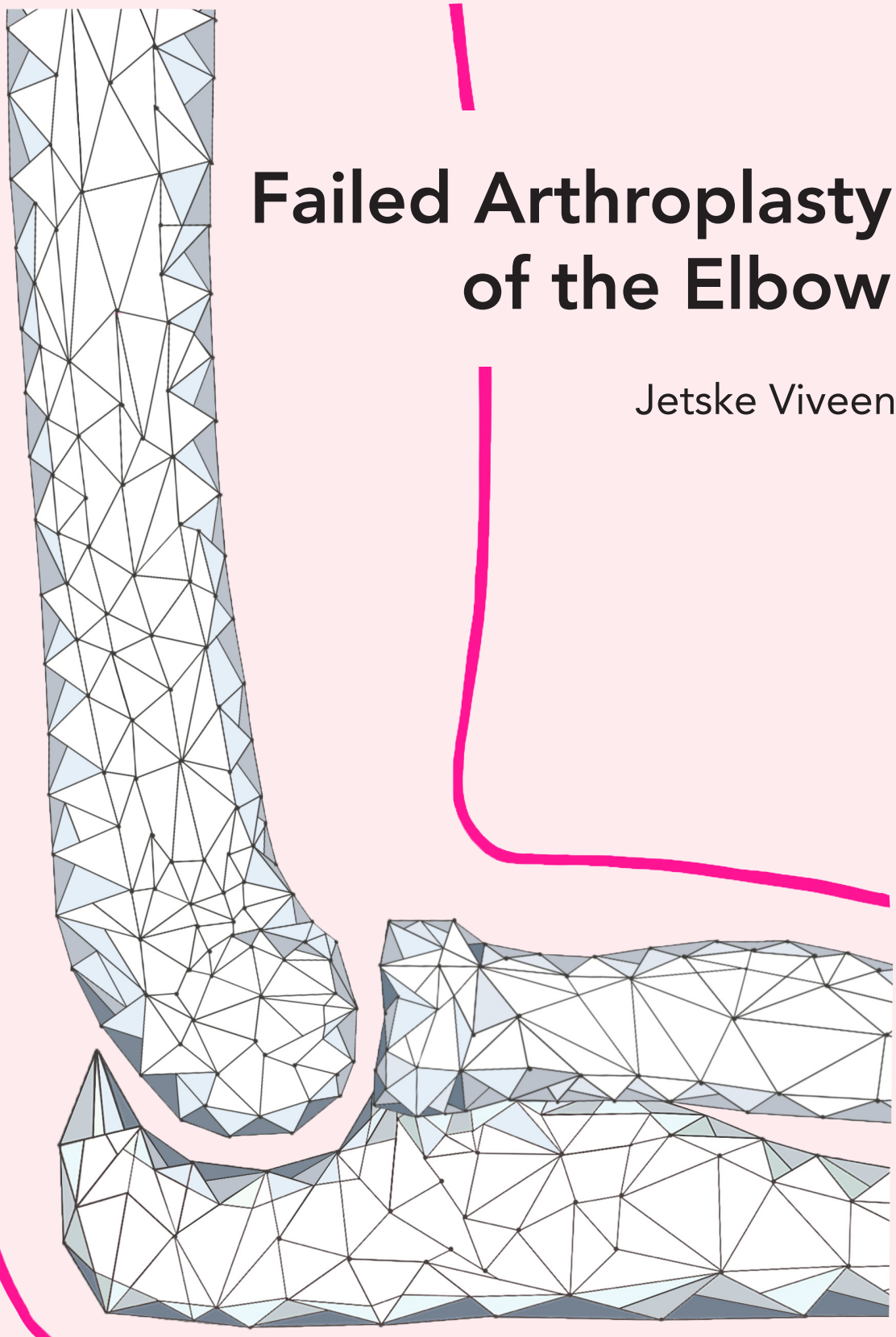
Failed Arthroplasty of the Elbow

Jetske Viveen



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Failed Arthroplasty of the Elbow

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Dit proefschrift is tot stand gekomen binnen een samenwerkingsverband tussen de Universiteit van Amsterdam en Flinders University met als doel het behalen van een gezamenlijk doctoraat. Het proefschrift is voorbereid aan de Faculteit der Geneeskunde van de Universiteit van Amsterdam en aan het College of Medicine and Public Health van Flinders University.

This thesis was prepared within the partnership between the University of Amsterdam and Flinders University with the purpose of obtaining a joint doctorate degree. The thesis was prepared in the Faculty of Medicine of the University of Amsterdam and in the College of Medicine and Public Health of Flinders University.

Failed Arthroplasty of the Elbow

By

Jetske Viveen

Thesis
Submitted to Flinders University
for the degree of

Doctor of Philosophy

College of Medicine and Public Health

15 May 2020

This thesis has been written within the framework of the Cotutelle Program, with the purpose of obtaining a joint doctorate degree. The thesis was prepared at the College of Medicine and Public Health of Flinders University and at the Faculty of Medicine of the University of Amsterdam.

I certify that this thesis does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any university; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text.

Jetske Viveen, 21-06-2019.

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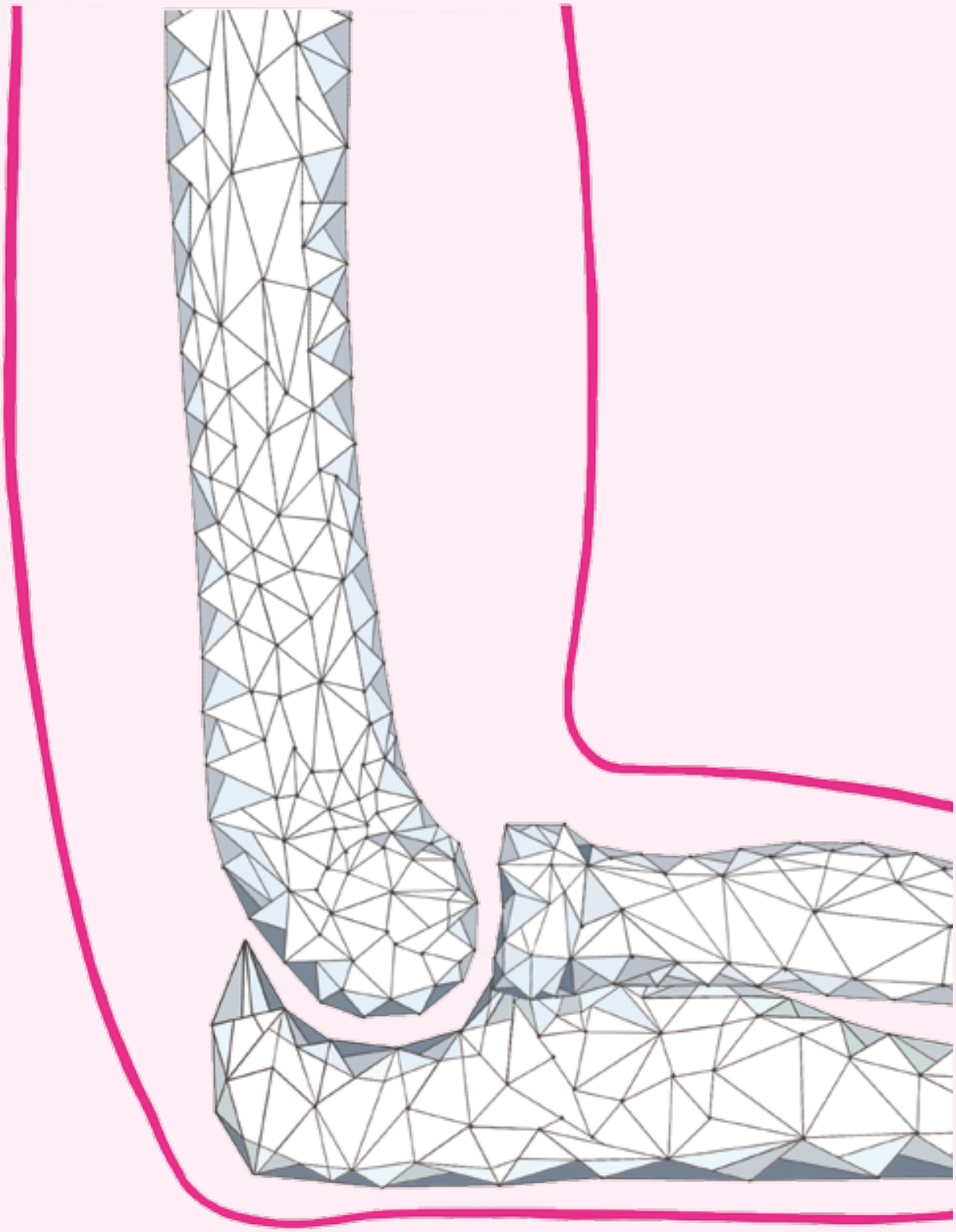

General introduction, aims and outline of the thesis

Failed arthroplasty of the elbow

Historical perspective

In elbow surgery, the first total elbow arthroplasty (TEA) procedure was performed by R. Robineau in 1925 who used an implant with a rubber coverage.[1] In 1972, the first commercial total elbow prosthesis became available, which was designed by R. Dee (Figure 1).[2] Concurrently, K. Speed introduced the first radial head arthroplasty (RHA) in the form of ferrule caps in the scientific literature in 1941 (Figure 2).[3] Since the introduction of both TEA and RHA, several prosthetic designs have been developed. The number of elbow arthroplasties performed has increased over the last decades and the indication for arthroplasty shifted from mainly post inflammatory to more (post)traumatic.[4-6]

Elbow arthroplasty in complex elbow trauma

Radial head fractures are relatively common and occur in 25-55 per 100.000 persons a year and account for approximately 4% of all fractures of the musculoskeletal system.[7, 8] Radial head fractures are frequently the result of a fall on an outstretched hand and occur typically in females above 50 years suffering from osteoporosis and in younger males due to a higher energy trauma.[8, 9] Fractures of the radial head may be categorized according to the Mason classification;[10] Mason type-1 fractures are nondisplaced fractures, Mason type-2 fractures are non-comminuted displaced fractures and Mason type-3 fractures are comminuted fractures.[11]

Radial head replacement is generally indicated for the latter type, where, in case of a comminuted fracture with 3 or more fragments where open reduction-internal fixation

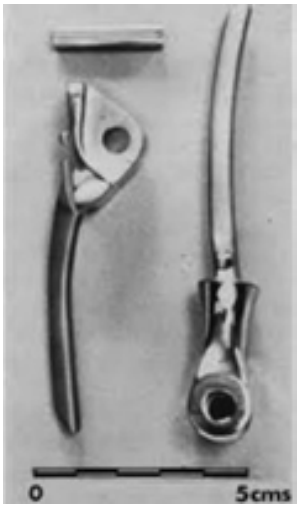

Figure 1. Total elbow prosthesis as designed by Dee. Reproduced with permission of British Editorial Society of Bone and Joint Surgery.[2]

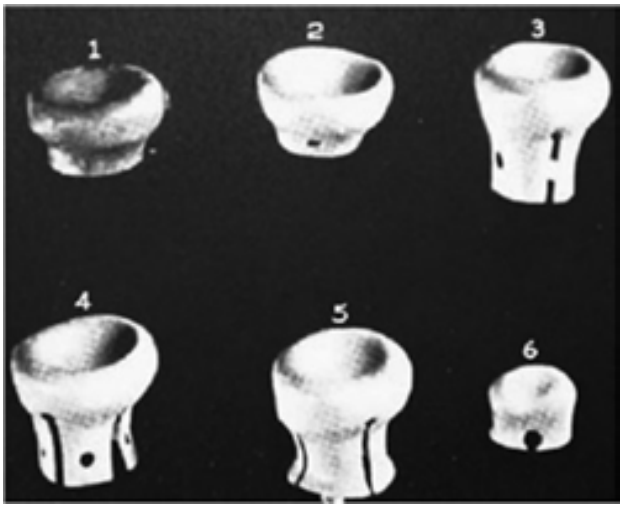

Figure 2. Ferrule caps for the radial head in different sizes as designed by Speed. Reproduced with permission of the Journal of the American College of Surgeons, formerly Surgery Gynecology & Obstetrics.[3]

(ORIF) is usually not feasible.[12] The purpose of radial head replacement is to restore the stability of the elbow joint and forearm, since the radial head is an important secondary stabilizer accounting for approximately 30% of valgus stability of the elbow joint.[13]

Distal humerus fractures are less common with an incidence of 5.7 per 100.000 persons a year.[14] There are peak incidences in young males as a result of a high energy trauma and a second peak in older females after a low energy fall.[14] Since acceptable functional results have been reported after ORIF in distal humerus fractures, this is the gold standard of treatment used to date.[15-17] However, in selective cases in the elderly with complex, communitive, intra-articular fractures, TEA is considered a salvage procedure in order to regain a functional range of motion (ROM) of the elbow joint.[6, 18] In fewer cases, elbow hemiarthroplasty of the distal humerus could be an option as well.[19]

Burden to society

Although the number of elbow arthroplasties worldwide has increased over the past decade or two, the number of procedures per year is still more than 200 times lower as compared to hip and knee replacements.[4, 20-22] This is mainly due to the fact that, in general, the upper limb is less susceptible to osteoarthritis than the lower limb.

Elbow arthroplasties though are more frequently used in acute and late posttraumatic sequelae as compared to primary osteoarthritis in hips and knees.[4, 21, 23, 24] In 2017 in the Netherlands, the incidence of TEA was 0.8 per 100.000 persons per year *versus* 172 total knee replacements and 176 total hip replacements per 100.000 persons per year.[25] The exact incidence of radial head replacement arthroplasty in the Netherlands is difficult to ascertain given that this kind of arthroplasty is not included in the Dutch National Arthroplasty Register.

Over the years, the clinical and radiographic outcomes after elbow arthroplasty have improved.[5, 26-29] However, despite all implant related innovations and improvements of the surgical technique, the complication rates remain relatively high with 23% in RHA[5] and 24% in TEA.[29] Average survival times before prostheses failure vary from approximately 38 months in RHA[30] to 77 months in TEA.[31] Therefore further improvement of the outcomes of both TEA and RHA is mandatory.

Aims and outline of the thesis

This thesis is divided into two parts, both aiming to analyze clinical failure mechanisms of elbow arthroplasties. This gives clinicians more insight so that it may improve the results of elbow arthroplasties, including the treatment of complex elbow trauma. **Part I** focusses on RHA with specific attention to indications, diagnosis and management of revision surgery and the radiographic and clinical outcomes thereafter. **Part II** centers around TEA, focusing on trends and indications for primary and revision surgery of TEA and radiographic and clinical outcomes after revision surgery.

Part I – Radial head arthroplasty

This part focuses on the revision surgery of RHA and is introduced by a micro-CT imaging study of the radial head. The elbow consists of three independent joints (radiohumeral, ulnohumeral and the proximal radioulnar joint), which collaborate to provide movement in all axes of freedom. It is the link between the shoulder and the hand, and in humans it has evolved from a bodyweight-bearing articulation to a complex non-weight-bearing joint.[32] Whilst in terrestrial bipeds, such as humans, the elbow is not a bodyweight bearing joint, it bears load, and is therefore subject to Wolff's law.[33] In some instances, three times the bodyweight can be developed in the elbow during strenuous lifting.[34] The bone of the proximal ulna, radius and distal humerus seem to adapt to mechanical forces the elbow joint is subjected to during these daily activities (Figure 3).[35, 36] However, the microstructural consequences of loading remain unknown in the upper extremity. Therefore, we describe the bone microstructure in **Chapter 1**, aiming to understand mechanical forces applied to the radial head and possible fracture patterns.

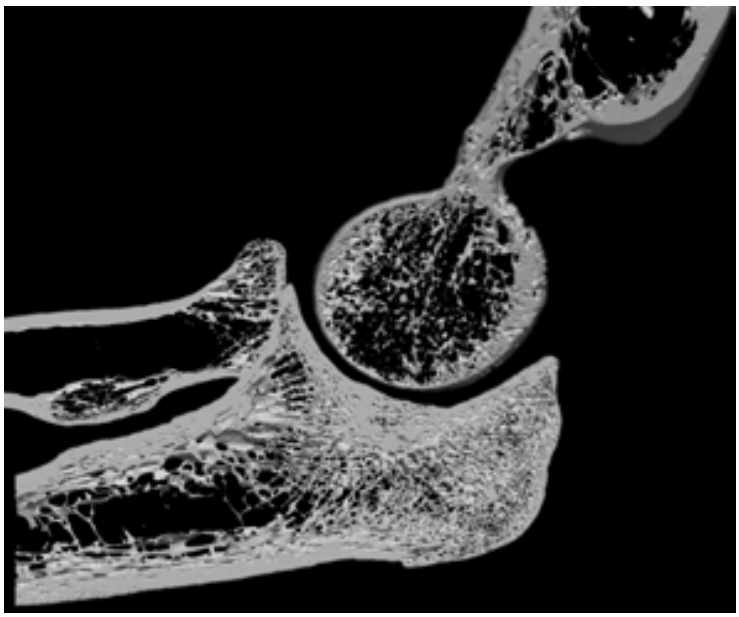

Figure 3. 3D-rendering (1.5 mm-thick volume) of sagittal micro-CT cross-section image stacks of the proximal ulna and radius and distal humerus.

Figure 4. Examples of different types of radial head prostheses. Monopolar modular prosthesis with an expandable stem (MoPyc). Intentionally loose-fit fixated monopolar modular prosthesis (Evolve). Bipolar modular press-fit prosthesis (RHS). Bipolar modular cemented prosthesis (Judet CRF II).

In case of comminuted radial head fractures, many different types of RHA are being used to date. They vary in terms of material, fixation technique, modularity and polarity (Figure 4). Overall good results have been reported on primary RHA, with the exception of silicone prostheses which have proven to be biologically insufficient.[37] Survival rates of metallic RHAs ranging from 61 to 97% at 10 years have been reported.[38, 39] However, implant removal- and revision rates of 8% at 4 years have been described as well.[5] Considering these discrepancies, a systematic review of the scientific literature was performed in **Chapter 2** to evaluate the indications for revision surgery and relate this to the type of prosthesis. Moreover, currently, the decision whether to remove, replace or revise a failed prosthesis seems to be based on the preference of the surgeon or hospital, rather than on some level of evidence.[40] Therefore, we discuss the diagnostics and management of failed RHA in **Chapter 3** in order to provide a treatment algorithm for daily practice.

One of the treatment options after a failed RHA is replacement with another RHA. However, studies reporting about the functional outcomes after this procedure are rare. Therefore, the purpose of **Chapter 4** is to evaluate the clinical and radiographic outcomes of patients who underwent revision surgery of their RHA.

Part II – Total elbow arthroplasty

This part focuses on primary and revision TEA for (late) posttraumatic conditions. Part II is introduced by **Chapter 5** in which the cortical and trabecular microstructure of the proximal ulna is characterized. The aim of this chapter is to better understand the bone distribution in relation to daily mechanical forces applied to the elbow joint and possible fracture patterns of the proximal ulna.

In TEA surgery, several types of linked, unlinked and convertible TEA designs are available (Figure 5). Linked designs provide more stability because of the linkage between the humeral and ulnar component. Therefore, these designs are predominantly used in case of acute fractures and revision procedures. Unlinked designs rely more on soft tissue, bone

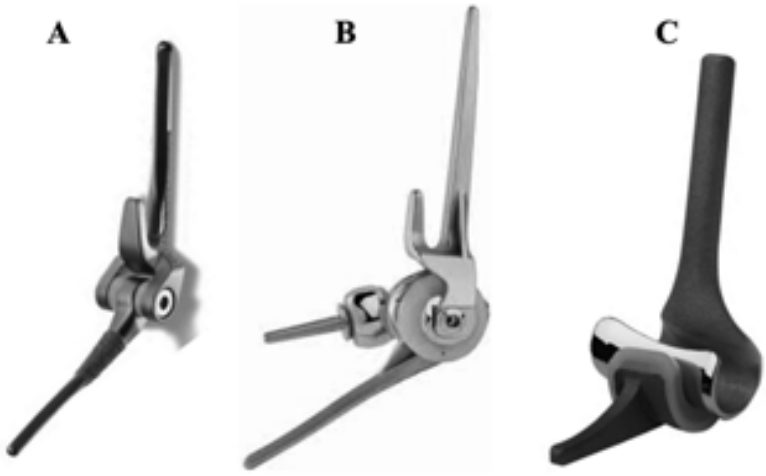

Figure 5. Examples of different types of total elbow prostheses. Linked prosthesis (Coonrad-Morrey). Prosthesis that can be placed either linked or unlinked with option of radial head replacement (Latitude). Unlinked prosthesis (iBP Total Elbow System).

stock and bearing surfaces for stability. Convertible designs could be placed either linked or unlinked and with or without a radial head component, depending on the quality of the soft tissue and bone stock.

The most frequently reported indications for TEA are rheumatoid arthritis (RA) and (posttraumatic) osteoarthritis (OA).[20, 41-43] However, TEA may be indicated after acute fractures as well.[6, 43] European registry studies described that TEA is now more frequently used in posttraumatic conditions compared to RA.[6, 42]

Following primary TEA surgery, in general, moderate to good results have been reported for all designs, with less pain, increase in ROM and improvement of patient reported outcome measures.[31, 45, 46] The average survival time of primary TEA is 77 months,[31] however the implant survival rate at 10 years may be influenced by the primary indication for TEA, with less favorable results in patients who received TEA for posttraumatic conditions (60%) compared to patients with RA (90%).[47, 48] Therefore, we evaluated the possible shift in indications from RA to acute fractures, the revision rates for the latter two and the most prevalent indications for revision surgery in **Chapter 6**, using data provided by the Australian Orthopedic Association National Joint Replacement Registry (AOANJRR).

The most prevalent indications for revision surgery of TEA are symptomatic aseptic loosening, deep infection, polyethylene wear and periprosthetic fractures.[31] Revision surgery of TEA remains technically demanding and challenging with second revision rates after primary revision ranging from 28 to 30% at 10 years.[49] Therefore, the purpose of **Chapter 7** was to report on the clinical and radiographic outcomes of patients who underwent revision surgery of their TEA. Since studies reporting on the functional outcomes after revision surgery of TEA generally include relatively low number of patients, we performed a systematic review of the scientific literature on the outcomes after revision surgery of TEA in **Chapter 8**.

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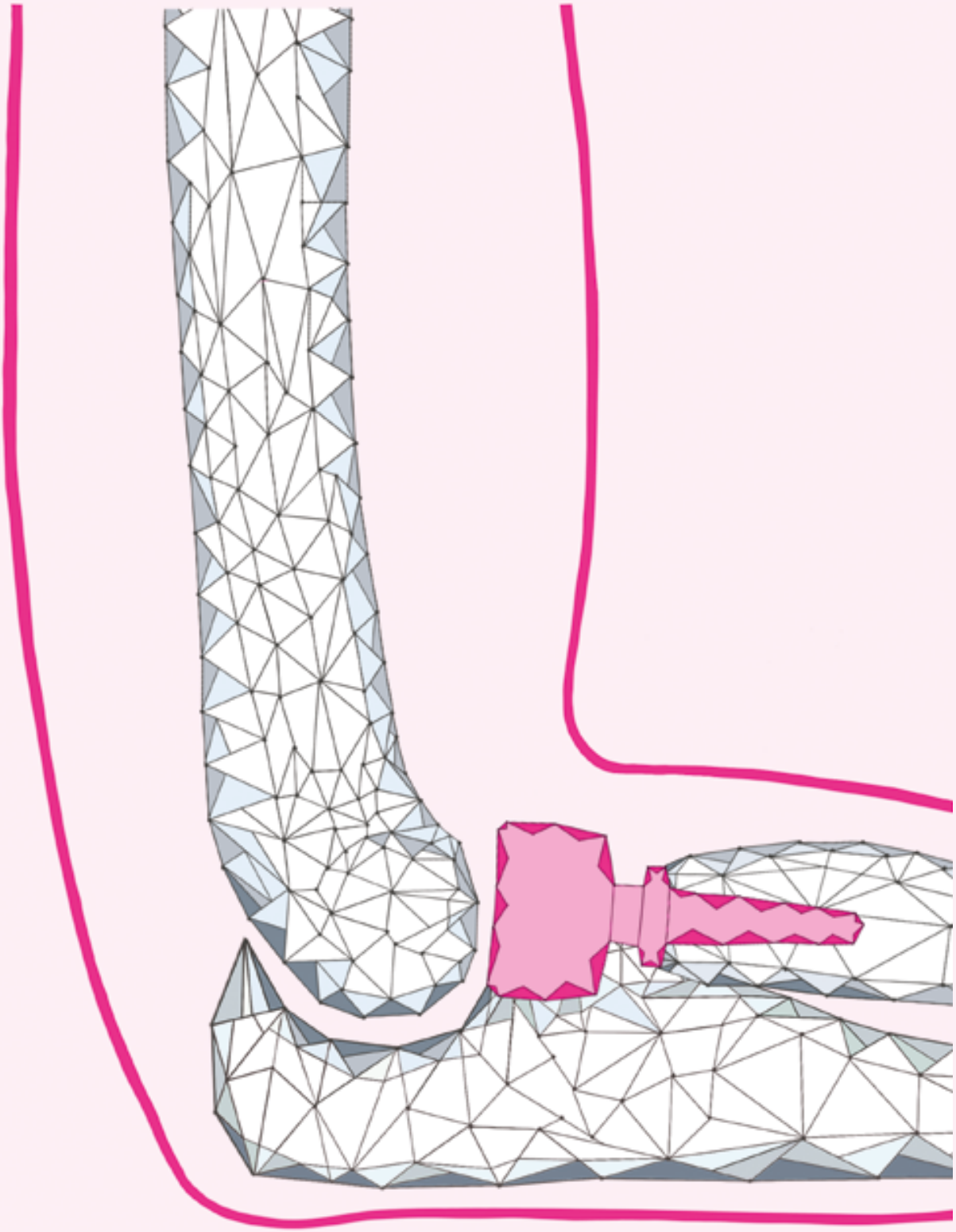
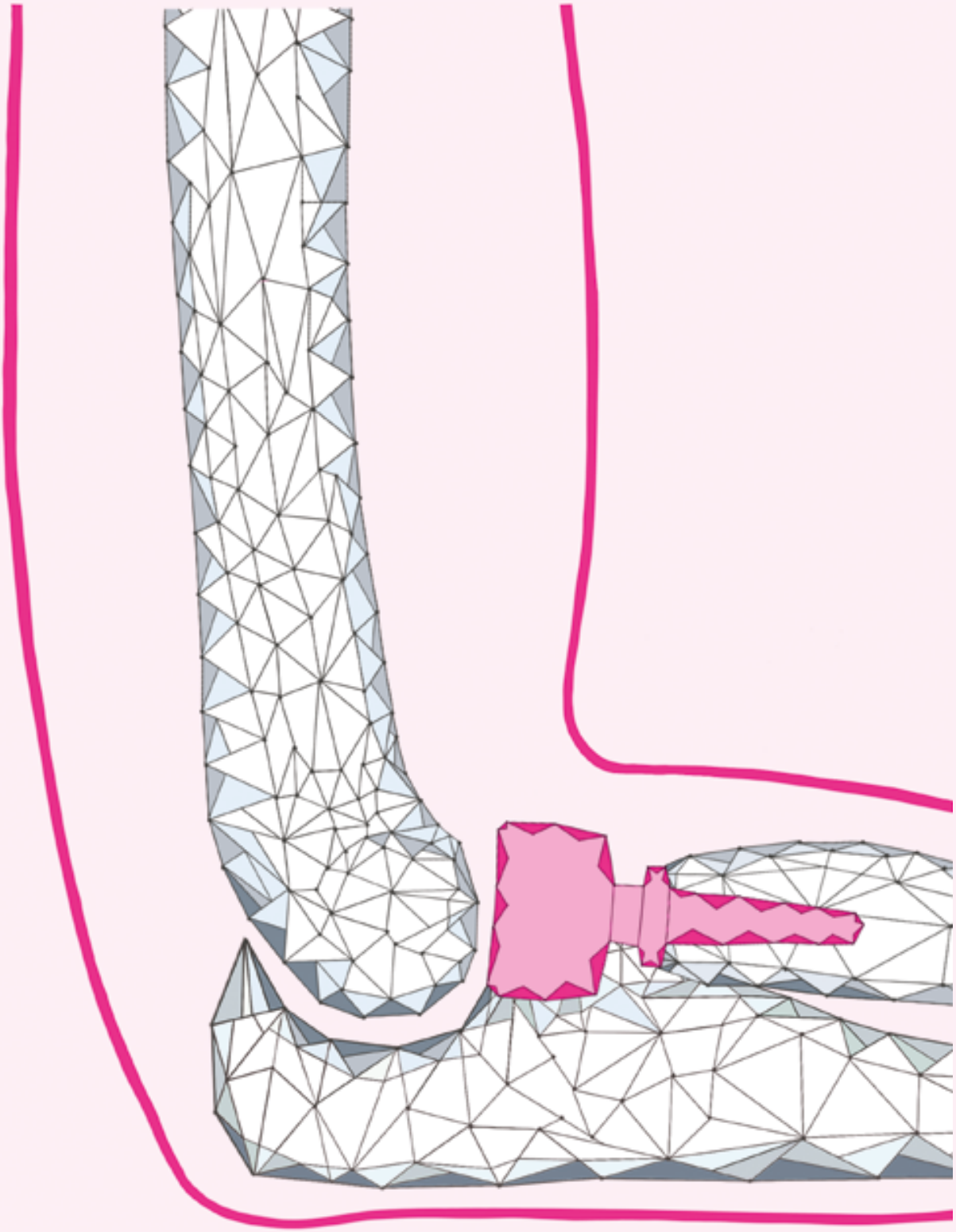


PART I

Radial head arthroplasty



Chapter 2

Why does radial head arthroplasty fail today? A systematic review of recent literature

J. Viveen
I.F. Kodde
A. Heijink
K.L.M. Koenraadt
M.P.J. van den Bekerom
D. Eygendaal

EFORT Open reviews – December 2019

Abstract

1. Since the introduction of the radial head prosthesis (RHP) in 1941, many designs have been introduced. It is not clear whether prosthesis design parameters are related to early failure. The aim of this systematic review is to report on failure modes and to explore the association between implant design and early failure.
2. A search was conducted to identify studies reporting on failed primary RHP. The results are clustered per type of RHP based on: material, fixation technique, modularity, and polarity. Chi-square tests are used to compare reasons for failure between the groups.
3. Thirty-four articles are included involving 152 failed radial head arthroplasties (RHAs) in 152 patients. Eighteen different types of RHPs have been used.
4. The most frequent reasons for revision surgery after RHA are (aseptic) loosening (30%), elbow stiffness (20%) and/or persisting pain (17%). Failure occurs after an average of 34 months (range, 0–348 months; median, 14 months).
5. Press-fit prostheses fail at a higher ratio because of symptomatic loosening than intentionally loose-fit prostheses and prostheses that are fixed with an expandable stem ($p < 0.01$).
6. Because of the many different types of RHP used to date and the limited numbers and evidence on early failure of RHA, the current data provide no evidence for a specific RHP design.

Introduction

Since the introduction of the radial head prosthesis (RHP) in 1941,[1] many alterations in designs and materials have been proposed and tried that have varied in terms of material, fixation technique, modularity, and polarity. Radial head arthroplasty (RHA) is predominantly used to treat comminuted radial head fractures and other, less common, chronic posttraumatic sequels as nonunion, posttraumatic arthritis and elbow instability.[2, 3]

During the past 75 years, moderate to good results have been reported for both primary[4, 5] and revision surgery of RHA.[6] Implant revision and removal rates up to 8% at four years have been described.[4] More recent studies showed conflicting 10-year survival numbers ranging from 61% to 97%.[5, 7]

This raises questions of whether implant- or fixation-related factors may be related to early failure. Except in the case of silicone RHPs, that have previously proved to be biologically and biomechanically insufficient, with a substantial risk of fragmentation of the implant[8–10] resulting in silicone synovitis, it is unclear which type of metallic RHP is superior. Taking the enormous discrepancies in failure rates into account, the aim of the current study was to report on failure modes of RHPs in recent years and to explore the association between implant design and early failure.

Material and methods

Search strategy

This systematic review was based on Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[11,12] A comprehensive literature search was conducted with the assistance or a clinical librarian using the following terms: radius[MeSH], radius fractures[MeSH], arthroplasty, replacement[MeSH], joint prosthesis[MeSH], radial head[tiab], replacement[tiab], arthroplasty[tiab], prosthesis implantation[tiab], and prosthesis[tiab]. The PubMed/MEDLINE and Embase databases were searched using the filters "English" and "humans" for the period from January 1941 to the date of search (10 September 2018). The start date was chosen as the first documentation of a radial head replacement by Speed dating back to 1941.[1]

Inclusion and exclusion criteria

This review was intended to include patients with a minimum age of 18 years who underwent revision surgery or their metallic of pyrocarbon RHA for any reason. Articles written in English and evaluating original clinical data on primary pyrocarbon or metallic RHPs requiring revision surgery were considered, regardless of the level of evidence. Only articles including at least five cases with a minimum of follow-up of two years were considered. No minimum of failed RHPs per article was set.

A study was excluded if the type of prosthesis and/or the mode of failure was not reported and was not provided by the author on request. Moreover, silicone RHPs were

excluded, since these prostheses have been shown to be inferior and presumably would not be implanted nowadays.[8]

Study selection

Three authors independently assessed all titles and abstracts and identified eligible articles (IFK, JV and AH). Two authors (IFK and JV) assessed the full text of all eligible studies and made the final decision regarding inclusion. Disagreements were settled by discussion. With the use of this strategy, 952 articles were identified. After the screening of the title, abstract, methodology and results, 72 articles were found to be potentially eligible for inclusion. The full text of these studies was analysed, and the reference lists of all eligible publications were manually checked for additional studies potentially meeting the inclusion criteria. After application of the inclusion and exclusion criteria, 34 studies were finally included. The additional 38 articles were excluded for various reasons (Figure 1).

Outcome parameters

The primary outcome of the current study is the failure mode of the RHP as defined in the included articles. Secondary outcome measures are (1) the time between primary surgery and failure (i.e. time to failure) and (2) the type of revision surgery (i.e. removal of the prosthesis, replacement with another RHP or revision surgery to a total elbow arthroplasty (TEA) or radiocapitellar prosthesis).

Data analysis

To summarize the data, descriptive statistics were used. Only 18 of the 34 included studies reported data on individual patients. The other 16 studies reported only pooled data on age at time of primary surgery. As a consequence, analyses covering all 34 studies had to be performed on the aggregated study level, with the data on the individual patients pooled per study. In 14 articles (67 patients), no data are available on the time to failure. In the remaining patients (n = 85), the Kruskal–Wallis test is used to compare time to failure per type of fixation. To compare the reason of failure related to polarity, Fisher's exact test is used. In addition, for comparison of the failure mode related to the type of fixation, Chi-square tests are used, followed by a post hoc analysis.

Results

Thirty-four articles involving a total of 152 failed RHAs in 152 individual patients were included. The number of failed RHAs per study ranged from 1 to 22. All studies were case series (level-IV therapeutic studies). The oldest article was published in 1993, and the most recent article was published in 2018.

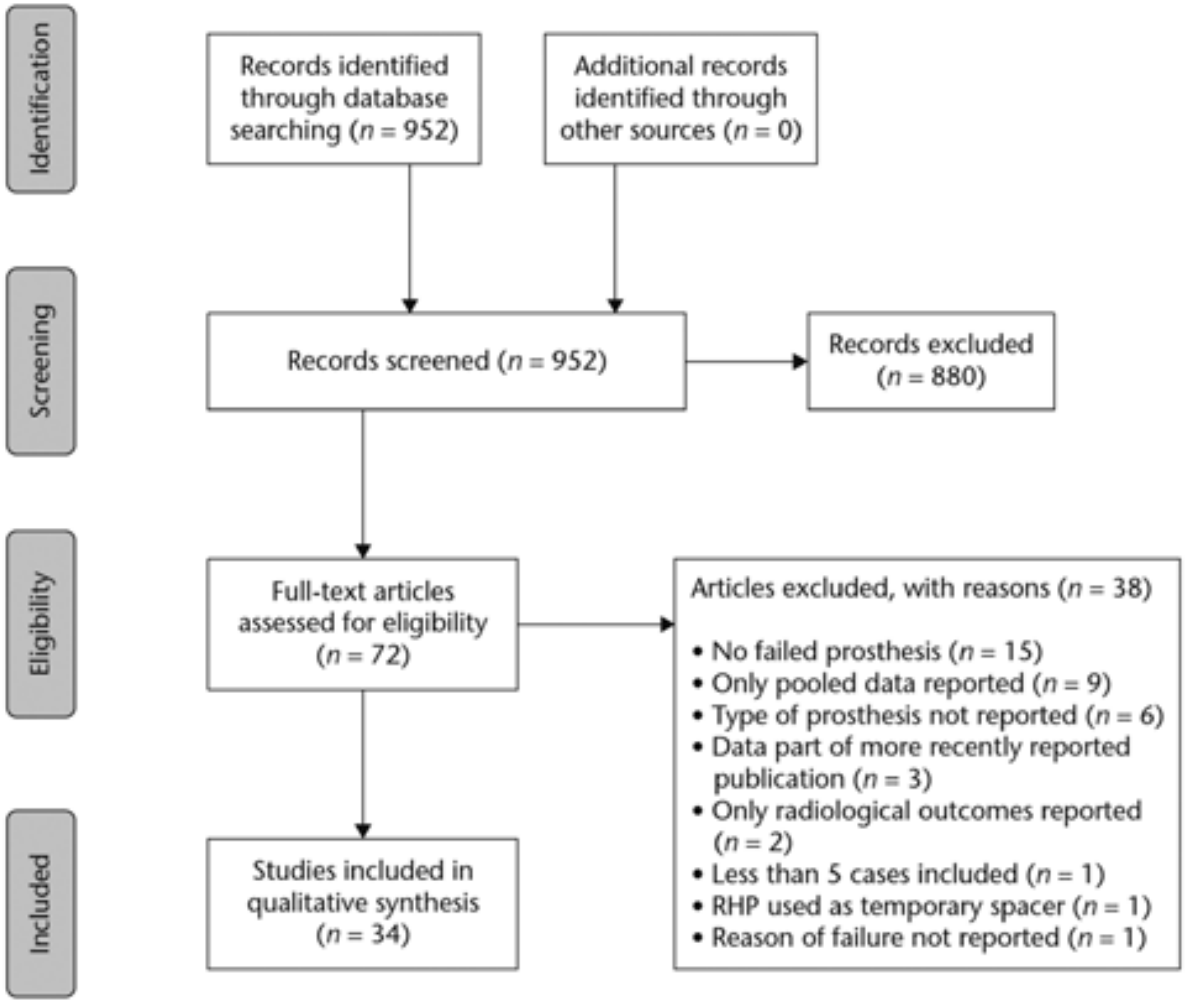


Figure 1. Flowchart. *Note*. RHP, radial head prosthesis.

Population characteristics

Mean age at time of primary surgery was 50 years (*SD* = 10). The studies included 18 different types of RHPs. Most frequent used prostheses, representing 53% of all prostheses, included the Evolve Modular Radial Head (Wright Medical) (*n* = 45, 30%), the MoPyC radial head (Tornier) (*n* = 23, 15%) and the Guepar (De Puy, Johnson & Johnson) (*n* = 15, 10%). Most prostheses were either intentionally loose-fit (*n* = 53, 35%) or press-fit (*n* = 47, 31%). A smaller proportion was placed with use of cement (*n* = 29, 19%) or had an expandable stem (*n* = 23, 15%). Regarding implant material, 127 implants (84%) were made of non-specified metal (including titanium and cobalt chromium), 23 (15%) were made of pyrocarbon and 2 (1%) were made of Vitallium. Regarding polarity, 106 prostheses (70%) were monopolar and 46 (30%) were bipolar (Table 1).

Primary outcome – failure mode

The most prevalent failure mode was symptomatic aseptic loosening, occurring in 46 (30% of all failures) patients (Figure 2). Of these 46 prostheses, 25 were placed press-fit, in 11

Table 1. Included studies.

Study number	First Author	Year	Study Design	Failed Prosthesis (n)	Type of Prosthesis	Material
1	Ricón[13]	2018	Case Series	3	MoPyC (Tornier)	PC
2	Kachooei[14]	2018	Case Series	3	Mixed	CC
3	Sershon[7]	2018	Case Series	1	Katalyst (Integra)	CC
4	Viveen[6]	2017	Case Series	8	Mixed	Mixed
5	Strelzow[15]	2017	Case Series	2	Evolve (Wright)	CC
6	Hackl[16]	2017	Case Series	5	MoPyC (Tornier)	PC
7	Laumonerie[5]	2017	Case Series	19	Mixed	CC
8	Laflamme[17]	2017	Case Series	1	ExploR (Biomet)	CC
9	Kachooei[18]	2016	Case Series	22	Mixed	CC
10	Van Hoecke[19]	2016	Case Series	2	Judet CRF II (Tornier)	CC
11	Lópiz[20]	2016	Case Series	4	MoPyC (Tornier)	PC
12	Heijink[21]	2016	Case Series	1	RHS (Tornier)	Metal
13	Kodde[22]	2016	Case Series	3	RHS (Tornier)	Metal
14	Moghaddam[23]	2016	Case Series	7	Evolve (Wright)	CC
15	Levy[24]	2016	Case Series	2	Acumed	CC
16	Yan[25]	2015	Case Series	1	Radius Head Comp. (Link)	CC
17	Neuhaus[26]	2015	Case Series	13	Mixed	CC
18	Schnetzke[27]	2014	Case Series	6	Evolve (Wright)	CC
19	Allavena[28]	2014	Case Series	5	Guepar (DePuy)	CC
20	Watters[29]	2014	Case Series	3	Evolve (Wright)	CC
21	Katthagen[30]	2013	Case Series	1	Corin Radial Head (Corin)	CC
22	Sarris[31]	2012	Case Series	2	MoPyC (Tornier)	PC
23	Flinkkilä[32]	2012	Case Series	9	Mixed	CC
24	Rotini[33]	2012	Case Series	2	rHead (Sbi)	CC
25	Zunkiewicz[34]	2012	Case Series	1	Katalyst (Integra)	CC
26	Ricón[35]	2012	Case Series	3	MoPyC (Tornier)	PC
27	Lamas[36]	2011	Case Series	5	MoPyC (Tornier)	PC
28	Burkhart[37]	2010	Case Series	2	Judet CRF II (Tornier)	CC
29	Doornberg[38]	2007	Case Series	2	Evolve (Wright)	CC
30	Wretenberg[39]	2006	Case Series	5	Radius Head Comp. (Link)	CC
31	Brinkman[40]	2005	Case Series	2	Judet CRF II (Tornier)	CC
32	Harrington[41]	2001	Case Series	4	Richards (Smith & Nephew)	Titanium
33	Smets[42]	2000	Case Series	1	Predecessor of Judet CRF II (Tornier)	CC
34	Knight[43]	1993	Case Series	2	Osteonics radial head prosthesis (Stryker Howmedica)	Vitallium
			Total	152		

Note. NA, Not applicable; RHP, radial head prosthesis; TEA, total elbow arthroplasty; RC, radiocapitellar prosthesis; CC, cobalt-chromium; PC, pyrocarbon; Mono, monopolar; Bi, bipolar; Int. Loose, intentionally loose-fit.

Polarity	Modularity	Fixation	Removals (n)	Replacement by RHP (n)	Revision to TEA or RC (n)	Mean follow-up (mo)
Mono	Modular	Expansion stem	3	0	0	72
Bi	Modular	Mixed	0	0	3 to RC	28
Bi	Modular	Int. Loose	0	1	0	1
Mixed	Mixed	Mixed	0	8	0	19
Mono	Modular	Int. Loose	0	2	0	NA
Mono	Modular	Expansion stem	0	4	1 to TEA	25
Mixed	Modular	Mixed	19	0	0	NA
Bi	Modular	Press-fit	0	1	0	6
Mono	Modular	Mixed	19	3	0	22
Bi	Modular	Cemented	1	0	1 to TEA	94
Mono	Modular	Expansion stem	1	3	0	NA
Bi	Modular	Cemented	1	0	0	24
Bi	Modular	Press-fit	0	2	1 to RC	62
Mono	Modular	Int. Loose	4	3	0	NA
Mono	Modular	Press-fit	0	2	0	12
Mono	Monoblock	Int. Loose	0	1	0	NA
Mixed	Mixed	Mixed	13	0	0	12
Mono	Modular	Int. Loose	4	2	0	NA
Bi	Modular	Cemented	4	1	0	28
Mono	Modular	Int. Loose	0	0	3 to TEA	NA
Mono	Monoblock	Press-fit	1	0	0	NA
Mono	Modular	Expansion stem	2	0	0	1
Mono	Modular	Press-fit	9	0	0	NA
Mixed	Modular	Press-fit	2	0	0	18
Bi	Modular	Int. Loose	0	1	0	NA
Mono	Modular	Expansion stem	3	0	0	38
Mono	Modular	Expansion stem	5	0	0	NA
Bi	Modular	Cemented	0	2	0	0
Mono	Modular	Int. Loose	2	0	0	NA
Mono	Monoblock	Int. Loose	5	0	0	NA
Bi	Modular	Cemented	0	2	0	9
Mono	Monoblock	Press-fit	4	0	0	237
Bi	Modular	Cemented	1	0	0	8
Mono	Monoblock	Press-fit	2	0	0	NA
			105	38	9	36

cement was used, six were intentionally loose-fit, and four had an expandable stem. Post hoc analyses revealed that symptomatic aseptic loosening was significantly more frequently the reason for revision in press-fit prostheses (25/47 press-fit prostheses) compared to intentionally loose-fit prostheses (11/29 intentionally loose-fit prostheses) and prostheses with an expandable stem (4/23 prostheses with an expandable stem) ($p < 0.01$) (Figure 2).

A second failure mode was elbow stiffness ($n = 30$, 20% of all failures). Intentionally loose-fit prostheses were more frequently revised for elbow stiffness than press-fit prostheses (20/53 loose-fit prostheses versus 3/47 press-fit prostheses, $p < 0.01$) (Figure 2). Among the 20 intentionally loose-fit prostheses, monoblock designs failed more often than modular designs (6/6 intentionally loose-fit monoblock prostheses versus 14/47 intentionally loose-fit modular prostheses, $p < 0.01$).

Other modes of failure were persistent pain ($n = 26$, 17% of all failures), overstuffing ($n = 13$, 9% of all failures) and dissociation of the prosthesis ($n = 8$, 5% of all failures). Of the eight dissociated prostheses, five were bipolar and three were monopolar (Figure 3). Ulnohumeral arthritis was the reason for revision in six cases. Cemented prostheses (5/29 cemented prostheses) were more often revised for ulnohumeral arthritis than press-fit (0/47 press-fit prostheses) and intentionally loose-fit prostheses (5/29 versus 0/47 versus 0/53 versus, $p < 0.01$) (Figure 2). All failures due to instability involved bipolar prostheses ($p < 0.01$) (Figure 3). In one case with instability, only the head of the prosthesis was revised because of under sizing.

Secondary outcomes

Time to failure

Time to failure was reported in 85 patients and ranged from 0–348 months (mean 34 months; median 14 months) (Table 1). Mean time to failure was 53 months for press-fit prostheses ($n = 29$), 36 months for prostheses with an expandable stem ($n = 14$), 27 months for cemented prostheses ($n = 16$), and 17 months for intentionally loose-fit prostheses ($n = 26$). Intentionally loose-fit prostheses failed earlier compared to press-fit prostheses ($p < 0.01$).

Type of revision surgery

Sixty-nine per cent ($n = 105$) of the revision surgeries involved removal of the prosthesis. In another 25% ($n = 38$) the prosthesis was removed and a new RHP was implanted. In addition, five RHPs were revised to TEAs (3%) and four RHPs were revised to radiocapitellar prostheses (3%) (Table 1). In only two out of five revisions to a TEA the indication for revision was ulnohumeral arthritis.

Discussion

This systematic review shows that the most frequent failure modes of RHAs are symptomatic aseptic loosening (30%), stiffness (20%) and persistent pain (17%) at an average time to failure of 34 months. Post hoc analyses revealed that press-fit RHPs failed more often because

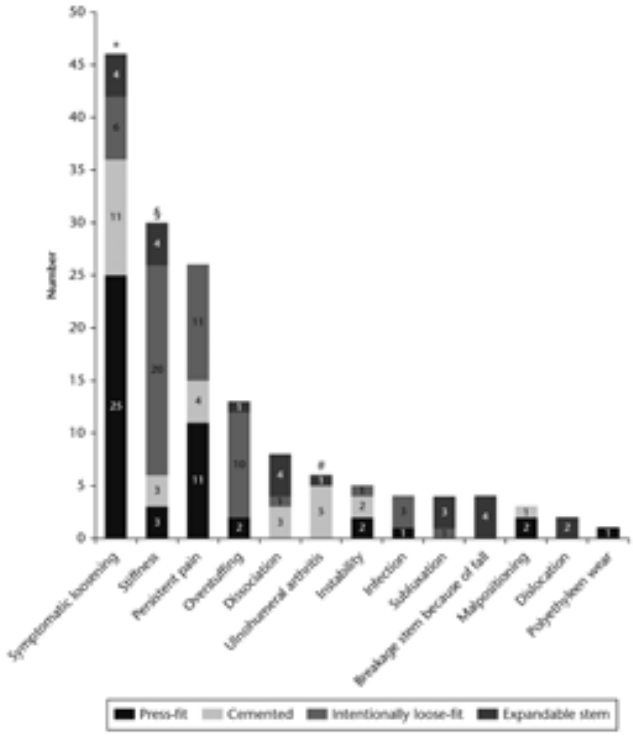


Figure 2. Failure modes divided per type of fixation. * Press-fit prostheses fail more often because of symptomatic loosening compared to intentionally loose-fit prostheses and prostheses with an expandable stem ($p < 0.01$). § Intentionally loose-fit prostheses fail more often because of stiffness compared to press-fit prostheses ($p < 0.01$). # Cemented prostheses fail more often because of ulnohumeral arthritis compared to press-fit prostheses and intentionally loose-fit prostheses ($p < 0.01$).

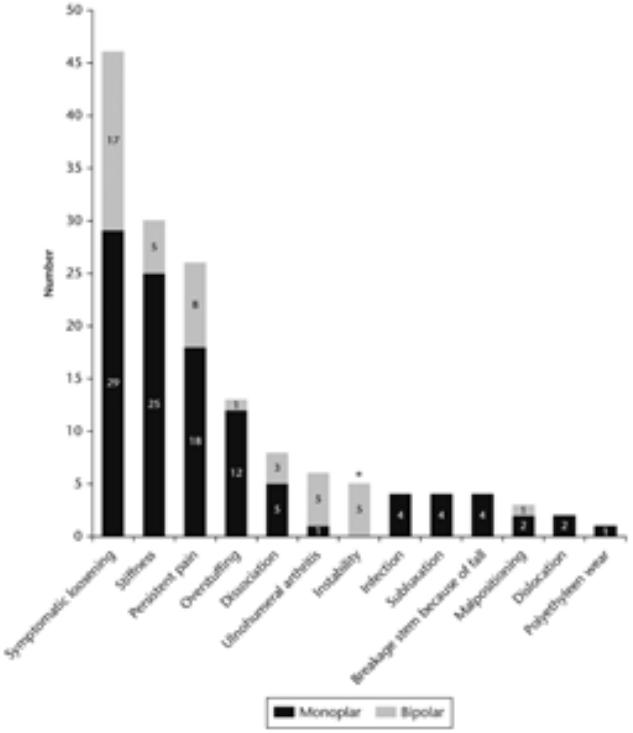


Figure 3. Failure modes divided in mono- and bipolar. * Bipolar prostheses fail more often because of instability compared to monopolar prostheses ($p < 0.01$).

of symptomatic aseptic loosening (25/47 prostheses) compared to intentionally loose-fit prostheses (5/43 prostheses) and prostheses with an expandable stem (4/23 prostheses). In addition, intentionally loose-fit prostheses failed earlier compared to press-fit prostheses (17 versus 53 months, respectively).

Aseptic loosening is a frequently encountered problem. Radiolucencies around the prosthesis are frequently reported and seem to occur mostly shortly after implantation. Whether these radiolucencies also mean that a prosthesis is loose, is not always not clear. Subcollar resorption is often reported with press-fit prostheses, but seems to be stationary after one to two years, without progression to loosening and without clinical symptoms.[22] In cases of progressive radiographic signs of loosening, a poor clinical outcome could be expected. In those cases, an additional computed tomography scan (CT scan) with or without a bone scan could be performed to investigate whether loose bodies are present and to assess the chondral condition of the capitellum and the ulnohumeral joint, in order to plan the appropriate treatment. Our analysis showed that 27% of the monopolar implants and 37% of the bipolar implants failed because of symptomatic aseptic loosening ($p = 0.3$). In contrast, van Riet et al. had observed more loosening with monopolar compared to bipolar prostheses.[44] It has been hypothesized that poor bone ingrowth onto the stem of the press-fit prosthesis due to micromotion of the prosthesis within the medullary canal is one of the causes of aseptic loosening in monopolar implants.[32,45] Possibly the bipolar design results in reduced stress and micromotion at the implant–bone interface.[32,45]

Obviously, most indications for revision of RHA are associated with pain in the elbow or forearm. Pain is the symptom, not the cause and pain can have many reasons other than a failed prosthesis. Interestingly, 26 patients (17% of all failures) underwent revision surgery solely for persisting pain. The question is what the underlying pathology (i.e. true failure mode) in these cases had been. O'Driscoll and Herald suggested that pain in the proximal forearm in patients with a press-fit RHP is a strong indicator for symptomatic loosening, even in the absence of radiographic signs of loosening.[46] In the analysis 11/26 revisions for pain involved press-fit prostheses. This could imply that the prostheses could have been loose in this group. However, the remaining 15/26 prostheses were cemented in place or intentionally loose-fit. Further studies on this phenomenon are needed.

Moreover, this study revealed that intentionally loose-fit prostheses failed earlier compared to press-fit prostheses (a mean time to failure of 17 versus 53 months, respectively). A possible explanation for this from our data could be that intentionally loose-fit prostheses failed more often because of stiffness compared to press-fit prostheses. In general, stiffness is a problem encountered early on after elbow trauma and/or surgery[47-49] and could have different underlying problems in the case of RHAs: over sizing of the head, stiffness because of the (surgically) injured soft tissues around the elbow joint or a loose stem followed by migration of the implant. A clear explanation in the cases of the patients included in this study remains unknown, since no additional data were available.

The strengths of the current review are the selection criteria for our studies that were set to include series with enough patients and follow-up time of the implants. As far as we

know, there has been only one other review on revisions of RHPs.[3] The primary objective of that review was to determine the incidence of revision or removal after RHPs placed for acute fractures. According to that review, the main reason for revision surgery was heterotopic ossification (HO). However, in the current study, there were no cases of HO at all. This discrepancy is likely the result of the fact that Kachooei et al.[3] included a radiographic outcome study by Ha et al. that described nearly all cases having HO (33 patients).[50] The study by Ha et al. was excluded in the current review because the follow-up was too short and the types of RHPs used unclear.

Several limitations are recognized. Due to the small numbers it was not possible to perform a meta-analysis on the extracted data. Since there are many different types of RHP included (n = 18), it is, with the relatively small numbers of primary implantations and revision cases, not possible to draw firm statistical conclusions. Moreover, prosthesis polarity, material, and fixation technique are not independent of each other. Thus, there are only eight combinations in practice, instead of the maximum of 32 possible combinations (two different polarities, four different materials, and four different techniques of fixation). These eight possible combinations reflect the true spectrum of available prostheses.[4]

Other limitations are the lack of reports in some studies on perioperative findings and individual time to failure of primary RHPs. In only 85 of the 152 patients the individual time to failure was reported. Then, although intentionally loose-fit prostheses were shown to fail earlier than press-fit prostheses, most other possible statistical comparisons of times to failure between the different fixation methods seemed to be underpowered. Also, studies regarding RHA are mostly mid-term follow-up. There are only a few studies with long-term follow-up (more than 10 years) available in the literature.[7, 19]

In order to make a meta-analysis possible, a more uniform way of reporting indications for revision surgery and results is important. We think that the development of guidelines for standardized patient reported outcome measures (PROMs) and registration of clinical and radiographic outcomes is essential. National arthroplasty registries should play a leading role in this. Moreover, the outcomes after removal or revision of an RHP should be registered as well, as it is currently unknown which one is the preferred treatment for failed RHA and this choice seems to be more dependent on the preference of the hospital or surgeon, rather than on some level of evidence.[18]

Conclusions

In conclusion, the most frequent reasons for revision surgery after primary RHA are symptomatic (aseptic) loosening, elbow stiffness and/or persisting pain. Other, less common indications are technical failures as overstuffing and dissociation of the implant. Failure occurs after an average of 34 months and the majority of the failed prostheses is removed. Taking into account the many different types of RHPs used and the various indications for revision surgery, the current data does not support a preference for a specific RHP design over one other. Guidelines for standardized follow-up are needed to improve our understanding of why RHPs fail.

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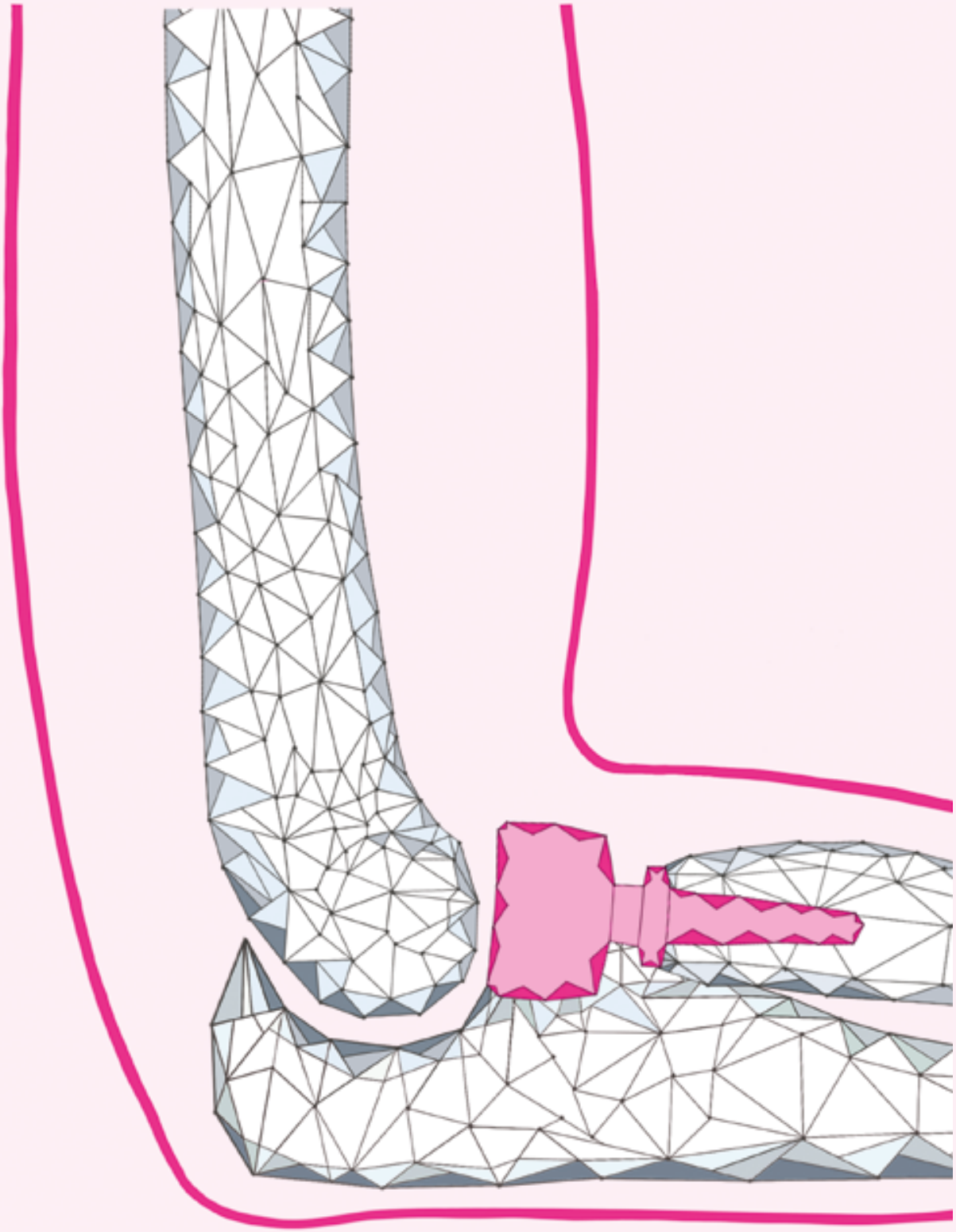

Chapter 3

Complications and revision of radial head arthroplasty: management and outcomes

J. Viveen
I.F. Kodde
A. Prkic
B. The
D. Eygendaal

Castoldi F, Giannicola G, Rotini R, Elbow Arthroplasty – 2020

Abstract

Since the introduction of radial head prostheses (RHP), comminuted fractures of the radial head are more frequently treated with use of a prosthesis. Good functional outcomes of primary RHP have been reported, although the complication and revision rates are still relatively high. If the prosthesis fails, several surgical interventions are possible, including removal, revision to a radiocapitellar or total elbow arthroplasty or replacement by another RHP. The decision which type of secondary surgery should be performed depends on the stability and chondral condition of the elbow joint. Unfortunately, to date, little is known about the functional outcomes after either removal or revision surgery of RHP. Some reports indicate improvement of pain and function after revision surgery, but these conclusions should be interpreted with some caution, since they were based on small patient cohorts with limited follow-up.

Introduction

During the past 75 years, radial head prostheses (RHP) have been used as treatment for a wide range of traumatic conditions, including acute comminuted radial head fractures and other posttraumatic deformities such as nonunion, malunion, posttraumatic osteoarthritis and chronic instability of the elbow or forearm.[1]

Since the introduction of RHP by Speed,[2] many modifications have been developed that varied in terms of material, fixation technique, modularity, and polarity. To date, it is unclear which type of RHP is superior. Silicone RHP have proved to be biologically and biomechanically insufficient, with a substantial risk of fragmentation of the implant[3] and silicone synovitis as a result. Although good results have been reported in primary[4] and revision surgery of RHP, complication rates up to 30% have been reported[4, 5] with implant revision- and removal rates of 8 to 10% at 3 to 4 years.[4, 6] This survival rate is far less favorable than rates reported for hip and knee arthroplasties.[7]

Because of the relatively high complication and failure rates of primary RHP, there is need for an algorithm whether to revise, replace or remove the failed prosthesis. An overview of the functional outcomes that can be expected after these different types of surgeries is provided in this chapter.

Complications and failures patterns of primary radial head arthroplasty

Many papers are available about the outcomes of different types of primary RHP. Complication rates up to 30% have been reported, including infection, persistent pain, stiffness, heterotopic ossifications (HO), loosening, overstuffing, oversizing of the head and dissociation of the head from the stem of the prosthesis.[4-6, 8, 9] The reason for this relatively high complication rate is still unclear, and it is questionable if this depends on the type of the prosthesis and fixation technique used or the applied surgical technique.

Interestingly, most revisions or removals are performed within 2 years after placement of the primary prosthesis.[6] Moreover, the decision whether to revise or remove the prosthesis seems more likely to depend on the preference of the surgeon or the hospital, rather than on objectifiable problems with the prosthesis.[10]

Therefore, it would be helpful to provide an algorithm whether to revise, replace or remove the prosthesis taking into account the failure pattern of the prosthesis and the chondral condition of the elbow joint. Because it is proven that silicone RHP are biologically and biomechanically insufficient,[3] it is not preferable to use this design anymore. Nevertheless, there are many more designs of RHP available which are varying in material (cobalt-chromium, titanium, pyrocarbon and vitallium), fixation technique (press-fit, intentional loose-fit, cemented or fixation by an expandable stem), modularity (monobloc or modular), and polarity (monopolar or bipolar).

Indications for revision or removal of RHP are excision of HO (47%) and stiffness (42%) and persistent pain. Less common indications are loosening of the implant (16%),

overstuffing (13%) and infection (8%).[4, 6] Although some suggested that revision and removal rates are not affected by the design of the prosthesis,[4] others reported that subgroup analyses showed the lowest incidence of RHP failure in cemented, long-stemmed, vitallium and bipolar prostheses.[6]

3

Revision of radial head arthroplasty – work-up

Revision surgery after radial head arthroplasty is predominately performed because of painful elbow stiffness, overstuffing of the prosthesis (overlengthening and oversizing), subluxation or dissociation of the prosthesis, loosening of the implant, painful erosion of capitellum or infection.[4] Before the decision to perform revision surgery is made, it is essential to define the potential problems that are likely to have caused failure of the implant. This is done by performing a broad workup to identify the mode of failure and to exclude other potential causes of failure.

As always, the work-up starts with careful history taking. The patient may have had pain from the first moment after the implantation of the radial head or may have developed pain later on. The first is more likely with overstuffing and malalignment or early failure either based on septic or aseptic failure of implant fixation. The latter may be the case in late loosening of the prosthesis or capitellar erosion. A history of wound healing problems may suggest an infection, whereas a prolonged period of immobilisation before or after surgery or malalignment may both result in elbow stiffness. In addition, a history of progressive (pain) complaints of the wrist may suggest proximal migration of the radius.

Physical examination focuses on scars around the elbow, range of motion, soft tissue swelling, joint effusion, pain on palpation or during loaded and unloaded motion of the joint, stability of the elbow and neurovascular status. Moreover, examination of the wrist and the distal radioulnar joint (DRUJ) should not be underestimated. Radiographs in anteroposterior (AP) and lateral direction give information on possible loosening, subluxation or dissociation of the prosthesis. It is essential to know that many radial head implants show signs of proximal, subcollar, osteolysis, but are not loose.[5] Additional imaging with CT is often needed to assess other variables needed for pinpointing the cause of failure. It is more accurate for assessment of overstuffing,[11] gives more detailed information on the exact location and geometry of HO, and can more accurately detect loose bodies, osteoarthritis or erosion of the capitellum. Dual Energy CT-scanning reduces the scattering that is produced by the prosthesis and makes further evaluation more accurate. Standard radiographs of both sides of the wrist can be useful in detecting proximal migration of the radius.[12]

Laboratory testing of inflammation parameters such as C-reactive protein (CRP) and subsequent aspiration for cultures may offer information on the possibility of an infection, but is less sensitive in comparison to its use in lower extremity infections.[13]

The planning of the surgery starts with patient positioning and planning the incision. If a previous incision was made posterior on the elbow, a lateral decubitus positioning may

be easier, whereas supine position with the arm on an arm table is adequate for a lateral incision. An advantage of using the posterior approach is the possibility to perform surgery on both the lateral, medial and posterior side of the elbow with easy access to the ulnar nerve, even if the patient has fairly limited shoulder motion. A lateral incision allows for good access to the RHP itself, as well as facilitating an anterior and posterior arthrotomy of the elbow joint but will have to be complemented by an additional medial incision if access to the ulnar nerve or the medial side of the joint is needed. This second incision may seem to be adding to the morbidity of the procedure, but an extensive posterior approach with development of large skin flaps may sometimes prove to be more of a risk, especially if wound breakdown is a concern in the case at hand. In some cases, the planned procedure will dictate the approach: A radiocapitellar prosthesis can be implanted through either a lateral or posterior approach whereas a total elbow prosthesis is always implanted through a posterior approach.

In case of stiffness, it is important to assess the RHP for possible overstuffing during the arthrolysis. Overstuffing can mean either oversizing, when the head of the prosthesis is too big, or overlengthening, when the head of the prosthesis is placed too high in relation to the ulna. In case of overstuffing, it is sometimes necessary to revise the implant, whereas some implants can be shortened in situ. For other – bipolar – implants changing the head component may be enough. Dissociation of the head component is clearly only seen in bipolar implants. In case of dissociation of the head it is essential to critically evaluate the snap-on mechanism, malalignment, malrotation and stability of both the radioulnar as well as the ulnohumeral joint as well as the congruity of the capitellum.[14] A new head component, or a complete new prosthesis may be needed, but more extensive surgery may be called for if instability is present. With unipolar designs, subluxation of the radial head is sometimes seen in cases of instability or chronic malalignment of the radius on the capitellum.[15] In these cases a revision with a cemented bipolar implant may compensate for a mild malalignment.[15] Otherwise, the source of malalignment may have to be addressed by repositioning of the stem during revision or stabilising the joint. In case of a chronic malalignment however, the capitellar cartilage may have been severely damaged, adding a difficult problem to solve. It should then be decided to either ignore the capitellum, 'understuff' the revised radial head, or remove it without replacing it with or without reconstruction of the interosseous membrane (IM).

The surgical plan for infection of a prosthesis depends on numerous factors including the type of micro-organism, comorbidity, soft tissue status and duration of the infection. There are two options available in case of infection. The surgeon can decide to perform an extended debridement of the elbow joint or to remove the prosthesis. In most cases, both treatment options are combined with antibiotics. The type and length of antibiotics depend on the type of micro-organism; therefore, perioperative cultures should always be taken before antibiotics are given. Guidelines on treatment options such as removal versus retention of the implant in case of prosthetic infection have been written by Morrey et al. previously.[13]

In all cases the surgeon should assess the stability of the elbow joint and the chondral status of the capitellum and ulnohumeral joint. In cases of instability with insufficiency of the LCL or MCL, IM or reduced buttress of the coronoid removal of the prosthesis should not be performed. In selected cases, revision of the implant is combined with reconstruction of the LCL, MCL, IM or coronoid. In cases of symptomatic osteoarthritis (chondromalacia grade IV) of the capitellum or erosion of the capitellum with an incongruency of the joint, resurfacing of the capitellum with a capitellar component is mandatory.[16] Symptomatic ulnohumeral osteoarthritis, or severe instability of the elbow in patients above 70 may be a reason to convert to a total elbow arthroplasty (TEA).

Outcomes of revision surgery of radial head arthroplasty

Concerning the outcomes of radial head arthroplasty revisions, subjective and objective outcomes clearly have to be distinguished. Gain in range of motion as an objective parameter and decrease of pain as a subjective parameter are generally the two main goals of revision surgery of RHP.

After primary radial head arthroplasty, range of motion varies between 115° to 125° of flexion-extension and 130° to 155° of pronation-supination.[4] Revision of the RHP may be helpful in increasing the range of motion, when stiffness interferes with the patient's demands of activity. A single study on revision of RHP for persistent pain in combination with loosening and instability showed that a flexion-extension range of motion of 105° improved to 127° and pronation-supination improved from 113° to 138°.[16] Pain scores lowered from 8 out of 10 with activity to 4 out of 10.[16] In addition, revision surgery also improved poor and fair patient-reported outcomes to excellent to fair on the Mayo Elbow Performance Score (MEPS).[16]

At a mean follow-up of 57 months, there was only one major complication: a dissociation of the head from the stem of the prosthesis, probably due to polyethylene wear. Other minor complications were transient ulnar nerve dysfunction (19%) and lateral epicondylitis (5%) which is probably unrelated to the surgery. 95% of patients were satisfied with the outcome after a mean follow-up period of 75 months.[16] No second revisions were performed, yet this may occur on the long-term.

When degeneration of the capitellum is present, revision to a radiocapitellar prosthesis or even a TEA might prove beneficial when the impairments after arthroplasty outweigh the symptoms of failed RHP.[17] When implanted for osteoarthritis, radiocapitellar prosthesis yields good outcomes, yet the ligamentous structures should be all intact.[18] When TEA is implanted for posttraumatic sequelae, only 8% involve primarily the radial head; majority of cases have a distal humeral fracture or severe ligamentous injury.[19] According to the Dutch Arthroplasty Register data, 6 out of 50 failed RHP are revised to a TEA in 2015; the remainder is either revised (5 out of 50) or removed (39 out of 50).[20, 21] Unfortunately, reasons for secondary surgery after primary RHP are not mentioned. Overall, revision of a RHP to a TEA remains uncommon and is only performed in selected cases.

Outcomes after removal of radial head arthroplasty

Another option to treat a patient with pain, restricted range of motion or infection of the elbow joint after radial head arthroplasty is removal of the prosthesis without replacement.

Pain can be the result of loosening, overstuffing of the radiocapitellar joint, infection, degeneration of the capitellum and instability.[9, 17] Restriction in range of motion often is the result of capsular adhesions or HO around the arthroplasty, leading to impingement. This can be managed by open or arthroscopic removal of the HO around the radial head.[9, 22] Administration of nonsteroidal anti-inflammatory drugs following surgery might prevent recurrence of HO.[23, 24]

After removal of the prosthesis, proximal radioulnar convergence or longitudinal forearm instability (especially after an initial acute longitudinal radioulnar dissociation injury) may occur.[25] Proximal migration of the radius may result in distal radioulnar incongruence, with a positive ulnar variance, leading to an ulnar impaction syndrome which is reported by the patient as ulnar-sided wrist pain.[26]

The radial head is considered to be a secondary stabiliser during valgus load, but when the medial collateral ligament is also insufficient, removal of a RHP leads to valgus instability with ulnar nerve overstretching and increased varus and valgus load on the ulnohumeral joint in the long-term.[9, 27] Therefore, during radial head arthroplasty removal careful assessment of the medial collateral ligament is necessary and ulnar nerve transposition can be considered when the medial collateral ligament is insufficient.[9, 28] Thus, removal of a failed RHP has to be seen in the light of its potential complications. In specific patient groups, for example low-demanding or elderly patients, these complications may outweigh the risk of a second re-operation after a RHP revision.[29, 30] In contrast, several studies are available about functional outcomes after radial head resection directly after trauma. Good functional outcomes are reported in the majority of these patients, including satisfying MEPS and DASH scores.[26, 27, 31, 32] However, in some patients radiological outcomes were poor.[33]

Conclusions

Indications for revision surgery of primary RHP are HO and stiffness, with or without persistent pain. Other less common indications are loosening and overstuffing. In case of overstuffing, instability or malalignment replacement of the RHP should be considered. If an infection occurred, removal of the prosthesis is usually preferred. Revision to a radiocapitellar should be considered in case of erosion of the capitellum. Replacement by a TEA is indicated if there is osteoarthritis of the entire elbow joint.

In short, whether to revise, replace or remove a failed RHP is based on the chondral condition and the stability of the joint. The clinical and functional outcomes after surgery of a failed RHP are in general satisfying; however, the complication rates are still relatively high.

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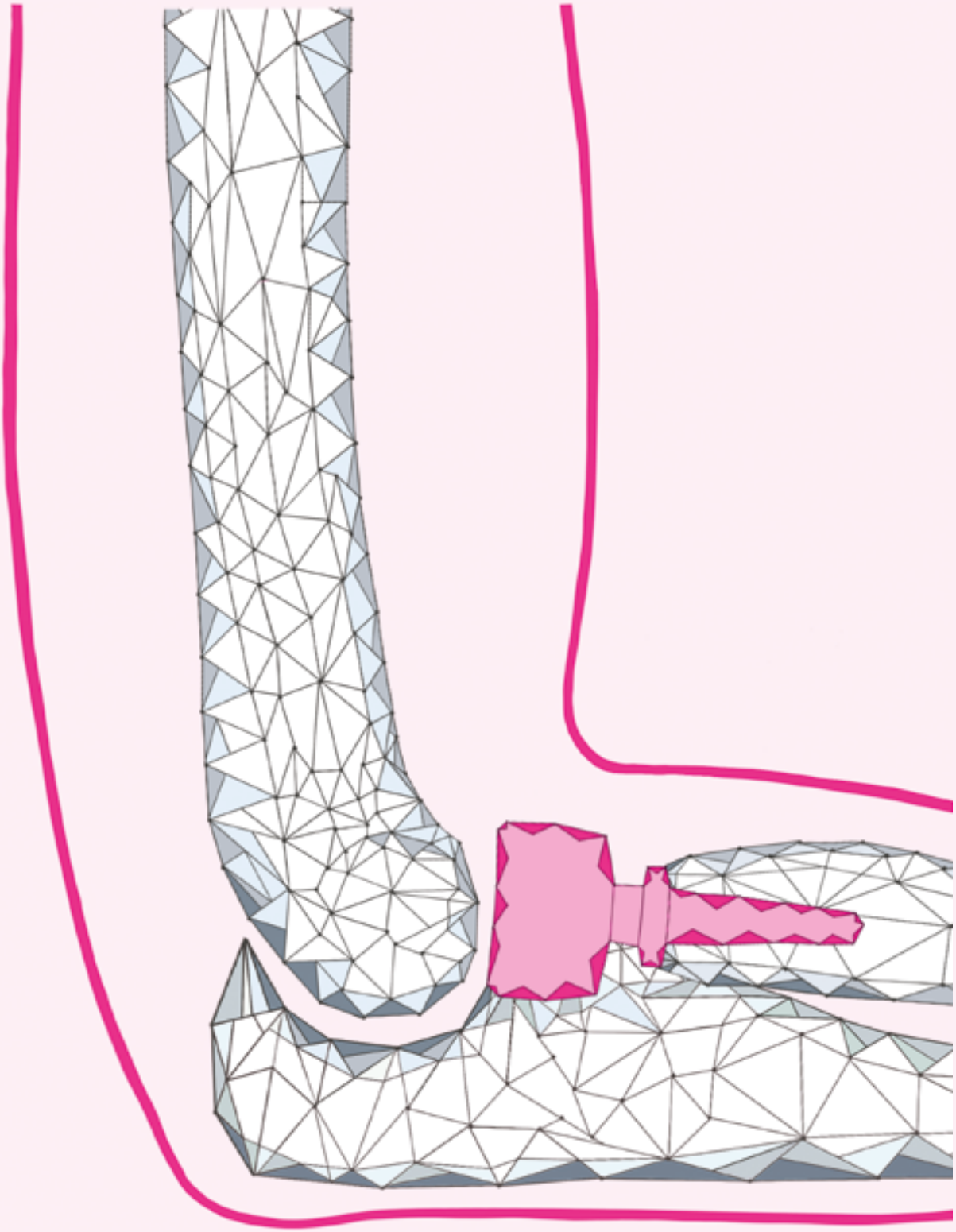

Chapter 4

Clinical and radiographic outcome of revision surgery of radial head prosthesis: midterm results in 16 patients

J. Viveen
I.F. Kodde
K.L.M. Koenraadt
A. Beumer
B. The
D. Eygendaal

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Abstract

Background

Little is known about revision surgery of radial head arthroplasty. The aim of this study was to report on the clinical and radiographic outcome of revision arthroplasty of the elbow with a bipolar metallic radial head prosthesis.

Methods

Between 2006 and 2013, we used either a press-fit or cemented RHS bipolar radial head prosthesis for revision surgery of radial head arthroplasty in 16 patients. Patients were prospectively enrolled in the study. Differences in outcome parameters before and after revision surgery were compared.

Results

At a mean follow-up of 75 months (range, 36-116 months), none of the revised radial head prostheses needed a second revision. None of the stems showed radiographic signs of loosening. In 1 patient the head was dissociated from the prosthesis. The average flexion-extension arc was 127° (range, 105°-140°) and the average pronation-supination arc was 138° (range, 90°-160°). Stability scores improved after revision surgery, resulting in 13 stable elbows ($p=0.01$). In 8 patients the Oxford Elbow Score was between 37 and 48 points. The percentage of patients with either good or excellent and good results according to the Mayo Elbow Performance Score was 63%. The mean score on the EuroQol Five Dimensions was 80 (range, 63-100) and the visual analogue pain scores both for pain at rest and for pain with activity improved to 3 (range, 0-9) and 4 (range, 0-9), respectively ($p<0.001$). All but 1 patient was satisfied with the results of the revision procedure.

Conclusions

The clinical and radiographic outcomes of revision surgery of radial head prosthesis are favorable.

Introduction

Since the initial report of Speed[1] on a radial head prosthesis (RHP) in 1941, the number of radial head arthroplasties has increased in the past few decades. While, historically, comminuted radial head fractures were treated by radial head excision or open reduction-internal fixation, nowadays RHPs are more frequently used.[2-4] Other less common indications for replacement of the radial head include chronic posttraumatic conditions such as nonunion, osteoarthritis and elbow instability.[5]

In primary radial head arthroplasty, complication rates of up to 30% have been described,[6, 7] and a systematic review on radial head arthroplasty showed revision and implant removal rates of 8% at 4 years.[6] Revision or removal rates for RHPs are higher in patients with silastic radial head implants (Dow Corning, Midland, MI, USA) and in young patients.[8] A silicone RHP has been shown to be biologically and biomechanically insufficient, which finally leads to fracturing of the implant with silicone synovitis as a result.[8] Other indications for revision surgery may be secondary erosion of the capitellum, stiffness, loosening, instability, or persistent pain.[9]

If the primary radial head arthroplasty has failed, the prosthesis can be removed, revised to another RHP, or replaced by a total elbow or radio-capitellar arthroplasty. Revision surgery is preferred over removal because it may prevent proximal migration of the radius, resulting in instability of the forearm and distal radioulnar joint. Moreover, the radial head allows for equal load transmission among the radius, ulna and the distal humerus, as well as proper tensioning of the lateral collateral ligament (LCL) complex, and it acts as a secondary stabilizer for valgus strain.

Reports on the clinical and radiographic outcome of revision surgery of the RHP are rare. To our knowledge, only one study has described the clinical outcome of revision surgery with a short mean follow-up of 3 months.[8] The aim of this study is to report on the clinical and radiographic outcome of revision surgery of the radial head with a bipolar RHP.

Materials and methods

Patient population

All patients who underwent revision surgery of an RHP between August 2006 and December 2015 were prospectively enrolled in this study and were assessed preoperatively and at 1, 3, 5, 7 and 10 years after surgery. Patients who forgot to make an appointment after surgery were actively recruited by telephone and asked to make an appointment. A bipolar-type RHP (Tornier, Montbonnot-Saint-Martin, France) was used in 16 revision arthroplasty cases in 16 patients. A highly experienced elbow surgeon (D.E.) performed all revision surgical procedures. Only 1 of 16 patients had undergone the primary surgical procedure at our hospital.

Preoperatively, the medical history of all patients was documented and range of motion (ROM) was measured with a goniometer. Patients completed the visual analog scales (VASs) (0 -10) for pain at rest and pain with activity, and function of the elbow was determined

using the Mayo Elbow Performance Score (MEPS). At serial postoperative follow-up visits, the assessments included the same parameters. However, since 2013, the Oxford Elbow Score (OES) and the EuroQol five dimensions (EQ-5D) (0-100) have been added to the questionnaires. In addition, the satisfaction of patients was assessed using the question 'are you satisfied with the result of the surgery?' to which patients could answer 'yes', 'moderately satisfied' or 'no'.

Preoperatively and at each follow-up visit, plain anteroposterior and lateral radiographs were obtained. Two surgeons (I.F.K. and B.T.) evaluated the radiographs regarding loosening of the implant, osteolysis of the radial neck, radiocapitellar alignment, radiolucency, ulnohumeral degeneration, and ossifications or erosion of the capitellum. If no agreement in the evaluation was shown, consensus was made. Osteolysis was evaluated by means of specific zones (zone 1 to 7) around the radial neck as described by Grewal et al[10] for uncemented implants and by Popovic et al[11] for cemented implants. Both abrasion of the capitellum and osteopenia were noted to be present or absent. Degenerative changes of the ulnohumeral joint were classified as none, slight, moderate, or severe as postulated by Broberg and Morrey.[12] Furthermore, the relation between the position of the head of the prosthesis and the capitellum was evaluated. Finally, possible failure of the snap-on mechanism was assessed as described by O'Driscoll and Herald.[13] Degeneration of the capitellum was evaluated perioperatively using the International Cartilage Repair Society grading system as follows: grade 0, normal; grade 1, nearly normal (soft indentation and/or superficial fissures and cracks); grade 2, abnormal (lesions extending down to <50% of cartilage depth); grade 3, severely abnormal (cartilage defects >50% of cartilage depth); or grade 4, severely abnormal (through the subchondral bone).

Surgical procedure

The surgeon assessed the valgus instability (grade 1, stable; grade 2, mild instability; or grade 3, severe instability) before making an incision (Table 1). During surgery, the patient was in the supine position with the arm on a side table. Prophylactic intravenous antibiotic coverage was routinely given because none of the elbows was suspected for deep infection. A silicone ring tourniquet was placed around the upper arm, as proximal as possible. If possible, a previous incision was used. The elbow joint was approached using an extensor split approach (Kaplan interval) and transection of the annular ligament. The implants were removed carefully to prevent further bone loss. In 3 patients cement had been used in the primary surgical procedure. In 2 patients all of the cement fragments in the medullary canal could be removed. In the remaining patient, only the head of the prosthesis was revised, and the stem was left in situ. In 1 more patient with uncemented RHP, only the head of the prosthesis was revised to a smaller size.

Either a press-fit or cemented RHS bipolar RHP (Tornier; Figure 1) was implanted. Before press-fit designs became available, we routinely performed radial head arthroplasty using cemented prostheses. After the introduction of press-fit prostheses, we started using them if bone quality was good and the trial components showed a good press fit whereas

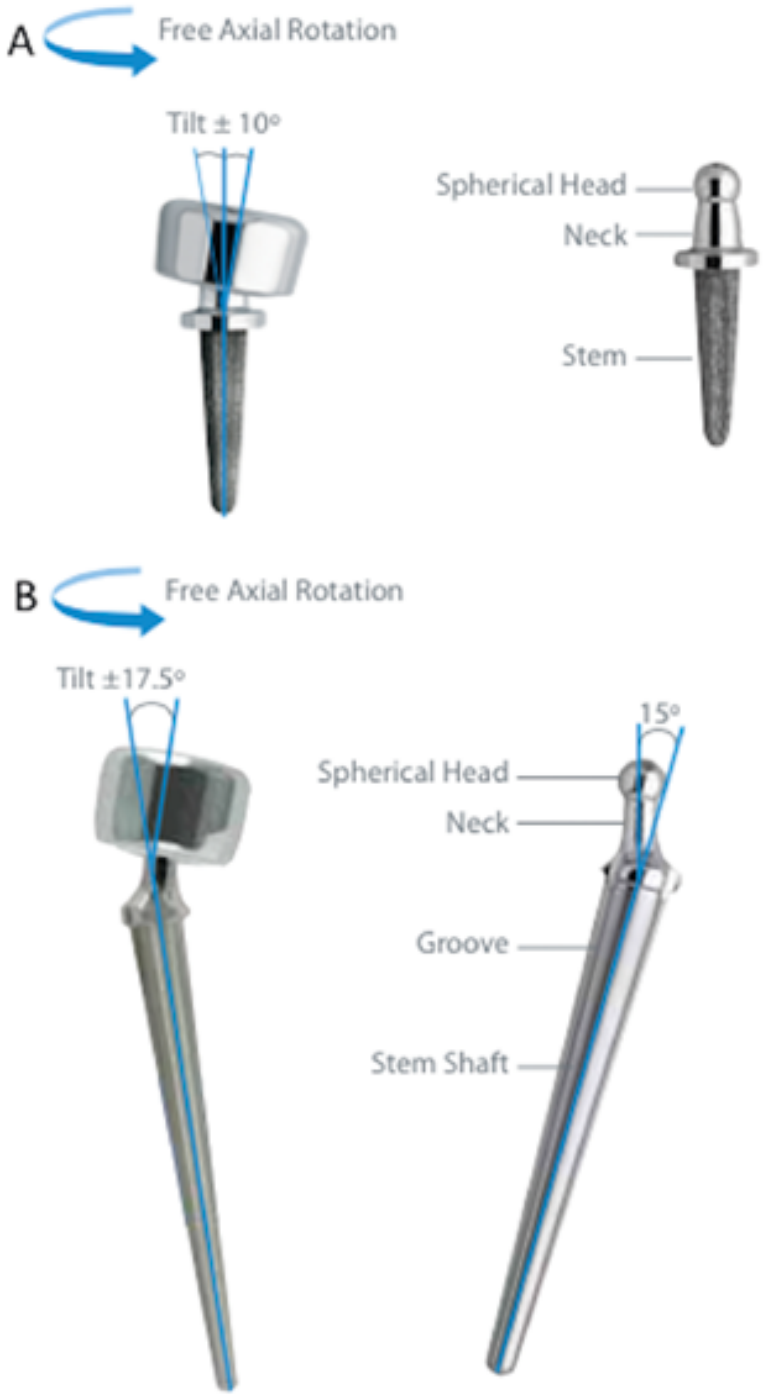

Figure 1. The press-fit (A) and cemented (B) RHS bipolar radial head prosthesis (Tornier, Montbonnot-Saint-Martin, France).

we used cemented prostheses if there was any doubt about bone quality or fixation of the trial components. This algorithm is as described by Kodde et al,[7] which we still use in our institution today.

The exact height of the prosthesis was evaluated with trial components and stability and ROM were assessed. After assessment of the joint the trial components were removed. In 7 patients the final implant was pressed fit in place. In 9 patients the final implant was placed with use of cement. In all patients concomitant surgical procedures were performed (Table

1). In 7 patients with previous silastic prostheses synovectomy was performed for moderate to severe synovitis because of reactive silicone synovitis due to breaking of the implant. In 15 patients additional surgery was performed: in 4 patients the LCL was reconstructed. In 7 patients an arthrolysis was performed to increase the ROM. In 4 patients the annular ligament AL was insufficient after previous surgery, and was reconstructed with al strip of triceps fascia. The wound was closed in layers.

After the surgical procedure, the silicone ring tourniquet was released and a pressure bandage was applied for 48 to 72 hours. Mobilization was started on the first postoperative day with supervision by an upper extremity-specialized physical therapist. For patients with additional LCL reconstruction, a splint was used for 10 days. It was no routine to use prophylaxis for heterotopic ossification.

Statistical methods

To summarize the data, descriptive statistics were used. Differences in outcome parameters before and after revision surgery were compared using *t* tests for normally distributed data.

Results

Patients and follow-up

Sixteen elbows in 16 patients were included in this study. There were 14 women and 2 men. The mean age at surgery was 49 years (range, 27-69 years). There were 11 right- and 5 left-handed patients, and 13 dominant arms involved. The index RHP had failed for a variety of reasons (Table 2), and the mean time between previous surgery and revision surgery was 93 months (range, 3-227 months). In 1 patient (case 4) there was a delay of 40 months between removal of the index prosthesis and implantation of the revision RHP. The index implant was removed because of failure of the implant and revision surgery was performed because of persistent instability of the elbow. The indication for index surgery was acute trauma in 12 patients, whereas 4 patients had late posttraumatic complaints. At the time of revision surgery, 3 elbows were documented to be stable versus 8 mildly and 5 severely unstable elbows. In 8 patients silastic prostheses were revised (Dow Corning Corporation Silastic Swanson Radial Head Implant, Midland, MI), the others were: 4 press-fit and 1 cemented RHS bipolar RHP (Tornier, Montbonnot-Saint-Martin, France), 1 Solar Radial Head prosthesis (Stryker Howmedica Osteonics), 1 Liverpool prosthesis (Biomet, Warsaw, IN) and 1 Mopyc pyrocarbon RHP (Bioprofile-Tornier, Cedex, France). In 2 patients only the head of the prosthesis was revised, one because of polyethylene wear and one because of oversizing of the head, while the stem was left in situ, because the stem was well fixed during surgery and was not overstuffed. Table 1 presents patient-specific data on the indication for revision surgery and interval between the primary and revision procedures. At a mean follow-up of 75 months (range, 36-116 months), there had been no second revisions and there was no patient lost to follow-up. Preoperative ROM and stability were known in all patients. In

Table 1. Demographic data of patients who received revision surgery.

Case No.	Sex	Age, y	Injured side	Dexterity	Revision prosthesis	Indication for revision surgery	Index prosthesis	Time since index surgery, mo	Concomitant surgical procedures
1	F	50	R	R	Tornier (cemented)	Fracture prosthesis	Swanson (silastic)	167	Synovectomy
2	F	69	L	L	Tornier (cemented)	Loosening	Tornier (cemented)	12	Arthrolysis and removal of OSM
3	F	42	R	R	Tornier (press-fit)	Polyethylene wear of the radial head	Tornier (press-fit)	3	Nettoyage and reconstruction of AL
4	F	58	L	L	Tornier (press-fit)	Instability after radial head prosthesis removal due to fracture of the prosthesis	Swanson (silastic)	159	Arthrolysis and reconstruction of AL
5	F	35	L	L	Tornier (cemented)	Fracture prosthesis	Swanson (silastic)	148	Synovectomy, nettoyage and reconstruction LCL and AL
6	F	45	L	L	Tornier (press-fit)	Fracture prosthesis	Swanson (silastic)	58	Synovectomy
7	F	46	R	L	Tornier (press-fit)	Fracture prosthesis	Swanson (silastic)	224	Synovectomy, nettoyage and reconstruction LCL
8	F	47	R	R	Tornier (press-fit)	Fracture prosthesis	Swanson (silastic)	215	Synovectomy and nettoyage
9	M	27	L	R	Tornier (cemented)	Loosening	MoPyC (press-fit)	45	Arthrolysis
10	F	54	R	R	Tornier (cemented)	Fracture prosthesis	Swanson (silastic)	48	Synovectomy
11	F	59	R	R	Tornier (press-fit)	Fracture prosthesis	Swanson (silastic)	227	Synovectomy and reconstruction of LCL and AL
12	F	46	R	R	Tornier (cemented)	Malposition	Liverpool (cemented)	13	Arthrolysis
13	F	60	L	R	Tornier (cemented)	Pain persistent	Tornier (press-fit)	12	Nettoyage
14	F	58	R	R	Tornier (cemented)	Proximalization of the radial head	Tornier (press-fit)	12	Arthrolysis, nettoyage. And fixation of LCL using a corkscrew
15	M	40	R	R	Tornier (cemented)	Proximalization of the radial head	Solar (cemented)	45	Arthrolysis and nettoyage
16	F	46	R	R	Tornier (press-fit)	Limited range of motion	Tornier (press-fit)	8	Arthrolysis

Al, annular ligament; F, female; L, left; LCL, lateral collateral ligament; M, male; R, right.

13 patients preoperative MEPS and VAS scores for pain at rest and pain with activity were known as well. These data are presented in Table 2 and served as baseline measurements.

Complications

In 1 patient (case 11) the head of the prosthesis was dissociated from the stem at 72 months after implantation. The patient had complaints of locking but refused a second revision surgical procedure because the dissociation was neither painful nor bothering the patient during daily activities. The other complications were non-operation-related problems and consisted of 1 patient (case 3) with a lateral epicondylitis that required treatment using autologous blood injection and minor ulnar nerve symptoms, which did not require additional treatment, in 3 patients.

Radiographic analysis

Radiographs were available for 15 patients. At last follow-up, none of these 15 prostheses showed radiographic signs of loosening. Radiographic osteolysis around the neck of the RHP was seen in 14 patients (93%). Among the 7 press-fit prosthesis, this osteolysis involved both zones 1 and 7 in five patients, and only zone 7 in two patients, only zone 1 in one patient. Among the 8 cemented prostheses, this osteolysis involved zone 7 in two patients, zone 1 in two patients, zones 6 and 7 in one patient, zones 2, 6 and 7 in one patient and zones 1, 2, 6, and 7 in one patient. In the last 2 patients these radiolucent lines already existed on the first postoperative radiograph and were a result of poor cementing technique. Among patients with either press-fit or cemented prostheses, grade 1 ulnohumeral degeneration developed in 6 patients (38%) and grade 2 ulnohumeral degeneration developed in 4 patients (25%). Progression or the occurrence of osteopenia of the capitellum was found in 7 (44%). Heterotopic ossification was observed in 2 patients (13%) but was not symptomatic. In 1 patient (6%) the snap-on mechanism had failed.

Range of motion (ROM)

No statistically significant improvements in ROM between baseline and last follow-up were observed. At baseline, the average flexion-extension arc was 105° (range, 35°-137°) and the average pronation-supination arc was 113° (range, 10°-165°). At last follow-up, the average flexion-extension arc was 127° (range, 105°-140°) and the average pronation-supination arc was 138° (range, 90°-160°). Detailed data are presented in Table 3. Increases in the flexion-extension arc and pronation-supination arc over time are presented in Figure 2.

Functional scores

According to the MEPS, at baseline, there were 7 fair results (54%) and 6 poor results (46%). The MEPS improved at last follow-up to 5 excellent results (31%), 5 good results (31%), 6 fair results (38%) and no poor results at last follow-up ($p<0.001$) (Table 3). Variations in

MEPS results regarding the follow-up moments are presented in Figure 3. No baseline measurements were available for the OES and the EQ-5D. The mean OES postoperatively was 34 points (range, 15-48 points). Of the patients, 4 scored between 13 and 24 points, 4 between 25 and 36 points and 8 scored between 37 and 48 points. The mean score on the EQ-5D was 80 (range, 63-100). Nine patients had a result of at least 80 according to the score assessing patients' general health (Table 3).

Pain

Before surgery, the mean VAS score for pain at rest was 5 (range, 0-10) and the mean VAS score for pain with activity was 8 (range, 6-10). The VAS scored improved both for pain at rest and for pain with activity (P<0.001) at last follow-up, to mean score of 3 (range, 0-9) for pain at rest and 4 (range, 0-9) for pain with activity. Patient-specific details are presented in Tables 2 and 3.

Stability

Improvement of stability of the elbow joint was observed between baseline and last follow-up (p=0.01). Before revision surgery 3 elbows appeared to be stable, 8 were mild

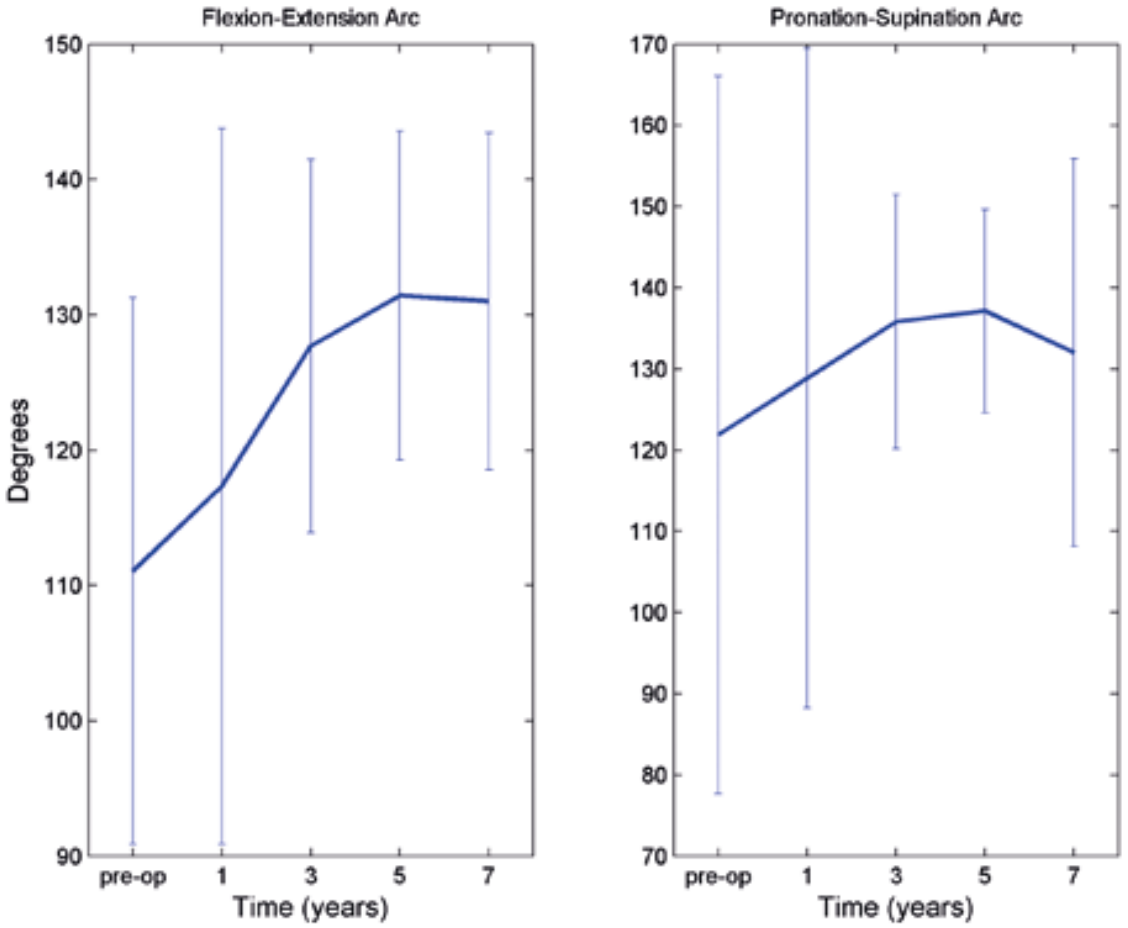

Figure 2. Pronation-supination arc and flexion-extension arc increase over time.

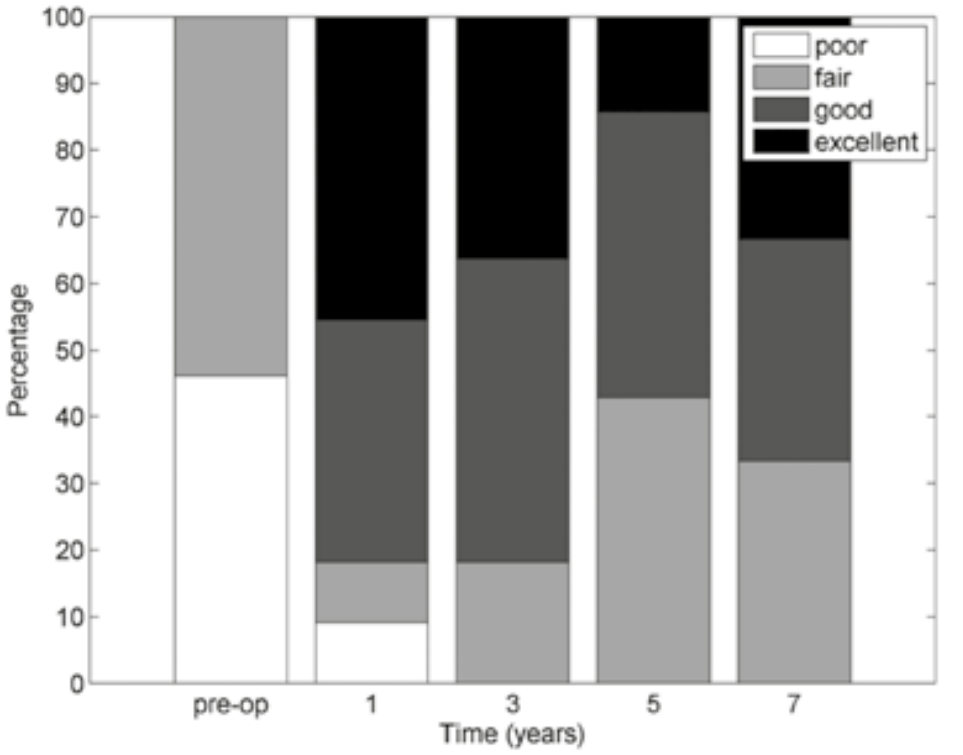

Figure 3. MEPS results over time.

unstable and 5 were severely unstable. After surgery, 14 elbows were stable, 1 elbow was mildly unstable and 1 elbow was severely unstable because of failure of the RHP (Table 3).

Patient satisfaction

During each postoperative assessment all but 1 patient answered yes to the question whether they were satisfied with the results of the revision surgery. Even the patient with failure of the RHP was satisfied, because the pain had decreased, and her elbow was not bothering her anymore during daily activities. Only 1 patient answered the question with 'moderately satisfied'.

Discussion

The number of radial head arthroplasties is small compared to the number of knee arthroplasties and hip arthroplasties. Thereby, little is known about the midterm results of primary RHP and revision surgery. To the best of our knowledge, this is the first report to describe the clinical and radiographic midterm results of revision surgery with metallic bipolar RHPs.

Nowadays, various RHPs are available, which may be classified according to polarity, material, method of fixation, or modularity. Although we prefer bipolar prostheses with either cementing or press-fitting at our institution, there is currently no evidence to prefer one type of modern RHP over another although a modular system seems preferable over a monoblock prosthesis for optimal sizing.[6] By use of diverse prostheses, good results are

Table 2. Clinical outcomes of patients before revision surgery.

Case No.	VAS score for pain at rest (0-10)	VAS score for pain with activity (0-10)	Flexion, °	Extension deficit, °	Flexion-extension arc, °	Pronation, °	Supination, °	Pronation-supination arc, °	Valgus instability during revision surgery*	Degeneration grade of capitellum†	MEPS, points§
1	4	6	140	15	125	80	80	160	3	1-2	60, fair
2	-	-	130	15	115	45	30	75	2	1-2	-
3	9	9	135	15	120	60	60	120	2	2	50, poor
4	10	9	140	3	137	80	70	150	3	3	45, poor
5	-	-	140	15	125	45	45	90	2	3	-
6	-	-	140	15	125	70	70	140	3	2	-
7	6	7	130	20	110	70	80	150	3	2	60, fair
8	5	7	140	15	125	80	70	150	2	3	65, fair
9	5	7	125	30	95	60	60	120	2	2-3	60, fair
10	3	7	140	15	125	70	80	150	2	1-2	70, fair
11	3	6	140	30	110	90	75	165	3	3	60, fair
12	4	10	120	40	80	5	5	10	1	2-3	50, poor
13	9	9	130	30	100	60	60	120	2	3	50, poor
14	7	9	110	30	80	30	20	50	2	4‡	25, poor
15	3	6	115	40	75	70	80	150	1	4‡	65, fair
16	0	7	95	60	35	0	10	10	1	1	55, poor

MEPS, Mayo Elbow Performance Score; VAS, visual analog scale.
* Valgus instability is graded as 1, stable; 2, mild instability; or 3, severe instability.
† Degeneration was graded as follows: grade 0, normal; grade 1, nearly normal (soft indentation and/or superficial fissures and cracks); grade 2, abnormal (lesions extending down to <50% of cartilage
depth); grade 3, severely abnormal (cartilage defects >50% of cartilage depth); or grade 4, severely abnormal (through the subchondral bone).
‡ The degeneration was local, and it was unclear whether the radial head prosthesis or trauma was the cause of the degeneration.
§ The MEPS is classified as excellent (≥90 points), good (75-89 points), fair (60-74 points), or poor (<60 points).

Table 3. Clinical outcomes of patients who underwent revision surgery.

Case No.	Follow-up, mo	VAS score for pain at rest (0-10)	VAS score for pain with activity (0-10)	Flexion, °	Extension deficit, °	Flexion-extension arc, °
1	116	0	2	140	10	130
2	100	1	5	140	10	130
3	98	0	4	140	0	140
4	96	9	9	140	0	140
5	96	5	5	140	5	135
6	90	3	6	140	0	140
7	91	5	7	140	10	130
8	78	0	0	140	0	140
9	57	3	3	140	0	140
10	49	3	5	140	10	130
11	102	2	5	140	30	110
12	47	5	6	130	20	110
13	38	0	3	130	25	105
14	38	6	7	140	20	120
15	36	0	1	125	10	115
16	46	0	0	130	20	110

ABI, autologous blood injection; EQ-5D, EuroQol Five Dimensions; MEPS, Mayo Elbow Performance Score; OES, Oxford Elbow Score; VAS, visual analog scale.
* Valgus instability is graded as 1, stable; 2, mild instability; or 3, severe instability.

obtained in up to 85% of the patients in whom arthroplasty surgery has been performed in the acute situation.[14] When it is performed in the delayed, posttraumatic situation, the percentage of favorable results is much lower, about 50%. Subsequently, there are a substantial number of patients with complaints after radial head arthroplasty, which may be because of instability, joint degeneration or hardware failure. This patient population was analyzed in our study. After revision surgery, stability of the elbow joint and the MEPS improved and a decrease in pain at rest and during activity was observed. ROM only slightly improved in patients who had functional ROM at baseline. Larger improvements were observed in patients who did not have functional ROM at baseline (Table 2 and 3). Preoperatively, 5 patients did not have a functional pronation-supination arc, whereas postoperatively, only 1 patient did not. Four patients did not have a functional flexion-extension arc at baseline; all of them improved to a functional arc. It is important to discuss the expected improvements preoperatively with patients in order to improve decision making in relation to whether to revise a RHP or not. In our series, the most prevalent indication for revision was pain and instability of the elbow joint due to loosening and

Pronation, °	Supination, °	Pronation-supination arc, °	Valgus instability*	MEPS†	OES, points‡	EQ-5D (0-100)	Complications and treatment
80	60	140	1	70, fair	38	63	
80	60	140	1	70, fair	32	49	
80	80	160	1	85, good	39	100	Lateral epicondylitis; ABI
70	80	150	2	65, fair	33	79	
50	40	90	1	70, fair	15	85	
80	80	160	1	85, good	27	69	
60	60	120	1	70, fair	21	83	Ulnar nerve dysfunction; no treatment
70	70	140	1	100, excellent	48	98	
70	70	140	1	100, excellent	40	100	
70	70	140	1	85, good	48	95	Ulnar nerve dysfunction; cno treatment
70	80	150	3	75, good	35	80	Subluxation of the head of the prosthesis; no treatment
60	70	130	1	70, fair	23	84	Ulnar nerve dysfunction; no treatment
70	60	130	1	100, excellent	37	90	
60	50	110	1	85, good	18	62	
80	80	160	1	100, excellent	46	62	
70	80	150	1	100, excellent	43	77	

† The MEPS is classified as excellent (≥90 points), good (75-89 points), fair (60-74 points), or poor (<60 points).
‡ The OES scale ranges from 0 to 48 points, where 0 points indicates worst elbow function and 48 points indicates normal elbow function.

fracturing of the implant. The mean OES of 33 points, with a maximum possible score of 48 points, indicates good results of revision surgery. The OES was not available at baseline because the questionnaire was not validated for Dutch practice at that time.

The radiographic results of revision radial head arthroplasty were extensively examined in this study. Several observations were made. Radiolucent lines or proximal osteolysis was frequently encountered for these implants. However, without clinical signs of loosening, nor were there any signs of loosening or migration on radiographs. This is in accord with other studies that described these radiographic changes without signs of loosening of these implants.[5, 15-18] Because proximal osteolysis occurs early and has been reported for different prosthetic designs (modular, monobloc, bipolar) and various fixation techniques (cemented, loose fit, expansion stem, press-fit), we attribute it to stress shielding rather than the result of particle wear. Another point of interest is the number of elbows with signs of joint degeneration (63% had ulnohumeral degeneration and 88% had capitellar degeneration) at latest follow-up. In our practice there was a discrepancy between these radiographic signs and clinical outcomes, as none of the patients reported complaints matching with

osteoarthritis. Although these signs are apprehensive, the clinical results seem to be forgiving, as patients do not report osteoarthritis complaints. It is currently unclear whether these radiographic signs correlate to clinical outcomes and/or complaints of pain. In addition, one may question how these patients will perform in the long-term, as this degeneration process will advance.

This study has several limitations. The number of patients is small, and because the primary surgical procedure in most patients was not performed at our hospital, information on concomitant surgical procedures such as ligamentous reconstruction and ulnar nerve transposition was not available. Because this is the first midterm report on revision surgery, we cannot compare our results with those of other authors. The strength of this study is the midterm follow-up and the fact that none of the patients was lost to follow-up.

Several studies have reported on the factors associated with removal or revision of RHPs. Our results are comparable to the results reported by Duckworth et al.[8] In 8 of 16 elbows in our study, silastic implants were revised, and the mean age at the time of surgery was relatively young, 49 years. On the other hand, Kachooei et al[18] did not report any factors associated with removal of RHPs placed for acute trauma. Their findings suggest that the decision to remove a RHP might depend more on surgeon- or hospital preferences than on objectivized problems with the prosthesis. Because our study reports on the outcome of revision surgical procedures in one institution, we cannot confirm this result.

Further studies are required to optimize the algorithm for revision or removal of the RHP after failure. It has been suggested that acute radial head arthroplasty may only serve as a spacer allowing the torn ligaments to heal. Various studies have reported satisfactory short-term results regarding ROM and decrease in pain after removal of the RHP.[8, 19] We believe that the radial head is essential for elbow stability, and removal should be avoided in posttraumatic cases. When the decision is made to revise the prosthesis, an algorithm is needed as well to indicate whether a radial head prosthesis, radiocapitellar prosthesis or total elbow prosthesis should be implanted. This algorithm is based on the integrity of the medial collateral ligament and LCL, the interosseous membrane and the distal radioulnar joint. The chondral condition of the capitellum and ulnohumeral joint determines whether a revision of the radial head will be sufficient or whether this procedure should be combined with replacement of the capitellum or even conversion to total elbow arthroplasty. With the mean age of the patients in our study being taken into account, the preferred treatment would be radial head arthroplasty with or without capitellar resurfacing. Total elbow arthroplasty is still considered a salvage procedure in this cohort.[3]

Conclusion

The overall midterm outcomes of this series of 16 revision surgical procedures of RHPs are satisfactory and can be considered favorable. No second revision surgery was performed, and all stems were well fixed. Although there was a discrepancy between radiographic

capitellar erosion and clinical symptoms in this study, the degeneration process will probably advance and may cause future problems. We therefore suggest considering radial head revision arthroplasty for failure of primary RHPs in unstable elbows with limited erosion of the capitellum.

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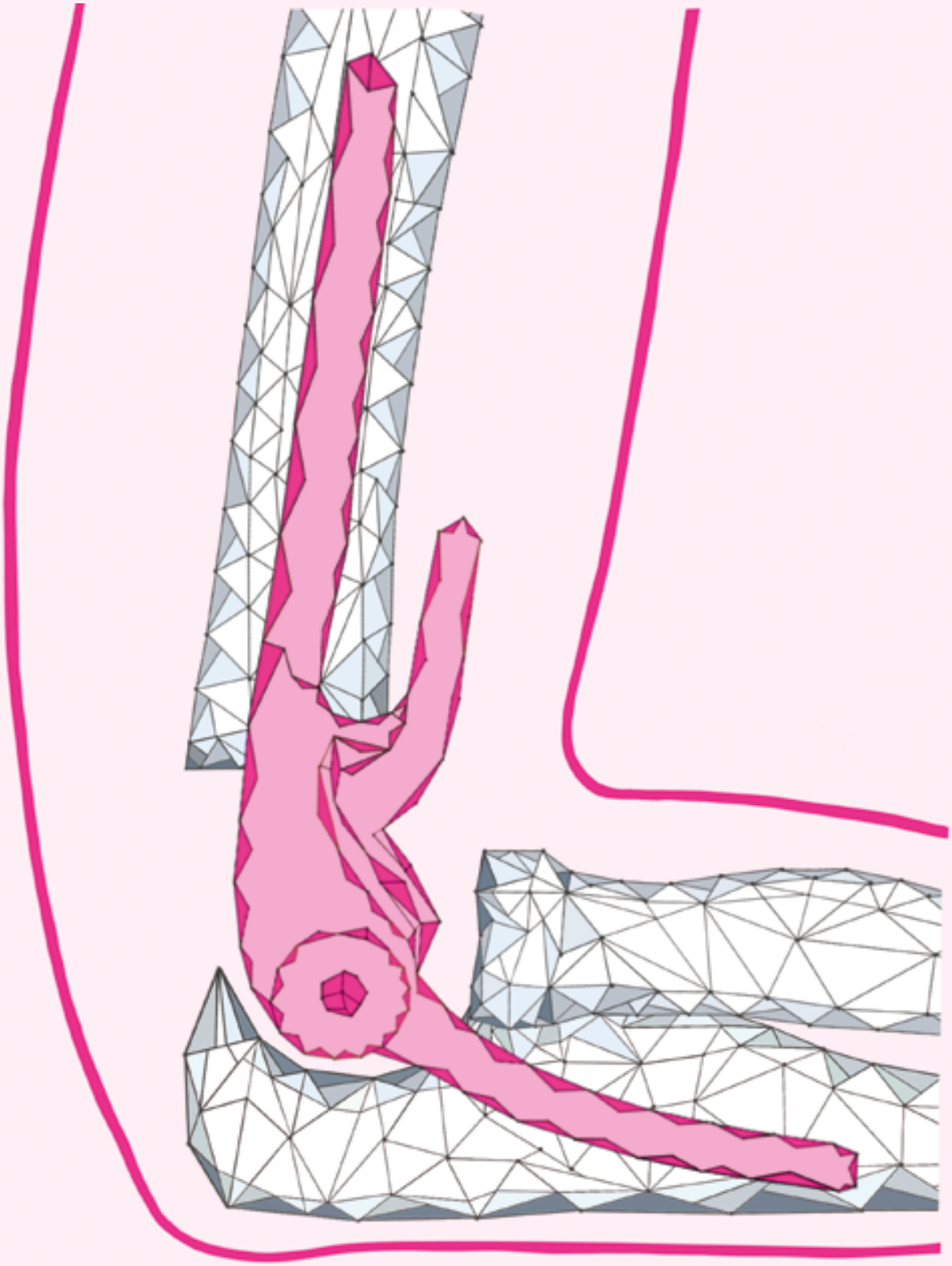
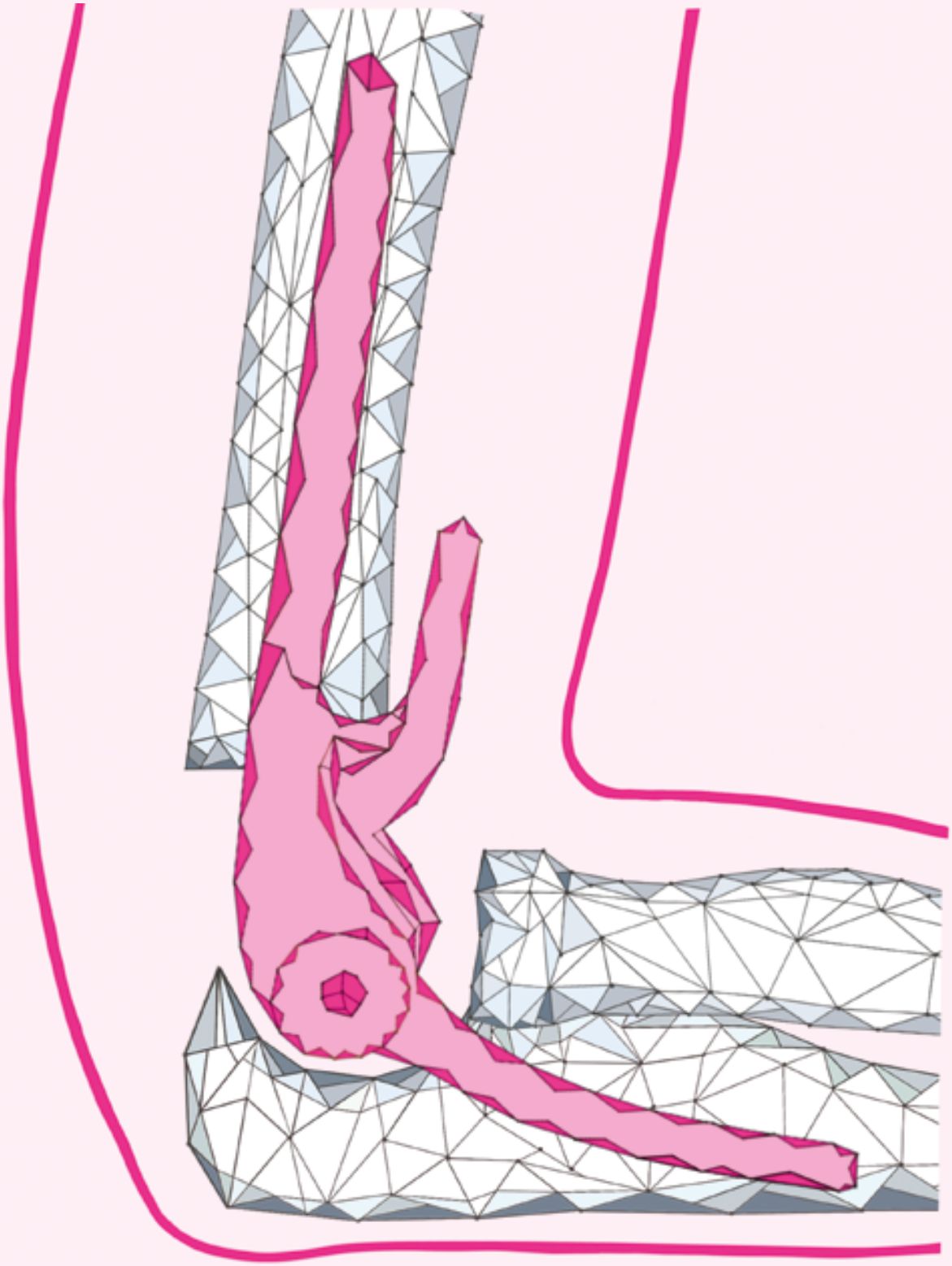


PART II

Total elbow arthroplasty



Chapter 6

Use and outcome of 1220 primary total elbow arthroplasties from the Australian Orthopaedic Association National Joint Arthroplasty Replacement Registry 2008 – 2018

J. Viveen
M.P.J. Van den Bekerom
J.N. Doornberg
A. Hatton
R. Page
K.L.M. Koenraadt
C. Wilson
G.I. Bain
R.L. Jaarsma
D. Eygendaal

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Abstract

Background and purpose

The Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR) was analyzed to determine trends in use of primary total elbow arthroplasty (TEA), the types of prostheses used, primary diagnoses, reasons for and types of revision, and whether the primary diagnosis or prosthesis design influenced the revision rate.

Patients and Methods

During 2008-2018, 1220 primary TEA procedures were reported of which 140 TEAs were revised. Kaplan-Meier estimates of survivorship were used to describe the time to first revision and hazard ratios (HR) from Cox proportional hazard models, adjusted for age and sex, were used to compare revision rates.

Results

The annual number of TEAs performed remained constant. The 3 most common diagnoses for primary TEA were fracture/dislocation (trauma) (36%), osteoarthritis (OA) (34%), and rheumatoid arthritis (RA) (26%). The cumulative percentage revision for all TEAs undertaken for any reason was 10%, 15%, and 19% at 3, 6, and 9 years. TEAs undertaken for OA had a higher revision rate compared with TEAs for trauma (HR = 1.8, 95% CI 1.1–3.0) and RA (HR = 2.0, CI 1.3–3.1). The Coonrad-Morrey (50%), Latitude (30%), Nexel (10%), and Discovery (9%) were the most used prosthesis designs. There was no difference in revision rates when these 4 designs were compared. The most common reasons for revision were infection (35%) and aseptic loosening (34%).

Interpretation

The indications for primary and revision TEA in Australia are similar to those reported for other registries. Revision for trauma is lower than previously reported.

Introduction

Total elbow arthroplasty (TEA) designs have improved and the use of TEA has increased worldwide.[1] However, the procedure remains challenging and the results variable. A number of studies including registry studies, have reported the outcomes of primary TEA. Although pain relief and improved function can be achieved in many patients, the complication and revision rates after TEA range from 20 to 62%[2-7] and are higher when compared to primary total hip arthroplasty (THA) and primary total knee arthroplasty (TKA).[7] Revision rates vary depending on primary diagnosis, with in general less favorable results in TEA placed for posttraumatic sequalae.[8-10] At 10 years TEA post trauma, prosthesis survival has been reported to be 60% and for RA it is reported to be 90%.[11, 12] The most common indications for revision surgery are symptomatic aseptic loosening, infection, polyethylene (PE) or bushing wear, and instability.[13, 14]

Primary TEA procedures are uncommon, with 0.5 procedures per 100,000 persons in Australia in 2018, compared with primary TKA and THA at 218 and 131 procedures per 100,000 persons per year respectively.[15] Nationwide registries are a valuable resource to assess the performance of this uncommon procedure. Prevalence and outcomes in TEA can be identified in a community-based setting with a larger number of procedures available for analysis compared with most other types of studies. To date there have been published reports on TEA from 5 registries. These include the Finnish,[16] Scottish,[17] Danish,[9] Norwegian,[8, 10] and Swedish[18] arthroplasty registries (Table 1).

This study reports the use and outcomes of primary TEA from the Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR) and compares these results with other reported studies including registry studies. This includes: 1) the number of primary TEAs performed per year; 2) the most common indications for primary TEA; 3) the reasons they were revised; 4) the overall revision rate; and 5) the effect of primary diagnosis and type of prosthesis on the rate of revision.

Patiens and methods

Australian Orthopaedic Association National Joint Replacement Registry

This study included all primary TEA procedures reported to the AOANJRR between January 1, 2008 and December 31, 2018. The AOANJRR commenced national data collection for TEA in 2007 and by 2017 94% of elbow arthroplasty procedures had been reported to the registry.[15] Registry data are validated against health department recorded data through a sequential multi-level matching process. A matching program is run monthly to search for all primary and revision arthroplasty procedures recorded in the Registry that involve the same side and joint of the same patient, thus enabling each revision to be linked to the primary procedure. Data are also matched biannually with the Department of Health and Ageing's National Death Index to obtain information on the date of death.[15]

When a bilateral primary TEA was performed, each TEA was considered separately. Demographic data including patient characteristics (age, sex and since 2012 ASA score),

primary diagnosis, fixation and type of prosthesis are reported. Fixation included cemented, hybrid, and cementless. Prosthesis design was identified by brand and classified as linked, unlinked, or convertible. First revision rates and reasons for revision were determined. The effect of primary diagnosis and prosthesis type on the rate of revision was also determined. The AOANJRR defines a revision as any re-operation of a previous TEA replacement where one or more of the prosthetic components are replaced, removed, or another component is added.

Statistical analysis

Kaplan-Meier estimates of survivorship were used to report the time to revision of a TEA, with censoring at the time of death or closure of the dataset at the end of December 2018. The unadjusted cumulative percent revision (CPR), with 95% confidence intervals (CI), were calculated using unadjusted point wise Greenwood estimates. Age and gender adjusted hazard ratios (HR) calculated from Cox proportional hazard models were used to compare the rate of revision between the groups. The assumption of proportional hazards was checked analytically for each model. If the interaction between the predictor and the log of time was statistically significant in the standard Cox model, then a time varying model was estimated. Time points were selected based on the greatest change in hazard, weighted by a function of events. Time points were iteratively chosen until the assumption of proportionality was met and HRs were calculated for each selected time-period. For the current study, if no time-period was specified, the HR was calculated over the entire follow-up period. All tests were 2-tailed at 5% levels of significance. Statistical analysis was performed using SAS software version 9.4 (SAS Institute Inc., Cary, NC, USA).

Ethics, funding, and potential conflicts of interest

Since no individual patient characteristics were available, approval by the human ethics research committee was not required. No funding for this study was received. JV received an unrestricted Research Grant from the Marti-Keuning-Eckhardt Foundation, Amsterdam Movement Sciences, Jo Kolk Foundation, and Michael-van Vloten Foundation. JND received an unrestricted Postdoc Research Grant from the Marti-Keuning-Eckhardt Foundation. MPJB declares that the OLVG Hospital receives research support from Wright/Tornier unrelated to this study.

Results

Demographic Characteristics

There were 1220 primary TEAs reported to the AOANJRR during the study period of which 140 were revised. The majority were female (73%). The mean age was 70 years (female 71 years and male 69 years). ASA score was available for 630 (52%) primary TEA procedures. The majority (59%) had an ASA score of 3 or 4.

Table 1. Registry studies of TEA.

Study	Registry (country)	No. of TEA	No. of prosthesis designs	Female (%)	Mean observation time (years)	No. of revisions	10-year survival (%)	Most common revision reason	Diagnosis
Skytta et al. (2009)	Finland	1457	9	87%	8	201	83	Loosening^ (47%, n= 95)	RA
Jenkins (2013)	Scotland	1146	NR	74%	NR	140	90	Infection (61%, n= 86)	RA, OA, trauma
Plaschke et al. (2014)	Denmark	324	7	82%	9	68	81	Loosening^ (57%, n= 39)	RA, OA, trauma
Fevang et al. (2009)	Norway	562	9	80%	6*	58	85	Loosening^ (33%, n= 19)	RA, OA, trauma
Krukhaug et al. (2018)	Norway	838	13	78%	9*	158	81	Loosening^ (42%, n= 66)	RA, OA, fracture$
Nestorson et al (2018)	Sweden	406	7	90%	6	18	90	Loosening^ (39%, n= 7)	Trauma

NR= not reported. RA= rheumatoid arthritis. OA= osteoarthritis.
* Median
^ Aseptic loosening
$ Fracture sequelae and acute fracture

Primary TEA Prostheses

9 different types of prostheses were used (Table 2). The 4 most common types were the Coonrad-Morrey (Zimmer, Inc., Warsaw, IN, USA) (n = 608; 50%) followed by the Latitude (Tornier, Montbonnot-Saint-Martin, France) (n=344 linked and n=17 unlinked; 30%), the Nexel (Zimmer, Inc., Warsaw, IN, USA; the Nexel only became available in Australia in 2013) (n=121; 10%), and the Discovery (Biomet Inc, Warsaw, IN, USA) (n=111; 9%) (Table 2). Of the types of TEA prostheses used, 4 were linked, 1 was a convertible and 2 were unlinked designs. 2 implants were classified as undefined, because they were custom-made designs. These implants were excluded from further analysis on linked versus unlinked designs. Almost all procedures used a linked design (n=1189, 98%). Most prostheses were cemented (n = 1119; 92%). The radial head was replaced in a small number of procedures (n=43). All involved the Latitude prosthesis. The radial head was replaced in only 12% of procedures when this device was used.

The number of primary TEAs performed each year remained constant (Table 3, see Supplementary data). The most common primary diagnoses were trauma (n=434, 36%), OA (n=414, 34%) and RA (n = 318, 26%). The proportion of primary TEA undertaken for trauma has increased in recent years and is now the most common reason (Figure 1).

Revisions of primary TEA

Of the 1,220 primary TEAs, 140 were revised. The CPR was 10%, 15%, and 19% at 3, 6, and 9 years, respectively (Table 4 and Figure 2). The revision rate varied depending on the primary diagnosis. Primary TEAs undertaken for OA were revised more frequently compared with both RA (entire period: HR = 2.0, CI 1.3–3.1) and trauma (entire period: HR = 1.8, CI 1.1–3.0).

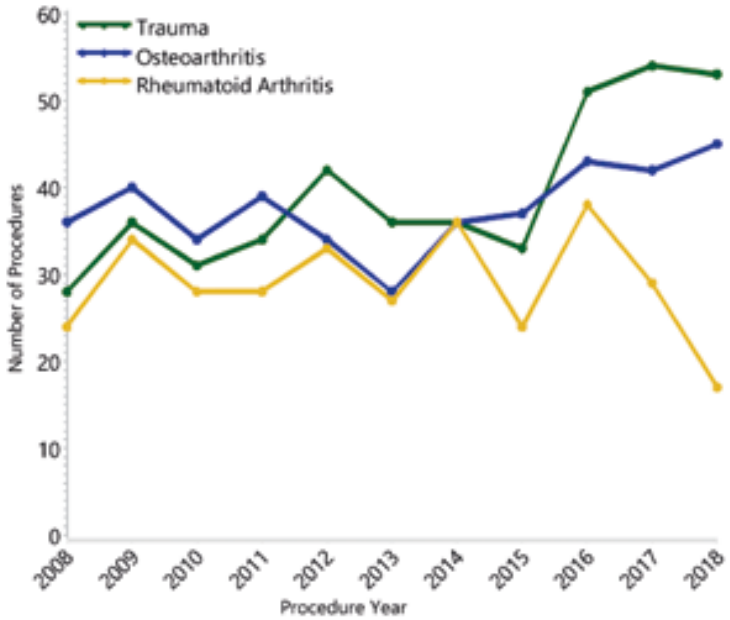


Figure 1. Primary total elbow replacement by primary diagnosis.

There was no statistically significant difference in the rate of revision when RA and trauma were compared (entire period: HR = 0.9, CI 0.5–1.6) (Figure 3).

There was no statistically significant difference in the rate of revision when a radial head was used (entire period: HR = 1.5, CI 0.7–2.9) (Figure 4, see Supplementary data).

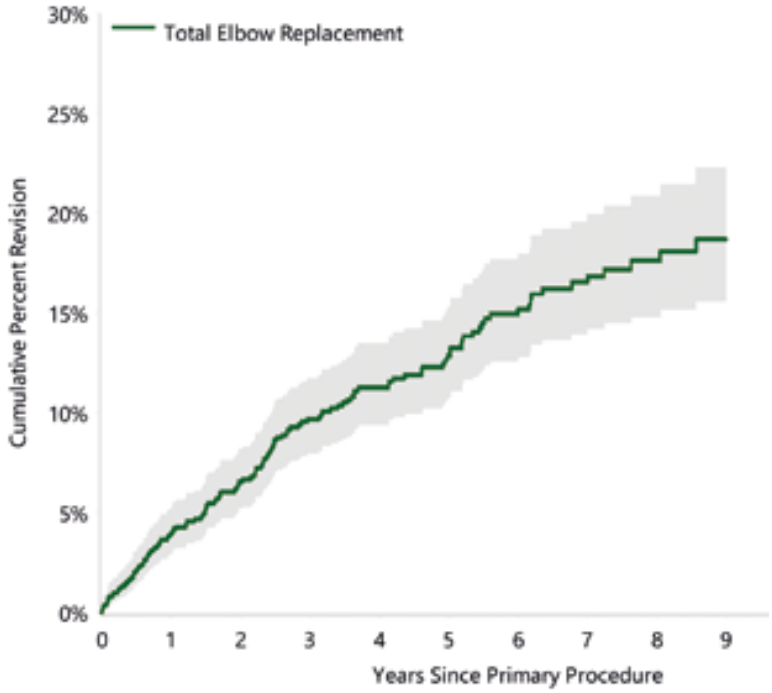


Figure 2. Cumulative percent revision of primary total elbow replacement (all diagnoses).

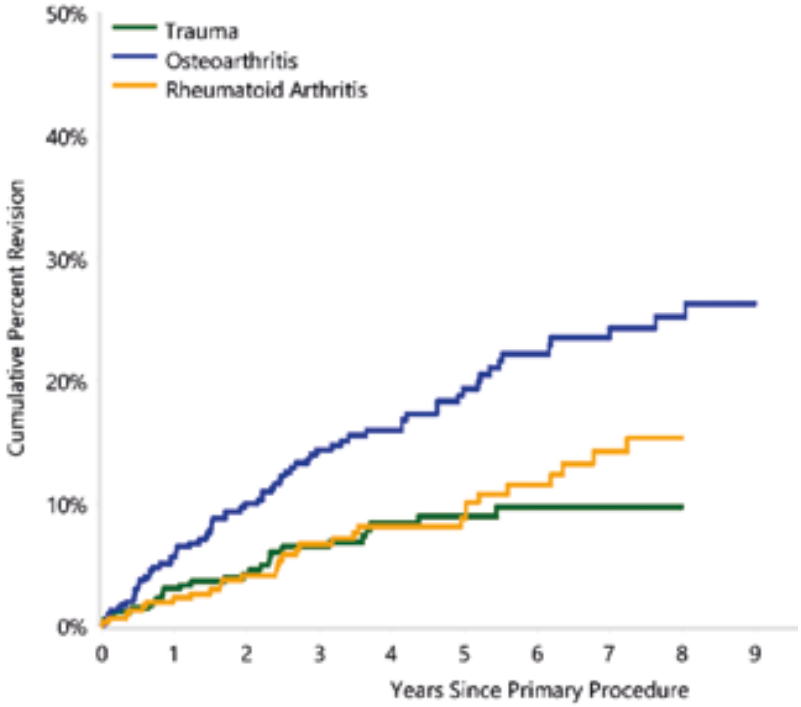


Figure 3. Cumulative percent revision of primary total elbow replacement by primary diagnosis.

Table 2. Data on 1220 primary TEA.

		Primary TEA	
		n	%
Elbow class			
	TEA without radial head component	1177	96
	TEA including radial head component	43	4
Prosthesis design			
Linked	Coonrad-Morrey*	608	50
	Latitude*§	344	28
	Nexel*	121	10
	Discovery*	111	9
	Mutars*	5	<1
Unlinked	Latitude*§	17	1
	IBP*	1	<1
	Souter Strathclyde*	7	1
Undefined	Comprehensive	4	<1
	Custom-made/other	2	<1
Fixation technique			
	Cemented	1119	92
	Hybrid (ulnar cemented)	65	5
	Hybrid (ulnar cementless)	32	3
	Cementless	4	<1

* Coonrad-Morrey (Zimmer, Inc., Warsaw, IN, USA), Discovery (Biomet, Inc., Warsaw, IN, USA), Nexel (Zimmer, Inc., Warsaw, IN, USA), Mutars (Implantcast GmbH, Buxtehude, Germany), Latitude (Tornier, Montbonnot-Saint-Martin, France), IBP (Biomet Inc, Warsaw, IN), Souter Strathclyde (Stryker, Rutherford, NJ, USA).
§ The Latitude elbow prosthesis is a convertible design and can be placed either linked or unlinked.

Table 4. Yearly unadjusted cumulative percentage revision (CPR (CI)) of primary total elbow replacement (all diagnoses).

	1 year	2 years	3 years	4 years	5 years
CPR (95% CI)	4 (2.9 - 5.2)	7 (5.2 - 8.2)	10 (8.0 - 11.7)	11 (9.4 - 13.5)	13 (10.8 - 15.3)
	6 years	**7 years**	**8 years**	**9 years**	
	15 (12.8 - 18.0)	17 (13.9 - 19.5)	18 (14.8 - 20.9)	19 (15.6 - 22.3)	

There was no statistically significant difference when linked and unlinked prostheses were compared (0–6 months: HR = 3.7, CI 0.9–15.6; > 6 months: HR = 0.8, CI 0.2–2.4) (Figure 5, see Supplementary data). Revision rates were similar for the 4 most used prostheses (Coonrad Morrey, Discovery, Latitude, and Nexel, Figure 6).

The most common reasons for revision were infection (35%) and aseptic loosening (34%) (Table 5). The most common type of revision for primary TEA procedures without

Table 5. Revision diagnosis of primary total elbow replacement by type of primary (all diagnoses). Values are frequency.

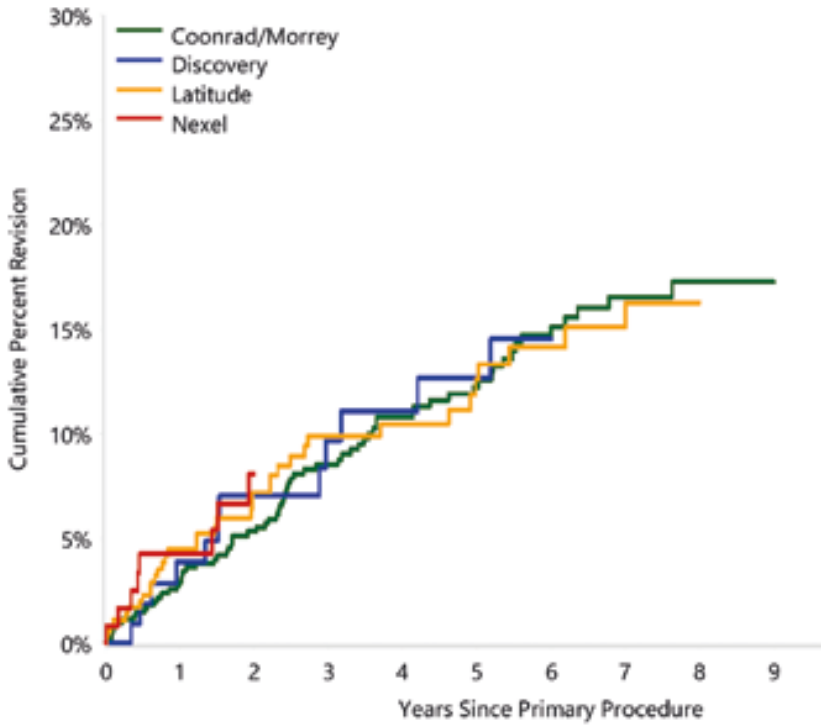
	Total elbow	Total elbow and radial
Revision diagnosis		
Infection	46	3
Loosening	44	3
Fracture	13	
Malposition	3	
Wear Bushing	3	
Implant Breakage Ulna	2	
Instability	1	2
Progression of Disease	2	
Arthrofibrosis	1	
Implant Breakage Humeral	1	
Incorrect Sizing	1	
Lysis	1	
Metal Related Pathology	1	
Prosthesis Dislocation	1	1
Wear Ulna	1	
Other	10	
No. revision	131	9
No. primary	1177	43

radial replacement undertaken for all diagnoses was of the humeral component (n=32; 24%), followed by an elbow linking pin only (n=25; 19%), ulnar component (n=122; 17%), humeral/ulnar (n = 21; 16%), and cement spacer (n=17; 13%) (Table 6, see Supplementary data). For primary TEA procedures with a radial head, the use of an ulnar component (n = 2; 22%), humeral/ulnar (n=2; 22%), and radial head only (n=2; 22%) were the most common types of revision (Table 6, see Supplementary data).

Discussion

This is one of the largest studies on the use and outcome of contemporary primary TEA prostheses. The annual use did not change over the 10-year period; however, there was a change in indications for primary TEA with an increase use for trauma. This has been reported previously.[19] A possible explanation for this increase is that it is being used more often as a salvage procedure in selective cases of complex, comminuted, intra-articular distal humerus fractures. Its use for this diagnosis has been reported to be associated with good results.[18, 20-22]

The percentage of patients with RA is low compared to other studies with reports of up to 70%.[8-10, 17, 23, 24] The most recent Norwegian registry study identified a substantial decrease



Number at risk at year	0	1	2	3	4	5	6	7	8	9
Coonrad-Morrey	608	539	478	392	336	267	204	149	100	59
Discovery	111	95	83	67	55	48	46	31	22	13
Latitude	361	284	229	176	147	120	94	72	52	34
Nexel	121	96	65	37	18	8	0	0	0	0

Figure 6. Cumulative percentage revision of primary total elbow replacement (all diagnoses). Only prostheses with over 100 procedures.

in the use of TEA for RA over the last decade.[8] This is likely due to the improved medical management of RA.[25-27] The low proportion of RA patients in this study may also reflect this.

The all-cause revision rate for all diagnoses combined reported in this study is comparable to other studies.[8-10] The revision rate for trauma is similar to 1 recent report.[18] These authors considered primary TEA as a reliable treatment option for the management of complex distal humeral fractures. Although these data are supportive of that conclusion, it is our view that the use of TEA for this diagnosis, while promising, needs to be considered with some caution. This is because higher revision rates in the longer term have been reported, particularly in younger patients with posttraumatic sequelae under 65 years of age.[11]

The low use of unlinked prostheses in Australia is notable. Unlinked prostheses have been popular in Europe.[8-10, 16, 17] There has, however, been an increase in the use of linked prostheses over the last decade.[8] Unlinked prostheses have been identified as having a higher risk of revision compared to linked designs.[9, 14] In this study, we were unable to

identify a difference between linked and unlinked prostheses because of the low use of unlinked prostheses. The main prostheses used in Australia are the Coonrad-Morrey and the Latitude (linked version). The risk of revision for these 2 devices is the same. In fact, there were similar revision rates of the 4 most commonly used prostheses, which include the Nexel and the Discovery.

The reasons for revision are similar to previous reports, with infection and aseptic loosening being the most common.[2, 9, 10, 13] The proportions of aseptic loosening, infection and periprosthetic fracture in this study are comparable to most other studies (Table 1). Only Jenkins et al. (2013) reported an extremely high infection rate of 61%.[17] However, it is uncertain whether this percentage is accurate, since no cases at all of aseptic loosening were reported in this study.

This study has several limitations. No functional or patient reported outcomes data are available. In addition, details on specific patient characteristics including individual comorbidities, other factors that may impact on outcome, and disease severity were not available. It was also not possible to separate acute management of trauma and later management of trauma into separate groups.

In summary, the annual use of TEA over the last decade is stable and TEA remains an uncommon procedure. The indications for primary TEA in Australia are similar to those reported by other registries. There was a trend toward the increased use of TEA for trauma and a decrease in the proportion of TEAs undertaken for RA, while the number of TEAs placed for OA remained stable. The main reasons for revision surgery (infection and aseptic loosening) and overall revision rate of 19% at 9 years are comparable to other studies as well. Primary diagnosis had a major impact on the risk of revision with procedures performed for OA having almost twice the risk compared with trauma and RA. The revision rate for TEA post trauma is lower than previously reported. The almost universal use of linked TEA designs is notable and is in contrast to the European experience.

Supplementary data

Tables 3 and 6 and Figures 4 and 5 are available as supplementary data in the online version of this article.

Acknowledgements

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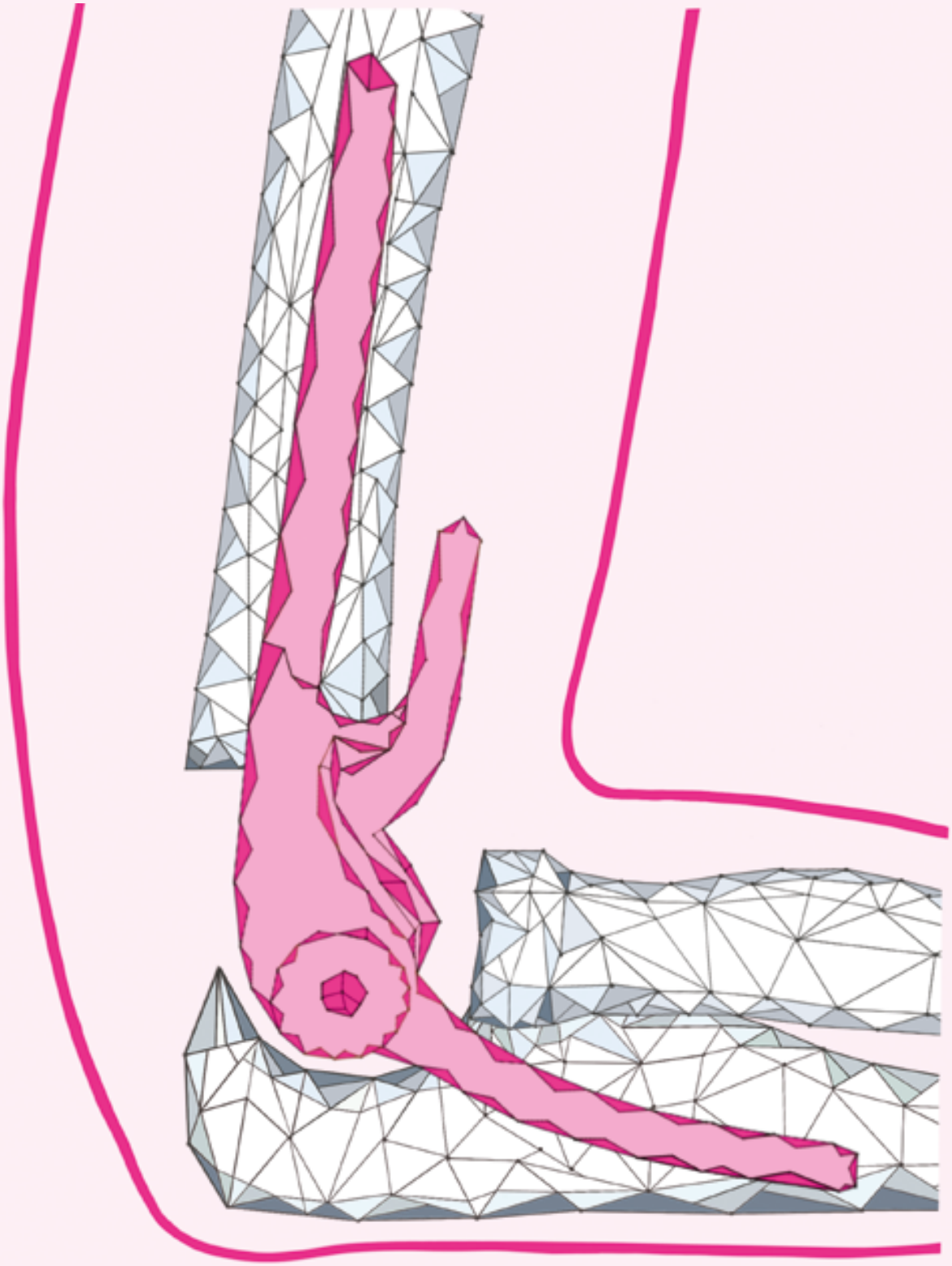

Chapter 7

Clinical and radiographic outcome of revision surgery of total elbow prosthesis: midterm results in 19 patients

J. Viveen
A. Prkic
I.F. Kodde
K.L.M. Koenraadt
B. The
D. Eygendaal

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Abstract

Background

The aim of this study is to report on the midterm outcomes and complications of revision surgery of total elbow arthroplasty.

Methods

All patients who had undergone total elbow arthroplasty revision surgery between 2009 and 2014 with semiconstrained total elbow prostheses were prospectively enrolled in the study. Records were reviewed for demographic data; baseline measurements; and several follow-up assessments including the Mayo Elbow Performance Score (MEPS), visual analog scale (VAS) score for pain, Oxford Elbow Score, range of motion, satisfaction and radiographs.

Results

A total of 19 revision arthroplasties were included. At a mean follow-up of 57 months, there had been 1 re-revision and 2 removals. One patient was excluded from follow-up because of confounding comorbidity. At last follow-up, MEPS and VAS pain scores both improved ($p<0.01$). The rate of combined good and excellent results on the was 53%. The mean VAS scores for pain at rest and with activity were 2 and 4, respectively. Fair results for the Oxford Elbow Score were reported, with a mean score of 28 points. Range of motion improved to an average flexion-extension arc of 108° ($p<0.01$), and the pronation-supination arc improved to an average of 123° ($p<0.01$). All elbows were stable at last follow-up ($p<0.01$). Radiographs showed non-progressive osteolysis around the prosthesis in 3 cases (19%) and suspicion of loosening in 1 (6%). In 11 patients postoperative complications occurred. Of 15 patients, 13 (87%) were satisfied with the result of the revision procedure.

Conclusion

Revision of total elbow prostheses leads to satisfactory results, less pain, and better elbow function. This procedure is related to a relatively high complication rate.

Introduction

According to implant databases, total elbow arthroplasty (TEA) has been performed more often in the past 4 decades.[1] TEA is considered a successful treatment for a variety of conditions, such as rheumatoid arthritis, acute fractures, and (posttraumatic) osteoarthritis.

Previous studies considered TEA to be successful. Although the results are improving, complication rates of up to 62% have been reported in primary TEA cases.[2-7] This percentage is much higher compared with hip and knee arthroplasties.[1] The long-term survival rates range from about 60% in posttraumatic cases to 90% in patients with rheumatoid arthritis after 10 years.[8, 9] As the number of total elbow replacements increases, more revision surgery can be expected. Aseptic loosening and instability are the most important reasons for revision.[2, 4, 6, 10-14] Polyethylene wear or malposition of the prosthesis can result in both loosening and instability.[2, 15] Other indications for revision are infection and periprosthetic fractures.[16]

Most surgeons use a semiconstrained type of TEA when performing a revision, as semiconstrained models provide intrinsic stability and relieve the often-affected ligamentous structures. Nevertheless, second revision rates remain high, with a rate of 28% to 30% after 10 years after primary revision.[16] Previous studies reporting on the outcome after revision surgery using the Coonrad-Morrey prosthesis showed good results in pain relief and elbow function, but improvement of range of motion (ROM) should not always be expected.[17-20]

Considering the expected increase in TEA procedures, it is important to evaluate the results after revision surgery critically to support decision-making on revision of TEA in the future. The aim of this study was to report on the clinical and radiographic outcomes of revision surgery of TEA using the Coonrad-Morrey total elbow (Zimmer, Warsaw, Indiana, USA) in a European non-designer center. We hypothesized that revision surgery would lead to improved elbow function.

Materials and methods

Patient population

All patients who received a revision of TEA at our institution between March 2009 and June 2014 were included. Preoperatively, patients were seen in the outpatient clinic and filled in patient-reported outcome questionnaires. The follow-up consisted of questionnaires at 1, 3, 5 and 7 years after revision and a visit to the outpatient clinic. Patients who forgot to make an appointment after surgery were actively recruited by telephone and asked to make an appointment. In all cases a Coonrad-Morrey TEA (Zimmer) TEA was used. A highly experienced elbow surgeon (D.E.) performed all revision surgical procedures.

The preoperative medical history of all patients was collected. During preoperative assessment, ROM was determined with a goniometer and elbow function was evaluated with use of the Mayo Elbow Performance Score (MEPS). In addition, the patients completed a visual analog scale (VAS) score (0 -10) for pain at rest and during activity. At postoperative

follow-up visits, the assessments included the same parameters. Since 2013, the Oxford Elbow Score (OES) has been added to the questionnaires. To assess patient satisfaction directly instead of retrieving it from other questions, a question regarding satisfaction with the revision was asked during all follow-up visits. This question could be answered yes, moderately satisfied or no.

Plain anteroposterior and lateral radiographs were obtained preoperatively and at each reassessment. Two surgeons (B.T. and D.E.) analyzed the radiographs for loosening of the implant, periprosthetic fracture, periarticular ossification, lucency, and dislocation or subluxation. Osteolysis was evaluated as described by King et al[17] (Figure 1). Periarticular ossification was scored as described by Hastings and Graham.[21] In case of discrepancy in analysis of the 2 observers a consensus was made.

Surgical technique

The surgeon assessed the stability of the elbow joint with the patient under anesthesia just before the surgical procedure (Table 1): grade 1, stable; grade 2, mild instability; or grade 3, severe instability. During surgery, the patient was placed in the lateral decubitus position with the arm on an armrest. Routine antibiotic prophylaxis was given in 18 of 19 cases, because in 1 case, deep infection was suspected, and valid surgical cultures had to be obtained. A sterile silicone ring tourniquet was placed around the upper arm, as proximally as possible to allow for proximal extension of the incision if needed. After incision, skin flaps were created as thick as possible to minimize the chances of necrosis. The ulnar nerve was routinely identified and cleared of scar tissue as needed but was not routinely transposed. Because all cases were

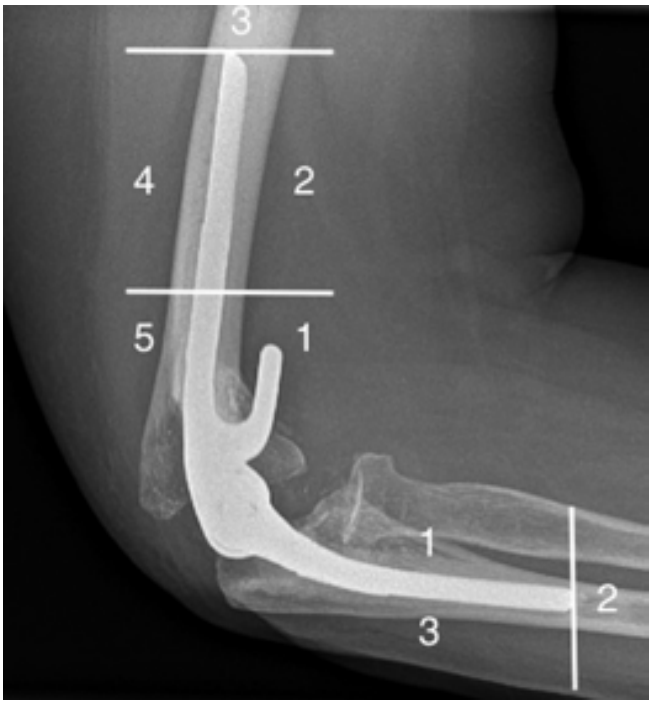

Figure 1. Regions of osteolysis as described by King et al.[17]

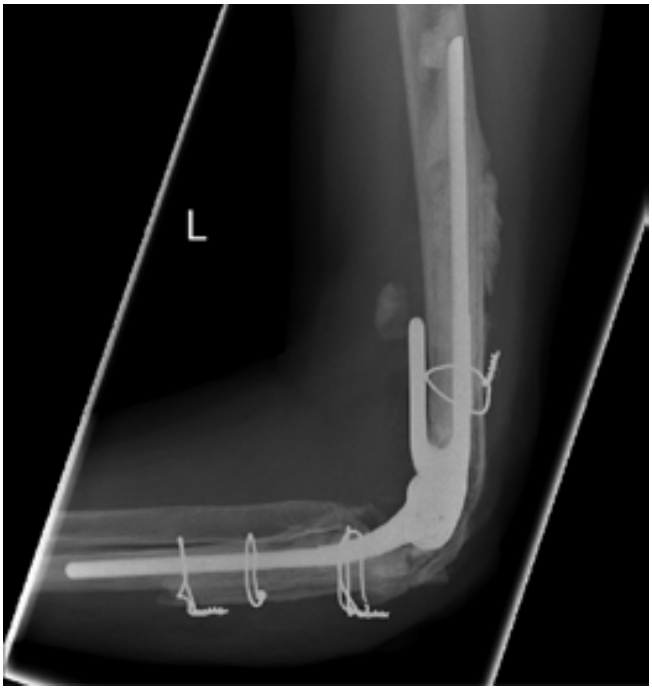

Figure 2. Use of an allograft strut graft of the fibula because of poor bone quality fixated with use of cerclage wires.

referred to our center, no complete data were available on the management of the ulnar nerve during the initial surgical procedures. However, previous ulnar nerve transposition was not observed.

A variation in the extensiveness of loosening of the primary prosthesis was noted, with a variety of remaining bone stock and in the quality of the soft tissues as triceps tendon. All patients had an intact radial head. A triceps-splitting approach was used in 2 cases, whereas the triceps-tongue approach was used in 17. Using the Wrightington approach, we released the annular ligament with a bony attachment that could be easily refixated using a transosseous suture.[22] Release of collateral stabilizing structures (if present) was performed by a sharp subperiosteal release from the medial and lateral epicondyle. In all patients cement was used in the primary surgical procedure. The complete cement mantle in the humeral and ulnar shaft was removed and in 8 patients an osteotomy (6 humerus and 2 ulna) was necessary to perform the removal.

In all patients a trial prosthesis was inserted to assess the correct height of the prosthesis and the elbow was tested for stability and ROM. Afterward, the trial components were removed. In all patients the final implant was placed with use of pressured vacuum-mixed cement. In 6 patients an allograft strut graft of the fibula was used and fixated with use of cerclage wires (Figure 2), because of poor bone quality. This was the ulna component in 2 patients, the humeral component in 1, and both component in 3. In 18 patients concomitant surgical procedures were performed, including osteotomy, ulnar nerve transposition, and synovectomy (Table 1).

After closure, the tourniquet was released and the elbow was immobilized in a posterior splint at 90° of flexion for 24 hours. Thereafter, the elbow was immobilized in a posterior removable splint in extension. From postoperative day 3, the elbow was mobilized under supervision of a specialized physiotherapist, but active extension was not performed during the first 6 weeks. Prophylaxis for heterotopic ossification was not routinely given.

Statistical methods

Kaplan-Meier survival analysis was used to assess the survival rate of prostheses, the endpoint being removal or second revision of one or more components. Data were censored for death unrelated to the prosthesis. To summarize the data, descriptive statistics were used and differences on outcome parameters before and after revision surgery were compared by use of the Student *t* test and Wilcoxon signed rank test for normally distributed data.

7

Results

Patients and follow-up

Nineteen elbows in 17 patients (3 men and 14 women) were included in this study. The mean age at revision surgery was 65 years (range, 48-80 years). All patients were right-handed and 6 dominant arms were involved. The index total elbow prosthesis failed for a variety of reasons (Table 1). Polyethylene wear, mostly in combination with loosening, instability and pain, was the most prevalent reason for revision. The mean time between index surgery and revision surgery was 136 months (range, 21-276 months), and the mean age at primary surgery was 54 years (range, 36-78 years). In 2 patients this was the second revision surgery. In one of the second revision cases, the first revision surgical procedure had been performed at our institution (case 19); in none of the regular revision cases had the index surgical procedure been performed at our institution. Two patients were lost to follow-up because of death unrelated to their total elbow prostheses. Demographic data are shown in Table 1, and baseline measurements are shown in Table 2. Type 4 and 5 Kudo total elbow prostheses (Biomet, Warsaw, IN, USA) were revised in 15 elbows, a Latitude total elbow prosthesis (Tornier, Stafford, TX, USA) in 2 elbows, a Souter-Strathclyde total elbow prosthesis (Stryker Howmedica Osteonics, Limerick, Ireland) in 1 elbow and a Coonrad-Morrey prosthesis in 1 elbow.

Complications and survival analysis

In 2 patients (cases 9 and 18) the prosthesis was removed at 16 and 30 months after surgery because of suspicion of deep infection. One patient (case 13) received a second revision arthroplasty because of failure of the ulnar component of the implant 41 months after the first revision surgical procedure. In 8 of the remaining 16 patients (50%) postoperative complications occurred; patient-specific details are shown in Table 3. The 2-year survival analysis showed a rate of 94.7% (95% confidence interval, 63.4%-100%), and the 5-year

Table 1. Demographic data.

Case No.	Sex	Age at surgery, y	Injured side	Handedness	Revision prosthesis	Indication for revision surgery	Index prosthesis	Interval between initial procedure and revision procedure, mo	Indication for index surgery	Concomitant surgical procedures
1	F	78	R	R	CM	Loosening and periprosthetic fracture	Kudo	39	RA	Use of partridge elbow plate and strut graft of the fibula for humeral component
2	F	64	R	R	CM	Luxation and fracture prosthesis	Kudo	165	RA	Transposition of the ulnar nerve, synovectomy, two strut grafts of the fibula for both humeral and ulnar component
3	F	61	L	R	CM	Loosening	Kudo	214	RA	Synovectomy
4	F	65	R	R	CM	Loosening	Kudo	276	LP	Transposition of the ulnar nerve
5	F	51	L	R	CM	Polyethylene wear	Kudo	194	RA	Strut grafts of the fibula both for humeral and ulnar component, fixation of the triceps on the strut graft, synovectomy
6	F	77	L	R	CM	Loosening and fracture prosthesis	Kudo	228	RA	Osteotomy of the humerus, strut graft of the fibula for ulnar component
7	F	61	R	R	CM	Loosening	Kudo	157	RA	Osteotomy of the humerus, synovectomy
8	M	74	L	R	CM	Polyethylene wear	Kudo	146	RA	Transposition of the ulnar nerve, osteotomy of the ulna, two strut grafts of the fibula for both humeral and ulnar component
9	F	65	L	R	CM	Polyethylene wear and periprosthetic fracture	Kudo	160	RA	Osteotomy humerus, synovectomy, strut graft of the fibula for ulnar component
10	F	73	R	R	CM	Polyethylene wear	Kudo	180	RA	Synovectomy, osteotomy ulna
11	M	60	L	R	CM	Polyethylene wear	Kudo	127	RA	Synovectomy, osteotomy humerus, perioperative fracture wherefore fixation with cerclages
12	F	53	R	R	CM	Polyethylene wear	Kudo	204	RA	Synovectomy
13	M	63	L	R	CM	Loosening	Souter	119	RA	Synovectomy

Table 1. (continueds)

Case No.	Sex	Age at surgery, y	Injured side	Handedness	Revision prosthesis	Indication for revision surgery	Index prosthesis	Interval between initial procedure and revision procedure, mo	Indication for index surgery	Concomitant surgical procedures
14	F	80	L	R	CM	Degeneration and malformation of elbow joint	Latitude	21	RA	
15	F	60	L	R	CM	Polyethylene wear	Kudo	58	RA	Synovectomy
16	F	70	L	R	CM	Polyethylene wear	Kudo	61	RA	Osteotomy humerus, synovectomy
17	F	48	R	R	CM	Polyethylene wear	Kudo	111	RA	Osteotomy humerus, synovectomy
18	F	63	L	R	CM	Deep infection	Latitude	84	LP	Removing of 10 gentamycin beads
19	M	67	L	R	CM (ulnar comp.)	Loosening	CM	42	RA	Synovectomy

CM, Coonrad-Morrey; F, female; L, left; M, male; R, right; RA, rheumatoid arthritis.

Table 2. Clinical outcomes before revision surgery.

Case No.	VAS for pain at rest (0-10)	VAS for pain with action (0-10)	Flexion, °	Extension deficit, °	Flexion-extension arc, °	Pronation, °	Supination, °	Pronation-supination arc, °	Valgus instability during revision surgery *	MEPS†
1	2	8	130	10	120	80	70	150	1-2	
2	-	-	120	20	100	40	40	80	3, flail	
3	1	4	130	30	100	80	45	125	3, flail	
4	6	7	110	60	50	70	80	150	3, flail	40, poor
5	3	8	140	40	100	60	60	120	3. flail	55, poor
6	-	-	90	10	80	30	30	60	3, flail	
7	8	10	120	30	90	90	60	150	3, flail	
8	5	8	100	60	40	40	40	80	3, flail	
9	-	-	120	20	100	40	40	80	3, flail	
10	2	4	145	30	115	70	30	100	3, flail	
11	4	8	130	5	125	60	60	120	3, flail	50, poor
12	3	6	140	10	130	30	50	80	3, flail	70, fair
13	6	8	120	40	80	60	60	120	3, flail	60, fair
14	9	9	125	25	100	70	70	140	3, flail	35, poor
15	6	9	120	20	100	90	90	180	3, flail	60, fair
16	7	7	110	25	85	90	80	170	3, flail	45, poor
17	2	7	140	40	100	80	70	150	3, flail	
18	3	10	110	30	80	70	70	140	3, flail	
19	1	3	130	15	115	20	20	40	1	85, good

MEPS, Mayo Elbow Performance Score; VAS, visual analog scale score.
* Valgus instability is graded as 1, stable; 2, mild instability; or 3, severe instability.
† The MEPS is classified as excellent (≥90 points), good (75-89 points), fair (60-74 points), or poor (<60 points).

survival analysis showed a rate of 82.0% (95% confidence interval, 63.4%-100%) (Figure 3). Patient specific data are shown in Table 3.

Radiographic analysis

At a mean follow-up of 57 months, radiographs of the remaining 16 elbows were analyzed. Assessment of postoperative radiographs at the last follow-up visit showed osteolysis around the prosthesis in 4 cases (25%). This osteolysis involved zones 1 through 5 (humeral) in 2 patients and both zone 2 and zone 3 (ulnar) in 1 patient. However, the osteolysis in these 3 patients already existed on the first postoperative radiographs and was therefore a result of poor cementing technique. One patient (case 17, Figure 4) had progressive osteolysis

Table 3. Clinical outcomes at last follow-up after revision surgery.

Case No.	Follow-up, mo	VAS for pain at rest (0-10)	VAS for pain at action (0-10)	Flexion, °	Extension deficit, °	Flexion-extension arc, °
1	52	5	7	130	20	110
2	82	2	7	130	30	100
3	82	1	6	140	0	140
4	78	1	7	130	50	80
5	30	0	0	140	30	110
6	79	-	-	120	25	95
7	69	NA	NA	NA	NA	NA
8	69	0	0	130	30	100
9	33	NA	NA	NA	NA	NA
10	61	4	5	130	50	80
11	59	2	7	120	10	100
12	54	0	0	140	30	110
13§	42	NA	NA	NA	NA	NA
14	43	1	1	140	15	125
15	43	5	8	140	20	120
16	38	5	6	140	5	130
17	37	1	3	140	30	110
18	16	NA	NA	NA	NA	NA
19§	24	2	6	140	30	110

MEPS, Mayo Elbow Performance Score; NA, not applicable; OES, Oxford Elbow Score; ORIF, open reduction–internal fixation; VAS, visual analog scale score.
* Valgus instability is graded as 1, stable; 2, mild instability; or 3, severe instability.
† The MEPS is classified as excellent (≥90 points), good (75-89 points), fair (60-74 points), or poor (<60 points).
‡ The OES scale ranges from 0 to 48 points, with 0 points indicating worst elbow function and 48 points indicating normal elbow function.
§ The same patient, who received re-revision of the ulnar component.

and suspicion of loosening of the implant but scored 100 on the MEPS, scored 32 points on the OES, had good ROM and did not have any symptoms. The patient was informed, and she undergoes assessment, including standard radiographs, once a year. One patient had a periprosthetic fracture of the humerus for which open reduction-internal fixation was performed. Heterotopic ossification was seen in 4 patients (25%) but was not symptomatic.

Clinical results

Clinical results are presented for 15 patients. The results of 2 removed and 1 re-revised prosthesis were excluded, and the results of case 7 were considered unreliable, because clinical and functional assessment was impossible as a result of comorbidities.

Pronation, °	Supination, °	Pronation-supination arc, °	Valgus instability*	MEPS†	OES°	Complications and treatment
60	60	120	1	65, fair	-	
70	60	130	1	65, fair	13	Radial nerve palsy
80	80	160	1	85, good	36	Triceps insufficiency; surgery
80	45	125	1	85, good	18	Triceps insufficiency; surgery
60	60	120	1	100, excellent	22	
60	60	120	1	-	-	
NA	NA	NA	NA	NA	NA	Periprosthetic fracture humerus; ORIF
70	50	120	1	95, excellent	46	
NA	NA	NA	NA	NA	NA	Deep infection; removal
70	60	130	1	80, good	34	
70	70	140	1	70, fair	17	Deep infection; debridement Triceps insufficiency; surgery
60	60	120	1	80, good	40	Deep infection with fistula; debridement
NA	NA	NA	NA	NA	NA	Loosening ulnar component; revision
70	60	130	1	65, fair	41	
70	40	110	1	65, fair	11	
70	70	140	1	70, fair	23	
60	60	120	1	100, excellent	32	Suspicion of loosening; no intervention yet
NA	NA	NA	NA	NA	NA	Ulnar nerve dysfunction; no treatment. Deep infection, loosening; removal
40	40	80	1	75, good	27	Triceps insufficiency; surgery

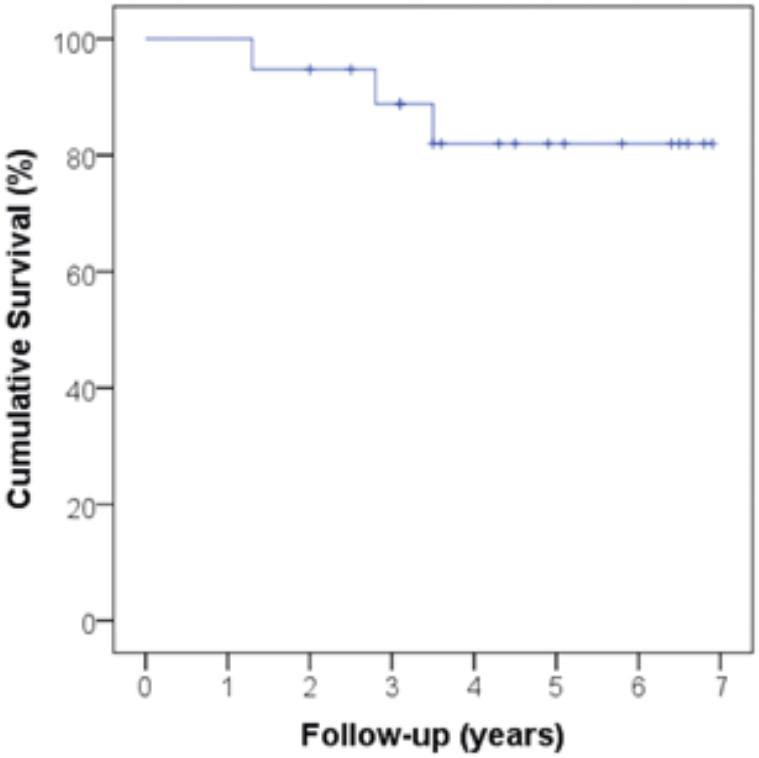

Figure 3. Kaplan-Meier survival analysis.

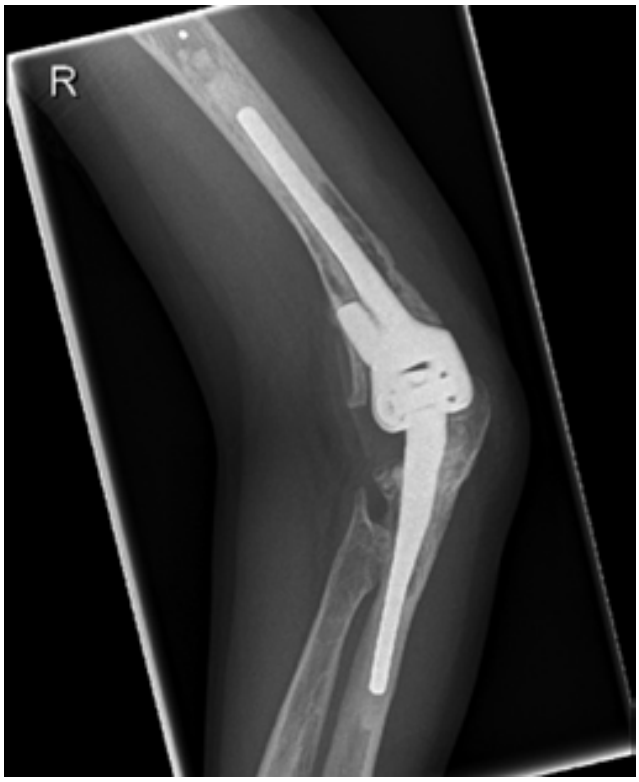

Figure 4. Suspicion of loosening of the humeral component in case 17.

At baseline, the mean flexion-extension arc was 96° (range, 40°-120°) and the mean pronation-supination arc was 120° (range, 40°-180°). At the last follow-up visit, the flexion-extension arc improved to 108° (range, 80°-140°) ($p<0.01$) and the mean pronation-supination arc improved to 123° (range, 40°-160°) ($p<0.01$). In Figure 5 results of ROM in 15 patients over time are presented. In addition, before surgery all but 2 elbows appeared to be flail elbows, graded as valgus instability grade 3. After surgery all elbows improved to stable elbows ($p<0.01$). Patient-specific details are shown in Tables 2 and 3.

At baseline, MEPS results were available in only 9 of 19 cases; there was 1 good result (11%), 3 fair results (33%) and 5 poor results (56%). At last follow-up, the results improved; there were 3 excellent results (20%), 5 good results (33%), 6 fair results (40%) and 1 poor result (7%) ($p<0.01$). In Figure 6 MEPS results in 15 patients over time are presented. No baseline measurements were available for the OES. The mean OES postoperatively was 28 points (range, 11-46 points). Six patients scored between 11 and 24 points, 4 patients between 25 and 36 points and 3 patients between 37 and 48 points. Before surgery, the mean VAS score for pain at rest was 4 (range, 1-9) and the mean VAS score for pain with activity was 7 (range, 3-10). The VAS score for pain at rest improved to a mean of 2 (range, 0-5) at last follow-up ($p<0.01$) and the mean VAS score for pain with activity improved to 4 (range, 0-8) ($p<0.01$).

At final follow-up, 13 of 15 patients (87%) were satisfied with the revision surgical procedure, 1 patient (7%) was moderately satisfied, and 1 patient (7%) was not satisfied at all.

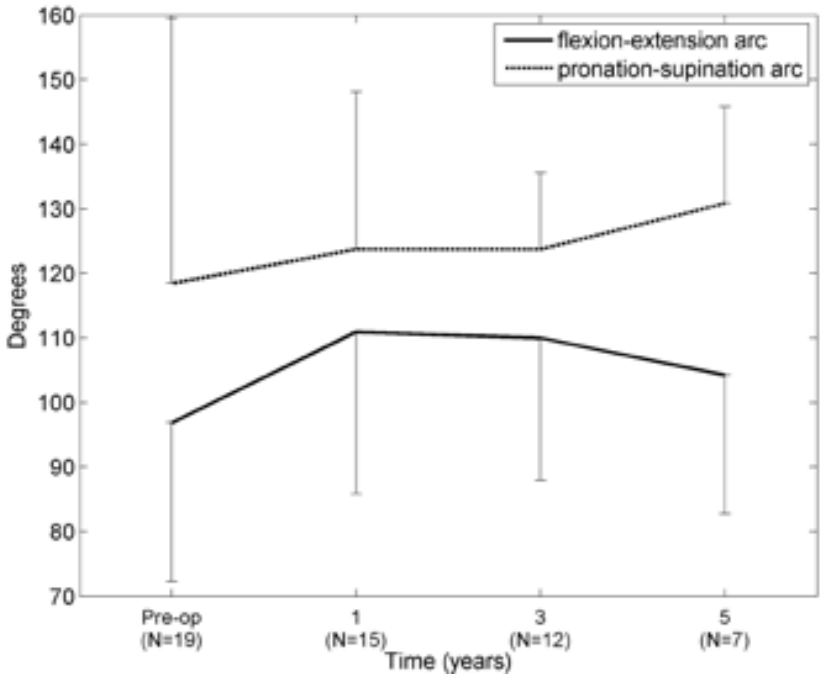

Figure 5. Range of motion over time presented 15 patients.

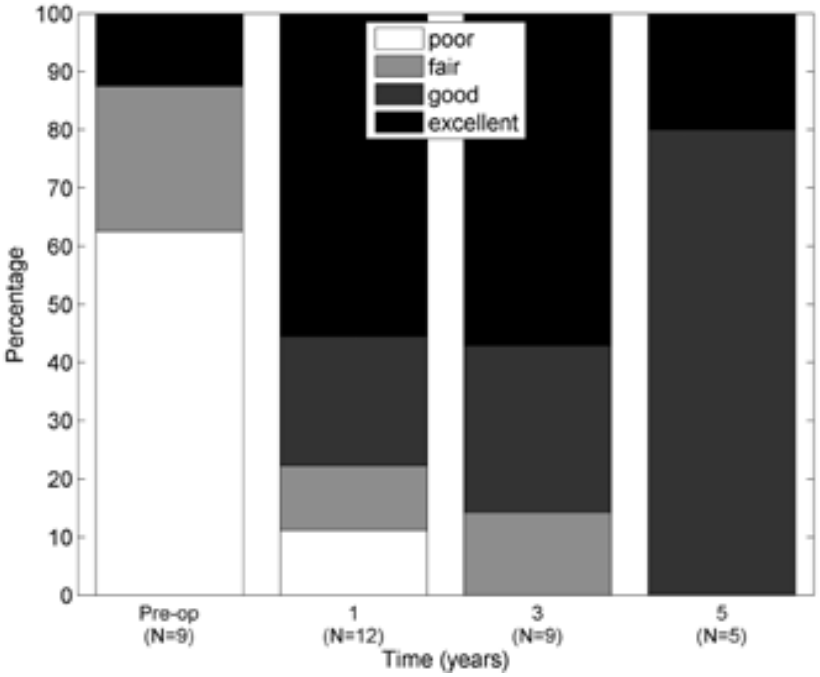

Figure 6. Mayo Elbow Performance Score Results over time presented for 15 patients.

Discussion

This study evaluated the clinical and radiographic outcome of revision surgery of TEA. In the 19 elbows included in this study 4 types of primary prostheses were revised: the Kudo prosthesis in 15 elbows, the semiconstrained version of the Latitude in 2, the Souter-Strathclyde in 1 and the Coonrad-Morrey prosthesis in 1. The Kudo and Souter-Strathclyde total elbow prostheses are both relatively short-stemmed unlinked prostheses compared with the Latitude and Coonrad-Morrey total elbow prostheses, which are both relatively long-stemmed semiconstrained prostheses. These differences could be related to the timeframe in which the primary arthroplasty was performed and might change in the future because more semiconstrained types are used today at our center. We observed that polyethylene wear of the unlinked Kudo prosthesis with forthcoming issues as metallosis and instability was the most reported reason for revision. These problems have been described previously.[2] Symptomatic loosening was the second most common indication for revision. Despite the loosening of the prosthesis in 37% of the cases in the current cohort, all surrounding cement had to be removed to lower the chances of infection of the existing cement mantle and to optimize the fixation of the revision TEA. This leads to more excessive debridement in the ulnar and humeral shafts and has led in our series to one perioperative fracture.

In this study clinical and functional scores improved on all parameters. After revision surgery, stability and ROM of the elbow joint improved, a decrease in pain at rest and during activity was observed, and MEPS results were either good or excellent at last follow-up in 8 of 15 patients (53%). The mean OES of 28 points, with a maximum of 48 points, indicates fair results of revision surgery. The OES was not available at baseline because

the questionnaire was not validated at that time. In Figure 5 ROM results over time are presented. The largest improvements were made in the first year after surgery. After 1 year, ROM remained good but no more improvements in flexion-extension arc were made. An interesting finding is that limited elbow motion was not a reason for revision; in most cases radiographic polyethylene wear, concomitant instability, and pain were reasons to consider revision arthroplasty.

Although clinical scores were good, complication rates in the study cohort were relatively high; in 11 of 19 elbows, postoperative complications occurred. In 1 patient (case 13) the ulnar component of the prosthesis was re-revised, and in 2 patients the revised TEA was removed in the end because of deep infection. We observed some interesting findings in the patients who had received re-revision or removal of their TEA. First, in both patients with indications of late posttraumatic arthritis for the primary prosthesis the revised prosthesis was removed or revised twice. Second, both patients who had undergone a second revision surgical procedure showed insufficiency of the triceps. This triceps insufficiency could be a result of multiple operations affecting the triceps muscle. In all patients who showed triceps insufficiency the triceps-tongue approach was performed. Nowadays, a 'triceps-on' technique is more frequently used at our institution, which is considered favorable in order to reduce complication rates in TEA.[23] However, further research is required to investigate the influence of the various approaches in TEA revision surgery. In addition, 4 smokers were identified in the cohort; 3 of them received a second revision surgical procedure or removal of the prosthesis. This outcome could suggest worse survival analyses in smokers. Statistical analysis on this was underpowered.

This study has several limitations. The number of patients is small, and because in all patients the index surgical procedure was not performed at our hospital, information regarding concomitant surgical procedures such as ulnar nerve transposition and ligamentous reconstruction was not available. In contrast to outcomes of primary TEA, relatively few results of revision surgery using the Coonrad-Morrey prostheses are found in the literature.[17-20, 24] These studies had comparably sized cohorts varying from 20 to 41 patients and a mean follow-up of approximately 5 years. In 2 of these studies, the authors were involved in the design of the implant, and the most recent study dates from 2013. In addition, none of the studies reported on differences in ROM and MEPS results over time. The data from our study may support the surgeon in managing the patient's expectations after revision surgery.

Even though we did not perform sample size calculations to determine statistical power, we observed a difference in ROM, MEPS and VAS scores after surgery, indicating that even relatively small numbers of patients led to significant differences. The strengths of this study are the midterm follow-up time of 57 months and the fact that none of the patients was lost to follow-up, resulting in no selection bias. Furthermore, all patients were operated on a uniform way. Even though our results were statistically significant, this does not guarantee success in clinical practice. However, we can state that patient satisfaction increased in this study. In our opinion, this is a more useful measure of success because patient satisfaction is

the individual interpretation of objective measures. Therefore, we consider our TEA revision surgery as a useful intervention.

Although we recommend revision surgery of TEA as a salvage procedure, an important observation in this study is the relatively young age (65 years) of the patient cohort. The mean age at the time of primary surgery was 54 years. This is essential to acknowledge because complication, removal, and (second) revision rates are still high. These high rates could be related a higher demand and use of the affected elbow and prolonged patient survival in younger patients. Current arthroscopic techniques for debridement of arthritic elbow joints in patients could possibly postpone the implantation of TEA.

Conclusion

The overall midterm outcome of this series of 19 revision surgical procedures of total elbow prosthesis can be considered satisfactory. Revision surgery using the semiconstrained Coonrad-Morrey prosthesis leads to less pain, better elbow performance, and prevention of further deterioration of elbow function. Nevertheless, it is essential to be aware of patients' age at the time of primary surgery and obtaining carful informed consent from patients before revision surgery is necessary because the complication rates are relatively high.

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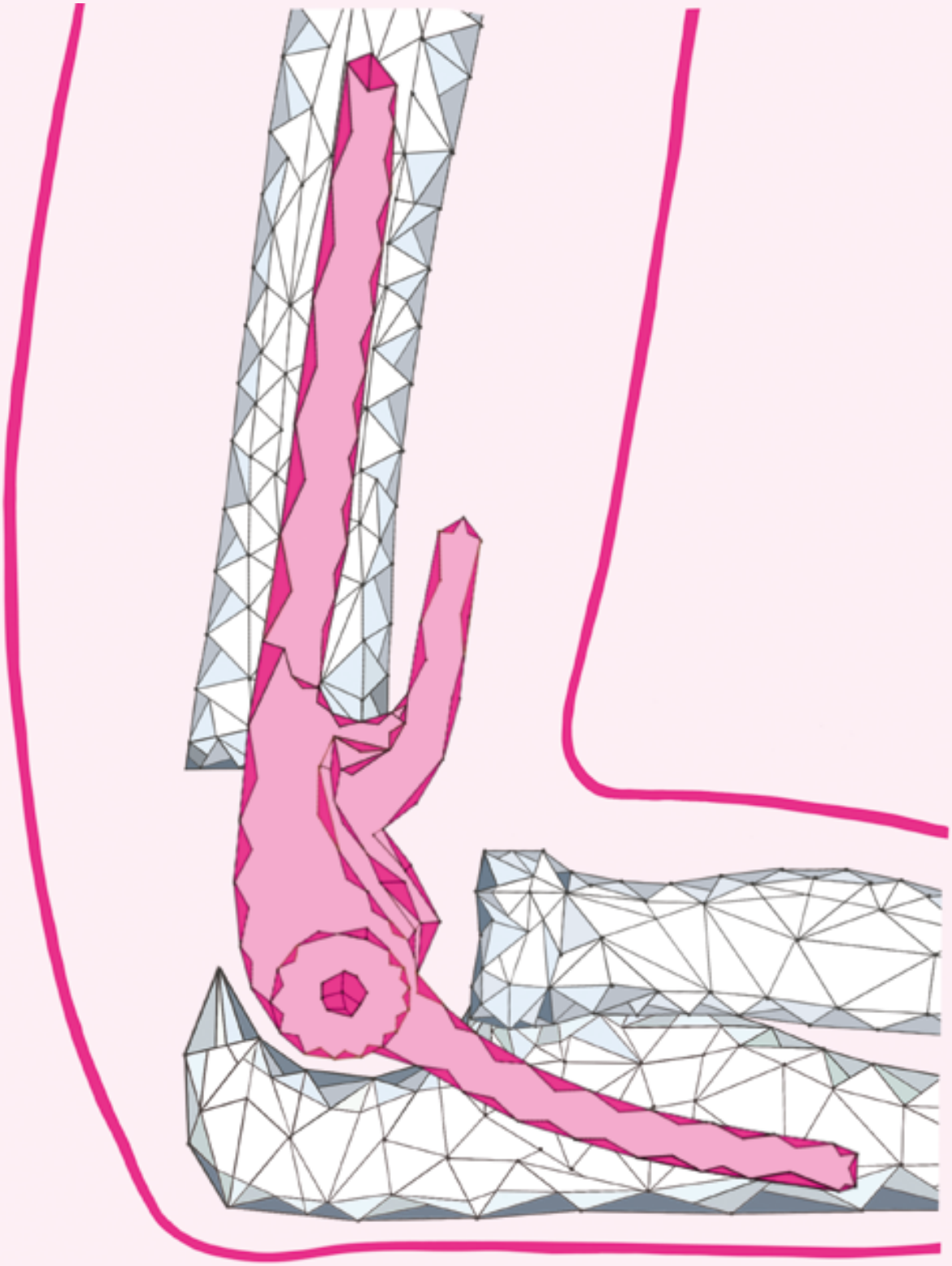

Chapter 8

Outcomes after revision total elbow arthroplasty: a systematic review

E.J. Geurts
J. Viveen
R.P. Van Riet
I.F. Kodde
D. Eygendaal

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Abstract

Background

Although revision arthroplasty surgery is a frequently used treatment for failed total elbow arthroplasty (TEA), published results are conflicting. The aim of this systematic review was to provide an overview of the outcomes of revision TEA surgery.

Methods

A systematic literature search was performed in major databases to find articles relating to outcomes after revision of TEA. Two reviewers independently screened the articles for inclusion and a third reviewer screened them before final inclusion.

Results

Twenty-one articles containing 532 cases were included. The mean age at revision was 61 years. The mean interval between primary and revision arthroplasty was 77 months, and the average follow-up period was 65 months. Different types of prostheses were included, with 69% of the revision prostheses having linked designs and 31% having unlinked designs. The visual analog scale score, Mayo Elbow Performance Score, Oxford Elbow Score, and range of motion improved significantly after revision surgery. Complications were reported in 232 of 532 cases (44%), leading to reoperations in 22%. After revision with linked prostheses, the Mayo Elbow Performance Score, range of flexion-extension, and pronation improved significantly more than with unlinked designs.

Conclusion

Improved functional outcome can be expected after revision TEA but the complication rate remains high. Revision TEA should still be considered as a salvage procedure for the failed TEA. Linked designs for revision TEA result in better outcomes compared to the unlinked designs in the midterm follow-up.

Introduction

Total elbow arthroplasty (TEA) is an effective and frequently used treatment for patients with severe, debilitating elbow pathology.[1, 2] Indications for TEA include rheumatoid arthritis, acute fractures, non-union, malunion, osteoarthritis, and posttraumatic arthritis.[3-6] Despite design developments and the increased frequency of TEA surgery, TEA remains a challenging and technically demanding surgical procedure.[7] Reported complication and failure rates are up to 62% and 90%, respectively.[8-12] In comparison with arthroplasty of the hip and knee, the complication and failure rates of TEA are relatively high.[2]

Revision is often indicated when a primary TEA fails. Instability and aseptic loosening of the implant are common indications for revision surgery.[8, 10, 13-16] Other indications include infection, periprosthetic fracture, and stiffness.[11, 17] Owing to the rise in TEAs, an increase in revision TEA can be expected.[18, 19] The underlying pathology, indication for revision surgery, and prosthetic design could influence the success of revision TEA. Complication rates in revision TEA of up to 30% to 61% have been reported.[20-23]

Satisfactory results have been reported for both linked and unlinked TEA designs.[24-26] Linked design supply superior stability because of a humeral and ulnar component connection through a sloppy hinge,[27-29] whereas unlinked designs use soft-tissue support, bone stock, and bearing surfaces of matching shape for stability.[30]

A large number of articles about the outcomes of the 2 different designs of revision TEA have been published, however, to our knowledge, the outcomes have never been systematically reviewed. The aim of this systematic review was therefore to present an overview of the outcomes of revision TEA and compare the outcomes of linked and unlinked revision TEA designs.

Methods

Study population

Studies containing patients aged 18 years and older who received a revision TEA were included in this review.

Inclusion criteria

The inclusion criteria were a follow-up period of at least 2 years after revision surgery, a minimum of 5 cases per report, and use of a non-custom revision prosthesis.

Search strategies and selection

With the assistance of a clinical librarian, a systematic literature search was performed in PubMed, Embase, and the Cochrane Central Register of Controlled Trials on February 1, 2017. The following terms were used: Arthroplasty[MeSH], Replacement[MeSH], Elbow[MeSH], Revision[MeSH], Total Elbow Replacement[tiab], Revision[tiab]. The search was performed using the filters "Dutch," "English," "German," and "humans."

A total of 1133 articles were found and assessed independently by two reviewers (E.J. G. and J.V.) on the basis of their title and abstract. Disagreements were settled by a third reviewer (S.K.). A total of 28 articles were considered eligible based on their title and abstract, and the full-text articles on these studies were assessed. After this assessment, 21 articles were included.

Outcome parameters

The outcome parameters used in this review were as follows: visual analog scale (VAS) score for pain (0-10); Mayo Elbow Performance Score (MEPS) for elbow function (0-100); Oxford Elbow Score (OES) for elbow function (0-100); and range-of-motion (ROM) aspects including flexion, extension, pronation, supination, arc of flexion-extension, and arc of pronation-supination. Moreover, numbers of complications and reoperations were included.

Data analysis

A database was made by extracting data form the included articles on follow-up time; sex; age; indication for primary TEA; type of primary prosthesis; survival time of primary prosthesis; interval between primary and revision surgery; indication for revision TEA; type of revision prosthesis; design of revision prosthesis; preoperative and postoperative VAS score at rest and with activity; preoperative and postoperative total MEPS and its individual parameters; preoperative and postoperative total OES and its individual parameters; preoperative and postoperative flexion, extension, range of flexion-extension, pronation, supination and range of pronation-supination; complications; and reoperations. Fifteen articles included pooled data; the other 6 articles contained data on individual patients. Because of the variability in reporting the types of complications and reoperations, we decided to report the number of complications and reoperations in separate groups. Radiographic evaluation was not included in this review because of the great variability in reporting this outcome. Regarding survival, multiple studies used different endpoints, had a variable follow-up, and were not always reported per case; therefore, we were unable to report on survival in this systematic review. All other outcome parameters (VAS score, MEPS, ROM, OES, complications and reoperations) were analyzed in the total patient population, as well as in the linked group and unlinked group.

Statistical analysis

VAS score, MEPS, OES and ROM before and after revision arthroplasty were specified using descriptive statistics. To compare different outcome parameters between the linked and unlinked groups, the paired *t* test and the 2-tailed independent-samples test were used. For all analyses, $p \leq 0.05$ was considered significant. Analyses were performed using SPSS software (version 21.0; IBM, Armonk, NY, USA).

Results

Patients characteristics

All 21 included reports (Supplementary Table S1) were case series (level IV therapeutic studies).[20-23, 29, 31-46] The studies contained a total of 532 patients. The number of patients per study ranged from 11 to 53 cases. The included articles originated from Europe (11 articles), North America (8 articles), and Asia (2 articles) and were published between 1987 and 2017. The mean age of the study population was 61 years, the mean follow-up period after revision surgery was 65 months, and the average time interval between primary TEA and revision TEA was 77 months. The 2 most frequently used prostheses were the Coonrad-Morrey prosthesis (Zimmer, Warsaw, IN, USA) (59%) and Souter-Strathclyde prosthesis (Stryker, Newbury, UK) (20%). These 2 prostheses accounted for 79% of the revision prostheses. Most of the prostheses in the current review (69%) were linked (with 31% unlinked). All of the prostheses used and their numbers are shown in Table 1.

Outcome parameters

In the total patient group, the VAS score at rest improved from 3.9 preoperatively to 1.5 postoperatively ($p<0.001$). With activity, the VAS score improved from 6.3 preoperatively to 3.1 postoperatively ($p<0.001$). The total MEPS improved significantly from 46 preoperatively to 80 postoperatively ($p<0.001$). The MEPS values for pain, motion, stability and function all improved significantly after revision surgery ($p<0.001$). Flexion improved significantly from 119˚ to 128˚, and the extension deficit improved significantly from 35˚ to 30˚, leading to an increased arc of flexion-extension from 87˚ to 99˚ ($p<0.001$). Average preoperative pronation and supination were 61˚; postoperatively, pronation and supination improved to 66˚ and 65˚, respectively, leading to an increased arc of pronation-supination from 124˚ to 134˚ ($p<0.001$). Preoperatively no articles described the OES, and postoperatively, the mean total OES was 65.

In 232 of 532 patients (44%), at least 1 complication occurred. The 3 most common complications were aseptic loosening (22%), transient ulnar and radial nerve symptoms (21%), and periprosthetic fractures (15%). The complications resulted in 128 reoperations in 116 cases (21.8%). Reoperations consisted of a second revision (57%) including a second revision with bone grafting (8%), removal of the prosthesis (22%), cerclage wiring (4%), cement spacer replacement (4%), and debridement with antibiotics (4%). The most common complications and reoperations are shown in Table 2.

Outcome measures for the linked and unlinked designs separately are included in Table 3. The MEPS, extension deficit, range of flexion-extension and pronation were better in the linked group and improved significantly more after revision surgery ($p<0.001$).

The linked group had a complication rate of 46% and reoperation rate of 26%, whereas the unlinked group had a complication rate of 45% and reoperation rate of 20%. The reoperation rate of the unlinked group was lower than that of the reoperation rate of the linked group ($p<0.001$). The indications for revision surgery were comparable in the 2 groups.

Table 1. Revision prostheses used in included articles.

	N
Linked prosthesis	
Coonrad-Morrey	315
Latitude	18
GSB	12
Pritchard-Walker Mark	12
Schlein	5
Triaxial	5
Total	367 (69%)
Unlinked prosthesis	
Souter-Strathclyde	106
Dogo Onsen Hospital	30
Wadsworth-Mark	9
Capitello-Condylar	8
Mayo	5
London	4
Kudo	3
Total	165 (31%)

Table 2. Most common complications and reoperations.

	%
Complication	
Aseptic loosening	22%
Transient ulnar and radial nerve symptoms	21%
Periprosthetic fracture	15%
Reoperation	
Second revision	49%
Removal of prosthesis	22%
Revision with bone grafting	8%

Discussion

This systematic review showed that, overall, functional outcomes and patient-reported outcome measures improved after revision elbow arthroplasty. Patients experienced less pain and an increased ROM. However, complication and reoperation rates of 44% and 22%, respectively, were found.

The linked group showed superior improvement in the MEPS and ROM compared with the unlinked group. Although the outcomes for linked prostheses were better, statistical analysis to compare the groups were underpowered because of the small group sizes. Patients who received linked prostheses underwent significantly more reoperations. In

Table 3. Outcome variables in linked and unlinked revision prostheses.

	Linked prostheses				Unlinked prostheses			
	Preoperative		Postoperative		Preoperative		Postoperative	
Outcome measure	**Mean**	**n**	**Mean**	**n**	**Mean**	**n**	**Mean**	**n**
VAS score at rest	3.87	50	1.51	47	NA	0	NA	0
VAS score with activity	6.28	50	3.06	47	NA	0	3.09	16
MEPS total	47.01*	179	80.89*	302	42.30	30	76.40	60
OES total	NA	0	64.33°	51	NA	0	68.30	10
Flexion	116.44°	157	128.77°	242	123.88°*	101	127.60°	128
Extension deficit	30.58°*	157	24.58°	236	41.79°	101	41.93°	121
Arc of flexion-extension	89.35°*	241	103.89°	320	81.63°	111	87.08°	131
Pronation	64.45°*	90	69.20°	124	58.49°	101	62.72°	107
Supination	57.10°	90	64.03°	121	64.79°*	101	65.89°	101
Arc of pronation-supination	123.35°	174	134.61°	230	125.10°	111	132.91°	131
Complications				169 (46%)				74 (45%)
Reoperations				96 (26%)				34 (20%)*

VAS, visual analog scale; NA, not available; MEPS, Mayo Elbow Performance Score; OES, Oxford Elbow Score.
* Significantly better outcome compared with other group.

general, unlinked designs can only be used in patients with sufficient bone stock and an adequate soft-tissue envelope to provide stability to the operated elbow. This may have introduced a bias and could be responsible for the increased reoperation rate in the linked TEA group.

A trend toward use of linked designs for revision TEA was found, as studies reporting on linked designs were more recent and of better quality than studies reporting on unlinked designs; the need for sufficient bone stock and soft tissue in the unlinked designs, which are often missing in the revision setting, might be the reason for this trend. The linked study group included more than twice as many patients as the unlinked group, and studies reporting on linked designs had a more complete dataset, which resulted in higher numbers of parameters that could be studied compared with the reports on unlinked designs. Considering the results of this systematic review and the lower requirement for sufficient bone stock and soft tissue, we suggest that the linked design might be a preferable option for revision TEA.

In this systematic review, several limitations are recognized. There was substantial variance in reporting results, particularly for radiographic parameters and survival. These outcome measures could therefore not be used in this systematic review. It is important that a more unambiguous way of reporting radiographic outcomes and survival be adopted in future reports on TEA revision. Radiographic outcomes should describe at least the analysis of radiolucency per zone, loosening, fractures, and heterotopic ossification and, preferably, signs of bushing wear. Because of missing information in the articles (not all cases had data

on all parameters), the database was incomplete. Consequently, some conclusions have less power than others owing to a small and varying sample size.

Some older studies were included in this systematic review. The designs of TEAs have developed over time, which has resulted in better prostheses and better outcomes. Not only prosthetic designs but also operative techniques have improved, so the inclusion of older studies could potentially have negatively biased the outcomes. Despite the improvements in the designs, a reserved attitude concerning primary TEA is expedient considering the high complication and failure rates in primary arthroplasties, which lead to challenging revision surgical procedures because of a lack of bone stock and soft tissue, resulting in infections, nerve pathology, and triceps insufficiency. Nowadays, postponing TEAs is possible because of the improvements in the arthroscopic techniques used for debridement in patients with primary or posttraumatic arthritis and the use of partial replacement of the elbow.

The underlying pathology and indication for revision arthroplasty can have a large effect on the outcome.[11, 26] Unfortunately, we were unable to differentiate outcomes between different indications for primary and revision surgery as the results were pooled or incomplete in most of the articles. Further research should focus on the outcomes of revision arthroplasty for different indications. Another suggestion for further research is assessment of the impact of risk factors such as rheumatoid arthritis or diabetes; to make this happen, it is crucial to report these factors as it was not done in most of the articles we found.

Conclusion

Revision TEA leads to improved pain scores, patients reported outcome measures, and ROM of the elbow. However, a high complication rate of 44% and reoperation rate of 22% were found. Therefore, we still consider revision TEA as a salvage procedure. The indication is an essential factor in the prognosis and success of a revision TEA. Primary TEA is an invasive procedure, so if possible, surgery without joint replacement is preferred. Despite the limited number of patients in the included studies, the outcome parameters of the linked prostheses improved more than those of the unlinked prosthesis designs in the midterm follow-up.

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Supplementary data

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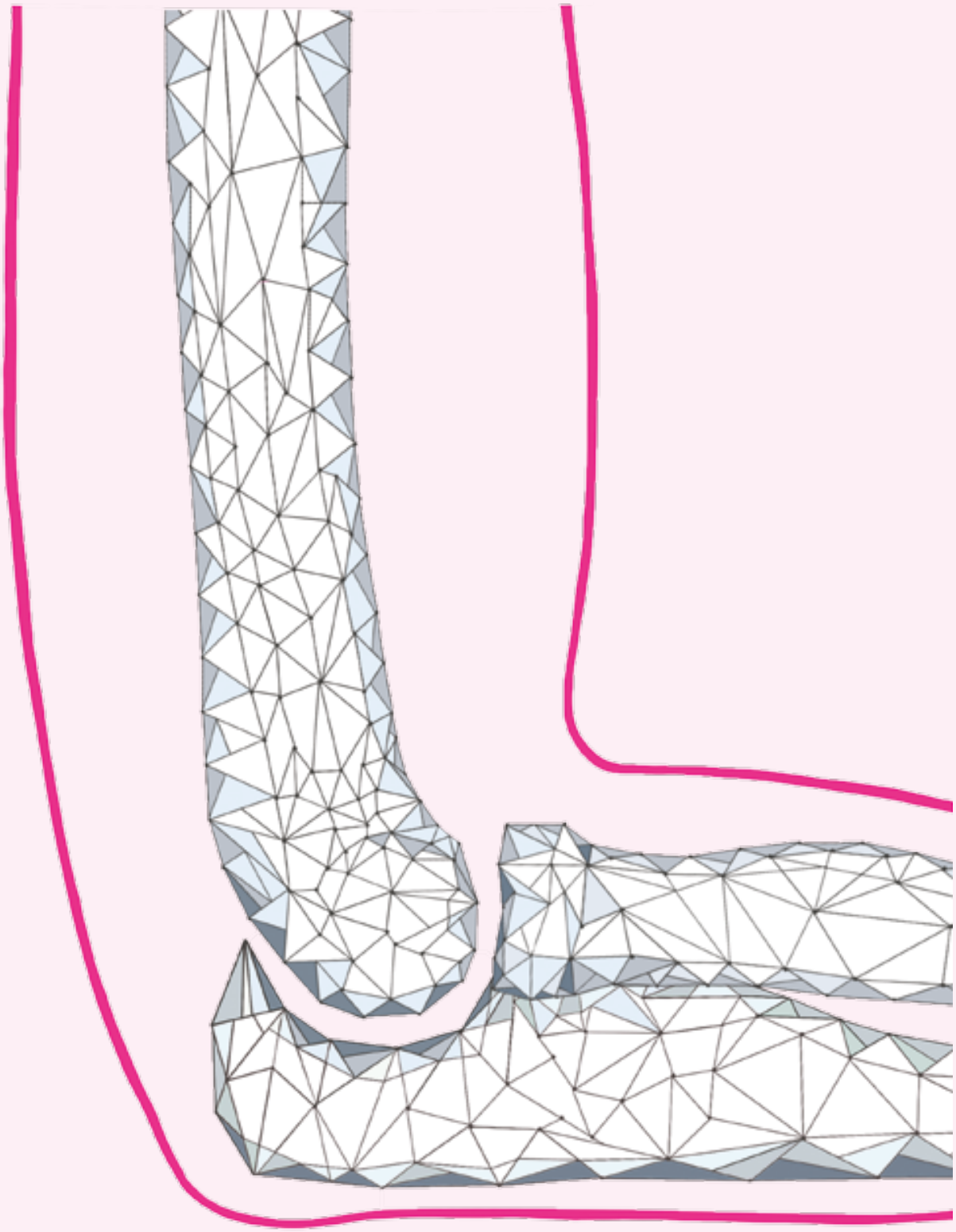

General discussion, future perspectives and conclusions

General discussion and future perspectives

the studies enclosed in this thesis focus on 2 specific types of arthroplasty of the upper extremity: radial head- and total elbow arthroplasty. After two chapters on the detailed anatomy of the radial head and the proximal ulna using micro-computed tomography (micro-CT) imaging, the clinical results of primary and revision surgery are described for the respective elbow prostheses, and the reasons for failure of primary arthroplasty are reported. In this section, our main findings are discussed and suggestions for future research are made. Finally, the clinical relevance of this thesis with recommendations for daily practice of trauma and orthopedic surgeons is given.

Micro-computed tomography imaging

In **Chapter 1 and 5**, the anatomy of the radial head and proximal ulna was studied in detail**,** using micro-CT imaging. The major benefit of micro-CT compared to clinical CT and/or magnetic resonance imaging (MRI) is the clear display of trabecular struts (which can be as thin as 100 µm)[1, 2] with a spatial resolution in the 10-20 µm range,[2-4] whereas clinical CT has a worse spatial resolution (of about 500 µm).[5]

An improved understanding of the bone microstructure (i.e. adaption of the trabecular number, thickness and separation to loading) of a non-weightbearing joint like the elbow[6] proved to be valuable and enhanced the knowledge about the trabecular structures in combination with patterns and treatment of fractures of the radial head and the proximal ulna. The results obtained in these 2 studies generated further biomechanical and clinical questions. Future answers to these questions can link our micro-CT findings to day to day practice. Micro-CT imaging could well pave the way to enhance clinical practice in elbow arthroplasty. Due to improved understanding of failure mechanisms in symptomatic (aseptic) loosening of elbow prostheses, micro-CT could be useful in the development and design of new elbow prostheses. Therefore, future studies should focus on micro-CT imaging of the complete elbow joint under loading in combination with biomechanical testing in order to improve the understanding of bone adaption[7] according to the load distribution through the elbow joint.

Radial head arthroplasty

This part focused on the reasons for failure of primary radial head arthroplasty (RHA), the treatment options thereafter and the functional outcomes after revision surgery.

In **Chapter 2**, we reported on the early failure of different types of metallic RHAs. Based on the existing data in the scientific literature, there was no evidence for superiority of a specific type of RHA. This was partially because there are many different types of RHA designs used to date, which impaired subgroup analysis. These designs vary in terms of material, fixation, polarity and modularity resulting in 32 possible combinations (4 different fixation techniques, 2 different polarities and 4 different materials). Not for all combinations a specific RHA type is designed, however for several combinations multiple RHA types

are designed by different companies (i.e. 18 different types divided over 8 combinations were reported in **Chapter 2**). In total, 152 failed arthroplasties were observed divided over 18 different RHA types. Of these 18 different types, 7 prostheses are either modified or not available anymore. Some of these 7 implants have been available for a short period and taken off the market for unclear reasons. Three of these implants have been recalled mainly because of adverse events involving dissociation of the prosthesis and problems during the surgical procedure.[8] The range of different RHA designs available to date in combination with the relative frequency of RHAs being taken off the market, could suggest that the development and introduction of new RHAs might be commercially driven. Moreover, the more different types of implants are available, the less large case series can be expected. In our opinion, it would be better to focus on a small number of different types of prostheses first in order to facilitate proper studies on clinical outcomes in larger groups of patients. Based on the results of these future studies, a limited number of RHA designs will be considered better than others. These RHA designs could thereafter be evolved, so that ultimately only a couple of solid RHA designs will be available on the market. This is a better strategy, instead of frequent introduction of new types of RHA. A joint registry would have to play an important role in this as well as studies using roentgen stereophotogrammetric analysis (RSA) in elbow arthroplasty. In TKA, the phased clinical introduction of new prostheses with two-year RSA results as a qualitative tool showed promising results ultimately leading to better patient care.[9]

Scientific literature reporting on the outcomes after treatment of failed RHAs is rare.[10-16] Surgical decision making on how to treat a failed RHA is challenging. In **Chapter 3,** different treatment options after a failed RHA are discussed: removal, replacement with another RHA with or without an interposition arthroplasty, or revision to a total elbow arthroplasty (TEA) in order to provide an algorithm that could be used in daily practice.

Radial head fractures are frequently accompanied with associated injuries to the ipsilateral upper limb, as medial and lateral collateral ligament (MCL and LCL) ruptures, rupture of the interosseous membrane (IM), chondral damage of the capitellum and coronoid and olecranon fractures.[17] Therefore, we suggest that resection of the radial head in the acute setting should not be performed. In the past, it has been proposed that RHA after trauma only serves as a temporary spacer, which could be removed after the injured ligaments were healed.[18] In contrast to this assumption, we believe that the radial head is the corner stone of the elbow in relation to stability of the elbow joint, especially in case of an associated injury to the coronoid, and therefore should not be removed in the setting of revision surgery either.

The radio-capitellar joint plays an important role in load transmission especially in extension. Moreover, the radial head tensions the LCL complex. Removal of a RHA should be avoided in posttraumatic cases to prevent axial migration of the radius, especially in combination with an insufficiency of the IM, and insufficiency of the LCL complex because of under-tensioning. In addition, the radial head is an important secondary stabilizer,

accounting for approximately 30% of valgus stability with an intact MCL.[19] In case of MCL insufficiency, the radial head becomes the primary stabilizer against valgus instability[19] and radial head resection should therefore be avoided. If a primary RHA failed, replacement with another RHA should be the preferred treatment in the above-mentioned cases.

The functional outcomes after revision surgery of a failed RHA with another RHA are reported in **Chapter 4**. The elbow function after revision surgery improved, resulting in less pain, improved stability scores and satisfied patients. Nevertheless, these results should be interpreted with caution, since the follow-up was midterm and ulnohumeral and capitellar degeneration was already present in respectively 63% and 88% of the patients at last follow-up. Although mid-term outcomes after primary and revision RHA are currently considered satisfactory, papers on long-term outcomes after primary RHA report a high re-operation rate of up to 39% within the first 3 years after implantation and conflicting survival rates varying from 61% to 97% at 10 years.[15, 20] We believe that a critical perioperative assessment at the index procedure should therefore be performed, to determine whether radial head replacement is necessary or if open reduction-internal fixation (ORIF) is favorable.

It is reported that RHA should be carried out in case of comminuted radial head fractures involving 3 or more fragments.[21] Others concluded that RHA is favorable when compared to ORIF.[21-24] More complications occurred in patients who underwent ORIF and their re-operation rate was higher due to frequent removal of the osteosynthesis material.[21-24] However, most studies are retrospective cohort studies and all studies included relatively small numbers of patients with short-term follow-up. Unfortunately, a well-performed randomized controlled trial (RCT) with long-term follow-up comparing ORIF and RHA is lacking. In addition, Hack et al. showed in a recent retrospective study of 466 patients with radial head fractures, that the complication rate after ORIF is considerably higher compared to the patients who received RHA. However, in most patients in this study ORIF was performed using hand plates rather than pre-contoured radial head locking plates.[25] Over the last decades, plate and screw designs for the radial head have been improved with 'low-profile' designs, leading to promising results.[26, 27] The low-profile plates possibly result in less need of a second surgical procedure for removal of osteosynthesis material. In particular, low-profile plates with locking head screws may provide a more stable fixation with less irritation of the soft tissue.

Moreover, good clinical outcomes after 'on-table' reconstruction of severely comminuted radial head fractures have been reported.[28] The reconstructed radial head serves as a natural spacer, resulting in a satisfying elbow function. This supports that the elbow joint is, as a non-weightbearing joint, more forgiving in case of posttraumatic radial head deformities, such as a subcapital non-union. Therefore, we believe that retaining the native head is favorable if ORIF is feasible when compared to RHA. If RHA is truly indicated, the procedure should be performed by an experienced surgeon, because RHA could be a challenging procedure with possible technical errors resulting in over and undersizing of the radial head, overlengthening and dissociation of the prosthesis.[29]

Future studies are needed to improve clinical practice in RHA. We suggest an individual and more uniform way of reporting radiographic findings in case of suspicion of a failed RHA, indications for revision surgery, perioperative findings and clinical and functional outcomes thereafter. This could help to investigate whether specific RHA designs are better than others in terms of survival rate and outcomes as well as specifying the underlying pathology of a failed RHA. National arthroplasty registries could be of paramount importance here, since data of these registries already enhanced our knowledge about trends and survival rates in TEA surgery.[30-33] However, data collection on RHAs has not been sufficient yet.

Follow-up after RHA should exist of clinical- and radiographic assessments in combination with patient reported outcome measures (PROMs). Follow-up including PROMs solely would not been sufficient, since these outcomes are not directly related to complications and/or loosening, like in 1 of the patients in **Chapter 4**.[34] In order to assess patients properly on a regular base, clinical and radiological follow-up should exist of at least 3 years[35] and preferably longer, with intervals of 2 years in order to detect aseptic loosening in an early phase.

Total elbow arthroplasty

This part focused on trends in TEA surgery including indications for primary and revision TEA. Moreover, the functional outcomes after revision surgery were evaluated.

In **Chapter 6**, data of the Australian Orthopedic Association National Joint Replacement Registry (AOANJRR) was analyzed. We found that acute fracture or fracture-dislocation was the most prevalent indication for TEA over time in Australia, whereas in other European studies, rheumatoid arthritis (RA) used to be the biggest group.[30, 31, 33, 36] We believe it is a positive trend that elbow replacements are currently less often performed in patients with RA. TEA can be postponed nowadays in patients with RA because of improved medical management as steroids and biologics (disease-modifying antirheumatic drugs (DMARDs))[37-39] and arthroscopic debridement techniques. In general, one should aim to postpone TEA as long as possible, since TEA is considered a salvage procedure with relatively high complication and revision rates.

Although we believe that postponing TEA should be applied to patients with complex, intra-articular, distal humerus fractures as well by performing ORIF, some studies reported good outcomes after TEA placed for acute fractures.[32, 40] McKee et al. compared the outcomes after ORIF and TEA for acute distal humerus fractures, and reported better outcomes and less re-operations in the TEA group.[40] However, it is questionable if the ORIF in this study was well-performed, since 6 surgeons performed all procedures during an unknown study period, while this could be a challenging procedure. Besides, innovation of distal humeral plating systems and surgical technique has been improved the last decade resulting in better outcomes.[41] ORIF is therefore still the gold standard in case of distal humerus fractures,[42] and TEA should only be performed in case of inability to perform an adequate osteosynthesis in the elderly.

Chapter 7 and 8 focused on the outcomes after revision surgery of TEA. Remarkable in both chapters is the relatively young age of the patient cohort, with mean ages of respectively 65 year and 61 year at the time of revision surgery.[43, 44] This is particularly remarkable because the complication rates in both cohorts were respectively 58% and 44%, resulting in a re-revision rate of respectively 16% and 22%. Therefore, it should be questioned if implantation of the primary TEA was correctly indicated in these patients. In case the primary indication was a complex, intra-articular distal humerus fracture in an elderly person where ORIF was not feasible, TEA would have been the best option in that case to regain a functional elbow.[32] However, in **Chapter 7**, 17 of the 19 patients received a primary TEA because of RA. This raises questions why postponing TEA in these patients was not performed or achievable, considering their young age and the expectation of extremely challenging (re)-revisions in the future. A possible explanation could be that DMARDs were not yet available at the time of their primary surgery. Nowadays DMARDs are available, and therefore we believe that TEA surgery should only be performed when medical management and joint sparing treatments as an arthroscopic synovectomy have had insufficient effect on pain relieve and elbow function.

Future studies on TEA should focus on the long-term outcomes in combination with PROMs. National implant registries could play an important role here, since demographic and perioperative data on TEA is already collected in several registries.[30-33, 36] However, PROMs are not collected automatically yet, whereas this already proved to be valuable in total hip and total knee arthroplasties (THA and TKA).[45-47] For the collection of PROMs, online questionnaires could be used for which response rates of up to 92% have been reported with minimal hospital resources required once the system is running.[48] Ultimately, PROMs could be useful in predicting the outcome after elbow arthroplasty in the future. However, as mentioned before, PROMs are not directly related to complications and/or loosening yet. For instance, excellent results could be obtained in patients with loosened prostheses and contradiction, moderate, results in patients with excellent radiographic findings. We think that the primary diagnosis could be of influence here, whereas patients with RA had a worse elbow function previous to the surgery, compared to patient with acute fractures, leading to different expectations after TEA. Confounding by indication is present in registry studies as well and therefore causality should be interpreted with caution.

Conclusions

RHA is commonly performed in case of comminuted radial head fractures. In the last decade, a similar trend has been observed for TEA in case of complex elbow fractures. Although the clinical outcomes after primary elbow arthroplasty are considered favorable under the circumstances, the long-term complication and failure rates remain relatively high in comparison to for example THA and TKA. The most prevalent indication for revision surgery in elbow arthroplasty is aseptic symptomatic loosening, followed by infection in TEA and stiffness and persistent pain in RHA. Despite a high complication rate, the functional outcomes after revision surgery of elbow arthroplasties are considered satisfactory, including improvement of range of motion (ROM), stability, pain scores and outcomes of PROMs. Therefore, revision surgery of elbow arthroplasties is regarded as a salvage procedure. However, this relatively high complication rate particularly in revision TEA should be discussed with the patient in advance. Considering the research performed in this thesis, some suggestions for daily practice are given:

1. *'Nothing is better than your own radial head.'* A critical perioperative assessment at the index procedure should be performed to determine whether a radial fracture is amendable to a sufficient osteosynthesis; radial head replacement can be an option in non-reconstructable radial heads, especially in patients over 60 years of age. The long-term survival and clinical outcomes of RHA remain far from excellent.
2. Because the radial head is an important stabilizer of the elbow joint, resection and/or removal of the radial head should be avoided in both acute, as well as in chronic posttraumatic conditions. We could even argue that some patients are better off with a posttraumatic deformed or a non-united head as natural spacer instead of resection.
3. In case of a failed RHA in an unstable elbow joint with limited erosion of the capitellum, satisfactory outcomes after revision surgery to another RHA could be expected.
4. TEA surgery is still a lag behind THA and TKA. The procedure is complex and challenging, with a relatively high complication and revision rate, especially in low-volume centers.[36] Therefore, TEA should be centralized in high-volume centers and patients should be treated by an experienced surgeon.
5. Only if ORIF of a complex, intra-articular fracture of the distal humerus is not feasible, TEA could be a reliable option in elderly with acceptable complication and revision rates after mid-term follow-up.
6. Revision surgery of TEA is a challenging procedure. Improvement of ROM, stability and pain scores could be expected; however, patients should be informed about the high complication, re-operation and revision rate.

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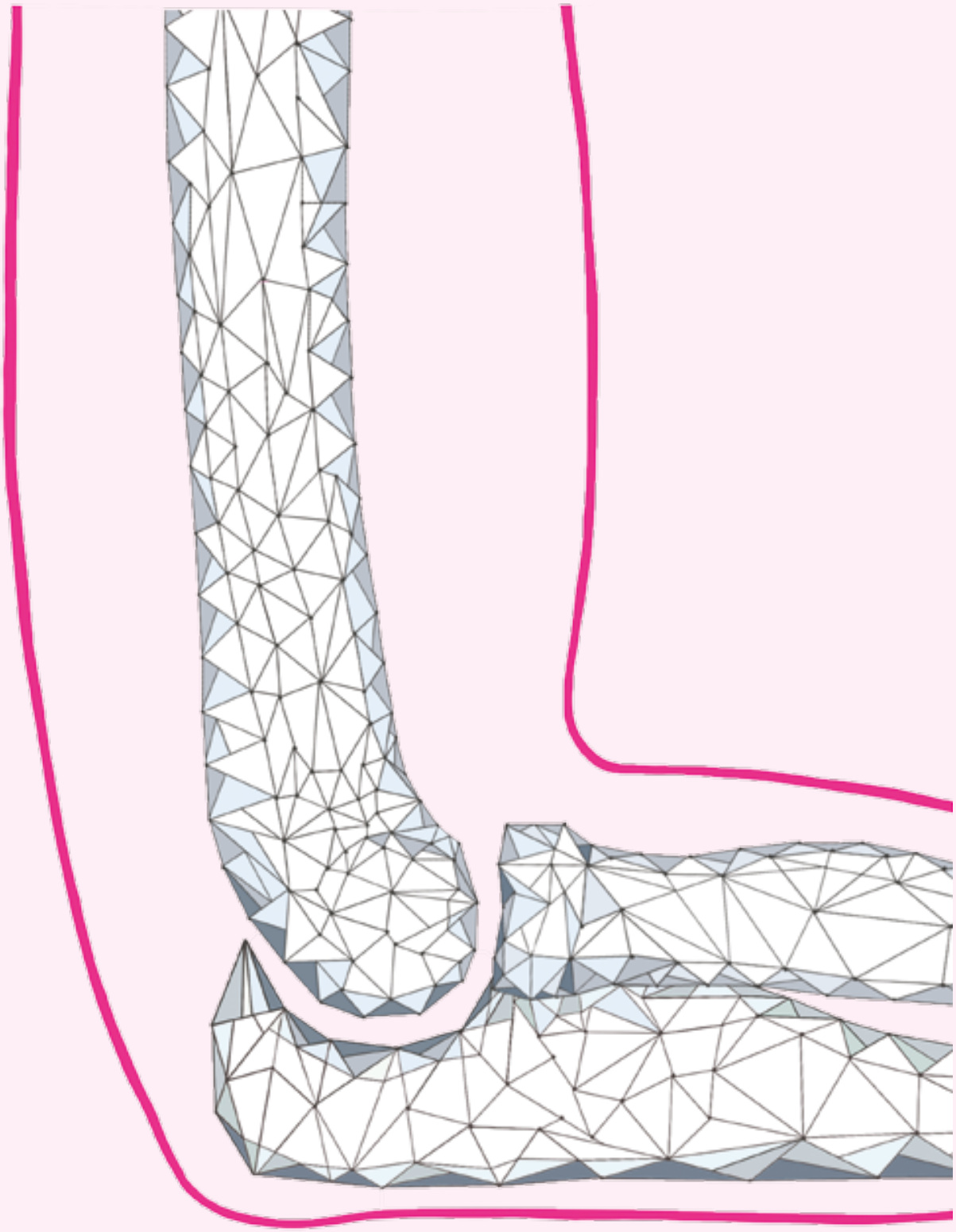


Summary

Summary

The elbow is an essential joint to position our hand in space and thus vital to be able to perform most basic daily activities. Therefore, it is important to restore elbow function after complex elbow fractures or sequalae of posttraumatic deformities. In selective trauma cases, when the fracture is considered not amenable to achieve the main goal of open reduction-internal fixation – a functional elbow – total or partial elbow arthroplasty can be an option. Functional outcomes after primary elbow arthroplasty are generally favorable, however the complication and revision rates remain relatively high and improvements to optimize outcomes could well be made.

Therefore, the general aim of this thesis was to improve the results of (failed) elbow arthroplasties, including the treatment of complex elbow trauma with arthroplasties. **Part I** focused on radial head arthroplasty (RHA) with specific interest in anatomy of the radial head, indications, diagnosis and management of revision surgery and the radiographic and clinical outcomes thereafter. In **Part II**, the focus was on total elbow arthroplasty (TEA); anatomy of the proximal ulna was studied in detail, analysis of global trends on indications for primary and revision surgery of TEA was done and radiographic and clinical outcomes after revision surgery were assessed.

Part I – Radial head arthroplasty

Chapter 1 – Regional differences in the three-dimensional bone microstructure of the radial head: Implications for observed fracture patterns

In this chapter, we used micro-computed tomography (micro-CT) imaging to quantify the trabecular bone microstructure of 6 dry human cadaveric proximal radii. A better characterization of the microstructure could help to better understand the most common fracture patterns of the radial head.

The lateral side of the radial head showed a lower bone volume fraction and less trabeculae with a higher separation compared to the medial side. This finding, in combination with the nature of the common trauma mechanism, could explain the possible fracture patterns of the radial head, particularly more frequently involving the anterolateral quadrant.

Chapter 2 – Why does radial head arthroplasty fail today? A systematic review of recent literature

To date, many different types of radial head arthroplasties (RHA) are available, varying in terms of material, fixation, polarity and modularity. The aim of this chapter was to systematically report on the early failure of different types of metallic RHAs and to study if specific RHA designs are better than others.

In 152 failed prostheses, with a mean survival time of 34 months, the most prevalent indications for revision surgery of RHA were symptomatic aseptic loosening (30%), stiffness

(20%) and persistent pain (17%). Since there are many different types of RHA used currently, with relatively low numbers of failed RHA reported in the scientific literature, the existing data provides no evidence for a specific RHA design.

Chapter 3 – Complications and revision of radial read arthroplasty: management and outcomes

In this chapter we provided a treatment algorithm on how to diagnose and manage a failed RHA, aiming to assist in decision-making in daily practice. The decision whether to remove, replace or revise a failed RHA depends on the chondral condition and stability of the elbow joint. In addition, the age and activity level of the patient should be taken into account. In case of a stable elbow joint, removal of the prosthesis could be performed. When the joint is unstable, replacement with another RHA is preferable. If erosion of the capitellum is present in combination with an unstable joint, revision to a radiocapitellar prosthesis could be considered. In older patients with an age of 70 and above with signs of ulnohumeral arthritis, revision to a total elbow arthroplasty (TEA) may be indicated.

Chapter 4 – Clinical and radiographic outcome of radial head prosthesis revision surgery

Since knowledge on clinical outcomes after revision surgery of RHA is limited, we performed a retrospective study of 16 patients who underwent revision surgery of their RHA. The aim of this chapter was to report on the radiographic and functional outcomes.

After revision surgery, the range of motion (ROM) remained the same and stability, pain scores and outcomes of patient reported outcome measures (PROMs) improved.

Part II – Total elbow arthroplasty

Chapter 5 – Three-dimensional microstructure of the proximal ulna

In this chapter, we used micro-CT imaging to describe the cortical and trabecular bone microstructure of 5 dry human cadaveric proximal ulnae. We aimed to better understand the loads applied to the elbow joint that could lead to possible fractures, both in the acute setting, as well as for (failed) ulnar components in TEA.

The bare area, located just below the trochlear notch, showed the highest bone volume fraction compared to the olecranon- (both medial and lateral part) and coronoid process. This is most likely where the compressive load from the humerus and tensile loads due to contraction of the triceps and brachialis overlap. Moreover, the coronoid displayed the thickest cortex, supporting that this structure – known as the anterior buttress – is the most important bony stabilizer of the elbow joint. The bone microstructure seems to adapt to everyday loading applied to the elbow and the detailed evaluation of the bone microstructure facilitates understanding of potential fracture patterns.

Chapter 6 – Use and outcome of 1220 primary total elbow arthroplasties from the Australian Orthopaedic Association National Joint Arthroplasty Replacement Registry 2008 – 2018

Studies reporting on national arthroplasty registries usually include a high number of arthroplasties and are therefore valuable in improving the results of TEA. The aim of this chapter was to assess the Australian Arthroplasty Registry – including 1220 primary TEAs – in order to enhance our understanding of possible trends in TEA surgery.

The total number of TEAs placed per year in time was stable. The most prevalent indications were fracture/dislocation (trauma) (36%), osteoarthritis (OA, 34%) and rheumatoid arthritis (RA, 26%). The failure rate was 10%, 15% and 19% at 3, 6 and 9 years, whereas TEAs placed for OA failed more often compared to TEAs placed for trauma and RA. The most common reasons for revision were infection (35%) and aseptic loosening (34%).

Chapter 7 – Clinical and radiographic outcome of revision surgery of total elbow prosthesis

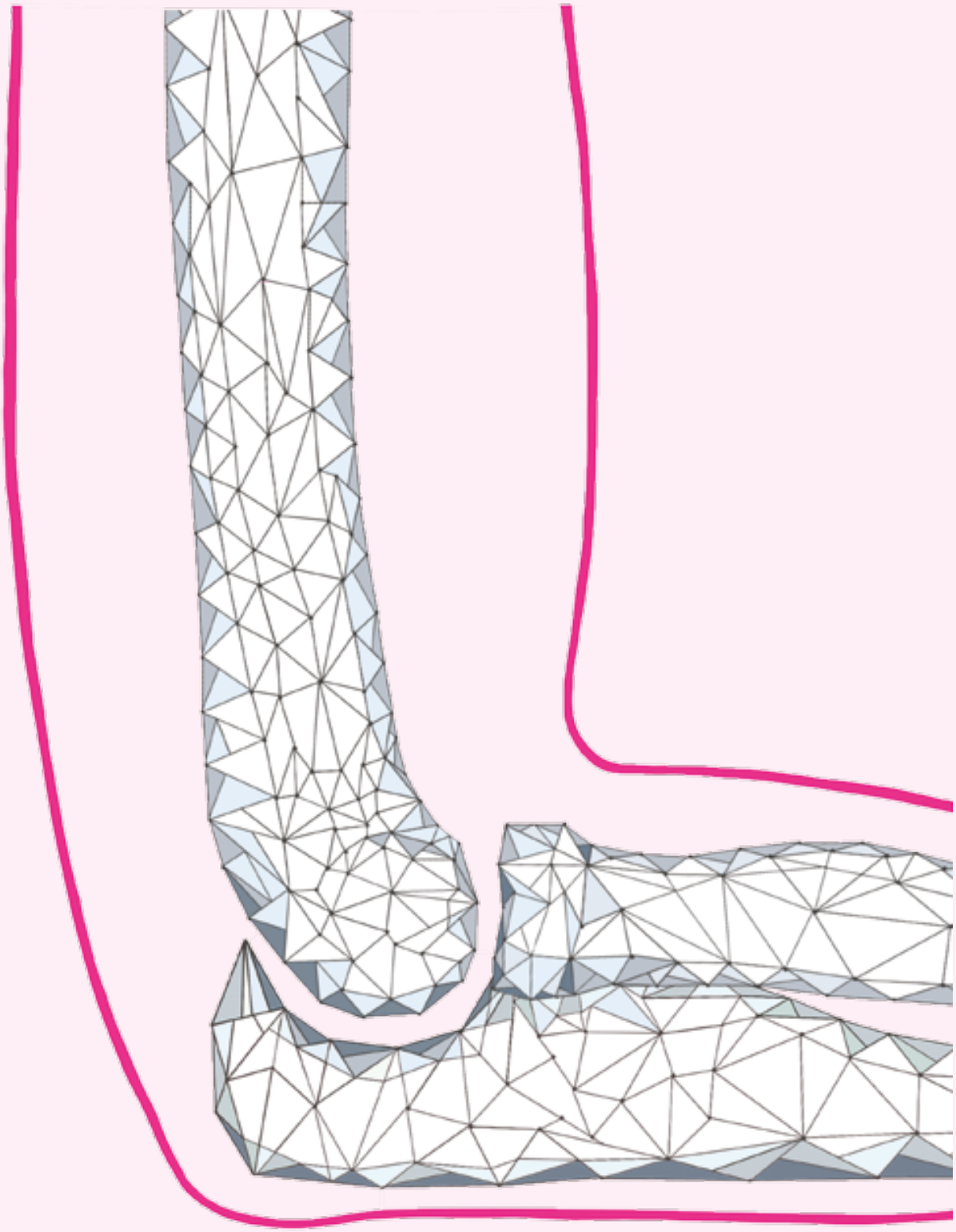
Revision surgery of TEA remains a challenging procedure. Therefore, we performed a retrospective study of 19 patients who underwent revision surgery of their TEA with use of a Coonrad-Morrey TEA, aiming to report on the radiographic and functional outcomes.

After a mean follow-up of 57 months, 1 second revision was needed, and 2 prostheses were removed. Although in 58% of the patients a complication occurred, 87% of the patients were satisfied with the outcomes after the revision procedure. The ROM, stability, pain scores and outcomes of PROMs improved. Consequently, revision surgery of TEA should be considered as a salvage procedure, informing patients on a relatively high complication rate.

Chapter 8 – Outcomes after revision surgery of total elbow prosthesis – a systematic review

Several studies – which all included relatively low numbers of patients – reported on the clinical outcomes after revision surgery of TEA. Therefore, we aimed to systematically compare and combine all these results (n = 532) in order to provide an overview of the outcome of revision TEA surgery.

The mean time between primary and revision surgery of TEA was 77 months. In most cases a linked prosthesis design (69%) was used compared to an unlinked prosthesis design (31%). At a mean follow-up of 65 months after revision, 232 patients (44%) reported a complication for which 22% of these patients required additional surgery. Overall, ROM, pain scores and outcomes of PROMs improved. A sub-analysis comparing linked and unlinked designs demonstrated that all outcomes in the patients with the linked prostheses were better. In conclusion, revision surgery of a TEA should be considered as a salvage procedure, with expected improved functional outcomes, despite a relatively high chance of complications.



Appendices &

Nederlandse samenvatting
Portfolio
List of publications
Abbreviations
Dankwoord
Curriculum vitae

Nederlandse samenvatting

De elleboog is een essentieel gewricht voor de positionering van de hand in de ruimte en is daarom belangrijk voor het uitvoeren van basale taken in het dagelijkse leven. Om deze reden is het van belang om de functie van de elleboog te herstellen na complexe elleboogfracturen of in het geval van posttraumatische deformiteiten. In bepaalde fracturen, waar het doel van chirurgische fixatie met platen en/of schroeven niet haalbaar is – een functionele elleboog – kan een partiele of totale elleboogprothese geïndiceerd zijn. Over het algemeen zijn de klinische uitkomsten na plaatsing van primaire elleboogprothesen bevredigend, maar het aantal complicaties en revisies is relatief hoog en kan mogelijk nog verbeterd worden.

Het algemene doel van dit proefschrift was daarom de uitkomsten na (gefaalde) elleboogprothesen te verbeteren, inclusief de behandeling van complexe elleboogfracturen met een prothese. In **Deel I** lag de focus op radiuskopprothesen (RKP's), met belangstelling voor de anatomie van de radiuskop, de indicaties, diagnostisering en management van revisiechirurgie van RKP's en de radiologische en klinische uitkomsten daarna. In **Deel II** stond de totale elleboogprothese (TEP) centraal; de anatomie van de proximale ulna werd gedetailleerd onderzocht, wereldwijde trends in primaire en revisiechirurgie van TEP's geanalyseerd en de radiologische en klinische uitkomsten na revisiechirurgie beschreven.

Deel I – Radiuskopprothesen

Hoofdstuk 1 – Regionale verschillen in de driedimensionale bot microstructuur van de radiuskop: implicaties voor waargenomen fractuurpatronen

In dit hoofdstuk hebben we micro-computed tomography (micro-CT) beeldvorming gebruikt om de trabeculaire microstructuur van het bot van 6 humane kadaver radii te kwantificeren. Een betere karakterisering van de trabeculaire microstructuur van de radiuskop kan zorgen voor een beter begrip van de meest voorkomende radiuskopfracturen.

In vergelijking met de mediale zijde, bevat de laterale zijde van de radiuskop minder bot (lagere botdichtheid en minder trabeculae) met een grotere ruimte tussen de trabeculae. De combinatie van deze resultaten en de aard van het meest gangbare traumamechanisme zou een verklaring kunnen zijn voor fractuurpatronen van de radiuskop, welke voornamelijk in het anterolaterale kwadrant voorkomen.

Hoofdstuk 2 – Waarom falen radiuskopprothesen hedendaags? Een systematische review van de recente literatuur

Tegenwoordig worden er veel verschillende typen RKP's gebruikt. Deze verschillen in materiaal, fixatie, polariteit en modulariteit. Het doel van dit hoofdstuk was het systematisch beschrijven van de meest voorkomende oorzaken voor het falen van verschillende typen

primaire RKP's (n = 152) zoals beschreven in de literatuur. Daarnaast onderzochten we of bepaalde typen prothesen beter zijn in vergelijking met anderen.

De gemiddelde tijd tot falen van de 152 prothesen was 34 maanden. De meest voorkomende redenen voor revisiechirurgie van RKP's waren: symptomatische aseptische loslating van de steel van de prothese (30%), stijfheid (20%) en aanhoudende pijnklachten (17%). Omdat er zoveel verschillende soorten RKP's in gebruik zijn en het aantal gefaalde RKP's relatief laag is, kan op dit moment geen specifiek type RKP aanbevolen worden.

Hoofdstuk 3 – Complicaties en revisiechirurgie na het plaatsen radiuskopprothesen: management en uitkomsten

In dit hoofdstuk wordt de diagnostiek en chirurgische opties bij een gefaalde RKP beschreven. Welk type secundaire chirurgie uitgevoerd moet worden (revisie naar een nieuwe RKP, radiocapitellaire prothese of TEP of verwijdering van de RKP), hangt met name af van de conditie van het kraakbeen en de stabiliteit van het gewricht. Daarnaast moet er ook rekening worden gehouden met de leeftijd en de mate van (lichamelijke) activiteit van de patiënt. Indien de elleboog stabiel is, kan er worden gekozen voor verwijdering van de prothese. Als het gewricht instabiel is, geniet revisie naar een nieuwe RKP de voorkeur. In het geval dat er naast instabiliteit ook erosie van het capitellum bestaat, moet revisie naar een radiocapitellaire prothese overwogen worden. Mocht de patiënt ouder zijn dan 70 jaar met tekenen van ulnohumerale artrose van het ellebooggewricht, dan kan een revisie naar een TEP geïndiceerd zijn.

Hoofdstuk 4 – Klinische en radiologische uitkomsten na revisiechirurgie van radiuskopprothesen

Omdat er nog weinig bekend is over de klinische uitkomsten na revisiechirurgie van RKP's, wordt in dit hoofdstuk retrospectief de uitkomsten van 16 patiënten beschreven, waarvan de RKP gereviseerd was naar een nieuwe RKP. Het doel van dit hoofdstuk was de functionele en radiologische uitkomsten te onderzoeken.

Na een gemiddelde follow-up van 75 maanden, was geen enkele RKP opnieuw gereviseerd en liet geen van de stelen radiologische tekenen van loslating zien. Na revisie bleven de bewegingsuitslagen van de elleboog hetzelfde en verbeterde de stabiliteit, pijnscores en uitkomsten van vragenlijsten met betrekking tot de elleboog. Daarom kunnen de uitkomsten na revisiechirurgie van RKP's als bevredigend worden beschouwd.

Deel II – Totale elleboogprothesen

Hoofdstuk 5 – De driedimensionale microstructuur van de proximale ulna

In dit hoofdstuk hebben we micro-CT beeldvorming gebruikt om de corticale en trabeculaire microstructuur van het bot van 5 humane kadaver proximale ulnae te beschrijven. Het doel was de invloed van krachten rondom het ellebooggewricht, die mogelijk tot fracturen

zouden kunnen leiden in de acute setting of tot het potentieel falen van de ulna component van een TEP, beter te begrijpen.

De “bare area”, welke onder het gewrichtsoppervlak met de humerus ligt, heeft de grootste botdichtheid in vergelijking met het olecranon (mediale- en laterale zijde) en het coronoid. Op dit punt lijken de drukkracht van de humerus en de trekkrachten, welke worden veroorzaakt door contractie van de triceps en brachialis, te overlappen. Daarnaast heeft het coronoid de dikste cortex, wat bevestigt dat deze structuur een belangrijke benige stabilisator is van het ellebooggewricht. De microstructuur van de proximale ulna lijkt zich dus aan te passen aan de dagelijkse krachten waaraan de elleboog wordt blootgesteld en kan ons helpen fractuur patronen beter te begrijpen.

Hoofdstuk 6 – Het gebruik en de uitkomsten van 1220 primaire totale elleboogprothesen van het Australische Orthopedische Nationale Gewrichtsprothese Register 2008-2018

Omdat studies op basis van data van nationale implantaten registers hoge aantallen omvatten, zijn dergelijke studies waardevol om de uitkomsten van TEP’s te verbeteren. Daarom was het doel van dit hoofdstuk om 1220 TEP’s uit het Australische implantaten register te onderzoeken om zo mogelijke trends in TEP-chirurgie te analyseren.

Het totale aantal TEP’s die per jaar geplaatst zijn was continu over de tijd. De primaire indicaties waren: fracturen/trauma (36%), artrose (34%) en reumatoïde artritis (RA, 26%). Het percentage gefaalde TEP’s was 10%, 15% en 19% na 3, 6 en 9 jaar, waarbij TEP’s, welke geplaatst waren voor artrose, vaker faalden in vergelijking tot TEP’s geplaatst voor een fractuur of RA. De meest voorkomende indicaties voor revisiechirurgie waren infectie (35%) en loslating van de prothese (34%).

Hoofdstuk 7 – Klinische en radiologische uitkomsten na revisiechirurgie van totale elleboogprothesen

Revisiechirurgie van TEP’s is nog steeds een moeilijke en uitdagende operatie. Daarom hebben we retrospectief 19 patiënten onderzocht waarvan de gefaalde TEP was gereviseerd naar een nieuwe TEP van het type Coonrad-Morrey. Het doel van dit hoofdstuk was het beschrijven van de functionele en radiologische uitkomsten na revisiechirurgie.

Na een gemiddelde follow-up van 57 maanden was er 1 TEP opnieuw gereviseerd en waren er 2 TEP’s verwijderd. Ondanks dat er bij 58% van de patiënten een complicatie optrad, was 87% van de patiënten tevreden met de uitkomst na revisie. De bewegingsuitslagen, stabiliteit, pijnscores en uitkomsten van vragenlijsten met betrekking tot de elleboog functie waren verbeterd. De uitkomsten na revisiechirurgie van gefaalde TEP’s zijn dus bevredigend, maar met een relatief hoge kans op complicaties.

Hoofdstuk 8 – Uitkomsten na revisiechirurgie van totale elleboogprothesen - een systematische review

Er zijn meerdere studies met relatief kleine aantallen beschikbaar die de uitkomsten na revisiechirurgie van TEP's beschrijven. Daarom hebben we in dit hoofdstuk al deze studieresultaten (totaal 532 patiënten) systematisch vergeleken, met als doel een beter inzicht te krijgen in de uitkomsten na revisiechirurgie van TEP's.

De gemiddelde tijd tussen de plaatsing van de primaire prothese en het falen daarvan, was 77 maanden. Tijdens de revisie werd er in het merendeel van de patiënten gekozen voor een gelinkte prothese (69%) in vergelijking met een ongelinkte prothese (31%). Na een gemiddelde follow-up van 65 maanden na de revisie, was er bij 232 van de patiënten (44%) een complicatie opgetreden. Hierdoor moest er bij 22% van deze patiënten operatief worden ingegrepen. Over het algemeen verbeterden de bewegingsuitslagen, pijnscores en uitkomsten van vragenlijsten met betrekking tot de elleboog. Een sub-analyse tussen gelinkte en ongelinkte prothesen liet betere resultaten zien in de groep met gelinkte prothesen. De functionele uitkomsten na revisiechirurgie van TEP's zijn acceptabel, maar de kans op een complicatie blijft hoog.

Portfolio

PhD Student: J. Viveen

PhD Period: 2016 – 2020

PhD Supervisors: Professor D. Eygendaal & Professor R.L. Jaarsma

PHD TRAINING	Year
Training	
Secondary School	2005 – 2011
M.D.	2011 – 2017
Research Fellowship at Department of Orthopedic and Trauma Surgery, Flinders Medical Centre, Adelaide (Australia)	2018 – 2019
Resident (ANIOS), General Surgery Department, OLVG West, Amsterdam	2019 – present
General courses	
GCP-WMO training	2016
Seminars, workshops and masterclasses	
Weekly research meetings Orthopedic & Trauma surgery Unit	2018 – 2019
(Inter)national conferences	
Ride for Research, Traumaplatform Foundation, Scotland	2016
Traumadagen NVT, the Netherlands	2016 & 2017
AAOS Annual Meeting, USA	2017
AOA Annual Scientific Meeting, Australia	2017 & 2018
SECEC-ESSSE Congress, Germany & Denmark	2017 & 2019
SEOHS-symposium, the Netherlands	2017 & 2019
Ski for Science, Traumaplatform Foundation, Switzerland	2018
ANZORS Annual Conference, Australia	2018
Oral presentations	
PhD Elevator Pitch "Posttraumatic Elbow Deformities" Ride for Research, Edinburgh, Scotland	2016
Clinical and radiographic outcome of revision surgery of radial head prosthesis. AAOS, Annual Meeting, San Diego, USA	2017
SECEC-ESSSE Congress, Berlin, Germany	2017
AOA Annual Scientific Meeting, Adelaide, Australia	2017
Effect of introducing an online system on the follow-up of elbow arthroplasty. AOA Annual Scientific Meeting, Adelaide, Australia	2017
Research Proposal Pitch: Presence of myofibroblasts in human elbow capsule after trauma. SEOHS Congres, Nijmegen, the Netherlands	2017
Accuracy of ulnar nerve localization during elbow arthroscopy AOA Annual Scientific Meeting, Perth, Australia	2018
Why does radial head arthroplasty fail today? AOA Annual Scientific Meeting, Perth, Australia	2018
Poster Presentations	
Clinical and radiographic outcome of revision surgery of total elbow prosthesis. SECEC-ESSSE Congress, Berlin, Germany	2017
Three-dimensional microarchitecture of the proximal ulna. ANZORS Annual Conference, Perth, Australia	2018
Regional differences in the three-dimensional bone microstructure of the radial head: Implications for observed fracture patterns SECEC-ESSSE Congress, Copenhagen, Denmark	2019

Portfolio (continued)

TEACHING	Year
Lecturing	
PhD talk: *Posttraumatic Elbow Deformities*	2017
OLVG West, Department of Orthopedic surgery	
ROA-dag 2017: *After Treatment of Stiff Elbow* Amsterdam Medical Centers, location AMC	2017
Supervising	
Student: Elze J. Geurts	2017
Organization	
Chair Ski for Science: Traumaplatform Foundation	2018
Member	
Dutch Orthopaedic Association (NOV)	2019
PARAMETERS OF ESTEEM	
Grants	
KNAW Van Walree Travel Grant	2016 & 2017
Professor. Michaël-van Vloten Foundation Grant	2017
Amphia Research Foundation: Research Grant	2017
Amphia Research Foundation Travel Grant	2017 & 2018
High Potential PhD Award Flinders University	2018
Flinders University PhD Scholarship	2018
Traumaplatform Foundation PhD Travel Grant	2018
Anna Fonds Travel Grant	2018
Jo Kolk Studiefonds	2018
Scholten-Cordes Fonds	2018
Marti-Keuning Eckhardt Stichting (Stichting MKE)	2018
Prins Bernhard Cultuurfonds	2018
Flinders University Student Association (FUSA)	2018
Amsterdam Movement Sciences	2018
Awards and Prizes	
SEOHS 2017: Prof. dr. P.J. Klopperprijs	2017
Traumaplatform Award: International Podium Presentation	2017
ANZORS: Annual Conference Travel Award	2018
FORCE Award	2019

List of publications

Viveen J, Perilli E, Jaarsma RL, Doornberg JN, Eygendaal D, Bain GI. Regional differences in the three-dimensional bone microstructure of the radial head: implications for observed fracture patterns. *J Orthop Trauma*. Submitted.

Viveen J, Perilli E, Zahrooni S, Jaarsma RL, Doornberg JN, Bain GI. Three-dimensional microstructure of the proximal ulna. *J Anatomy*. Submitted.

Hilgersom NFJ, Viveen J, Tuijthof GJM, Bleys RLAW, van den Bekerom MPJ, Eygendaal D. Accuracy of ulnar nerve localization during elbow arthroscopy. *Knee Surg Sports Traumatol Arthrosc*. Submitted.

Kodde IF, Viveen J, The B, van Riet R, Eygendaal D. Complications after Radial Head Arthroplasty: an algorithm for work-up and management. *EFORT Open Reviews*. Revision submitted.

Prkic A, Viveen J, The B, Goossens P, Koenraadt KLM, Eygendaal D. Early mobilization and functional discharge affecting length of stay after total elbow arthroplasty. *Acta Chir Orthop Traumatol Cech*. Revision submitted.

Viveen J, Kodde IF, Heijink A, Koenraadt KLM, van den Bekerom MPJ, Eygendaal D. Why does radial head arthroplasty fail today? A systematic review of recent literature. *EFORT Open Reviews*. In press.

Viveen J, van den Bekerom MPJ, Doornberg JN, Hatton A, Page R, Koenraadt KLM, Wilson C, Bain GI, Jaarsma RL, Eygendaal D. Use and outcome of 1220 primary total elbow arthroplasties from the Australian Orthopaedic Association National Joint Arthroplasty Replacement Registry 2008 – 2018. *Acta Orthop.* 2019: 1-6.

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Viveen J, Somford MP, Koenraadt KLM, et al. The Use of Eponyms for Surgical Approaches and Fractures in Elbow Surgery: Accuracy and Reliability Pre- and Post-Training. *Arch Bone Jt Surg.* 2019; 7: 191-8.

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Viveen J, Doornberg JN, Kodde IF, et al. Continuous passive motion and physical therapy (CPM) versus physical therapy (PT) versus delayed physical therapy (DPT) after surgical release for elbow contractures; a study protocol for a prospective randomized controlled trial. *BMC Musculoskelet Disord*. 2017; 18: 484.

Viveen J, Kodde IF, Koenraadt KL, Beumer A, The B and Eygendaal D. Clinical and radiographic outcome of revision surgery of radial head prostheses: midterm results in 16 patients. *J Shoulder Elbow Surg*. 2017; 26: 394-402.

Viveen J, Prkic A, Koenraadt KL, Kodde IF, The B and Eygendaal D. Clinical and radiographic outcome of revision surgery of total elbow prosthesis: midterm results in 19 cases. *J Shoulder Elbow Surg*. 2017; 26: 716-22.

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Abbreviations

3D = Three-dimensional
AL = Annular ligament
AL = Anterolateral
AM = Anteromedial
AOANJRR = Australian Orthopedic Association National Joint Replacement Registry
CI = Confidence interval
CPR = Cumulative percent revision
CT = Computed tomography
DMARDs = Disease-modifying antirheumatic drugs
EQ-5D = EuroQol five dimensions
HR = Hazard ratio
IM = Interosseous membrane
LCL = Lateral collateral ligament
MCL = Medical collateral ligament
MEPS = Mayo elbow performance score
Micro-CT = Micro-computed tomography
MRI = Magnetic resonance imaging
OA = Osteoarthritis
OES = Oxford elbow score
ORIF = Open reduction-internal fixation
PL = Posterolateral
PM = Posteromedial
PROMs = Patient reported outcome measures
RA = Rheumatoid arthritis
RCT = Randomized controlled trial
RHA = Radial head arthroplasty
RHP = Radial head prosthesis
RHS = Radial head system
ROM = Range of motion
RSA = Roentgen stereophotogrammetric analysis
SD = Standard deviation
SMI = Structure model index
Tb.N = Trabecular number
Tb.Sp = Trabecular separation
Tb.Th = Trabecular thickness
TEA = Total elbow arthroplasty
TEP = Total elbow prosthesis
THA = Total hip arthroplasty
TKA = Total knee arthroplasty
VOI = Volume of interest

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Curriculum vitae

Jetske Viveen was born in Gorinchem, the Netherlands, on the 31th of March 1994. After graduating from the Gymnasium Camphusianum in Gorinchem, she was admitted to Medical School at the VU University, Amsterdam, in 2011. During her studies, she undertook a research internship at the Department of Orthopedic Surgery at the Amphia Hospital, Breda, under supervision of Prof. Dr. D. Eygendaal and guidance of Dr. J.N. Doornberg and Dr. I.F. Kodde. The foundations of her PhD were laid here, and she continued her research activities during her subsequent internships. She presented her first paper in 2017, in San Diego, USA, at the AAOS Annual Meeting. Other papers were presented at national and international conferences, including the SECEC-ESSSE 2017 Congress in Berlin, Germany, and the AOA Scientific Meetings in 2017 and 2018 in Adelaide and Perth, Australia. Besides her studies and research activities, Jetske served as chair during Traumaplatform Foundation's Ski for Science in 2018. After her graduation in December 2017, she became part of the "Cotutelle PhD Program"; an official collaboration between the University of Amsterdam, the Netherlands, and the Flinders University, Adelaide. She was rewarded multiple grants, enabling her to work as a Research Fellow at the Department of Orthopedic and Trauma Surgery at the Flinders Medical Centre and University. During this fellowship, she was supervised by Prof. Dr. R.L. Jaarsma and Dr. J.N. Doornberg. Upon the conclusion of this research fellowship, she started as a Resident not in training at the Department of General Surgery at the OLVG Hospital (location west), Amsterdam, under supervision of Dr. B.C. Vrouenraets.

Amsterdam Movement Sciences

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