparing the effect of physiotherapy with and without accupuncture on pain and function of patients with carpal tunnel syndrome.

2020	First Advisor	Mohammad BehAzin	Orthopedic Resident	Arthroscopic tennis elbow surgery
2020	First Advisor	Hadi Rajabi	Orthopedic Resident	Results of arthroscopic arthrolysis of the elbow following traumatic elbow stiffness

Certificates

2019	Recognizing and reporting child abuse: reporting in Pennsylvania
2019	PA-PDMP: Evidence-Based Prescribing: Tools You Can Use to Fight the Opioid Epidemic Module 3
2019	PA-PDMP: Evidence-Based Prescribing: Tools You Can Use to Fight the Opioid Epidemic Module 4
2019	PA-PDMP: Evidence-Based Prescribing: Tools You Can Use to Fight the Opioid Epidemic Module 6
2019	PA-PDMP: Evidence-Based Prescribing: Tools You Can Use to Fight the Opioid Epidemic Module 7
2014	"Applied Biostatistics for Clinical Trial" Massachusetts General Hospital, Boston, USA
2014	"Problem-base Biostatistics" Massachusetts General Hospital, Boston, USA
2014	"Basic statistics for clinical research" Massachusetts General Hospital, Boston, USA
2014	"CRC spotlight series: Managing and reporting unanticipated problems including adverse events" Massachusetts General Hospital, Boston, USA
2014	"Welcome to the genetic code: an overview of basic genetics" Massachusetts General Hospital, Boston
2014	"PHE-EPIC" Massachusetts General Hospital, Boston, USA
2014	"Cochrane standard training workshop" Mashhad, Iran
2014	"International congress on publication ethics (COPE)" Shiraz, Iran
2013	"Workshop on study design" Massachusetts General Hospital, Boston, USA
2013	"Orientation program: Clinical research resources at MGH" Massachusetts General Hospital, Boston,
2013	"Study Electronic Data Capture: REDCap and StudyTRAX" Massachusetts General Hospital, Boston
2013	"Study electronic data capture: StudyTRAX overview" Massachusetts General Hospital, Boston, USA
2013	"How to give a presentation" Massachusetts General Hospital, Boston, USA
2013	"Endnote X6 workshop" Mashhad, Iran
2013	"Endnote web" Mashhad, Iran
2013	"SPSS workshop" Mashhad, Iran
2013	"Wiley Online Library" Mashhad, Iran
2013	"Essay Writing" Mashhad, Iran
2013	"Research Training workshop" Mashhad, Iran
2013	"Using MGH clinical care data for clinical effectiveness research", Massachusetts general Hospital, Boston

2013 "MGH CAP training" Massachusetts General Hospital, Boston, USA
2013 "Collaborative Institutional Training Initiative (CITI" Boston, USA
2013 "Systematic review workshop" Mashhad, Iran
2012 “Peer Review Workshop” Mashhad, Iran
2012 "Lecture Presentation workshop" Mashhad, Iran
2012 "MCQ workshop" Mashhad, Iran
2012 "OSCE workshop" Mashhad, Iran
2012 "Communication skills of doctor and patient", Mashhad, Iran
2007 "Research Training workshop" Mashhad, Iran
2007 "Medical Journal Searching workshop" Mashhad, Iran
2005 "Research Training workshop" Mashhad, Iran

Language Skills

- Persian, English, French, Arabic
- Job experiences in teaching English in Mashhad (Imam Hossein English School 2001-2002, Kishair English School 2003-2005, and Gaame Andishe English School 2009-2010).

Skills

- SPSS statistics, Stata statistics, Osirix, 3D slicer, Rhinoceros, Comprehensive Meta-analysis, Endnote, Microsoft Word, Excel, PowerPoint, Outlook, Internet Explorer, PubMed.

Hobbies

- Swimming, Basketball
- Playing Violin

PhD Portfolio

Name PhD Student: Amir R. Kachooei
PhD Period: 2013-2021
Name PhD Supervisor: Niek van Dijk, Denise Eygendaal, David Ring

1. PHD TRAINING

Workload	Year	
		Statistics
	2014	"*Applied Biostatistics for Clinical Trial*" Massachusetts General Hospital, Boston, USA
50 hours	2014	"*Problem-base Biostatistics*" Massachusetts General Hospital, Boston, USA
	2014	"*Basic statistics for clinical research*" Massachusetts General Hospital, Boston, USA
		Workshops
	2014	*"Cochrane standard training workshop" Mashhad, Iran*
	2013	"*Workshop on study design*" Massachusetts General Hospital, Boston, USA
	2013	*"Endnote X6 workshop"* Mashhad, Iran
	2013	*"Endnote web"* workshop, Mashhad, Iran
160 hours	2013	*"SPSS workshop"* Mashhad, Iran
	2013	*"Research Training workshop"* Mashhad, Iran
	2013	*"Systematic review workshop" Mashhad, Iran*
	2012	*"Peer Review Workshop"* Mashhad, Iran
	2012	*"Lecture Presentation workshop"* Mashhad, Iran
		General
	2014	"*CRC spotlight series: Managing and reporting unanticipated problems including adverse events*" Massachusetts General Hospital, Boston, USA
	2014	"Welcome to the genetic code: an overview of basic genetics" Massachusetts General Hospital, Boston
	2014	*"PHE-EPIC" Massachusetts General Hospital, Boston, USA*
60 hours	2014	*"Publication ethics (COPE)" Shiraz, Iran*
	2013	"*Orientation program: Clinical research resources at MGH*" Massachusetts General Hospital, Boston,
	2013	"*Study Electronic Data Capture: REDCap and StudyTRAX*" Massachusetts General Hospital, Boston

2013	"*Study electronic data capture: StudyTRAX overview*" Massachusetts General Hospital, Boston, USA
2013	"*How to give a presentation*" Massachusetts General Hospital, Boston, USA
2013	*"Wiley Online Library"* Mashhad, Iran
2013	*"Essay Writing"* Mashhad, Iran
2013	*"Using MGH clinical care data for clinical effectiveness research", Massachusetts general Hospital, Boston*
2013	*"MGH CAP training" Massachusetts General Hospital, Boston, USA*
2013	*"Collaborative Institutional Training Initiative (CITI" Boston, USA*

2. PRESENTATIONS

Year	
	Podium presentation
2019	74th Annual Meeting of the American Society for Surgery of the Hand (ASSH), Las Vegas, USA
2019	14th IFSSH & 11th IFSHT Triennial Congress with combined FESSH Congress, Berlin Germany x5
2018	26th Annual Meeting of Iranian Orthopedic Association, Tehran x7
2018	AAOS, New Orleans, USA
2018	5th Biennial International Congress of ISKAST, Kish Iran
2017	25th Annual Meeting of Iranian Orthopedic Association, Tehran, Iran x7
2017	11th Biennial ISAKOS Congress, Shanghai, China
2016	Orthopaedic Summit 2016 Evolving Techniques, Las Vegas, USA
2016	IFSSH 50th anniversary, Buenos-Aires, Argentina x2
2016	24th Annual Meeting of the Iranian Orthopedic Association, Tehran
2016	71st Annual Meeting of the American Society for Surgery of the Hand, Austin, USA
2015	43rd annual meeting of New England Hand Society, Sturbridge, USA
2015	5th Harvard Orthopedic Trauma Research Day, Boston, USA
2015	26th Annual Smith's Day, Boston, USA
2015	70th American Society for Surgery of the Hand (ASSH), Seattle, USA
2014	Orthopedic Trauma Association (OTA), Tampa, USA
2014	4th annual Harvard Orthopedic Trauma Research Day, Boston, USA
2014	25th Annual Smith’s Day, Boston, USA
	Poster presentation
2019	14th IFSSH & 11th IFSHT Triennial Congress with combined FESSH Congress, Berlin, Germany
2018	26th Annual Metting of Iranian Orthopedic Association, Tehran, Iran
2017	ORS 2017 Annual Meeting, SanDiego, USA
2017	AAOS American Academy of Orthopedic Surgeons, San Diego
2016	American Association of Orthopedic Surgeons (AAOS), Orlando, USA
2016	American Association of Hand Surgery (AAHS), Scottsdale, USA

2015	70th American Society for Surgery of the Hand (ASSH), Seattle, USA x7
2014	69th American Society for Surgery of the Hand (ASSH), Boston, USA

3. TEACHING EXPERIENCE

Year	
	Theses
2014-2020	Theses, First Advisor x12
2014-2020	Thesis, Second Advisor x1
2014-2020	Theses, Consultant x9
	Teaching
2014-2020	Orthopedic course for Medical students of Mashhad University of Medical Sciences
2014-2020	Orthopedic Surgery for Orthopedic Residents of Mashhad University of Medical Sciences
2014-2020	Orthopedic course for Midwifery students of Mashhad University of Medical Sciences
2014-2020	Orthopedic course for Operating Nurses of Mashhad University of Medical Sciences
	Mentoring & Supervising
2015-2020	Post doc and Research Fellows x5

4. PARAMETERS OF ESTEEM

Year	
	Grants
2015	Co-investigator, AO Trauma North America
2015	Co-investigator, OREF
	Awards
2018	Top Innovative Design for the Radial Head Prosthesis, Start-up Demo
2018	Elected Top Researcher in Orthopedic Surgery
2018	Top Technology Promoter, Mashhad University of Medical Sciences
2017	Second Top Paper, 25th Meeting of the Iranian Orthopedic Association
2016	3rd Top Technology Promoter, Mashhad University of Medical Sciences
2016	Elected Top Resercher in Orthopedic Surgery
2016	Collaboration in an awarded grant: AO North America
2016	Collaboration in an awarded grant: Orthopaedic Research and Education Foundation (OREF)
2016	Poster chosen to be highlighted for the (Hand and Wrist) Guided Poster Tour, AAOS, Orlando
2015	Top reviewer at Harvard Medical School, Publons
2014	ABJS Journal Promotion, Dean of the Medical School
	Travelling Grants
2014	AO Fellowship, Boston, USA

Patents

2020	Apparatus for Anatomic Three Dimensional Scanning and Automated Three Dimensional Cast and Splint Design
2019	3D Printed Anatomical Model
2018	Elbow Exoskeleton Utilizing A Combination Of Electrical Stimulation And Near-Infrared Spectroscopy,
2018	Mechanical Elbow Locomotor
2018	Customized 3D printed radial head prosthesis
2015	System and Method for an External Hip Fixator
2014	Orthopedic Dual Sliding Compression Plate (ODSCP)

Journal reviewer

BMC Musculoskeletal disorders
BMJ case reports (British Medical Journal)
Iranian Red Crescent Medical Journal
Health and Quality of Life Outcomes (HQLO) Journal
Medical Journal of Mashhad University of Medical Sciences
Razavi International Journal of Medicine
African Journal of Microbiology Research
Case Reports in Orthopedics
Archives of Trauma Research
Patents, Mashhad University of Medical Sciences
McMaster Online Rating of Evidence (MORE)
Disability and Rehabilization
PLOS ONE Journal.
Stem Cells and Translational Medicine
Journal of International Medical Research (JIMR)

Editorial Board

Austin Pain & relief
Luz Y Saber
Archives of Bone and Joint Surgery

5. PUBLICATIONS

Year	
2020	Javadi Hedayatabad J, **Kachooei AR**, Taher Chaharjouy N, Vaziri N, Mehrad-Majd H, Emadzadeh M, Abolghasemian M, Ebrahimzadeh MH. The Effect of Ozone (O3) versus Hyaluronic Acid on Pain and Function in Patients with Knee Osteoarthritis: A Systematic Review and Meta-Analysis. Arch Bone Jt Surg. 2020 May;8(3):343-354.

2020 Javadi I, Sargazi R, Daryaee MR, **Kachooei AR**. Influencing Factors on COVID-19 Infection Despite Protective Measures Among Orthopedic Residents: Air Ventilation and Contact Duration. Arch Bone Jt Surg. 2020 Apr;8(Suppl 1):310-312.

2020 Sedigh A, **Kachooei AR**, Beredjiklian PK, Vaccaro AR, Rivlin M. Safety and Efficacy of Casting during COVID-19 Pandemic: A Comparison of the Mechanical Properties of Polymers Used for 3D Printing to Conventional Materials Used for the Generation of Orthopaedic Orthoses. Arch Bone Jt Surg. 2020 Apr;8(Suppl 1):281-285.

2020 Baradaran A, Ebrahimzadeh MH, Baradaran A, **Kachooei AR**. Prevalence of Comorbidities in COVID-19 Patients: A Systematic Review and Meta-Analysis. Arch Bone Jt Surg. 2020 Apr;8(Suppl 1):247-255.

2020 Abolghasemian M, Ebrahimzadeh MH, Enayatollahi M, Honarmand K, **Kachooei AR,** Mehdipoor S, Mortazavi MJ, Mousavian A, Parsa A, Akasheh G, Bagheri F, Ebrahimpour A, Fakoor M, Moradi R, Razi M. Iranian Orthopedic Association (IOA) Response Guidance to COVID-19 Pandemic April 2020. Arch Bone Jt Surg. 2020 Apr;8(Suppl 1):209-217.

2020 Shariyate MJ, **Kachooei AR.** Association of New Coronavirus Disease with Fragility Hip and Lower Limb Fractures in Elderly Patients. Arch Bone Jt Surg. 2020 Apr;8(Suppl1):297-301.

2020 **Kachooei AR**, Heidari A, Divband G, Zandinezhad ME, Mousavian A, Farhangi H, Aminzadeh B, Zarifian A, Bagheri F, Badiei Z. Rhenium-188 radiosynovectomy for chronic haemophilic synovitis: Evaluation of its safety and efficacy in haemophilic patients. Haemophilia. 2020 Jan;26(1):142-150.

2019 Esmaeilzadeh J, Hesaraki S, Ebrahimzadeh MH, Asghari GH, **Kachooei AR**. Creep behavior of Biodegradable Triple-component Nanocomposites Based on PLA/PCL/bioactive Glass for ACL Interference Screws. Arch Bone Jt Surg. 2019 Nov;7(6):531-537.

2019 von Keudell A, **Kachooei A,** Mohamadi A, Mortensen SJ, Okajima S, Egan J, Weaver M, Dyer GSM, Nazarian A. Biomechanical properties of an intramedullary suture anchor fixation compared to tension band wiring in osteoporotic olecranon fractures- A cadaveric study. J Orthop. 2019 Aug 7;17:144-149.

2019 Said J, Frizzell K, Heimur J, **Kachooei A**, Beredjiklian P, Rivlin M. Visualization During Endoscopic Versus Open Cubital Tunnel Decompression: A Cadaveric Study.J Hand Surg Am. 2019 Aug;44(8):697.e1-697.e6. doi: 10.1016/j.jhsa.2018.10.004.

2019 Lans J, Alvarez J, **Kachooei AR**, Ozkan S, Jupiter JB. Dorsal Lunate Facet Fracture Reduction Using a Bone Reduction Forceps. J Wrist Surg. 2019 Apr;8(2):118-123. doi: 10.1055/s-0038-1673407.

2019	Tulipan JE, **Kachooei AR**, Shearin J, Braun Y, Wang ML, Rivlin M. Ultrasound Evaluation for Incomplete Carpal Tunnel Release. Hand (N Y). 2019 Mar 12:1558944719832040. doi: 10.1177/1558944719832040
2019	Deml C, Baradaran A, Chen N, Nasr M, **Kachooei AR**. Fowler Central Slip Tenotomy or Spiral Oblique Retinacular Ligament Reconstruction? A Cadaveric Biomechanical Study in Swan-Neck Deformity. Hand (N Y). 2019 Mar 8:1558944719834643. doi: 10.1177/1558944719834643.
2019	Ebrahimzadeh A, **Kachooei AR**. Reality Does Not Recognize Borders. Arch Bone Jt Surg. 2019 Jan;7(1):2.
2019	Jimenez ML, Hioe SD, **Kachooei AR**, Shearin JW, Jones CM, Rivlin M.Single-Bundle vs Double-Bundle (Anatomical) Reconstruction of the Thumb Ulnar Collateral Ligament: Biomechanical Study. Hand (N Y). 2019 Jul;14(4):483-486. doi: 10.1177/1558944717744338.
2018	Baradaran A, Baradaran A, Ebrahimzadeh MH, Kachooei AR, Rivlin M, Beredjiklian P. Comparison of Custom-made Versus Prefabricated Thumb Splinting for Carpometacarpal Arthrosis: A Systematic Review and Meta-analysis.Arch Bone Jt Surg. 2018 Nov;6(6):478-485. Review.
2018	Stephen Hioe, Christopher Jones, Megan Jimenez, **Amir R. Kachooei**, Michael Rivlin. The Effect of Distal Pole Scaphoid Resection on Wrist Biomechanics. HAND. 2018
2018	Wu F, **Kachooei AR (Corresponding author)**, Ebrahimzadeh MH, Bagheri F, Hakimi E, Shojaie B, Nazarian A. Bilateral Arm-Abduction Shoulder Radiography to Determine the Involvement of the Scapulothoracic Motion in Frozen Shoulder.Arch Bone Jt Surg. 2018 May;6(3):225-232.
2018	Ghale-Noie ZN, Hassani M, **Kachooei AR**, Kerachian MA. High Serum Alpha-2-Macroglobulin Level in Patients with Osteonecrosis of the Femoral Head. Arch Bone Jt Surg. 2018 May;6(3):219-224.
2018	Hassankhani GG, Moradi A, Birjandinejad A, Vahedi E, **Kachooei AR**, Ebrahimzadeh MH. Translation and Validation of the Persian Version the Boston Carpal Tunnel Syndrome Questionnaire. Arch Bone Jt Surg. 2018 Jan;6(1):71-77.
2018	**Kachooei AR,** Heesakkers NAM, Heijink A, The B, Eygendaal D. Radiocapitellar prosthetic arthroplasty: short-term to midterm results of 19 elbows. J Shoulder Elbow Surg. 2018 Apr;27(4):726-732. doi: 10.1016/j.jse.2017.12.013.
2018	Rivlin M, **Kachooei AR**, Wang ML, Ilyas AM. Electrodiagnostic Grade and Carpal Tunnel Release Outcomes: A Prospective Analysis. J Hand Surg Am. 2018 Jan 31. pii: S0363-5023(16)31148-0. doi: 10.1016/j.jhsa.2017.12.002.

2018 **Kachooei AR,** Baradaran A, Ebrahimzadeh MH, van Dijk CN, Chen N. The Rate of Radial Head Prosthesis Removal or Revision: A Systematic Review and Meta-Analysis. J Hand Surg Am. 2018 Jan;43(1):39-53.e1. doi: 10.1016/j.jhsa.2017.08.031.

2017 **Kachooei AR,** Ring D. Evaluation of radiocapitellar arthritis in patients with a second radiograph at least 2 years after nonoperative treatment of an isolated radial head fracture. Arch Bone Jt Surg. 2017. 5(6). 375-379

2017 Shariati MJ, **Kachooei AR,** Ebrahimzadeh MH. Massive Emphysema and Pneumothorax Following Shoulder Arthroscopy under General Anaesthesia: A Case Report. Arch Bone Jt Surg. 2017. 5(6). 459-463

2017 **Kachooei AR**, Ring D. Persistent Medial Subluxation of the Ulna with Radiotrochlear Articulation. Arch Bone Jt Surg. 2017 Jul;5(4):263-268.

2017 Sabzevari S, **Kachooei AR**, Giugale J, Lin A. One-stage surgical treatment for concomitant rotator cuff tears with shoulder stiffness has comparable results with isolated rotator cuff tears: a systematic review. J Shoulder Elbow Surg. 2017 Aug;26(8):e252-e258. doi: 10.1016/j.jse.2017.03.005. Epub 2017 May 3. Review.

2017 Ebrahimzadeh MH, **Kachooei AR**. Crash in Publication Ethics in 2016 in a Glance: Avoid Paper Retraction. Arch Bone Jt Surg. 2017 Jan;5(1):1.

2017 Orbay JL, Ring D, **Kachooei AR (Corrsponding author)**, Santiago-Figueroa J, Bolano L, Pirela-Cruz M, Hausman M, Papandrea RF. Multicenter trial of an internal joint stabilizer for the elbow. J Shoulder Elbow Surg. 2017 Jan;26(1):125-132. doi: 10.1016/j.jse.2016.09.023

2016 Moradi A, Menendez ME, **Kachooei AR**, Isakov A, Ring D. Update of the Quick DASH Questionnaire to Account for Modern Technology. Hand (N Y). 2016 Dec;11(4):403-409. doi: 10.1177/1558944715628006.

2016 Claessen FM, Heesters BA, Chan JJ, **Kachooei AR**, Ring D. A Meta-Analysis of the Effect of Corticosteroid Injection for Enthesopathy of the Extensor Carpi Radialis Brevis Origin. J Hand Surg Am. 2016 Oct;41(10):988-998.e2. doi: 10.1016/j.jhsa.2016.07.097.

2016 Ebrahimzadeh MH, Vahedi E, Baradaran A, Birjandinejad A, Seyyed-Hoseinian SH, Bagheri F, **Kachooei AR**. Psychometric Properties of the Persian Version of the Simple Shoulder Test (SST) Questionnaire.Arch Bone Jt Surg. 2016 Oct;4(4):387-392

2016 Soheila Refahi, Amir Reza Kachooei, Majid Farsadpour, Ramin Shahrayeni, Maryam Goudarzian , Yasamin Molavi Taleghani, Samira Foji, Parastoo Amiri, Akram Malekkahi, Mozhdeh Salari, Marjan Vejdani. Is Prescription Of Knee MRI According To Standard Clinical Guideline? Acta Medica Mediterranea, 2016, 32: 1207

2016	Claessen FM**, Kachooei AR**, Verheij KK, Kolovich GP, Mudgal CS. Outcomes of Concomitant Fractures of the Radial Head and Capitellum: The "Kissing Lesion". J Hand Microsurg. 2016 Aug;8(2):100-5. doi: 10.1055/s-0036-1585430. Epub 2016 Jul 15.
2016	Sabzevari S, Ebrahimpour A, Roudi MK, **Kachooei AR (Corresponding author).** High Tibial Osteotomy: A Systematic Review and Current Concept.Arch Bone Jt Surg. 2016 Jun;4(3):204-12.
2016	Rivlin M, Eberlin KR, **Kachooei AR**, Hosseini A, Zivaljevic N5, Li G, Mudgal C.. Side-to-Side Versus Pulvertaft Extensor Tenorrhaphy-A Biomechanical Study. J Hand Surg Am. 2016 Aug 18. pii: S0363-5023(16)30418-X. doi: 10.1016/j.jhsa.2016.07.106.
2016	Femke M. A. P. Claessen, **Amir R. Kachooei (Co-first authors)** · Gregory P. Kolovich ·Geert A. Buijze · Luke S. Oh · Michel P. J. van den Bekerom · Job N. Doornberg. Portal placement in elbow arthroscopy by novice surgeons: cadaver study. Knee Surg Sports Traumatol Arthrosc. 2016 Jun 28 DOI 10.1007/s00167-016-4186-y
2016	**Kachooei AR**, Mellema JJ, Tarabochia MA, Chen N, van Dijk CN, Ring D. Involvement of the lesser sigmoid notch in elbow fracture dislocations. J Shoulder Elbow Surg. 2016 May 24. pii: S1058-2746(16)00121-X. doi: 10.1016/j.jse.2016.02.013
2016	Baradaran A, Ebrahimzadeh MH, Birjandinejad A, **Kachooei AR (Corresponding author)**. Cross-Cultural Adaptation, Validation, and Reliability Testing of the Modified Oswestry Disability Questionnaire in Persian Population with Low Back Pain. Asian Spine J. 2016 Apr;10(2):215-9. doi: 10.4184/asj.2016.10.2.215.
2016	**Kachooei AR**, Talaei-Khoei M, Faghfouri A, Ring D. Factors associated with operative treatment of enthesopathy of the extensor carpi radialis brevis origin. J Shoulder Elbow Surg. 2016 Apr;25(4):666-670. doi: 10.1016/j.jse.2015.12.019.
2016	**Kachooei AR**, Claessen FM, Chase SM, Verheij KK, van Dijk CN, Ring D. Factors associated with removal of a radial head prosthesis placed for acute trauma. Injury. 2016 Mar 3. pii: S0020-1383(16)30022-5. doi: 10.1016/j.injury.2016.02.023.
2016	**Kachooei AR**, Tarabochia M, Jupiter JB. Distal Radius Volar Rim Fracture Fixation Using DePuy-Synthes Volar Rim Plate.J Wrist Surg. 2016 Mar;5(1):2-8. doi: 10.1055/s-0035-1570740.
2016	Von Keudell A, **Kachooei AR (Co-first author)**, Moradi A, Jupiter JB. Outcome of surgical fixation of lateral column distal humerus fractures. J Orthop Trauma. 2016 May;30(5):245-50. doi: 10.1097/BOT.000000 0000000496.

2015 Ebrahimzadeh MH, Moradi A, Vahedi E, **Kachooei AR**. Mid-term clinical outcome of radial shortening for kienbock disease. J Res Med Sci. 2015 Feb;20(2):146-9.

2015 **Kachooei AR**, Moradi A, Janssen SJ, Ring D. The influence of dominant limb involvement on DASH and QuickDASH. Hand (N Y). 2015 Sep;10(3):512-5. doi: 10.1007/s11552-014-9734-7.

2015 Ebrahimzadeh MH, Birjandinejad A, **Kachooei AR (Corresponding author).** Cross-Cultural Adaptation, Validation, and Reliability of the Michigan Hand Outcomes Questionnaire among Persian Population. *Hand Surg*. 2015; 20(1):25-31. doi: 10.1142/S0218810415500033

2015 **Kachooei AR**, Ebrahimzadeh MH, Erfani-Sayyar R, Salehi M, Salimi E, Razi S. Short Form-McGill Pain Questionnaire-2 (SF-MPQ-2): A Cross-Cultural Adaptation and Validation Study of the Persian Version in Patients with Knee Osteoarthritis. Arch Bone Jt Surg. 2015 Jan;3(1):45-50. Epub 2015 Jan 15

2015 Ebrahimzadeh MH, Birjandinejad A, Mardani-Kivi M, Razi S, **Kachooei AR (Corresponding author)**. Oxford Shoulder Score: A Cross-Cultural Adaptation and Validation Study of the Persian Version in Iran. Iranian Journal of Medical Sciences. 2015; 40(5):404-410

2015 Ebrahimzadeh MH, Moradi A, Vahedi E, **Kachooei AR**, Birjandinejad A. Validity and Reliability of the Persian Version of Shortened Disabilities of the Arm, Shoulder and Hand Questionnaire (Quick-DASH). Int J Prev Med. 2015 Jul 8;6:59. doi: 10.4103/2008-7802.160336.

2015 **Kachooei AR**, Rivlin M, Wu F, Faghfouri A, Eberlin KR, Ring D. Intraoperative Physical Examination for Diagnosis of Interosseous Ligament Rupture-Cadaveric Study. J Hand Surg Am. 2015 Sep;40(9):1785-1790.e1. doi: 10.1016/j.jhsa.2015.06.004.

2015 Neuhaus V, Christoforou DC, **Kachooei AR**, Jupiter JB, Ring DC, Mudgal CS. Radial Head Prosthesis Removal: a Retrospective Case Series of 14 Patients. Arch Bone Jt Surg. 2015 Apr;3(2):88-93.

2015 **Kachooei AR**, Nota SP, Menendez ME, Dyer GS, Ring D. Factors Associated with Operative Treatment of De Quervain Tendinopathy. Arch Bone Jt Surg. 2015 Jul;3(3):198-203.

2015 **Kachooei AR**. Self-archiving of Our Own Articles: Romeo and Juliet Notes. Arch Bone Jt Surg. 2015 Oct;3(4):218-9.

2015 **Kachooei AR**, Rivlin M, Shojaie B, van Dijk CN, Mudgal C. Intraoperative Technique for Evaluation of the Interosseous Ligament of the Forearm. J Hand Surg Am. 2015 Dec;40(12):2372-2376.e1.

2015 Mousavian A, Ebrahimzadeh MH, Birjandinejad A, Omidi-Kashani F, **Kachooei AR**. Translation and cultural adaptation of the Manchester-Oxford Foot Questionnaire (MOXFQ) into Persian language. Foot (Edinb). 2015 Dec;25(4):224-7.

2015 **Kachooei AR**, Moradi A, Mudgal CS. Non-Simultaneous Bilateral Closed Rupture of the Triceps Tendon in a Woman. J Hand Microsurg. 2015 Jun;7(1):205-7. doi: 10.1007/s12593-014-0159-x.

2015 Russchen M, **Kachooei AR**, Teunis T, Ring D. Acute Proximal Row Carpectomy after Complex Carpal Fracture Dislocation. J Hand Microsurg. 2015 Jun;7(1):212-5. doi: 10.1007/s12593-014-0162-2.

2014 Mohammad Taghi Peyvandi,Mahdi Mazloumi, Mohammad Garadaghi,Ali Parsa, Hassan Bahrami Nassab, Amir Reza Kachooei, Ali Reza Hootkani. Clinical trial on femoral head osteonecrosis: simple core decompression vs. core decompression and fibular allo-graft placement. J Am Sci 2014;10(1s):74-77]. (ISSN: 1545-1003).

2014 Ali Birjandinejad1, Mohammad Taghi Peivandi1, Amir Reza Kachooei2, Amin Razi3, Sara Amelfarzad4, Farzad Omidi Kashani. The necessity of MRI in acute and mild knee trauma. Journal of American Science 2014;10(1)

2014 Ebrahimzadeh MH, Moradi A, Khorasani MR, Hallaj-Moghaddam M, **Kachooei AR**. Long-term clinical outcomes of war-related bilateral lower extremities amputations. Injury. 2014 Nov 4. pii: S0020-1383(14)00528-2. doi: 10.1016/j.injury.2014.10.043.

2014 Ebrahimzadeh MH, Birjandinejad A, Golhasani F, Moradi A, Vahedi E, **Kachooei AR (corresponding author)**. Cross-cultural adaptation, validation, and reliability testing of the Shoulder Pain and Disability Index in the Persian population with shoulder problems. Int J Rehabil Res. 2014 Oct 9. PMID: 25305009.

2014 **Kachooei AR**, Chase SM, Jupiter JB. Outcome assessment after Aptis distal radioulnar joint (DRUJ) implant arthroplasty. Arch Bone Jt Surg. 2014; 2(3): 180-184.

2014 Ebrahimzadeh MH, Moradi A, Khalili Pour M, Hallaj-Moghaddam M, **Kachooei AR**. Clinical outcomes after arthroscopic release for recalcitrant frozen shoulder. Arch Bone Jt Surg. 2014; 2(3):220-224.

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Acknowledgments

Professor Denise Eygendaal
I would like to thank my supervisor, Professor Denise Eygendaal, for her dedicated support and guidance. Denise continuously encouraged and was always willing and enthusiastic to assist in any way she could throughout the research project.

Professor Niek van Dijk
I would like to thank my supervisor, Prof. Niek van Dijk, for the thoughtful comments and recommendations on this dissertation.

Professor David Ring
I would like to thank my mentor, Prof. David Ring, for his consistent support and guidance during the running of this project. Dr. Ring has been countable support during my whole academic journey.

Professor Mohammad Ebrahimzadeh
I would like to express my gratitude and appreciation for Professor Mohamad Ebrahimzadeh, whose guidance, support and encouragement have been invaluable throughout this endeavor. I'm standing on the shoulders of a giant, which helped me throughout my academic life.

Professor Pedro Beredjiklian
Thank you for your support and the highest number of recommendation letters you submitted for me with no question. This journey would not have been possible without your kind help. You are exemplary of always being available no matter for whom.

Dr. Michael Rivlin
Thank you for being a real friend and a sincere brother to me, just a call far away. I feel we have many things in common in our life. I optimistically look forward to being your partner. Don't forget I owe you washing your car!

Professor Jesse Jupiter
Thank you for being the name that I am always proud of the opportunity you gave me to work with you.

Dr. Chaitanya Mudgal
I always remember this quote on your door "Every morning in Africa, a gazelle wakes up, it knows it must outrun the fastest lion or it will be killed. Every morning in Africa, a lion wakes up. It knows it must run faster than the slowest gazelle, or it will starve. It doesn't matter whether you're the lion or a gazelle-when the sun comes up; you'd better be running."

Professor Asif Ilyas
Thank you for your trust. I'm always grateful for your generosity.

Dr. Neal Chen
Thank you for warmly accepting new ideas and welcoming new team members.

Professor Steven Raikin
Thank you for being tough to make me stronger and ready for a vigorous life. I learned many surgical skills, yet when I thought I knew them.

Dr. Joseph Daniel
Thank you for being a mentor, both in practice and in personal life, with who I can share my life stories. I'm confident that I count on your advice and help over the rest of my life.

Dr. David Pedowitz
Thank you for giving me the privilege to start working as an orthopedic surgeon in the United States. As a director, race, religion, and nationality has no place in your minded attitude. I always appreciated your friendly attitude toward every person regardless of the position.

Dr. Luke Oh
Thank you for the nights working with me on preparing the Advanced Elbow Arthroscopy video; my son was born the next morning of the night we were meeting.

Dr. Ara Nazarian
Thank you for accompanying me on this journey. You have always been compassionate. Your lab was generously open to research any time.

Dr. Ehsan Sarafraz
Many thanks for your brotherhood. I don't forget the night you picked us up with an American Dodge, and we slept on the floor in a 5-star hotel. We have too many stories to go over and laugh together. We also have written goals to achieve. I look forward to a day treating cancer patients with your drug.

Dr. Babak Shojaie
Ghorban. It's incredible how life brought us together in Boston, and we created a deep and trustworthy friendship. You are like a family to me, and I'm proud of you.

Dr. Ali Moradi
Thank you for being a competitor and a rival. We were motivators of each other for taking steps after another.

Ashkan Sedigh
Don't forget that we are going to become rich together. We started going up the hill in a car together. We will make it.

Dr. Fei Wu
You are the Uncle Wu. Remember when we were spending at the bus stop to go to the OR. I look forward to coming to Wuhan.

Dr. Mojtaba Talaei
I remember spending too much time chatting and confabulating about Ph.D., residency, and fellowship. I'm confident that we both have stepped into the right path.

Dr. Christian Deml
You are my good friend visiting Iran. I think you enjoyed it otherwise you wouldn't have come twice! You are always welcome to my house, buddy.

Dr. Annechien Beumer
I'm grateful to you for the hospitality in Breda with your lovely family. We have started a research project together, and I'm sure we will continue this path.

Dr. Bertram The
Thank you for your hospitality. Your sense of humor and laughs are unforgettable.

Parisa Ahmadi, Niloofar Alavi, Hanieh Ebrahimi, Yas Erfani, Niloofar Vaziri
Thank you for your help and support and the time you devoted to research projects and works to help me make this endeavor. You have always been there when I needed you. Without our teamwork, I can't

think of any other way to overcome the obstacles.

Shiva Razi
I would like to thank my wife, shiva, for being passionate next to me for half of our age until now. Thank you for keeping the family together and dedicating your life to raising our sons.

Mom and Dad
The most beautiful thing in this world is to see your parents smiling and knowing that you are the reason behind that smile.

Kiarash and Adrian
My loves. My motivation to work harder and stay stronger. I wish to see you happy and blessed by achieving your own goals in your lives.