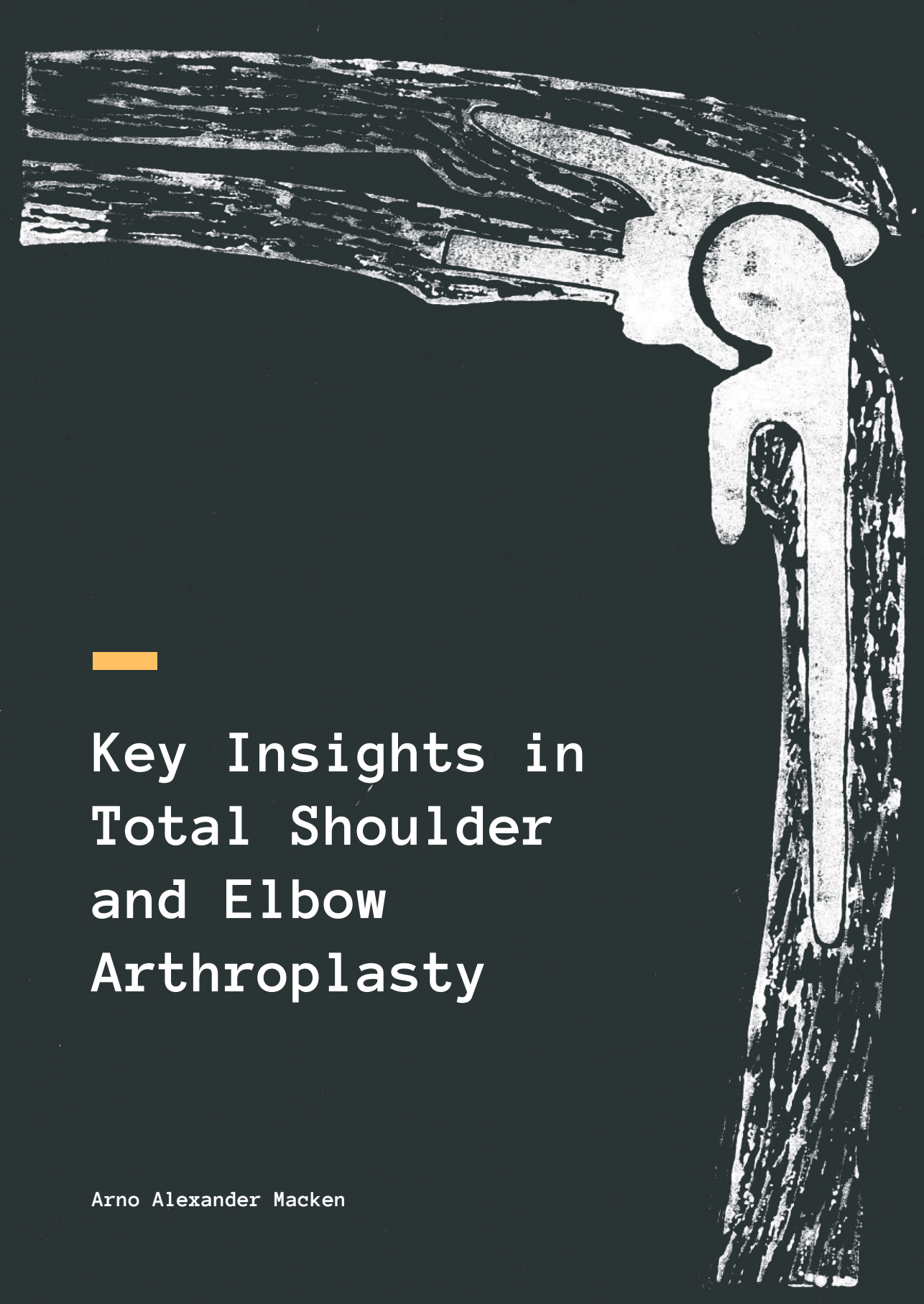

Key Insights in Total Shoulder and Elbow Arthroplasty

Arno Alexander Macken

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Key Insights in Total Shoulder and Elbow Arthroplasty

Essentiële inzichten in de totale schouder- en elleboogprothese

Proefschrift

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Table of contents

Chapter 1

Introduction

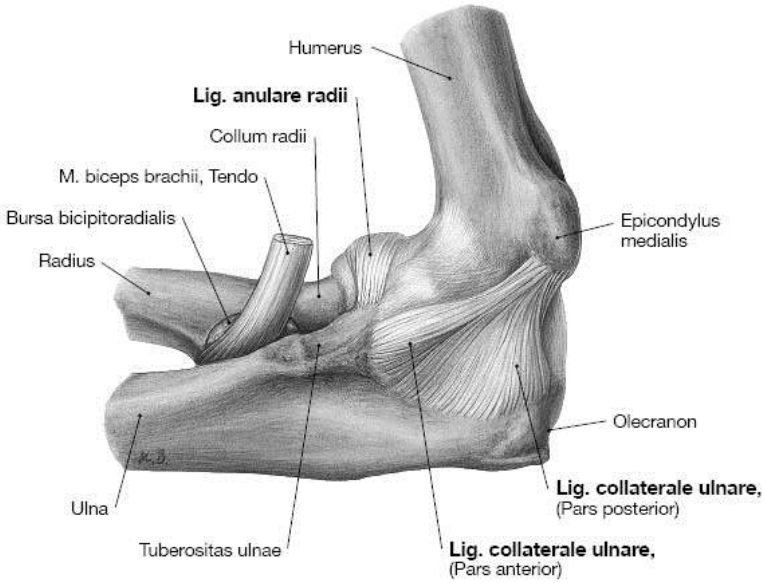
Arthroplasty, originating from the Greek words for joint (arthro-) and the process of reforming or reshaping (-plasty), is a surgical treatment in which a joint of the human body is partially or totally replaced with an implant. The aim of arthroplasty is to reduce pain or restore the function of the joint. The most common reason to perform arthroplasty is osteoarthritis, a degenerative condition that can affect any joint in the human body but most frequently occurs in the hand and the knee joints.[1] However, arthroplasty may also be used to treat a variety of other conditions in joints, including complex fractures, posttraumatic sequelae, metastases, and rheumatoid arthritis. These indications are relatively more common in arthroplasty of the upper extremity.[2,3] This thesis focuses on total joint arthroplasty at both ends of the humerus: the elbow and the shoulder.

Functional anatomy of the elbow and shoulder

The elbow joint consists of three bones: the distal humerus, the proximal radius, and the proximal ulna, together forming three joints; the ulnohumeral, radiohumeral, and proximal radioulnar joint, surrounded by a common joint capsule. Together, these joints facilitate flexion and extension of the elbow, as well as pronation and supination of the forearm. The shoulder joint consists of the humeral head articulating with the glenoid portion of the scapula. The glenohumeral joint, assisted by the scapulothoracic movement, the acromioclavicular joint, and the sternoclavicular joint, provides elevation, abduction, retropulsion, and rotation of the humerus. The combined purpose of both joints is to position the hand in space. Through this joint complex, a remarkably wide range of motion is made possible. This enables humans to perform specific movements that are exceptional for mammals, such as overhead throwing. However, a well-functioning complex of ligaments and muscles is of paramount importance to maintain joint stability throughout the range of motion.

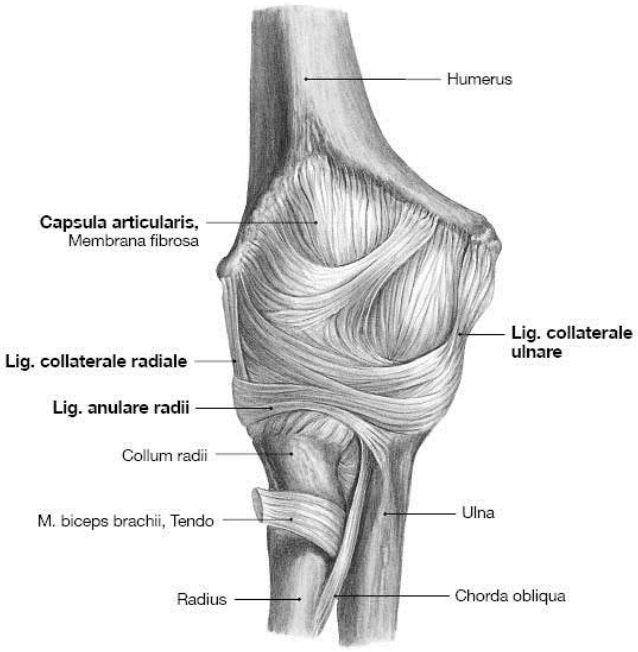
The stability of the elbow joint is often described using the three-column concept, consisting of a lateral column (radial head and capitellum), a middle column (anterolateral facet of the coronoid process and lateral part of the trochlea), and a medial column (anteromedial facet of the coronoid process and medial part of the trochlea).[4,5] These are supported by the lateral collateral ligament and ulnar collateral ligament. (Figures 1 and 2) Furthermore, active support is provided by the common flexor and extensor groups, which reinforce valgus and varus stability.[4,5] Laterally, the stability of the elbow is more dependent on soft-tissue structures, as is demonstrated by the lower degree of bony coverage between the radius and the capitellum.[5] The osseous structures are relatively congruent in the elbow, providing part of the stability of the joint.

Figure 1: ligaments of the elbow (medial)



Anatomical drawing of the elbow viewed from the medial side showing the ligaments around the joint. (Rights and permission: 3.36 a elbow: U. Brugger aus Paulsen/Waschke. Sobotta Atlas der Anatomie. 25. A. 2022 © Elsevier GmbH)

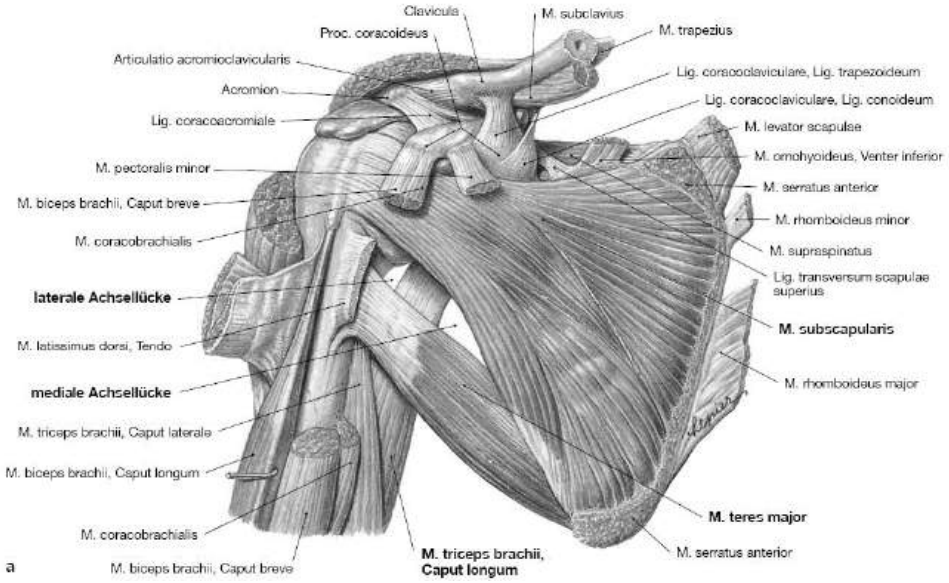
Figure 2: ligaments of the elbow (anterior)



Anatomical drawing of the elbow viewed from the anterior side showing the ligaments around the joint. (Rights and permission: 3.36 b elbow: U. Brugger aus Paulsen/Waschke. Sobotta Atlas der Anatomie. 25. A. 2022 © Elsevier GmbH)

In contrast, the shoulder joint is inherently more unstable due to the small size and shallow concavity of the glenoid in comparison to the humeral head. Consequently, stability must be actively maintained by the surrounding muscles during motion. The supraspinatus, infraspinatus, teres minor, and subscapularis muscles together form the rotator cuff, which acts as an active stabiliser of the glenohumeral joint, supported by ligaments, joint capsule, and the labrum. (Figure 3) When moving the humerus, the rotator cuff muscles act as a counterweight to keep the glenohumeral joint centred, which must be coordinated with the movement of the scapula.

Figure 3: the rotator cuff



Anatomical drawing of the shoulder viewed from the anterior side showing the rotator cuff and surrounding muscles. (Rights and permission: 3.66a Shoulder : Sobotta-Archiv aus Paulsen/Waschke. Sobotta Atlas der Anatomie. 25. A. 2022 © Elsevier GmbH)

For activities in current daily life, such as manual work, household tasks, or personal hygiene, a pain-free and functional upper extremity is essential. For most activities, multiple of the aforementioned movements are combined, requiring sufficient range of motion and stability of both joints. For example, reaching the lower back for personal hygiene requires not only internal rotation in the shoulder, but also retropulsion, and abduction of the shoulder combined with elbow flexion and pronation of the forearm.

Pathologies and indications for upper extremity arthroplasty

Similar pathologies that may occur in the shoulder and elbow can lead to the necessity for joint replacement surgery. In both joints, arthroplasty is used for select cases of complex, comminuted fractures, specifically in the elderly population.[6–8] Apart from acute fractures, sequelae after trauma are also a prominent indication for arthroplasty in both joints, such as posttraumatic osteoarthritis and non- or malunion.[2,3] Furthermore, primary osteoarthritis is a common indication for arthroplasty in both joints, although more common in the shoulder.[2,3]

In the elbow, rheumatoid and other forms of inflammatory arthritis are relatively more common as an indication for arthroplasty.[2,3] Globally, indications for total elbow arthroplasty are broadening due to the continuous development of surgical techniques, implant designs and alternative treatment options. For example, the success of disease-modifying drugs for rheumatoid arthritis has led to a relative shift in indications.

For the shoulder specifically, rotator cuff pathology can lead to the need for arthroplasty. An untreated rotator cuff tear may lead to an imbalance in opposing force couples in the shoulder. As a result, the rotator cuff fails to keep the humeral head well centred on the glenoid surface. Over time, the disbalance in forces leads to eccentric wear of the joint surface, also known as cuff tear arthropathy. Furthermore, a massive, irreparable rotator cuff tear may be treated with reverse total shoulder arthroplasty. In this case, the adjusted joint biomechanics due to the reversed prosthesis design restores joint stability.[9,10] Similar to the elbow, the range of indications for reverse total shoulder arthroplasty is expanding. Although initially introduced for rotator cuff arthropathy and irreparable rotator cuff tears, the range of indications now includes many more conditions, including primary osteoarthritis, fractures, and posttraumatic sequelae.[3] Furthermore, the proportion of reverse total shoulder arthroplasties is increasing compared to hemi- and anatomic total shoulder arthroplasty.[3]

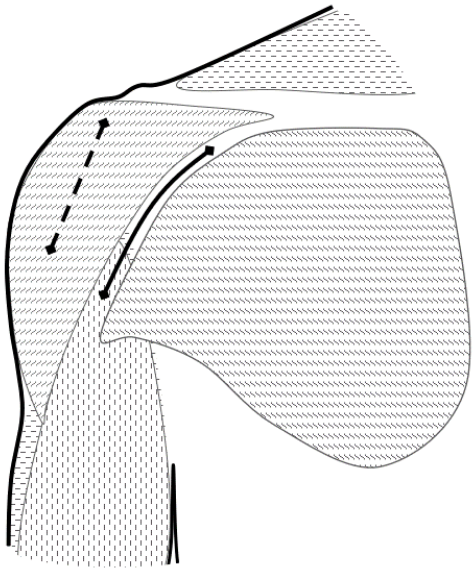
However, data on the current indications for upper extremity arthroplasty mainly relies on literature reviews, including individual single-centre studies, which are highly heterogeneous and prone to publication bias.[11–13] Some national arthroplasty registries publish annual reports,[14–19] but reliable and up-to-date national or international overviews are lacking, complicating the assessment of current practice and trends in indications for upper extremity arthroplasty.

Surgical approach

For total elbow arthroplasty, the current approaches in use are the posterior approach tenotomising the triceps, splitting the triceps, or sparing the triceps. Less common approaches are the lateral (paraolecranon) approach and the medial approach. At the moment, the posterior approach is used in the majority of cases in the Netherlands.[2]

Two main approaches are used for reverse total shoulder arthroplasty: the deltopectoral approach and the anterosuperior or deltoid-split approach. (Figure 4) The deltopectoral approach follows the deltopectoral groove and has the advantage of leaving the deltoid muscle intact but requires detachment of the subscapularis tendon to gain access to the joint. The anterosuperior approach provides a more direct view of the glenoid. It can be performed leaving the subscapularis tendon intact but requires splitting the deltoid along the direction of the muscle fibres. The current evidence comparing the two techniques is limited.[20–24] Despite each technique having specific advantages and disadvantages, there is no conclusive evidence supporting the superiority of one of the two techniques.

Figure 4: the deltopectoral and anterosuperior approach



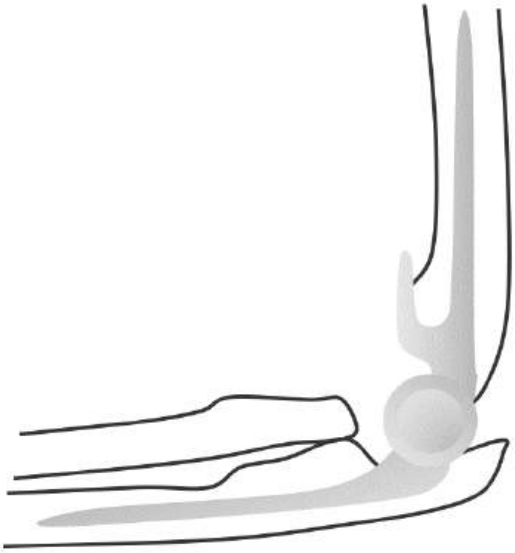
Schematic illustration of the shoulder viewed from the anterior side showing the shoulder musculature (grey fields) and the location of the deltopectoral (continuous line) and anterosuperior approach (dotted line), which are used for reverse total shoulder arthroplasty. (Rights and permission: own material. Copyright: A.A. Macken, 2025)

Implant design

The first results of a commercially available total elbow arthroplasty were published in 1972, using a non-anatomic, hinged implant design to treat rheumatoid arthritis.[25] In this design, the two elements of the prosthesis implanted in the humerus and ulna are connected with a solid hinge, allowing for flexion and extension without relying on the surrounding soft tissues for stability. (Figure 5) The design was constrained, meaning that the implant allows no freedom of varus-valgus, rotational, or translational movement. Although early results were encouraging, this design resulted in a high rate of aseptic loosening, which was attributed to increased stress and shear forces on the bone-implant interface due to the constrained nature of the design. To circumvent this issue, unlinked and unconstrained designs were introduced, resembling the original anatomy more closely. In unlinked designs, the two elements of the prosthesis are not connected by a hinge but have an articulating surface. Unconstrained designs allow more freedom of movement apart from flexion and extension. A downside of these designs is that the success of the arthroplasty heavily relies on the integrity of the collateral ligaments and soft-tissue balance.[26] Consequently, a semi-constrained design with a ‘sloppy hinge’

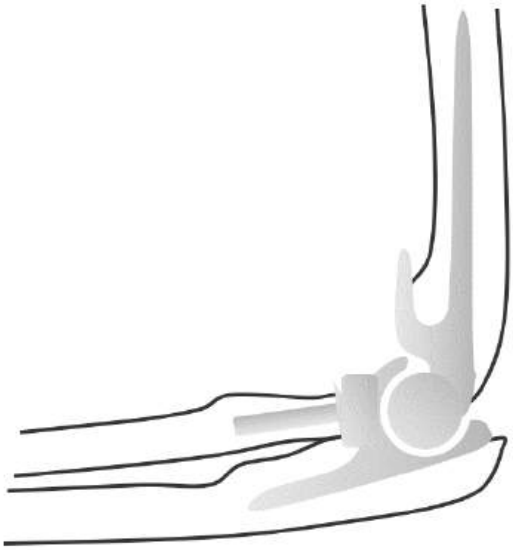
was introduced, allowing for a limited varus-valgus motion of about 6 to 15 degrees, depending on the implant design.[25,27] Recent trends include the introduction of a convertible design, which can be converted from an unlinked configuration to a linked prosthesis intra-operatively, a radial head component can be added, and sutures can be passed through the axis of the prosthesis to aid in restoring stability and repairing the collateral ligaments.[28] (Figure 6)

Figure 5: Total elbow arthroplasty, linked design



Schematic illustration of a total elbow arthroplasty (silver) viewed from the lateral side showing a linked implant design, in which the humeral and ulnar components are connected by a hinge. (Rights and permission: own material. Copyright: A.A. Macken, 2025)

Figure 6: Total elbow arthroplasty, anatomic design

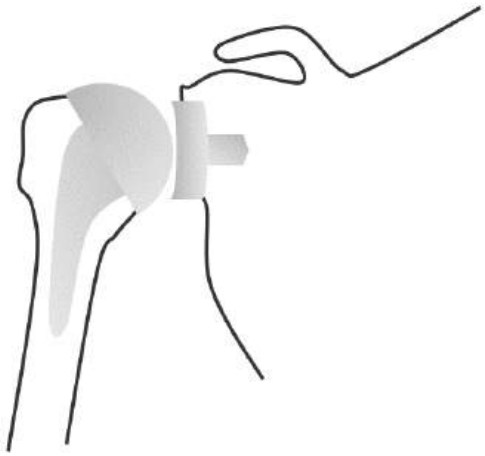


Schematic illustration of a total elbow arthroplasty (silver) viewed from the lateral side showing an anatomic implant design including a radial head component. (Rights and permission: own material. Copyright: A.A. Macken, 2025)

In shoulder arthroplasty, an opposite trend is observed, moving away from anatomic to more adapted designs. The initial designs of the total shoulder arthroplasty were anatomic, aiming to replace the joint surface without further altering the original biomechanics of the shoulder. (Figure 7) In 1985, the reverse shoulder arthroplasty design was introduced by Grammont.[10,29] In the reverse shoulder prosthesis, the concave glenoid is replaced by a convex half-sphere (the glenosphere) and the convex humeral head is replaced by a concave socket. (Figure 8) This results in a medialisation of the centre of rotation, moving from the centre of the humeral head to the centre of the glenosphere. Furthermore, the humerus is distalised. These alterations result in a larger lever arm and higher tension on the deltoid, facilitating elevation of the humerus. In addition, the compressive force on the joint is increased; during movement, the humerus is pulled towards the glenosphere, resulting in greater stability in the absence of a well-functioning rotator cuff.[30] However, some drawbacks of this design have been identified in recent years, including prosthetic instability, deficient internal and external rotation, aesthetic complaints due to loss of shoulder contour, scapular impingement leading to notching, deltoid failure, and scapular or acromial stress fractures.[31] All of these can be attributed entirely or partially to the medialisation and distalisation of the humerus. This has led to the current trends in prosthetic design tending to increase the offset of the prosthesis. The offset can be increased in several ways, such as prosthesis designs that are lateralised in the glenoid component, humeral component or both, which leads to

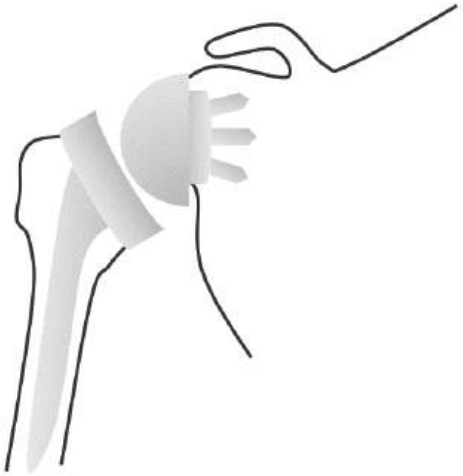
the reversed prosthesis being configured in an increasingly more anatomic position.[32] The offset can be inherent to the implant design (i.e., a smaller neck-shaft angle, onlay instead of inlay design, or using a larger glenosphere) or added as an augment to the component (i.e., an augmented baseplate).[32] The baseplate can be lateralised by a flat augment or by using a stepped or wedged augment to compensate for a defect in the glenoid morphology. Another technique to lateralise the baseplate is using a bone-graft to increase the offset of the glenoid component (BIO-RSA), first described by Boileau et al.[33] (Figure 9) Similarly, a wedged bone graft can be used to compensate for a defect or to correct glenoid angulation. A recent randomized controlled trial showed no substantial difference in clinical outcomes between bony increased offset and metallic increased offset reverse total shoulder arthroplasty at a 2-year follow-up.[34] However, the literature on the different methods of increasing offset in reverse total shoulder arthroplasty (an altered implant design or sizing, a metal augmentation, or using a bonegraft) is limited, and there is no evidence supporting the superiority of one of the techniques.[35–38]

Figure 7: Anatomic total shoulder arthroplasty



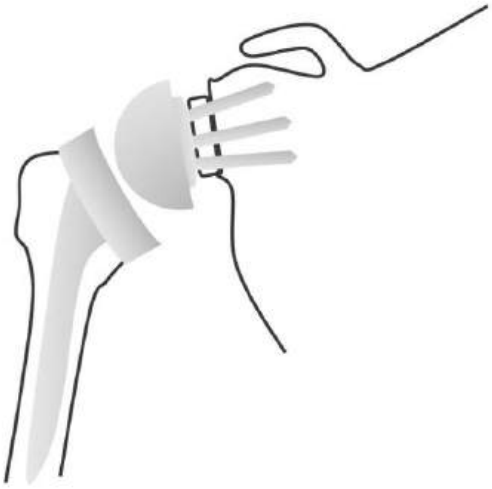
Schematic illustration of an anatomic total shoulder arthroplasty (silver) viewed from the anterior side. (Rights and permission: own material. Copyright: A.A. Macken, 2025)

Figure 8: Reverse total shoulder arthroplasty



Schematic illustration of a reverse total shoulder arthroplasty (silver) viewed from the anterior side. (Rights and permission: own material. Copyright: A.A. Macken, 2025)

Figure 9: Bony increased offset reverse shoulder arthroplasty (BIO-RSA)



Schematic illustration of a reverse total shoulder arthroplasty (silver) viewed from the anterior side, which is lateralised by using a bonegraft (rectangle with black lines) behind the glenoid baseplate. (Rights and permission: own material. Copyright: A.A. Macken, 2025)

Volume

Reverse total shoulder arthroplasty is relatively rare compared to total hip or knee arthroplasty, and total elbow arthroplasty is even more uncommon.[39]. Despite lower overall volumes, shoulder and elbow arthroplasty is still performed at many different centres. Previous studies have linked centre- and surgeon-volume to postoperative outcomes after shoulder and elbow arthroplasty.[40,41] However, previous literature on the relation between volume and outcomes is contradictory, and an accurate overview of the current distribution of total shoulder and elbow arthroplasty is lacking.

Follow-up

Patient-reported outcomes are of paramount importance in assessing the results after upper extremity arthroplasty and comparing different techniques. However, there is a wide variety of current methods of collecting outcomes. Many different patient-reported outcome measure questionnaires are used, leading to questionnaire fatigue and poor comparability between studies. The acquisition of patient-reported outcomes is further complicated by potential low literacy in a portion of the population, time burden, questionnaire fatigue, and data collection issues. This highlights the need for simplification of the follow-up after total shoulder and elbow arthroplasty. A simplification of the follow-up metrics is already widely adopted for shoulder arthroplasty, using a Single Assessment Numeric Evaluation: the Subjective Shoulder Value. This assessment is commonly used for monitoring patients after shoulder arthroplasty and for research purposes.[42] However, few previous studies have investigated a similar assessment for the elbow, such as the Subjective Elbow Value (SEV),[43–50] and no previous studies have addressed elbow arthroplasty specifically.

Long-term results

The long-term implant survival and functional results are important when deciding between arthroplasty and alternative (surgical) options. Common reasons for revision for both shoulder and elbow arthroplasty are an infection, aseptic loosening, and instability.[2,3] Furthermore, in total elbow arthroplasty, polyethylene wear over time is a concern but not always recognised as such. Polyethylene wear may lead to instability or loosening due to the release of debris particles that induce bone resorption and may initiate an inflammatory cascade leading to osteolysis. This process, in turn, may result in aseptic loosening of the implant.[51] In addition, due to the thin subdermal layer surrounding the elbow and limited muscular coverage, soft-tissue complications may occur after total elbow arthroplasty.[52] This is less of a concern in the shoulder, where the implant is covered by a thicker muscular layer. For both total elbow and reverse total shoulder arthroplasty, concerns are raised about the longevity of the implant.[53] For total elbow arthroplasty, the current data on mid-term results is limited to relatively small cohort studies, and long-term results are lacking.[27,55–62] For reverse total shoulder arthroplasty, studies reporting mid-term follow-up are promising. However, the literature on long-term (>10 years) follow-up is sparse.[9,54] For an informed decision when

considering total elbow or reverse total shoulder arthroplasty, more accurate mid- to long-term data is required.

Aims and outline of the thesis

To address the aforementioned gaps in the current knowledge regarding upper extremity total joint arthroplasty, this thesis aims to assess and optimise the outcomes of total elbow and reverse total shoulder arthroplasty. To reach this goal, the chapters in this thesis aim to assess current practice, optimise the follow-up and the results after total shoulder and elbow arthroplasty, and report long-term outcomes. The thesis is subdivided into two parts; **part 1** (chapters 2-4) focuses on total elbow arthroplasty and **part 2** (chapters 5-7) discusses reverse total shoulder arthroplasty.

In order to assess and optimise the outcomes of total shoulder and elbow arthroplasty, current practice in indications and used techniques must first be addressed. **Chapter 2** aims to report the current trends in indications for total elbow arthroplasty worldwide. The aims of **chapter 4** and **chapter 5** include assessment of the current indications and techniques used in the Netherlands for elbow and shoulder arthroplasty.

Second, to optimise the assessment of outcomes after upper extremity arthroplasty, a novel proposal to simplify the follow-up after total elbow arthroplasty, a Single Assessment Numeric Evaluation for the elbow, is analysed in **chapter 3**.

Third, outcomes are compared for several techniques and practices in total shoulder and elbow arthroplasty, aiming to optimise the results. Three of the most prominent topics of debate are selected: the concentration of care in high-volume centres, the surgical approach, and the method of increasing the offset in reverse total shoulder arthroplasty. In **chapter 4**, the association between centre-volume and implant survival is assessed to gain insight into the effect of the distribution of expertise on the outcomes after total elbow arthroplasty. In **chapter 5,** the results of two main surgical approaches that are used for reverse total shoulder arthroplasty are compared, the anterosuperior and deltopectoral approach, in order to assess the effect of the choice of surgical approach on the results after reverse shoulder arthroplasty. In **chapter 6,** two methods to increase the offset in the reverse total shoulder arthroplasty are compared, using a bonegraft and using a larger glenosphere, to investigate if the choice between these techniques influences the outcomes after reverse shoulder arthroplasty.

Last, mid- to long-term results are assessed and reported after total elbow arthroplasty (**chapter 4**) and reverse total shoulder arthroplasty (**chapter 7**), to provide insight into the longevity of upper extremity arthroplasty.

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Part I

Elbow

Chapter 2

Global Trends in Indications for Total Elbow Arthroplasty: a systematic review of national registries.

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Part I

Abstract

National registries provide useful information in understanding outcomes of surgeries that have late sequelae, especially for rare operations such as total elbow arthroplasty (TEA).

A systematic search was performed, and data were compiled from the registries to compare total elbow arthroplasty outcomes and evaluate trends. We included six registries from Australia, the Netherlands, New Zealand, Norway, the United Kingdom and Sweden.

Inflammatory arthritis was the most common indication for total elbow arthroplasty, followed by acute fracture and osteoarthritis. When comparing 2000–2009 to 2010–2017 data, total elbow arthroplasty for inflammatory arthritis decreased and total elbow arthroplasty for fracture and osteoarthritis increased. There was an increase in the number of revision TEAs over this time period.

The range of indications for total elbow arthroplasty is broadening; total elbow arthroplasty for acute trauma and osteoarthritis is becoming increasingly more common. However, inflammatory arthritis remains the most common indication in recent years. This change is accompanied by an increase in the incidence of revision surgery.

Introduction

Despite technical improvements over the past 40 years, the long-term clinical results after total elbow arthroplasty (TEA) are not comparable to those of hip and knee arthroplasty.[1,2] The number of TEAs placed annually is less than that of total hip or total knee arthroplasties (THA, TKA); in the United Kingdom the incidence of TEA was 612 in 2017 compared to 91,698 for THA and 102,177 for TKA.[3]

In arthroplasty, it is difficult to identify meaningful trends without large cohorts of patients. This is especially true for TEA as the incidence is low. TEA is included in few national registries and has been added more recently compared to THA and TKA. Moreover, disparities exist between cohort studies. For example, two large studies at tertiary academic medical centres in the USA reported implant survival rates ranging between 60% and 95%.[4,5] National arthroplasty registries are therefore a valuable data source when patient demographics, the number of arthroplasties, indications for arthroplasty and several outcome measures are recorded.

Many articles have been published on the indications and outcomes of TEA, but large reviews, meta-analyses, as well as systematic pooling of data of national registries are sparse.[1,6,7] Therefore, we sought to perform a systematic review of the data from available national registries and compare the indications for TEA and revision surgery rates between 2000 and 2017. We tested the null hypothesis that there is no difference in indications for primary TEA and number of TEAs that underwent revision surgery between 2000–2009 and 2010–2017.

Methods

Literature search

A systematic search was performed using internet search engines (Google, Alphabet Inc., Mountain view, California, USA) and PubMed (US national library of medicine, Rockville Pike, Bethesda, Maryland, USA) for all national joint replacement registries that included elbow arthroplasty. The MeSH terms that were searched included *elbow*, *elbow joint*, *joint prosthesis*, *arthroplasty*, *replacement* and *registries*, and additional terms were *elbow replacement*, *elbow arthroplasty*, *elbow prosthesis*, *national* and *national registry*. The reference lists of the included articles were manually checked to avoid missing relevant registries.

Inclusion and exclusion criteria

All national registries that reported original data on TEAs were included. Independent databases studies, local registries or registries that included elbow surgery later than 2017, were excluded.

Data extraction

From the included databases, data were extracted from the annual or periodical reports. From the websites of national orthopaedic associations and their annual reports meta-data on the registries was gathered. The indications were divided into five categories: *acute fracture*, *primary osteoarthritis*, *inflammatory arthritis*, *post-traumatic sequelae* and *other*. The category *acute fracture* was defined as all categories specifying acute trauma or acute fracture without other cause. *Primary osteoarthritis* was defined as degenerative disease without other cause. *Inflammatory arthritis* was defined as all primary inflammatory causes and almost completely consisted of rheumatoid arthritis. In the category *post-traumatic sequelae*, we included all secondary-trauma-related reports, including secondary osteoarthritis, late trauma complications and trauma sequalae. All other indications were included in the category *other*. Neoplasms and necrosis were added to *other* as occurrences were rare. Data were grouped into the time periods 2000–2009 and 2010–2017 for comparison of indications for TEA and revision surgery rates.

Twelve national joint replacement registries were identified, registries from Canada, Denmark and Iran did not include elbow arthroplasties and The American Joint Replacement Registry (USA) only included elbow arthroplasty starting in 2018. Scotland did not report any specifics on TEA and Finland did not publish reports. We included registries from Australia (AUS), the Netherlands (NL), New Zealand (NZ), Norway (NOR), the United Kingdom (UK) and Sweden (SE) and included patients from 1994–2017 (Table 1).

Table 1: included registries

	Year	Organization	Obligatory	Source	Patient consent	Validation	Completeness	Ref	Outcome
United Kingdom http://www.njrreports.org.uk	2012-2017	NJR	No	Annual report	Yes	Yes	95%	[8]	Revision, Mortality
Australia https://aoanjrr.sahmri.com	2004-2017	AOANJRR	No	Annual report	No	Yes	94%	[9]	Revision
Norway http://nrlweb.ihelse.net	1994-2017	NRL	No	Annual report	Yes	Yes	97%	[10]	Revision
New Zealand https://nzoa.org.nz	1999-2017	NZOA	Yes	Annual report	Yes	Yes	Not reported	[11]	Revision, Oxford Elbow Score
Netherlands www.lroi-rapportage.nl	2014-2017	LROI	No	Annual report	Yes	Yes	91%	[12]	Revision
Sweden http://www.ssas.se	1999-2017	SSAS	No	Annual report	No	Yes	> 90%	[13]	Revision, QuickDash

NJR, National Joint Registry; AOANJRR, Australian Orthopaedic Association National Joint Replacement Registry; NRL, Nasjonalt Register for Leddproteser; NZOA, New Zealand Orthopedic Association; LROI, Landelijke Registratie Orthopedische Implantaten; SSAS, Svenska Skulder- och Armbågssällskapet.

Risk of bias was assessed for each registry. All were large databases without comparison or analysis and the reported data were validated with hospital records to assess completeness. Data on completeness rate was collected from the latest reports and was higher than 90% in all registries that disclosed completeness. Risk of bias was determined to be low.

In the Netherlands, TEA was included starting from 2014. The Australian Orthopaedic Association reported data from 2004 but lacked annual reports. The United Kingdom included data from England, Northern Ireland, Wales and the Isle of Man. Scotland's national registry included elbow surgery but did not report indications for TEA. The New Zealand registry did not differentiate between acute fracture and secondary-trauma-related diagnoses, the category *trauma* from this registry was added to *acute fracture*. All registries published periodical reports at least yearly.

New Zealand, Norway and Sweden included data from 2000, and these three registries were used to make a comparison between the time periods 2000–2009 and 2010–2017. Some data could not be compared, for example due to initial diagnoses being categorized differently or different collection of patient-related outcomes. None of the registries reported any outcome measures per indication for surgery, therefore we were unable to compare surgery outcomes between the categories. Only the registries from Sweden (QuickDash) and New Zealand (Oxford Elbow Score) included specific measures evaluating elbow outcomes.

Four registries (AUS, NL, NOR, UK; $n = 9037$) included both total elbow arthroplasties and other types of elbow arthroplasties (partial arthroplasties). Of all the elbow arthroplasties 50% (4511) were TEAs. In the UK, TEA made up the biggest portion of all elbow arthroplasties (78%), followed by Norway (76%) and the Netherlands (53%). In Australia, partial arthroplasties were more common than TEA (28%) ($p < 0.0001$). The Swedish and New Zealand registries only included TEAs. Overall, a total of 6544 total elbow arthroplasties from these six registries were included. Analysis was performed including all total elbow arthroplasties.

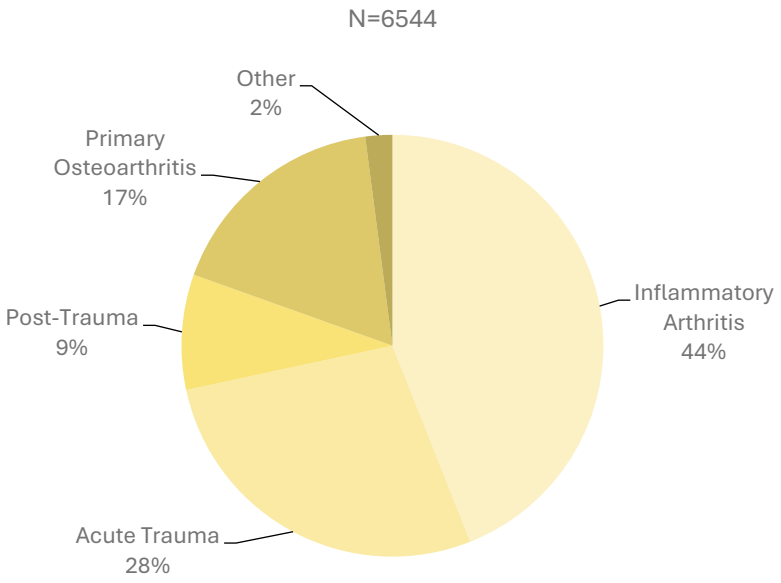
Statistical analysis

Fisher's exact test was used to compare indication rates between the time periods 2000–2009 and 2010–2017. Linear regression was used to assess changes in the incidence of revision surgery between 2000–2017. STATA software (StataCorp, College Station, Texas, USA) was used to perform data analysis. A p-value of < 0.05 was considered statistically significant.

Results

Inflammatory arthritis was the most common indication for TEA (44%) followed by acute fracture (28%), primary osteoarthritis (17%), post-traumatic sequelae (9%) and other (2%) (all registries, Figure 1).

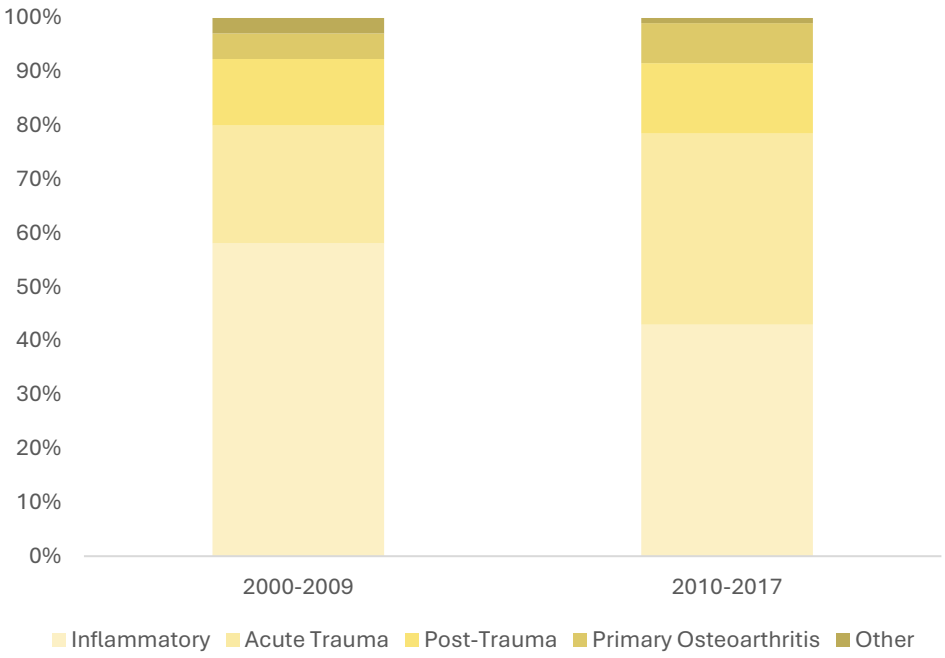
Figure 1: Global indications for total elbow arthroplasty



Pie-chart showing the accumulated proportions in percentage of the most common indications for total elbow arthroplasty worldwide.

When comparing the time periods 2000–2009 and 2010–2017 there was a smaller proportion of TEAs performed for *inflammatory arthritis* (61% vs. 46%, $p < 0.0001$) and a larger proportion of TEAs performed for *acute fracture* (23% vs. 38%, $p < 0.0001$) and *primary osteoarthritis* (5% vs. 8%, $p = 0.0004$) (Figure 2).

Figure 2: Indications for total elbow arthroplasty (Norway, New Zealand, Sweden)

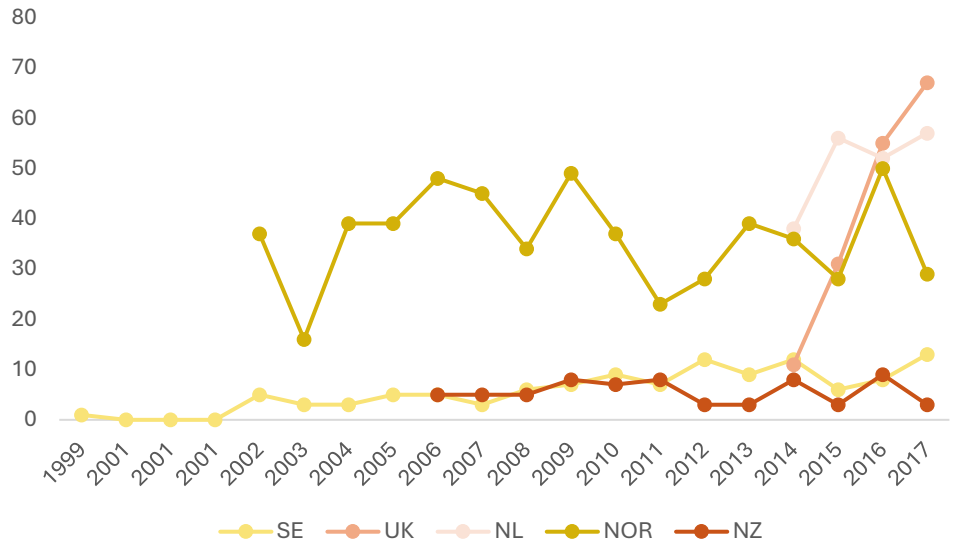


Bar-chart showing the accumulated proportions of the most common indications for total elbow arthroplasty in Norway, New Zealand, and Sweden for the periods 2000-2009 and 2010-2017.

When comparing geographical regions, the percentage of TEAs for *primary osteoarthritis* in Scandinavian countries (3%) was lower compared to other countries (27%) ($p < 0.0001$). Oceanic countries reported few *post-traumatic*-related indications for TEA (Australia: 1%) or did not report post-traumatic sequelae at all (NZ) compared to 12% in the other countries ($p < 0.0001$).

There was an increase in the number of revisions in all five registries that included elbow arthroplasty revision surgery individually ($p < 0.05$). When compiling data from all five of these countries for 2014–2017, an increase in the total amount of elbow revisions could also be identified from 105 in 2014, 124 in 2015, 174 in 2016 to 169 in 2017 ($p = 0.003$, Figure 3).

Figure 3: Revision elbow surgery



Graph showing the number of revision total elbow arthroplasties performed in each country per year.

Discussion

The purpose of this study was to assess the changes in indications for TEA over the last decades. We observed that the proportion of TEA cases performed for rheumatoid arthritis was smaller when comparing the time periods 2000–2009 and 2010–2017. This is possibly related to the increase in novel, successful non-surgical treatment options for rheumatoid arthritis, such as biologicals.[14,15] The rise in acute fracture as an indication for TEA could be explained because some surgeons have espoused TEA as an option for fractures of the distal humerus due to the possibility of performing the procedure while leaving the extensor mechanism intact, leading to faster and easier rehabilitation when compared with internal fixation.[16]

We identified several differences between countries. The data suggest that European countries use more TEA than partial arthroplasties, while Australia reports much lower numbers of TEA surgeries compared to partial arthroplasties. A factor that could influence this number is the fact that hemi-arthroplasty is currently not approved by some regulatory offices such as the Food and Drug Administration in the United States, narrowing the options for affected radio-capitellar articulation down to conservative treatment, radial head resection, or TEA.[17]

We also identified differences in indications for TEA between geographical regions; Scandinavian countries reported notably fewer TEAs for osteoarthritis and Oceanic countries fewer TEA for post-traumatic indications. These differences could be explained by location-dependent factors such as surgeon trends, healthcare and insurance systems, and infrastructure.

Additionally, we identified an increasing trend in the incidence of elbow revision surgery. Considering that the population is staying active for longer and patients are therefore less inclined to adapt their lifestyle to a prosthesis with limitations, it is likely that this increasing trend will continue. This would create a larger demand for surgeons specialized in elbow revision surgery. The revision rate of TEA could not be compared because for most countries incidences were reported separately per year.

Advantages of this study include the large pool of data that was used, gathered from several countries, which diminished the biases a specific country or region might bring – such as insurances, local preferences, high- or low-volume centres – and therefore made the overview more generalizable to elbow surgery worldwide. With this large pool of international data, we were able to create a clear and accurate overview.

This review had several limitations. The collection of data was limited by the available reports from national registries, for example the Australian registry did not separately report data from each year. Registries reported the indication for TEA in different categories which made it difficult to generalize the outcomes, it would be desirable to streamline these categories as a step towards international co-operation, which could provide more and more accurate data. Data collection may differ between registries; therefore, it is difficult to make a comparison between registries. Only the UK and New Zealand used obligatory reporting, for the other registries reporting was not mandatory, which may compromise completeness of the data. However, all registries were validated with hospital records and completeness was assessed. Of the registries that reported completeness, none was below 90%. The only registry that did not report on completeness was from New Zealand, but this registry did have obligatory reporting. New Zealand and Sweden did not include hemi-arthroplasties, which may affect the assessment of indications for all elbow arthroplasties. It could be possible that this is a factor influencing the low rate of TEA for primary osteoarthritis in Scandinavia. However, the percentage of TEA for osteoarthritis was similar in Norway and Sweden (6% and 1%). Many national registries did not include elbow surgery. Though fewer in number compared to hip or knee surgery, data on TEA are essential to improve the outcome for this type of surgery. None of the registries made a distinction of outcomes between indications for surgery. This information could point out for which indications TEA is effective and could therefore contribute to decision making when considering TEA. Many registries included patient reported outcome measures (PROMs) for hip, knee and shoulder surgery, but only two included such outcome measures for elbow surgery. PROMs can be an effective tool to assess the success of an operation and should therefore be included in national registries where possible. Ideally, a single PROM score would be used in all registries to facilitate comparison between registries and possible contribution to an international registry. The Oxford Elbow Score (OES) or

the Mayo Elbow Performance Index (MEPI) are popular PROMs, and the OES is used by the New Zealand registry for elbow outcomes.

Much information can be extracted from national registries. Nonetheless, there is improvement that could be made for comparison between registries. Several national registries are not publicly available, and increasing public accessibility of more registries would facilitate larger combined studies. The inclusion of elbow surgery in all national registries, complete and clear annual reporting, using the same categories for indications, reporting of outcome measures per indication and the inclusion of PROMs in registries could contribute greatly to the available knowledge and development of elbow surgery.

A valuable tool to optimize registry effectiveness and completeness could be the implementation of an electronic follow-up system such as the one used by Viveen et al.[18] These improvements could also be the first steps towards an international registry such as the Nordic Arthroplasty Registry Association (NARA). NARA started as a collaboration between registries from Norway, Sweden and Denmark in 2007, Finland joined the association in 2010. A code set was defined for all parameters that the registries had in common, which allowed for the merger of data and comparison between countries. However, because only parameters and data that the registries had in common could be included, the merged registry contained fewer parameters and details.[19] Since the foundation of NARA, several studies have been performed using the common database.[20–25] Future collaboration between registries could consist of the merger of data to create larger databases. To avoid the problem of decreasing parameters and details when adding more registries other options can be explored. When applying a universal coding system and universal access without compiling data, the integrity of national registries would be preserved while allowing studies to be performed on specific parameters, including only those registries that specify the parameters needed for a particular study. Another option would be to convince as many registries as possible to start adopting universal categories of parameters, thereby increasing the possibility of collaboration without decreasing the total number of parameters. However, questions could be raised about the feasibility of this option as some countries might have to make changes in their diagnostic and reporting systems.

Conclusion

We performed a systematic review of six national registries including a total of 6544 TEAs. We found that the range of indications for TEA is broadening, with TEA for acute trauma and osteoarthritis becoming increasingly more common. However, inflammatory arthritis remains the most common indication for TEA in recent years. When comparing geographical regions, we conclude that Scandinavian countries report fewer TEAs for osteoarthritis and Oceanic countries fewer for post-traumatic sequelae. We also observed an increase in the incidence of revision surgery.

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Chapter 3

Can a Single Question Replace Patient-reported Outcomes in the Follow-up of Elbow Arthroplasty? Validation of the Subjective Elbow Value.

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Part I

Abstract

Background

To assess the results after elbow arthroplasty it is essential to gather patient-reported outcome measures (PROMs). However, the acquisition of PROMs poses a challenge because of potential low literacy, lengthiness and diversity of questionnaires, and questionnaire fatigue. Instead of a questionnaire, patient-reported outcomes can be collected using a single assessment numeric evaluation (SANE), the subjective elbow value (SEV). The aim of this pilot study is to assess the correlation between the SEV and conventionally used Patient Reported Outcome Measures (PROMs) after elbow arthroplasty.

Methods

The SEV was added to our follow-up system in 2021, consisting of a scale from 0 to 10 in which the patients are asked to rate the overall functionality of their elbow, 0 corresponds to very poor functionality and 10 to a perfectly functional or healthy elbow. All patients who underwent elbow arthroplasty (total or radial head) and responded to the SEV question were retrospectively identified and included. The correlation between the SEV at the final follow-up and the Oxford Elbow Score (OES), and between the SEV and the Quick Disbailities of the Arm, Shoulder, and Hand (quickDASH) score was assessed using Pearson's r.

Results

In total, 82 patients responded to the SEV question and were included in the study, with a median follow-up of 5 years (interquartile range; IQR: 3-7). Of these patients, 17 (21%) underwent radial head arthroplasty and 65 (79%) total elbow arthroplasty. The Pearson's r for the correlation between SEV and OES was 0.502 ($p<0.001$) and between the SEV and the QuickDASH -0.537 ($p<0.001$), which correspond to a moderate correlation.

Conclusion

The SEV shows a moderate correlation with conventional PROMs, demonstrating its potential in simplifying the follow-up of elbow arthroplasty, possibly decreasing time, costs, and patients' questionnaire fatigue compared to conventional PROM questionnaires.

Introduction

To assess the results of an intervention it is essential to gather patient-reported outcome measures (PROMs). Interest in PROMs in orthopaedics has increased dramatically over the last few decades, as is demonstrated by a comparison of PubMed (MEDLINE) search terms for PROMs yielding 500 results in 2000 and 6188 results in 2020. However, the acquisition of PROMs poses a challenge because of potential low literacy, lengthiness and diversity of questionnaires, time burden, questionnaire fatigue, and data collection issues. Many different PROMs are used, complicating the comparison of results. There is currently no consensus on which outcomes should be gathered after elbow arthroplasty.

Instead of a questionnaire, patient-reported outcomes can be collected using a single question assessing the overall functionality of the joint, as is demonstrated by the Subjective Shoulder Value (SSV).[1] A single assessment numeric evaluation (SANE) such as the SSV is commonly used in shoulder research, with some authors arguing that it can be used as a stand-alone outcome instrument after shoulder procedures.[2] Previous studies report moderate to high correlation of the SSV with conventional shoulder PROMs (r = 0.50-0.88).[3] Furthermore, the test-retest reliability of the SSV has been shown to be similar to that of the American Shoulder and Elbow Surgeons (ASES) score (Interclass correlation; ICC = 0.84 versus ICC = 0.82), suggesting that the SSV is at least as reliable as more complex PROMs.[4] However, relatively very few studies report a SANE as a follow-up metric after elbow procedures or injuries, such as the Subjective Elbow Value (SEV).[5–12]

In previous literature, moderate to high correlations were found between the SANE for the elbow and conventional elbow PROMs administered during outpatient clinic visits for elbow-related problems, such as the Oxford Elbow Score (OES; r = 0.903) and the ASES-Elbow (r = 0.623), and the physician-administered Mayo Elbow Performance Index (MEPI; r = 0.671).[13–16] However, for more specific PROMs such as the Patient-rated Tennis Elbow Evaluation (PRTEE), a weaker correlation was found (r = 0.391), although statistically significant (p=0.017).[17] The elbow conditions in these studies are very heterogenous and mostly concern first-time clinical visits, they do not assess the SEV as outcome metric during follow-up for specific procedures. Furthermore, many studies reporting the SEV concern sports injuries.[9,11,12,18]

Three studies attempted to validate the SEV as an outcome metric after elbow injuries reporting high correlations with Disability of the Arm, Shoulder, and Hand (DASH; r = -0.85), MEPI (r = 0.80 and r = 0.710, respectively), and OES (r = 0.764 and r = 0.76).[5,18,19] However, the outcomes were concentrated towards the positive end of the scale in two out of the three studies (mean SEV: 90% and 87%), which increases homogeneity. For other procedures, such as arthroplasty, no previous studies assess the correlation of SEV with conventional PROMs as an outcome metric. However, simplification of the follow-up after arthroplasty is especially relevant. Besides decreasing patient burden and costs, it may also be used for arthroplasty registries to increase

simplicity and uniformity, thereby facilitating international comparison and collaboration between arthroplasty registries.

The aim of this pilot study is to establish whether a Single Assessment Numeric Evaluation (SANE), the Subjective Elbow Value (SEV), is correlated to conventionally used Patient Reported Outcome Measures (PROMs) after elbow arthroplasty, which could lead to a simplification and reduction of questionnaires during follow-up. Besides, it could serve as a simple, uniform question for (inter)national elbow arthroplasty registries, which is currently lacking.

Materials and Methods

The protocol for this study was reviewed and approved by the institutional review board. Patients that undergo an elbow prosthesis at our institution are routinely contacted by e-mail for follow-up 1, 3, 5, 7, and 10 years after surgery, and every 5 years afterwards. A Single Assessment Numeric Evaluation (SANE) question, the Subjective Elbow Value (SEV), was added to the follow-up system in 2021. This question consists of a scale from 0 to 10 in which the patients are asked to rate the overall functionality of their elbow, 0 corresponds to very poor functionality and 10 to a perfectly functional or healthy elbow. The SEV can also be expressed in percentages (0-100%). All patients that underwent primary total elbow arthroplasty (TEA) or radial head arthroplasty (RHA) in our centre's online follow-up system (onlinePROMS, 's-Hertogenbosch, the Netherlands), operated between January 2012 and June 2022, were retrospectively identified. Inclusion criteria were: patients that underwent primary total elbow or radial head arthroplasty for any indication, a minimum follow-up of 1 year, and at least one response to the SEV question in the follow-up system. Patients without a response to the SEV question in the follow-up system were excluded. Patient and treatment characteristics were extracted from the local registry and patients' charts.

Statistical analysis was performed according to a pre-defined plan. Descriptive statistics, including means or medians and standard deviations (SD) or interquartile ranges (IQR), were calculated for the demographic and surgical data. For the primary hypothesis of this study, the size and significance of the correlation between the SEV and the OES, and between the SEV and the quickDASH score was assessed. Only the most recent follow-up including the SEV question was used for the analysis, regardless of whether patients had undergone revision surgery. All other outcomes from the same follow-up period were used. The correlation between the SEV and the PROMs was visualised using scatterplots. In case of a linear correlation without significant outliers, Pearson's r was used to assess the strength of the correlation between the two variables. Pearson's test results in a p-value representing the statistical significance of the correlation and a correlation size ranging from -1 (strong negative correlation) to 0 (no correlation) to 1 (strong positive correlation). A value from 0.9-1.0 is considered a very high correlation, 0.7-0.9 high correlation, 0.5-0.7 moderate correlation, 0.3-0.5 low correlation, and 0-0.3 negligible correlation.

The same classification applies to negative numbers for negative correlations. In case of a non-linear correlation, transformations were attempted to arrive at a linear correlation. In case no transformation leads to a linear correlation, Spearman's ρ was used. In case of significant outliers Kendall's τ was used.

In addition, linear regression models were built with OES and quickDASH as the outcome and the SEV as the independent variable together with the two other single numeric questions (visual analogue scale; VAS for pain in rest and VAS for pain during activity). Next, independent variables without a significant correlation to the outcome were removed. The initial and final regression models were reported. For the final model, multicollinearity was assessed using variance inflation factors. A variance inflation factor below 2.5 was considered acceptable. Furthermore, normality of the residuals was tested using QQ plots.

A p-value of 0.05 was considered statistically significant. Statistical analysis was performed using R version 4.0.5 (R Foundation for Statistical Computing, Vienna, Austria).

Results

Cohort

After approval of the institutional review board, 296 patients were retrospectively identified in the online follow-up system. 214 patients did not respond to the follow-up request or did not reach one of the standardised follow-up time-points since the introduction of the SEV in 2021 and were excluded. In total, 82 patients responded to the SEV question and were included in the study, with a median follow-up of 5 years (IQR: 3-7). Of these patients, 17 (21%) underwent RHA and 65 (79%) TEA.

The mean age was 67 years (SD: 9) and the majority of patients were female (77%; Table 1). The most common indication for surgery was post-traumatic sequelae (43%), followed by an acute fracture (18%), and rheumatoid arthritis (18%; Table 2). Pre-operatively, patients reported a median VAS pain score of 8.4 (IQR: 7.1-9.3) during activity and 5.2 (IQR: 3.0-6.9) in rest. The mean pre-operative OES was 16 (SD: 8).

Table 1. Cohort characteristics (n=82)	
Total elbow arthroplasty, n (%)	65 (79)
Radial head arthroplasty, n (%)	17 (21)
Female, n (%)	66 (77)
Age, mean years (SD)	67 (9)
Smoking, n (%)	5 (6)
BMI, mean kg/m2 (SD)	27 (5)
ASA classification, n (%)	
I	7 (8)
II	53 (82)
III	15 (82)
IV	1 (1)
Previous surgery, n (%)	39 (48)
Arthroscopy	8 (10)
Arthrotomy	22 (27)
Osteosynthesis	18 (22)
Material removal	6 (7)

ASA: American Society of Anesthesiologists, BMI: body mass index, SD: standard deviation

Table 2. Treatment characteristics (n=82)	
Surgical indication, n (%)	
Post-traumatic	36 (43)
Acute fracture	15 (18)
Rheumatoid arthritis	15 (18)
Osteoarthritis	10 (12)
Revision to TEA	4 (5)
Other or unknown	3 (3)
Left side affected, n (%)	48 (59)
Surgical approach, n (%)	
Posterior, triceps-on	39 (48)
Posterior, triceps-flap	25 (30)
Lateral, LCL intact	10 (12)
Lateral, LCL detached	4 (5)
Other or unknown	5 (6)
Cemented, n (%)	74 (90)
Bone graft, n (%)	5 (6)
Follow-up, median years (IQR)	5 (3-7)

IQR: interquartile range, SD: standard deviation, TEA: total elbow arthroplasty

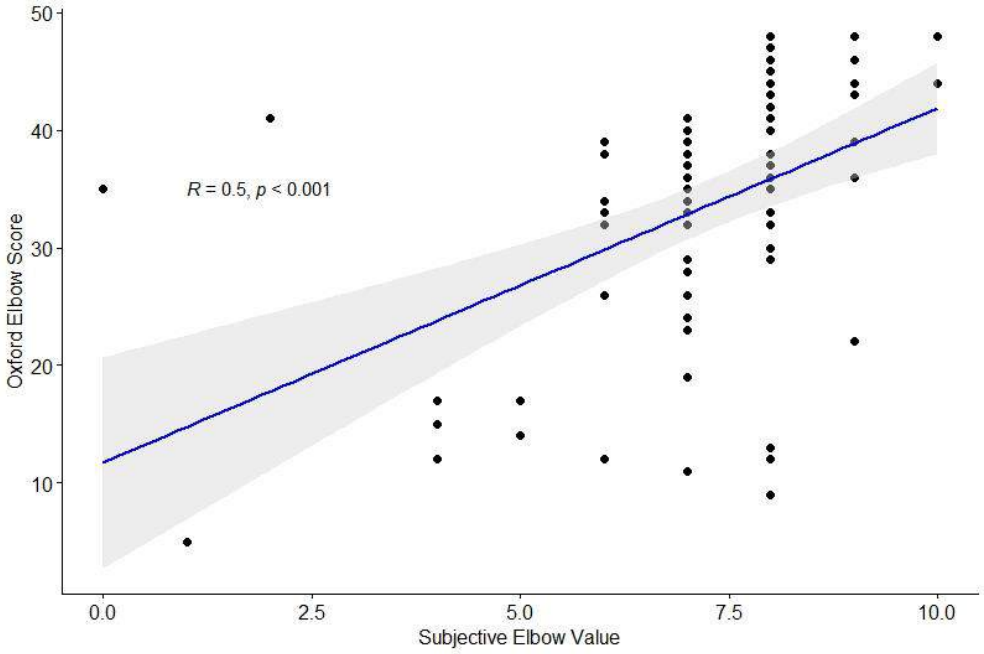
Two fellowship-trained, specialised elbow surgeons performed the procedures on all patients in the cohort. The left side was operated in 48 patients (59%) and the right side in 34 (41%), there were no cases of bilateral arthroplasty. For the TEAs, a Coonrad-Morrey total elbow prosthesis (ZimmerBiomet, Warsaw, Indiana, United States) was used in 80 cases (98%) and a Latitude (Wright Medical Group, Memphis, Tennessee, United States) in 2 cases (2%). For all RHA cases, a Tornier Radial Head System was used (Wright Medical Group).

In total, 18 patients (22%) underwent a secondary intervention to the ipsilateral elbow at a median of 8.5 months after the primary procedure (IQR: 2.3-29). There were 6 cases of infection (5 deep, 1 superficial), 4 cases in which the ulnar nerve was released, and 2 cases in which a contracture was released. Furthermore, there were single cases of proximal radio-ulnar osteoarthritis, aseptic loosening, bushing wear, link breakage, peri-prosthetic fracture, and wound necrosis. Two cases required a third intervention for a contracture and aseptic loosening of the ulnar component.

Primary outcomes

At the final follow-up, the median SEV in the cohort was 8 (IQR: 7-8). The median VAS for pain during rest was 0.8 (IQR: 0.2-2.4) and the median VAS for pain during activity was 1.7 (IQR: 0.5-4.8). The median OES was 36 (IQR: 29-41) and the median QuickDASH score was 25 (IQR: 18-52). Correlation of the SEV with the OES resulted in a Pearson's r of 0.502 ($p<0.001$), which corresponds to a statistically significant, moderate correlation (Figure 1).

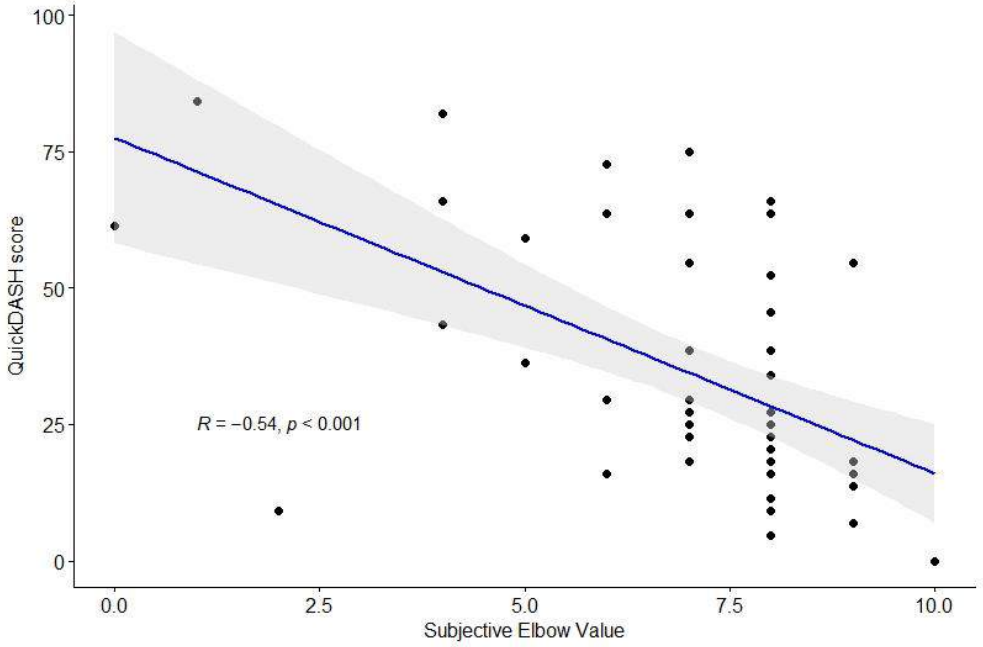
Figure 1: Correlation between the Subjective Elbow Value and the Oxford Elbow Score



Scatterplot showing the correlation between the Subjective Elbow Value and Oxford Elbow Score, showing a statistically significant correlation ($p < 0.001$) with a Pearson's r of 0.5 (moderate correlation).

Correlation of the SEV with the QuickDASH score resulted in a Pearson's r of -0.537 ($p<0.001$), which corresponds to a statistically significant, moderate correlation (Figure 2).

Figure 2: Correlation between the Subjective Elbow Value and the Quick Disabilities of the Arm, Shoulder, and Hand score.



Scatterplot showing the correlation between the Subjective Elbow Value and Quick Disabilities of the Arm, Shoulder, and Hand score, showing a statistically significant correlation ($p < 0.001$) with a Pearson's r of -0.54 (moderate correlation).

Regression analyses

In the regression analyses, the SEV and VAS for pain during activity were significantly associated with OES and QuickDASH, (Tables 3 and 4) while the VAS for pain in rest was not significant (p=0.636 and p=0.771, respectively). In the final models the adjusted R^2 was 0.5056 and 0.6302, meaning that the variables in the model explain 51 and 63 percent of the variance in the outcome. For both outcomes (OES and QuickDASH) the R^2 improved when the VAS for pain during activity was added (0.240 to 0.506 and 0.275 to 0.630, respectively).

Table 3. Linear regression for OES

	Coefficient	Error	t-value	p-value	VIF
Initial model					
SANE	3.013	0.600	5.030	<0.00001	
		Adjusted R^2: 0.2399			
Final model					
SANE	1.602	0.539	2.975	0.00396	1.223
VAS activity	-0.212	0.034	-6.345	<0.00001	1.223
		Adjusted R^2: 0.5056,			

SANE: Single Assessment Numeric Evaluation, VAS: Visual Analogue Scale, VIF: variance inflation factor

Table 4. Linear regression for QuickDASH

	Coefficient	Error	t-value	p-value	VIF
Initial model					
SANE	-6.146	1.302	-4.720	<0.00001	
		Adjusted R^2: 0.2754			
Final model					
SANE	-2.898	1.030	-2.813	0.00683	1.223
VAS activity	0.517	0.070	7.332	<0.00001	1.223
		Adjusted R^2: 0.6302			

SANE: Single Assessment Numeric Evaluation, VAS: Visual Analogue Scale, VIF: variance inflation factor

Discussion

This study aimed to assess the correlation between a SANE for the elbow, the SEV, and commonly used PROMs, the OES and QuickDASH score, for the follow-up of RHA and TEA. Moderate but statistically significant correlations were found for both PROMs (r = 0.50 and r = -0.54). Furthermore, the regression analyses showed that a VAS for pain during activity is of added value to the SEV.

Correlation with conventional PROMs

Despite the common use of a SANE, the SSV, in shoulder research,[2–4] relatively few studies have attempted to validate the SEV for elbow pathology. Some studies have correlated the SEV with other patient-reported metrics in patients during a first-time visit to the outpatient clinic. In previous studies the SANE for the elbow was proven to be highly correlated to the OES (r = 0.903), and moderately correlated to the ASES-E (r = 0.623) and the physician-administered MEPI (r = 0.671) during outpatient clinic visits for elbow-related problems.[13–16] However, for more specific metrics, the SEV showed a lower correlation. For example, in one study, a low correlation was found between the SEV and the PRTEE (r = 0.391) scale.[17] In all studies, the correlation was significant. The correlations found in the current study when using the SEV for follow-up (r = 0.50 and r = -0.54) is generally lower than those found in patients presenting with new elbow pathology.

Few studies have assessed the SEV as a follow-up metric after elbow procedures or injuries. In one study of 40 patients that underwent fixation of an olecranon fracture, the SEV was highly correlated with the DASH score (r = -0.85) and MEPI (r = 0.80).[5] In another study of 114 patients following an elbow dislocation, the SEV was also highly correlated with both MEPI (r = 0.710) and OES (r = 0.764).[18] One study of 75 patients with varying elbow pathology assessing the correlation between SEV and OES before injury, one week after injury, and 3-5 months after injury found an equally high correlation (r = 0.76).[19] These results are markedly higher than the correlations with OES and QuickDASH found in the current study (r = 0.50 and r = -0.54). Several factors may explain this discrepancy. First, the MEPI score is a partly physician-assessed and partly patient-reported, potentially leading to differences in the results. In the current study, only correlations with patient-reported outcomes were assessed. Furthermore, the SEV in both studies was high (median 90% and mean 87%, respectively). This suggest that outcomes were concentrated towards the positive part of the spectrum, thereby increasing heterogeneity and leading to a higher correlation. In the current study, the median SEV was 80%. The discrepancy may also be related to the nature of the procedure or condition, it is possible that follow-up of elbow arthroplasty requires a more multifactorial approach than less complicated procedures or less severe conditions.

Interestingly, in the current study, there were several outliers of patients which reported a high OES or low DASH in combination with a low SEV. It is possible that this is related to a misinterpretation of the SANE question, reversing the score. However, the question includes examples (0 = very poor functionality and 10 = a perfect elbow) and is not easily misinterpreted. It is also possible that low literacy in certain patients leads to a misinterpretation of the OES or quickDASH. Another explanation could be that some patients have higher demands of their elbow in daily activities or higher pre-operative expectations, resulting in a mismatch between objective functionality and the SEV. Furthermore, a previous study in shoulder arthroplasty showed that pre-operative Mental Component Score was correlated with post-operative pain and functional scores, suggesting that psychological aspects may also play a role in the perception of post-operative upper extremity function.[20]

Can the SEV be a standalone metric?

In the current study, the correlation between the SEV and conventional PROMs was moderate, suggesting that it is insufficient to replace these methods as a standalone follow-up metric for elbow arthroplasty. However, the true value of a follow-up metric should not be compared to the current golden standard but to the goal of the metric and the added value to the patient and healthcare provider. Common reasons to use validated follow-up metrics are to assess and report results, to detect a deterioration in the results, or for early prediction of failure of the intervention. Unfortunately, these goals could not be directly assessed in the current study. It is possible that for these purposes, the SEV performs equally well or even superior to the current standard PROMs. Furthermore, since the SEV directly asks the patient what they think of their elbow function, the result will also more closely reflect patient satisfaction. Future studies may focus on clarifying the usefulness of the SEV, not just by correlating it with existing PROMs, but by assessing its value in attaining the forementioned goals.

The regression analyses in the current study showed that a single question VAS score for pain during activity was of added value for predicting the variation in both OES and QuickDASH scores. This is demonstrated by an increase in R^2 when adding the VAS score to the model, meaning that the ability of the model to predict the variance in the outcome is increased. The VAS score for pain during rest was not of added value. This suggest that the SEV is not sufficient as a standalone metric for the follow-up of elbow arthroplasty. However, adding one or more 'single-question' metrics may be sufficient for obtaining the same results as several longer questionnaires. Although not assessed in the current study, a question assessing psychological factors may also be of added value. Previous studies have shown that many psychological factors, such as depression, resilience, pain catastrophising, and kinesiophobia, may influence PROMs in orthopaedic conditions.[20–23] Future studies may identify which specific SANE should belong to the core set of questions used for the follow-up of elbow conditions, potentially replacing several longer questionnaires by a handful of focused questions.

Limitations

The results of this study must be interpreted in light of its limitations. First, the SEV was only recently introduced in our centre's follow-up system. Therefore, a substantial number of cases was excluded due to the patients not having reached their follow-up timepoint since the introduction of the SEV. Second, due to the relatively small cohort and differences in follow-up, there was not enough follow-up data to assess each timepoint separately or to assess the evolution of the SEV over time. Instead, we opted to use the most recent follow-up for each patient. Third, only the correlation between the SEV and conventional PROMs was assessed in this study. Other validation requirements, such as the test re-test reliability and responsiveness, could not be assessed.

Conclusion

A statistically significant but moderate correlation was found between the SEV and the OES and QuickDASH scores as a follow-up metric after elbow arthroplasty. Although the SEV may not be sufficient as a standalone metric, it shows potential in simplifying the follow-up of elbow arthroplasty, possibly decreasing time, costs, and patients' questionnaire fatigue compared to conventional PROM questionnaires. Future studies may identify a core set of 'single-question' assessments that may be used for the follow-up of elbow arthroplasty and attempt to simplify and replace conventional PROMs.

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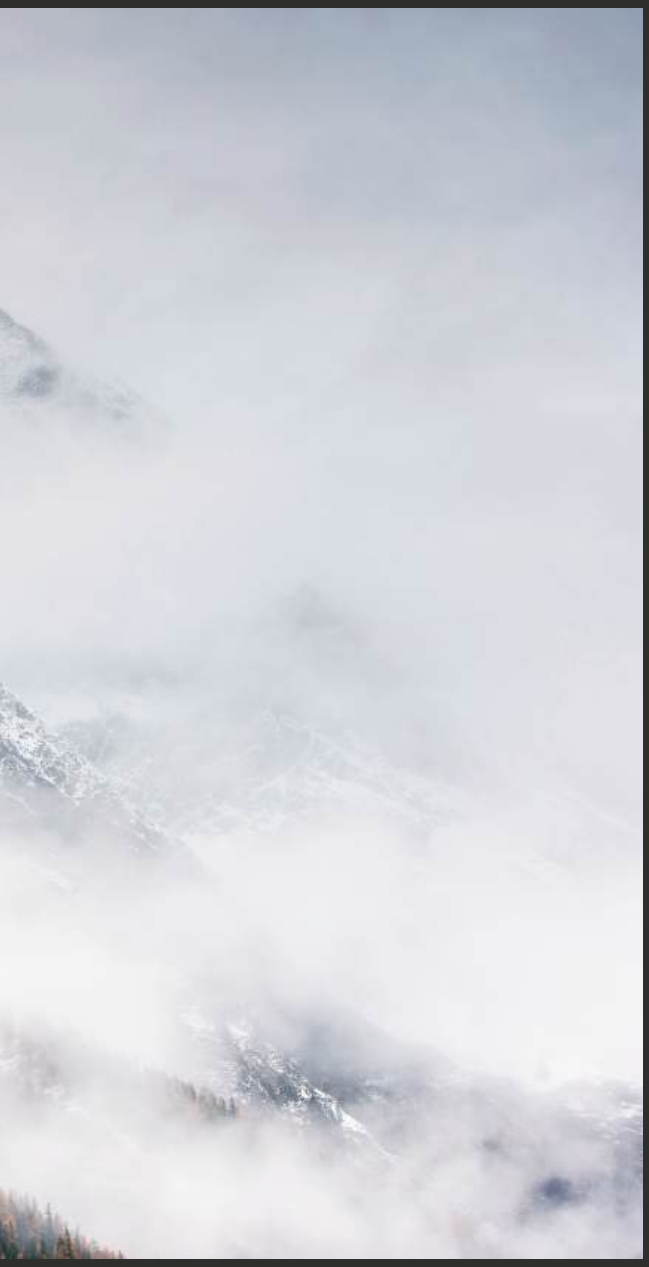

Chapter 4

Implant Survival of Total Elbow Arthroplasty: analysis of 514 cases from the Dutch Arthroplasty Registry.

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Part I

Abstract

Background

The aim of this study is to report the implant survival and factors associated with revision of total elbow arthroplasty (TEA) using data from the Dutch national registry.

Methods

All TEAs recorded in the Dutch national registry between 2014 and 2020 were included. The Kaplan-Meier method was used for survival analysis and a logistic regression model was used to assess the factors associated with revision.

Results

A total of 514 TEAs were included, of which 35 were revised. The five-year implant survival was 91%. Male sex, a higher BMI and previous surgery to the same elbow showed a statistically significant association with revision ($p<0.036$). Of the 35 revised implants, 29% (10/35) underwent a second revision.

Conclusion

This study reports a five-year implant survival of TEA of 91%. Patient factors associated with revision are defined and can be used to optimize informed consent and shared decision-making. There was a high rate of secondary revisions.

Introduction

Total elbow arthroplasty (TEA) is indicated for severe symptomatic cases of rheumatoid arthritis, primary osteoarthritis, posttraumatic sequelae, and in selective trauma cases.[1–4] The revision rate of TEA is relatively high compared to arthroplasties of other joints; a systematic review of 9308 cases found a revision rate of 14% with a mean follow-up of 82 months.[2] Common reasons for revision are polyethylene or bushing wear, aseptic and septic loosening ultimately leading to instability, or dislocation in some cases. Previous studies examining the factors influencing the risk of revision or a complication highlighted age, sex, socioeconomic status, smoking, indication for surgery, co-morbidity, implant designs, and hospital or surgeon volume as potential factors of influence.[4–13]

A revision comprises a significant burden on the patient and healthcare system. Consequently, expected implant survival plays an important role in the shared decision-making process when considering TEA. The currently available follow-up data for total elbow implants are limited to relatively small cohort studies, except for one study including 461 elbows published by the designer of the implant.[3,14–21] Cohort studies are potentially prone to bias and conflicts of interest. To circumvent these issues, data from a national registry can be used. Furthermore, analysis of a large cohort may aid in identifying trends and factors associated with revision, which may prove helpful in reducing the revision rate in the future. This is specifically relevant for prostheses that are placed in limited numbers such as TEA.

Although some national registries include TEA (Australia, New Zealand, Norway, Sweden, and the UK) and publish annual reports, they generally do not include comparative analyses of the outcomes.[22,23] To our knowledge, only five studies have been published using registry data to analyse and compare the outcomes of TEA.[7,12,13,24,25] Therefore, the primary aim of this study is to report the implant survival of TEA, using data from the Dutch arthroplasty registry (Landelijke Registratie Orthopedische Implantaten; LROI). The secondary aim is to identify factors associated with revision.

Patients and methods

Data acquisition

Data on elbow arthroplasties are recorded in the registry since January 2014. Data were extracted from the LROI for all primary TEA procedures between January 2014 and December 2020. Data are reported to the registry using a standardized form for all primary or revision elbow arthroplasties, which is completed after surgery (see Supplementary material). Demographic and surgical data are collected (implant characteristics and surgical techniques). Although registration is not strictly obligatory for TEA, it is required by the Netherlands Orthopaedic Association (NOV) and routinely

monitored. The registration of TEAs is considered an important quality metric during hospital audits. The completeness is checked annually with hospital records. The overall completeness was 86% for primary TEA from 2014 to 2020 and 83% for revision arthroplasties from 2014 to 2020.[26] Patient's death is obtained by actively cross-checking with Vektis, the national healthcare insurance database, which records deaths of Dutch citizens. After approval of the study protocol by the LROI, anonymous data were made available for analysis by the research team. These data cannot be traced back to individual patients, surgeons, or institutions. Implant model and manufacturers were blinded, but the implant design (linked or unlinked) was made available.

Data classification

Based on previous literature, centres that performed an average of 18 procedures or more annually were considered high-volume centres.[10] For the implant survival analysis, a revision was set as the end point and defined as an operation to the same elbow with removal or exchange of at least one of the components of the implant. Survival time was defined as time from the primary TEA to a revision or the end of the study period. Deceased patients were censored at the time of death. To differentiate between a re-revision and a two-stage revision, the characteristics for both procedures were compared; if the first procedure is logically followed by the second procedure (i.e. removal and placement of a spacer followed by placement of a new implant in a second procedure), it is considered a two-stage revision. If the two procedures are unrelated, they are considered separate revisions.

Statistical analysis

Demographic, surgical, and outcome data are reported using descriptive statistics. Kaplan-Meier survival analysis was performed and a survival plot including a 95% confidence interval (CI) was generated.

Statistical analysis was performed comparing the patient and treatment characteristics of patients that underwent a revision with patients that did not undergo revision surgery. For this analysis, the minimum follow-up was set at one year by excluding the primary surgeries performed in 2020. For categorical data, chi-squared tests were used. If the expected value for a cell was less than five, a Fisher's exact test was used. For continuous data with a normal distribution, student *t*-tests were used, and in case of skewed data, Mann-Whitney U tests were used. To avoid excluding patients due to missing data and thereby introducing a potential source of bias, each analysis was performed with all the available data and data completeness was reported. A Benjamini-Hochberg procedure was performed to correct for multiple testing. A p-value of 0.05 (after correction) was considered statistically significant.

Additionally, a multiple logistic regression model was fitted by including all variables with a p-value below 0.1 on the initial bivariable analysis. Backwards elimination was used to arrive at a model containing a maximum of one independent variable per ten revisions. Due to the limited

capacity of the regression analysis, not all confounding factors could be included. Therefore, other potential confounding factors outside the final regression model were identified by analysing associations between the variables in the final regression model and the remaining patient and treatment characteristics not included in the model. Furthermore, the frequency of specific reasons for revision was assessed separately for each of the variables in the final model.

Statistical analysis was performed using R version 4.0.5 (R Foundation for Statistical Computing, Vienna, Austria).

Results

A total of 514 patients that underwent a TEA between 2014 and 2020 were included with a median follow-up of four years (interquartile range; IQR: 2-6 years). The mean age at the time of surgery was 66 years (Standard deviation; SD: 12), and most patients were female (75%; 386/514). The most common indication for a TEA was rheumatoid arthritis (33%; 170/514), followed by posttraumatic sequelae (28%; 145/514), osteoarthritis (21%; 106/514), and an acute fracture (10%; 52/514). Overall, 42% of patients (215/514) had undergone previous surgery of the same elbow (Table I). The most common previous surgeries were osteosynthesis (20%; 105/514), (subsequent) hardware removal (12%; 64/514) and decompression or transposition of the ulnar nerve (8%; 40/514). Surgeries were performed at 24 different centres. Of the 24 included centres, only one was considered high-volume, performing 20 procedures a year on average. A total of 28% of surgeries (142/514) were performed in this centre. The most common surgical approach was a posterior approach leaving the triceps intact (42%; 218/514). In total, seven different implant models were used; 76% of the implants were a linked design (392/514) and 10% unlinked (53/514). (Table II) Overall data completeness for the variables stated in table I and II was 98.4%.

Table I. Characteristics of patients undergoing a primary total elbow arthroplasty in the Netherlands between 2014-2020 (n=514)

Age, mean (SD)	66 (12)	**Previous surgery, n (%)**	215 (42)	**Indication for TEA, n (%)**	
Female, n (%)	386 (75)	Arthroscopy	17 (3)	Rheumatoid arthritis	170 (33)
Smoking, n (%)	63 (12)	Lateral arthrotomy	101 (20)	Posttraumatic sequelae	145 (28)
BMI, mean (SD)	27 (5)	Medial arthrotomy	27 (5)	Osteoarthritis	106 (21)
ASA classification, n (%)		Posterior arthrotomy	69 (13)	Acute fracture	52 (10)
I	45 (9)	Ulnar nerve decompression	29 (6)	Inflammatory arthritis	4 (1)
II	294 (57)	Ulnar nerve transposition	11 (2)	Haemophilic arthropathy	4 (1)
III-IV	174 (34)	Osteosynthesis	105 (20)	Osteonecrosis	4 (1)
Unspecified	1 (0)	Arthrodesis	3 (1)	Primary tumour	3 (1)
		Hardware removal	64 (12)	Metastasis of a tumour	3 (1)
		Other	56 (11)	Other	23 (4)

ASA: American Society of Anesthesiology, BMI: Body Mass Index, SD: standard deviation

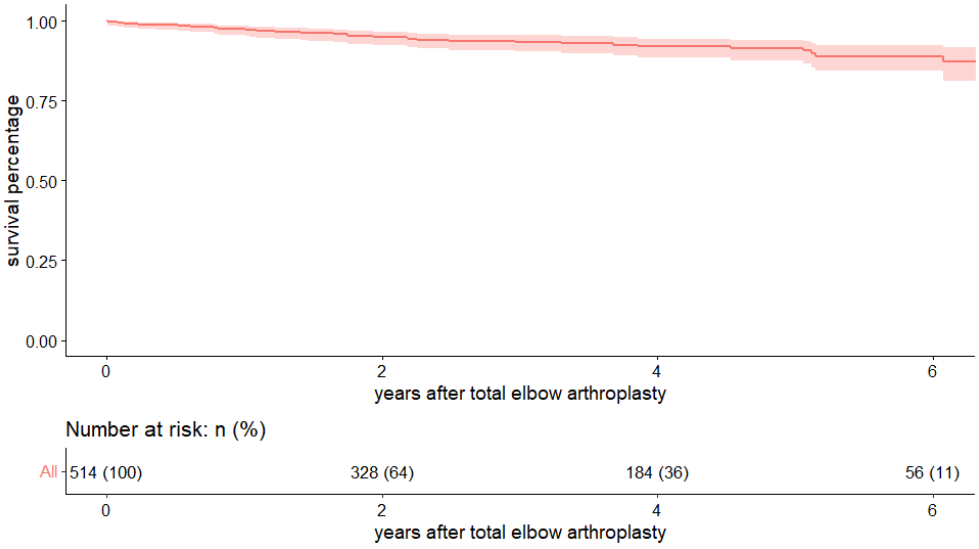
Table II. Treatment characteristics of primary total elbow arthroplasty performed in the Netherlands between 2014-2020 (n=514)

Surgery on dominant limb, n (%)	215 (42)	Implant design, n (%)	
High-volume centre, n (%)	142 (28)	Linked	392 (76)
Surgical approach, n (%)		Unlinked	53 (10)
Posterior	487 (95)	Unspecified	69 (13)
Triceps on	218 (42)	Fixation, n (%)	
Triceps off	179 (35)	All components cemented	480 (94)
Triceps split	38 (7)	Ulnar component cemented	16 (3)
Olecranon osteotomy	2 (0)	Humeral component cemented	1 (0)
Unspecified	50 (10)	Uncemented	7 (1)
Lateral	8 (2)	Unspecified	10 (2)
LCL intact	1 (0)	Autograft bone used, n (%)	81 (16)
LCL off	7 (1)	Allograft bone used, n (%)	3 (1)
Other	19 (4)	Ulnar nerve decompression, n (%)	298 (58)
		Ulnar nerve transposition, n (%)	123 (24)

LCL: lateral colateral ligament

Of the 514 included patients, 35 patients underwent a subsequent revision within five years, which was performed at 14 different centres. The median time to revision was 1.5 years (IQR: 0.7-2.7 years). The implant survival was 98% after one year (95% CI: 96-99%), 93% after three years (95% CI: 90-95%) and 91% after five years (95% CI: 88-94%; Figure 1).

Figure 1: Implant survival of total elbow arthroplasty



Kaplan-Meier plot showing the revision-free survival of total elbow arthroplasties performed in the Netherlands between 2014-2020.

The exclusion of surgeries performed in 2020 resulted in 436 patients with a minimum follow-up of one year, of which 34 underwent a revision; one patient that received TEA in 2020 underwent a revision within the same year. After correction of the p-values, none of the characteristics was associated with revision surgery. (Table III and IV) After backwards elimination of the least influential variables, the multiple logistic regression analysis found a higher body mass index (BMI), previous surgery of the same elbow, and male sex to be independently associated with revision surgery (Table V). Potential confounding factors outside the regression model were identified; patients with obesity (BMI > 30 kg/m^2) receiving a TEA were younger compared to non-obese patients (mean age of 62.8 years versus 66.9; p=0.01). Patients that had undergone previous surgery were older, underwent TEA more often due to posttraumatic sequelae, were more often treated in the high-volume centre, more often received ulnar nerve decompression, and more often had a linked design compared to patients without previous surgery (p<0.04). Male patients were also younger, underwent TEA more often due to osteoarthritis, were less likely to smoke, had a lower American Society of Anesthesiology (ASA) classification, and were more often treated in the high-volume centre compared to female patients (p<0.033). Other potential confounding factors were not significantly associated with BMI, previous surgery, or sex.

Table III. Patient characteristics associated with revision of primary total elbow arthroplasty

	No revision (n=402)	**Revision** (n=34)	**P-value**	**Corrected P-value***
Age, mean (SD)	66 (12)	62 (10)	0.059[A]	0.221
Female, n (%)	302 (75)	21 (62)	0.088[B]	0.264
Smoking, n (%)	52 (13)	8 (24)	0.114[C]	0.285
BMI, mean (SD)	27 (5)	30 (7)	**0.00361[A]**	0.054
ASA classification, n (%)			0.510[C]	0.588
I	35 (9)	4 (12)		
II	235 (58)	21 (64)		
III - IV	132 (33)	8 (24)		
Previous surgery, n (%)	158 (39)	21 (62)	**0.01057[B]**	0.080
Indication, n (%)			0.240[C]	0.393
Rheumatoid arthritis	145 (36)	8 (25)		
Posttraumatic sequelae	107 (27)	13 (41)		
Osteoarthritis	76 (19)	7 (22)		
Acute fracture	45 (11)	1 (3)		
Other	28 (7)	3 (9)		

[A]T-test, [B]Chi-squared test, [C]Fisher's exact test, *P-values corrected using Benjamini-Hochberg procedure.
P-values in bold: variables were added to the initial regression model.
ASA: American Society of Anesthesiology, BMI: body mass index, SD: standard deviation

Table IV. Treatment characteristics associated with revision of total elbow arthroplasty

	No revision (n=402)	Revision (n=34)	P-value	Corrected P-value*
Surgery on dominant limb, n (%)	169 (42)	10 (29)	0.151[B]	0.345
High volume centre, n (%)	110 (27)	7 (21)	0.392[B]	0.570
Implant model (anonymised)			0.262[C]	0.420
Implant design, n (%)			0.784[c]	0.896
Linked	308 (87)	29 (91)		
Unlinked	48 (13)	3 (10)		
All components cemented, n (%)	374 (93)	32 (94)	1.000[C]	1.000
Bonegraft used, n (%)	71 (18)	3 (9)	0.187[B]	0.374
Ulnar nerve decompression, n (%)	217 (54)	12 (35)	**0.03616[B]**	0.193
Ulnar nerve transposition, n (%)	85 (21)	9 (26)	0.468[B]	0.624
Surgical approach, n (%)			0.850[C]	0.907
Posterior, triceps on	151 (42)	12 (43)		
Posterior, triceps off	157 (44)	11 (39)		
Posterior, triceps split	31 (9)	3 (11)		
Other	19 (5)	2 (7)		

[B]Chi-squared test, [C]Fisher's exact test. *P-values corrected using Benjamini-Hochberg procedure. P-values in bold: variables were added to the initial regression model. CI: confidence interval.

Table V. Logistic regression analysis of factors associated with revision of primary total elbow arthroplasty – final model

Variable	Coefficient	Standard Error	Z-value	P-value
Female sex	-0.814	0.388	-2.100	0.03577
BMI	0.089	0.032	2.810	0.00495
Previous surgery	1.000	0.383	2.582	0.00981
AIC: 222.21, McFadden's pseudo R2: 0.0781 (p-value: <0.0005)				

BMI: Body mass index, AIC: Akaike information criterion

The 35 patients who underwent a revision had a median age of 66 years (IQR: 58-73) and a median BMI of 29 kg/m^2 (IQR: 25-36) at the time of revision surgery. (Table VI) The most common reason for revision was aseptic loosening (34%; 12/35), followed by an infection (23%; 8/35) and elbow instability (23%; 8/35), and polyethylene wear (14%; 5/35) and a periprosthetic fracture (14%; 5/35). Polyethylene wear was more common in male patients (3% versus 0.3%, p=0.0173) and instability was more common in obese patients (4% versus 1%, p=0.0386). (Table VII) In some

cases, there were several reasons for a revision or loosening of several components. There were no cases of two-stage revisions.

Table VI. Characteristics of primary revision cases of total elbow arthroplasty (n=35)

Patient characteristics		**Revision characteristics**	
Age, median (IQR)	66 (58-73)	Revision type, n (%)	
BMI, median (IQR)	28 (25-33)	Total replacement	8 (23)
ASA classification, n (%)		Partial replacement	16 (46)
I	3 (9)	Humeral component	2 (6)
II	18 (51)	Ulnar component	12 (34)
III-IV	13 (37)	Radial component	1 (3)
Unspecified	1 (3)	Unspecified	1 (3)
Smoking, n (%)	7 (20)	Removal and spacer placement	1 (3)
		Allograft bone used, n (%)	2 (6)

ASA: American Society of Anesthesiology, BMI: body mass index, IQR: Interquartile range

Table VII. Indications primary revision cases of total elbow arthroplasty (n=35)

Previous surgeries before TEA, n (%)	22 (63)	**Indications for primary TEA**, n (%)		**Reasons for revision**, n (%)	
Arthroscopy	3 (9)	Rheumatoid arthritis	8 (23)	Aseptic loosening	12 (34)
Lateral arthrotomy	9 (26)	Posttraumatic sequelae	14 (40)	Humeral component	5 (14)
Medial arthrotomy	3 (9)	Osteoarthritis	7 (20)	Ulnar component	7 (20)
Posterior arthrotomy	9 (26)	Acute fracture	1 (3)	Radial component	3 (9)
Ulnar nerve decompression	2 (6)	Inflammatory arthritis	0 (0)	Infection	8 (23)
Ulnar nerve transposition	0 (0)	Haemophilic arthropathy	0 (0)	Instability	8 (23)
Osteosynthesis	9 (26)	Osteonecrosis	1 (3)	Polyethylene wear	5 (14)
Arthrodesis	0 (0)	Primary tumour	0 (0)	Periprosthetic fracture	5 (14)
Hardware removal	9 (26)	Metastasis of a tumour	0 (0)	Metallosis	4 (11)
Other	2 (6)	Other	2 (6)	Other	6 (17)

TEA: total elbow arthroplasty

After the first revision, the median follow-up was 2.8 years (IQR 1.5-4.5). Overall, 10/35 patients (29%) underwent a secondary revision within the inclusion period, with a median time between the primary and secondary revision of 1.4 years (IQR: 0.3-2.6). In seven cases, one or more components were replaced. In the remaining three cases, the implant was removed and replaced with a spacer. The characteristics of the patients that underwent a secondary revision are described in table VIII and IX.

Table VIII. Characteristics of secondary revision cases of total elbow arthroplasty (n=10)

Case	Sex	Age (years)	BMI	ASA	Components replaced	Cemented
1	Female	55-60	35-40	II	Ulnar	Yes
2	Female	55-60	35-40	II	Ulnar	Yes
3	Female	75-80	20-25	II	Removed and spacer placed	No
4	Female	55-60	25-30	II	Ulnar	Yes
5	Male	45-50	20-25	II	Removed and spacer placed	No
6	Male	70-75	20-25	III-IV	Removed and spacer placed	No
7	Female	50-55	Missing	Missing	Ulnar	Yes
8	Male	55-60	≥40	II	Humeral and radial	Yes
9	Male	65-70	35-40	III-IV	Ulnar	Yes
10	Female	65-70	20-25	II	Ulnar	No

ASA: American Society of Anesthesiology classification at primary arthroplasty, Age: patient's age category at primary arthroplasty, BMI: body mass index at primary arthroplasty

Table IX. Indications in secondary revision cases of total elbow arthroplasty (n=10)

Case	Initial diagnosis	Reason for primary revision	Reason for secondary revision
1	Osteoarthritis	Aseptic loosening	Periprosthetic fracture
2	Osteoarthritis	Aseptic loosening	Periprosthetic fracture
3	Rheumatoid arthritis	Infection	Infection
4	Other	Other	Periprosthetic fracture
5	Posttraumatic sequelae	Infection	Infection
6	Rheumatoid arthritis	Infection	Infection and loosening
7	Other	Aseptic loosening	Instability and aseptic loosening
8	Osteonecrosis	Polyethylene wear	Polyethylene wear, metallosis, and loosening
9	Rheumatoid arthritis	Polyethylene wear and instability	Aseptic loosening
10	Posttraumatic sequelae	Infection	Infection

Discussion

This study includes 514 TEAs from the LROI, with a median follow-up of four years. Overall, 35 TEAs were revised, resulting in a five-year implant survival of 91%. A higher BMI, previous surgery of the ipsilateral elbow, and male sex showed a statistically significant association with revision. Notably, of the 35 patients who underwent a revision, ten patients required a second revision.

The most common indication for a TEA was rheumatoid arthritis (33%), followed by posttraumatic sequelae (28%). This is congruent with other registry studies, reporting rheumatoid arthritis as the most common indication.[1,24,25] Globally, the indications for total elbow arthroplasty are shifting from rheumatoid arthritis to trauma-related indications.[1] The trend toward traumatic indications for TEA is supported by a study by McKee et al. which to date has been cited 439 times.[27] In this study, patients over the age of 65 years with a complex distal humerus fracture who were randomized to TEA had favourable PROM scores compared to patients who underwent open reduction and internal fixation.[27] Long-term results of this study revealed no difference in complications between the groups after a mean follow-up of 7.7 years.[28] Instead of using a national implant registry, other options exist to assess data on a national level. Two studies from the United States using data from the Integrated Health Care System and the National Surgical Quality Improvement Program revealed that the most common indication for TEA was a fracture (40.6% in both studies). This is in contrast with data from the European, Australian and New Zealand registries.[1] It must be noted that these studies do not mention the completeness of the data and

are therefore more at risk of selection bias and missing data compared to the national registries, which are actively monitored.

The implant survival after five years was 91% in the Netherlands. These results are in line with the three previously published studies of national registries reporting five-year survival rates between 90% and 95%.[13,24,25] Considering the amount of low-volume centres in the current study, these results may reflect a lack of experience; it may be beneficial to concentrate TEA in fewer centres.

The most common reason for revision of TEA in the Netherlands was aseptic loosening, followed by a peri-prosthetic joint infection and instability. This is in line with results from the Norwegian and Danish arthroplasty registry, as well as other previous studies.[13,15,25] In contrast, in a study from the Australian registry, an infection was a more common reason for revision than aseptic loosening (35% versus 34%, respectively).[7] A low-grade infection may be misdiagnosed as aseptic loosening, especially in infections with microorganisms which are low-virulent. Previous studies have shown the relevance of occult or chronic infections with low-virulent organisms such as Cutibacterium Acnes to the outcomes of upper extremity arthroplasty.[29,30] Low-grade, occult infections can lead to loosening and pain and are difficult to detect.[31,32] Furthermore, instability may also be caused by polyethylene wear, but not reported as such, leading to an underrepresentation of cases with polyethylene wear.

This study revealed BMI to be associated with a higher risk of revision. Although significant (p=0.00495), the coefficient (0.089) demonstrates only a weak correlation. The correlation between BMI and risk of revision has reported in previous literature; a meta-analysis of 12 studies showed that obesity increases the chance of an infection and venous thromboembolism after upper limb arthroplasty. The odds of infection were five times greater in morbidly obese patients (BMI of 40 kg/m^2 or higher) compared to non-obese patients (BMI of 30 kg/m^2 or lower).[33] Increased risk of infection due to a thicker layer of poorly vascularized adipose tissue, attenuated immune systems, and a proinflammatory state has been suggested as a possible explanation for this association.[34] In the current study, infections were not significantly more common in obese patients. Another factor that may contribute to higher revision rates in obese patients is accelerated implant wear or loosening due to increased and altered mechanical forces on the elbow.[34] Our results indicate that obese patients are more likely to undergo a revision due to instability (4% versus 1%), which may occur secondary to polyethylene wear. As a result of the larger circumference of the chest and upper arm in obese patients, the shoulder is naturally held more in abduction.[35,36] In contrast to non-obese patients, this altered position leads to increased torsional and varus forces on the elbow joint. Previous studies have suggested torsional, asymmetrical and gravitational forces to be the major drivers in implant wear and loosening.[37,38] Although the forearm mass as a percentage of the total body mass is lower in obese patients (1.39% versus 1.56%),[39] the increased total mass still leads to a significant increase in forces on the elbow. The combination of these factors in obese patients may put a greater strain on the

implant leading to increased polyethylene wear resulting in instability and ultimately early loosening.[34]

This study also found previous surgery of the same elbow before TEA to be associated with a higher risk of revision. To our knowledge, previous studies have not found this association. One previous study identified previous surgery as a risk factor for infection specifically.[40] In the current study, 6 of the eight infections that led to a revision occurred in patients that underwent previous surgery before TEA, resulting in an infection rate of 2.8% versus 0.7% in patients that did not undergo previous surgery, which was not statistically significant. Furthermore, pseudoarthrosis or non-union after open reduction and internal fixation of a distal humerus fracture may occur due to an undiagnosed low-grade infection; a TEA placed in such conditions would consequentially have a higher chance of loosening, without being recognized as septic. A study of 17 patients undergoing total shoulder arthroplasty due to failed open reduction and internal fixation found positive pre-operative bacterial aspirations in four patients (24%), six revisions (35%) were performed after a 4.6-year follow-up, of which two were due to aseptic loosening.[41] Age, comorbidity, and compromised bone and soft-tissue conditions may also influence the chance of a revision.[42] In our study, previous surgery was significantly associated with posttraumatic sequelae as an indication for TEA, older age, treatment in the high-volume centre, and ulnar nerve decompression.

In the current study, male sex was associated with a higher risk of revision. A possible explanation for this could be a lower proportion of traumatic indications in males, which has been linked with revision rates in previous studies. However, the correlation is still unclear; some studies have associated trauma-related TEA with lower revision rates compared to other indications,[15] while other studies have identified traumatic indications as a risk factor for revision.[5,25,43,44] Trauma-related TEA was significantly less common in males (30% versus 41% in females). Male sex was also associated with lower age, a lower percentage of smokers, lower ASA classification, and treatment in the high-volume centre. Logically, these factors would decrease rather than increase the chance of complications. However, they may also influence decision-making favouring revision surgery. Other factors may also play a role, such as level of activity, strength, and weight, leading to accelerated implant wear or loosening. As a percentage of total body mass, the male forearm weighs more (1,58% compared to 1,37% in females).[39] One previous study found a higher incidence of radiological signs of loosening or bushing wear in males (71% vs 25%).[45] In the current cohort, polyethylene wear was more common in males compared to females (3% versus 0.3%).

Interestingly, the number of patients that had to undergo a second revision in this study is high; ten patients (29%) had to undergo another operation after their first revision of a TEA. This is in line with previous literature. A systematic review of 532 patients that underwent a revision after TEA reported a secondary revision in 21.8% of cases.[46] In the current study, two out of three cases where a periprosthetic fracture was the reason for the secondary revision, aseptic loosening was the indication for the first revision, which is suggestive of poor bone conditions. Four out of

eight patients (50%) with a revision for an infection underwent a second revision. In all four cases the indication for the second revision was the same as the first, highlighting the difficulty in treating (chronic) infections. Surprisingly, there were no cases of a two-stage revision for an infected implant. Previous studies report recurrence rates between zero and 20 per cent after two-stage revisions, which is considerably lower than the current study (50%).[47–50] However, these studies include few patients and in a about a quarter of cases the second stage is never completed.[51] Furthermore, a systematic review comparing infection recurrence rate between one- and two-stage revisions did not find a significant difference.[50] The 35 revisions in the current cohort were performed at 14 different centres. This is an underestimation of the centre volume since revisions of primary TEAs performed before 2014 are not taken into account. However, the high re-revision rate may reflect a low level of experience and it may be beneficial to the re-revision rate to concentrate the revisions in fewer, high-volume centres.

The results of this study must be interpreted considering its limitations. First, in collecting data from a registry, the study relies on the completeness and accuracy of reporting by third parties. The overall completeness was 86% in the study period. Second, data from the registry is less detailed in comparison to hospital records. For example, volume can be calculated per centre, but not per individual surgeon. Furthermore, only revision operations including placement, replacement, or removal of an implant are included in the registry. Complications that do not lead to a revision of the implant are not included. The registry also doesn't record clinical outcomes such as range of motion or patient-reported outcomes. However, using data from a registry also provides several advantages; it allows for the identification of trends and associations in a larger cohort, which is specifically relevant for rare procedures, and it increases the generalisability of the results. Third, despite using a large database, the regression analysis was limited to three variables. As a result, not all confounding factors could be taken into account. However, potential confounding factors are reported separately and should be considered when interpreting the results. Last, only one centre was classified as high-volume, introducing a chance of bias.

In conclusion, this study reports the implant survival of TEA, factors associated with revision and a high rate of re-revisions. The survival estimate from a large national database will aid orthopaedic care providers to optimize shared decision making. The risk factors for revision and the high risk of a second revision should be taken into account when considering TEA in suboptimal conditions and attention should be paid to conditions influencing polyethylene wear such as altered angles of force transmission over the elbow or increased load bearing in obese or male patients. Concentrating revision TEA in high-volume centres may proof beneficial to the outcomes. Future research could focus on early identification and treatment of complications after TEA in order to curb the downward spiral of complications and revisions in complex cases.

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Part II

Shoulder

Chapter 5

Anterosuperior versus Deltopectoral Approach for Primary Reverse Total Shoulder Arthroplasty: a study of 3902 cases from the Dutch National Arthroplasty Registry with a minimum follow-up of 5 years.

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Part II

Abstract

Background

The current evidence comparing the two most common approaches for reverse shoulder arthroplasty (rTSA), the deltopectoral and anterosuperior approach, is limited. This study aims to compare the rate of loosening, instability, and implant survival between the two approaches for rTSA using data from the Dutch National Arthroplasty Registry with a minimum follow-up of five years.

Methods

All patients in the registry who underwent a primary rTSA between January 2014 and December 2016 using an anterosuperior or deltopectoral approach were included, with a minimum follow-up of five years. Cox and logistic regression models were used to assess the association between the approach and the implant survival, instability, and glenoid loosening, independent of confounders.

Results

In total, 3,902 rTSAs were included. A deltopectoral approach was used in 54% (2099/3902) and an anterosuperior approach in 46% (1803/3902). Overall, the mean age in the cohort was 75 years (50 to 96) and the most common indication for rTSA was cuff tear arthropathy (35%, n = 1,375), followed by osteoarthritis (29%, n = 1,126), acute fracture (13%, n = 517), post-traumatic sequelae (10%, n = 398), and an irreparable cuff rupture (5%, n = 199). The two high-volume centres performed the anterosuperior approach more often compared to the medium- and low-volume centres ($p < 0.001$). Of the 3,902 rTSAs, 187 were revised (5%), resulting in a five-year survival of 95.4% (95% confidence interval 94.7 to 96.0; 3,137 at risk). The most common reason for revision was a periprosthetic infection (35%, n = 65), followed by instability (25% n = 46), and loosening (25%, n = 46). After correcting for relevant confounders, the revision rate for glenoid loosening, instability, and the overall implant survival did not differ significantly between the two approaches ($p = 0.494$, $p = 0.826$, and $p = 0.101$, respectively).

Conclusion

The surgical approach used for rTSA did not influence the overall implant survival or the revision rate for instability or glenoid loosening.

Introduction

The two most common surgical approaches for reverse total shoulder arthroplasty (rTSA) are the anterosuperior and deltopectoral approach.[1] The deltopectoral approach follows the deltopectoral groove, with the advantage of not compromising the deltoid muscle.[2] Using this approach, the subscapularis tendon is most commonly tenotomised at its insertion to allow access to the joint.[3,4] For the anterosuperior approach, the anterior deltoid muscle and coracoacromial ligament are released.[5,6] Advantages of the anterosuperior approach are preserving the subscapularis tendon and the anterior ligament complex, as well as a more direct lateral exposure of the glenoid. A downside of the anterosuperior approach is that it requires splitting of the deltoid, putting the axillary nerve at risk distally,[6,7] as well as risking acromiodeltoid discontinuity proximally when the approach is slightly extended.

Complications occur in one in five patients undergoing rTSA, and negatively impact the outcomes.[8] Some studies have compared the complications between the two approaches (Table 1).[6,9–16] Some studies have linked the anterosuperior with a lower postoperative instability rate compared to the deltopectoral approach, which is attributed to preserving the subscapularis and anterior ligament complex.[5,6] Previous studies have also associated the anterosuperior approach with a more superior placement and superior tilt of the metaglene compared to the deltopectoral approach.[17,18] The glenoid component placement is an important factor influencing implant loosening.[7,19,20] Conversely, a recent systematic review and meta-analysis comparing the two surgical approaches found a significantly lower rate of glenoid component loosening with the anterosuperior approach.[16] There remain many discrepancies in the literature comparing the complications between the two approaches, with several studies reporting contradicting results.[6,7,20–22,9–16] Furthermore, the current evidence comparing the two techniques relies on separate prospective cohort studies or retrospective comparative studies that are relatively small, have short follow-up periods and are susceptible to selection and publication bias.[1,6,7,21,23] There is no conclusive evidence supporting the superiority of one of the two techniques.

Table I. Suggested associations from the literature for each approach.

	Anterosuperior	Deltopectoral
Potential advantages	Straight glenoid exposure Preserving the subscapularis tendon Easier access to posterior structures	Preserving the deltoid muscle Better anterior elevation Easier access to inferior structures Glenoid exposure at an angle
Potential disadvantages	Splitting the deltoid muscle Glenoid component placement tends toward superior position and tilt Axillary nerve at risk Acromiodeltoid continuity at risk More scapular notching	Detachment of the subscapularis tendon More instability More dislocation More acromial and scapular spine fractures

Shoulder arthroplasties have been added to the Dutch National Arthroplasty Registry (LROI) since 2014, but an analysis comparing the approaches using this registry data has not been performed to date. Using a large national database allows for the identification of trends in relatively rare complications such as glenoid component loosening, occurring in 1% to 4% of patients.[8,24,25] The large database also makes it possible to statistically correct for confounding factors, which is lacking in previous studies.

Therefore, this study aims to compare the rate of glenoid component loosening, instability, and implant survival between the anterosuperior approach and the deltopectoral approach for rTSA using data from the LROI.

Methods

Data on shoulder arthroplasties are recorded by the LROI since January 2014. The completeness is checked with hospital records and was 89% for primary elective shoulder arthroplasties between 2014 and 2016.[26] Demographic, surgical, and implant-related data can be extracted from the registry. Deceased patients are documented by cross-checking the register with government administration using patients' social security numbers. After approval of the protocol by the national registry, the anonymized data were made available for analysis. The provided data cannot be traced back to individual patients, surgeons, or institutions.

Inclusion

All primary reverse total shoulder arthroplasties registered in the national registry between 2014 and 2016 were included to ensure a minimum follow-up of five years. Patients under the age of 50 and patients with a tumour (primary or metastasis) as the indication for rTSA were excluded, as well as patients with a Walch type C classification (glenoid retroversion > 25°) or implants with the use of a bone-increased offset (BIO-rTSA) due to the substantial influence of these factors on the decision for the surgical approach.[1,27]

Variables

Patients were divided into two groups by approach: deltopectoral or anterolateral. Based on a previous study reporting significant cut-off values for volume based on 90-day revision rates after rTSA, a centre performing 17 procedures or more annually was considered a medium-volume centre and 54 or more annually a high-volume centre.[28] Glenoid loosening was defined as a reported revision for loosening of the glenoid or a revision for a peri-prosthetic fracture in which the glenoid baseplate is replaced. The latter is considered breaking out of the glenoid baseplate as a result of loosening.[29] Revision-free implant survival was estimated with a revision in which at least one of the components is removed or replaced as the event and the time until a revision or follow-up as the survival time, deceased patients are censored at the time of death.

Statistical analysis

First, the patient, treatment, and implant characteristics were compared between the two groups using independent-sample *t*-tests and chi-squared tests. Second, three regression models were built with the approach as the central determinant: two forward selection stepwise association regression models with glenoid loosening and shoulder instability leading to a revision as the outcome and one cox regression model with the revision-free implant survival as the outcome. Relevant variables were selected based on associations reported in the literature and clinical experience. Starting with the outcome and the central determinant, variables were added one by one, keeping those variables which are most influential on the regression coefficient. Variables with an influence of less than 10% were not included in the model. The maximum number of included variables was set at one per ten outcome events.

A p-value < 0.05 was considered statistically significant. Statistical analysis was performed using R version 4.0.5 (R Foundation for Statistical Computing, Vienna, Austria).

Results

In total, 4,449 rTSAs were registered during the study period of which of 547 were excluded (30 patients younger than 50 years, 21 cases with Walch classification C, 491 cases of BIO-rTSA, and five patients with a tumour (primary or metastasis) as the indication for RSA), resulting in a cohort of 3,902 rTSAs. The demographic characteristics, indications, and anatomical findings and approaches are described in Table II. At the time of the study, 22% of the patients (849/3,902) were deceased. There was no difference in the characteristics between the two approaches except for the deltopectoral group, who were slightly older compared with the anterosuperior group (mean 74.8 years vs mean 74.2 years; p = 0.011, independent-samples *t*-test), although statistically significant, this had doubtful clinical relevance. Marginal differences were noted in the distribution of the indications for rTSA between the two groups which, in some instances, had statistical significance but questionable clinical relevance (Table II).

Table II. Comparison of patient characteristics

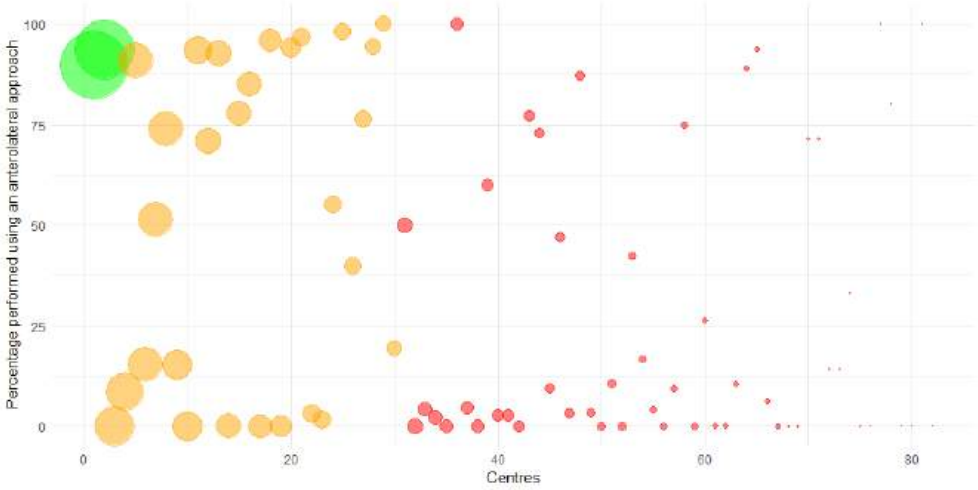
	Deltopectoral, n=2099	Anterosuperior, n=1803	p-value
Age, mean (SD)	74.8 (7.1)	74.2 (7.2)	**0.01072**
Female, n (%)	1654 (78.8)	1409 (78.1)	0.649
BMI, mean (SD)	28.2 (5.3)	28.1 (5.2)	0.662
ASA classification, n (%)			0.869
I	125 (6.3)	99 (5.5)	
II	1329 (63.3)	1133 (62.8)	
III-IV	639 (30.4)	565 (31.3)	
Previous surgery, n (%)	366 (17.4)	313 (17.4)	0.950
Indication for RSA, n (%)			**0.003291**
Cuff tear arthropathy	700 (33.3)	675 (37.4)	**0.007692**
Osteoarthritis	627 (30.0)	499 (27.7)	0.131
Acute fracture	285 (13.6)	232 (12.9)	0.514
Post-traumatic	232 (11.1)	166 (9.2)	0.057
Irreparable cuff tear	90 (4.3)	109 (6.0)	**0.01284**
Osteonecrosis	78 (3.7)	50 (2.8)	0.099
Rheumatoid arthritis	39 (1.9)	45 (2.5)	0.171
Inflammatory arthritis	9 (0.5)	9 (0.4)	0.746
Other			
Walch classification, n (%)			**0.002728**
A1	1098 (52.3)	1080 (59.9)	**0.000002**
A2	423 (20.2)	383 (21.2)	0.402
B1	265 (12.7)	177 (9.8)	**0.005791**
B2	75 (3.6)	70 (3.9)	0.611
B3	19 (0.9)	9 (0.5)	0.134

ASA: American Society of Anesthesiologists, BMI: body mass index, RSA: reverse shoulder arthroplasty, SD: standard deviation.

The two high-volume centres (>53 procedures per year) treated 11% of patients (n = 429). The proportion of each approach performed at the different centres suggests a preference for one of the two approaches in most of the centres (Figure 1). Further details on the distribution of the approaches by centre volume, the make of implant, and method of fixation can be found in Tables III and IV. The median glenosphere diameter for all shoulders was 38 mm (interquartile range (IQR) 36 to 42), and the median insert height was 3 mm (IQR 3 to 6). Apart from whether the dominant

side was operated (p = 0.077, chi-squared test), all treatment and implant characteristics were significantly different between the two groups (Tables III and IV).

Figure 1: Preferred approach by centre size



Graph displaying the preferred approach for reverse shoulder arthroplasty in the Netherlands for each centre with regards to their volume. Each dot represents a centre preforming reverse shoulder arthroplasty, the size corresponds to the centre volume and the colours indicate high (green), medium (orange), and low (red) volumes. The y-axis indicates the percentage of the reverse shoulder arthroplasties performed at each centre through an anterolateral approach; the higher the centre is on the chart, the larger the proportion of cases in which an anterolateral approach was used at this centre.

Table III. Comparison of treatment characteristics			
	Deltopectoral, n=2099	**Anterosuperior, n=1803**	**p-value**
Centre volume, n (%)			**<0.000001**
High *(>53/year)*	37 (1.8)	392 (21.7)	**<0.000001**
Medium *(17-53/year)*	1135 (54.1)	1110 (61.6)	**0.000002**
Low *(<17/year)*	927 (44.2)	301 (16.7)	**<0.000001**
Dominant side operated, n (%)	722 (34.4)	572 (31.7)	0.077
Fixation, n (%)			**<0.000001**
Cementless	1379 (66.0)	1379 (76.7)	**<0.000001**
Fully cemented	147 (7.0)	79 (4.4)	**0.000433**
Only humeral component cemented	553 (26.5)	340 (18.9)	**<0.000001**
Only glenoid component cemented	9 (0.4)	1 (0.0)	**0.02576**

Table IV. Comparison of implant characteristics

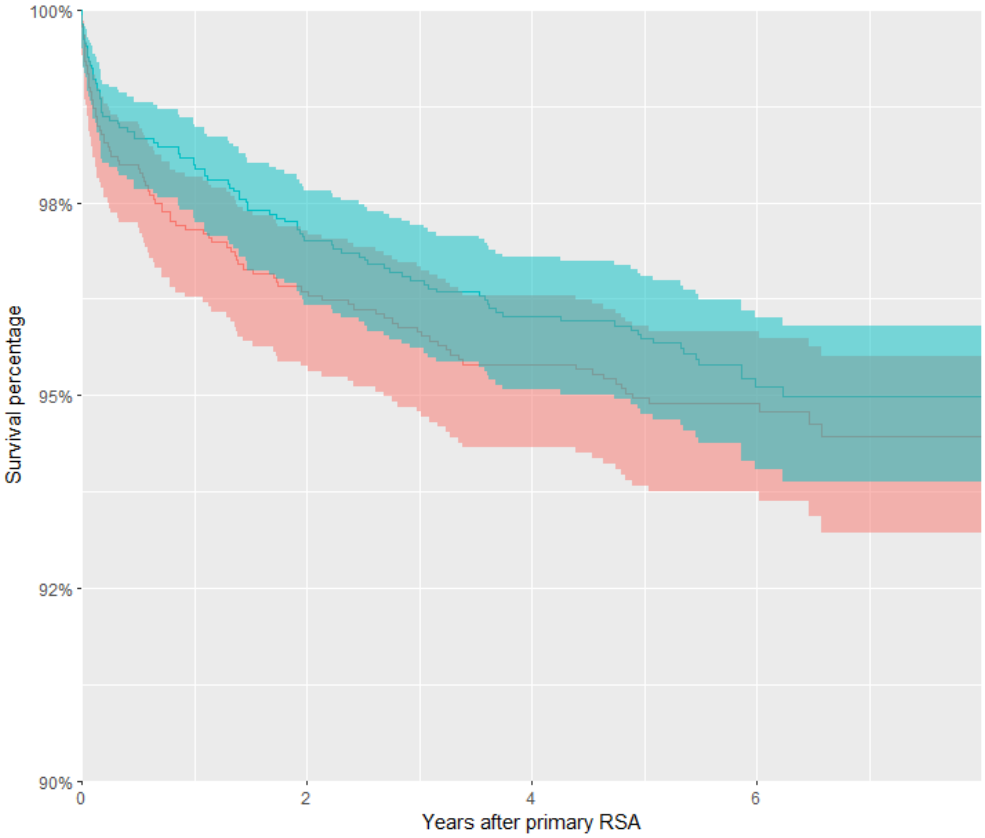
	Deltopectoral, n=2099	Anterosuperior, n=1803	p-value
Prosthesis model, n (%)			**<0.000001**
Delta Xtend (Johnson & Johnson)	267 (13.1)	1158 (64.9)	**<0.000001**
Aequalis (Stryker)	902 (44.2)	298 (16.7)	**<0.000001**
Comprehensive Reverse (Zimmer Biomet)	449 (22.0)	21 (1.2)	**<0.000001**
Trabecular Metal Reverse (Zimmer Biomet)	156 (7.6)	76 (4.3)	**0.000012**
Equinoxe (Exactec)	105 (5.1)	74 (4.1)	0.146
Affinis Inverse (Mathys)	41 (2.0)	113 (6.3)	**<0.000001**
SMR Reverse (Lima)	54 (2.6)	42 (2.4)	0.567
Univers Revers (Arthrex)	68 (3.3)	2 (0.1)	**<0.000001**
Other or unknown			
Humeral stem material, n (%)			**<0.000001**
Titanium	1597 (81.3)	1372 (83.1)	0.175
Tantalum	278 (16.8)	279 (14.2)	**0.02955**
Cobalt chrome	88 (4.5)	2 (0.1)	**<0.000001**
Glenosphere material, n (%)			**<0.000001**
Cobalt chrome	1886 (95.5)	1611 (92.4)	**0.000079**
Standard PE	39 (2.0)	111 (6.3)	**<0.000001**
Cross-linked PE	36 (1.8)	19 (1.1)	0.065
Titanium	14 (0.7)	2 (0.1)	**0.00575**
Glenosphere diameter, mean (SD)	37.2 (2.1)	39.3 (2.3)	**<0.000001**
Insert size, mean (SD)	4.7 (3.7)	4.3 (2.5)	**0.000652**

SD: standard deviation

Revision

Of the 3,902 rTSAs, 187 (5%) were revised at a mean period of one year (SD 1.78) after the primary procedure, resulting in a five-year survival of 95.4% (95% confidence interval (CI) 94.7 to 96.0; 3,137 at risk Figure 2). The most common reason for revision was a periprosthetic joint infection (35%, n = 65), followed by instability (25%, n = 46), and loosening (25%, n = 46; Table V). In some cases, there were several reasons for a revision.

Figure 2: Survival of reverse shoulder arthroplasty using a deltopectoral or anterosuperior approach.



Kaplan-Meier plot including 95% confidence intervals for revision-free survival of reverse shoulder arthroplasty using a deltopectoral (blue) or anterosuperior approach (red).

Table V. Revisions characteristics, n=187	
Reason for revision, n (%)	
Infection	65 (35)
Instability	46 (25)
Glenoid component loosening	27 (14)
Malalignment	18 (10)
Humeral component loosening	16 (9)
Peri-prosthetic fracture	13 (7)
Both components loosening	3 (2)
Other	23 (13)
Revision procedure, n (%)	
Partial revision	121 (65)
Removal of prosthesis	21 (11)
Total revision	31 (17)
Other	14 (7)
Component replaced, n (%)	
Humeral head inlay	87 (47)
Glenosphere	56 (30)
Metaphysis taper	36 (19)
Glenoid baseplate	32 (17)
Humeral stem	25 (13)

Regression analyses

After correcting for potential confounders (Tables II to IV), the surgical approach was not significantly correlated with a revision for glenoid loosening, a revision for instability, or overall revision-free implant survival. In the initial bivariable regression model, the deltopectoral approach was correlated with a higher risk of a revision for glenoid loosening (relative risk 2.362 (95% CI 1.054 to 5.292); p = 0.037). However, when correcting for confounding factors, the surgical approach was not significantly correlated with glenoid component loosening (p=0.494; confounders: implant model and BMI). Similarly, no significant correlation was found between the surgical approach and a revision for instability (p = 0.267; confounders: glenosphere diameter, patient sex, and implant model) or the overall revision-free implant survival (p = 0.101; confounders: glenosphere diameter, patient sex, Walch classification, centre volume, BMI, humeral stem material, indication for rTSA, insert size, previous surgery, implant model, glenosphere material, age, fixation, American Society of Anesthesiologists grade, dominant side

operated, and the interactions between use of the Delta Xtend prosthesis and a deltopectoral approach, and patient sex and osteoarthritis as the indication for rTSA).

Discussion

In total, of the 3,902 patients who underwent rTSA in the study period, 187 underwent a revision. When correcting for potential confounders, there was no difference between the two approaches overall implant survival, revision rate for glenoid component loosening, or revision rate for instability.

Of the 187 revisions, 30 were performed for glenoid component loosening, which was not significantly associated with the surgical approach in the final regression model. Interestingly, this result is in contrast with a recent meta-analysis.[16] In their analysis of 136 cases from 2 studies, Seok et al found a lower rate of glenoid loosening with the anterosuperior approach (odds ratio 0.10 (95% CI 0.01 to 0.093),[16] which is similar to our initial bivariable model. However, the CI approaches 0, suggesting a poor correlation. Furthermore, the meta-analysis did not correct for confounding factors. In contrast, the results of the current study suggest that when using a large national database and correcting for confounding factors such as the implant model, there is no correlation between the surgical approach and glenoid component loosening. It is possible that both the choice for the surgical approach and the implant model is based on other factors, such as the surgeons experience and centre volume. For example, the Delta Xtend prosthesis was implanted more often using an anterosuperior approach.

Our results show no significant difference in the rate of instability leading to a revision between the two approaches. Previous studies have reported the deltopectoral approach to be associated with a higher rate of instability, which is attributed to sacrificing the subscapularis muscle and anterior ligament structures (with or without subsequent repair).[6,9–11,15] We could not replicate these results in a large national cohort. However, the current study includes only complications that led to a revision. It is possible that a difference in instability rates exists, but that these implants are not all revised.

The two high-volume centres in this study used the anterosuperior approach more frequently compared to medium- and low-volume centres ($p<0.001$). The higher level of expertise in these centres may influence the outcome. In the literature, higher surgeon volume has been associated with lower complication rates and a shorter length of stay.[30] Patient demographics may also differ between high- and low-volume centres.[31,32] Our results also show that different prostheses designs and sizes are preferred by surgeons using one of both approaches. The centre volume was a confounding factor in one of three regression analyses and the prosthesis model in all three regression analyses.

The current study also suggests a preference for one of the two approaches in most centres. It was rare that both approaches were approximately equally frequent. This implicates that the choice of approach is mostly based on surgeon's preference or institutional guidelines, rather than case-by-case decision-making. However, patient characteristics may make one of the two approaches more favourable in certain cases. For example, the posterior structures are more easily accessible through the anterosuperior approach,[6] whereas the deltopectoral approach provides easier access to inferior structures.[2] Glenoid morphology plays a role in the need to adequately access or view these structures. Where posterior bone loss has occurred, an anterosuperior approach may provide a better overview of the posterior part of the glenoid, resulting in more accurate placement. In the current study, Walch classification was a factor of influence in the regression analyses for implant survival. Furthermore, previous studies have identified younger patients and male patients to be at a higher risk of instability,[15,33] while the deltopectoral approach is also linked to instability and dislocation.[6,9–11,15] An anterosuperior approach could be considered in these patients. In contrast, deltopectoral approach may be more favourable in case of inferior procedures, such as removal of osteophytes. This approach can also be extended inferiorly to expose the humerus if needed. The deltopectoral approach is also advised when using lateralisation techniques to decrease instability, such as BIO-rTSA, which were excluded from the current study.[27] The influence of these factors suggests a benefit in choosing the approach individually for each case, taking into account the glenoid morphology, additional procedures, and patient characteristics such as age and sex.

The results of this study must be interpreted considering its limitations. First, data from a national registry are less detailed and less accurate than data acquired through clinical studies. For example, there are no data on handling of the subscapularis muscle during surgery, which has been shown to be a factor of influence on postoperative stability.[13,14] Radiographic data, such as scapular notching or fissures, are also not gathered in the registry. Furthermore, only revisions in which at least one of the implant components is removed or replaced are included in the registry. Complications that do not require an implant revision, such as acromion or scapular stress fractures, are therefore not included. The quality and consistency of the data collection is dependent on third parties reporting to the national registry. These limitations are inherent to the study design. The advantage of using data from the national registry is the greater size of the cohort compared to previous studies, decreasing the chance of bias and allowing for statistical correction of confounding variables. Using registry data also reduces institution-related bias and increases the generalizability and applicability of the results. Furthermore, only two centres were classified as high-volume, potentially introducing bias. However, the high-, medium-, and low-volume cut-off values were based on previous literature reporting differences in revision rates. In addition, exclusion criteria were applied to create a homogenous cohort. The results of this study cannot be extended to these groups. Last, despite using a large national cohort, a revision for glenoid loosening occurred only 30 times, limiting the regression analysis to three variables. It is possible that more confounding variables would be found in a larger cohort.

Currently, the decision for the surgical approach in rTSA procedures is based on surgeon's preference or institutional guidelines. The current study of primary rTSA (not including BIO-rTSA) did not find a significant correlation between the surgical approach and glenoid loosening, instability, or overall implant survival when correcting for confounding patient, treatment, and implant factors. This is in contrast with previous literature reporting lower rates of glenoid loosening with the anterosuperior approach, but without correction for confounding variables. In conclusion, the surgical approach for rTSA should be decided on a case-by-case basis, taking into account the morphology of the glenoid, the possibilities to extend the incision if additional procedures may be required, and the patient's age and sex.

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Chapter 6

Lateralising Reverse Shoulder arthroplasty using Bony Increased Offset (BIO-RSA) or Increased Glenoid Component Diameter: comparison of clinical, radiographic, and patient reported outcomes in a matched cohort.

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Part II

Abstract

Background

This study aims to compare the range of motion (ROM) of reverse shoulder arthroplasty lateralised by bony increased offset (BIO-RSA) using a standard 38-millimetre (mm) component to regular reverse shoulder arthroplasty (RSA) lateralised by using a 42-mm glenoid component. The secondary aims are to compare patient-reported and radiographic outcomes between the two groups.

Methods

All patients with a BIO-RSA and size 38 glenosphere were retrospectively identified and matched to patients with a regular RSA and size 42 glenosphere. Matched patients were invited for a follow-up visit. ROM was assessed as well as radiographic outcomes (lateralisation, distalisation, inferior overhang, scapular notching, heterotopic bone formation, radiolucency, stress shielding, bone graft healing and viability, and complications), and patient-reported outcomes (subjective shoulder value, Constant score, American Shoulder and Elbow Surgeons score, activities of daily living which require internal rotation, activities of daily living which require external rotation and a visual analogue scale for pain). Outcomes were compared between the two groups.

Results

In total, 38 BIO-RSAs with a size 38 glenosphere were matched to 38 regular RSAs with a size 42 glenosphere. Of the 76 matched patients, 74 could be contacted and 70 (95%) were included. At the final follow-up, there were no differences between the two groups in ROM, patient-reported outcomes, or radiographic outcomes ($p>0.485$).

Conclusion

Using a larger glenosphere is a feasible alternative to BIO-RSA for lateralising RSA, providing comparable ROM, patient-reported, and radiographic results, while potentially decreasing costs, operative time, and complication rates.

Introduction

The introduction of the reverse shoulder arthroplasty (RSA) design by Grammont revolutionized surgical treatment for shoulder pathologies.[1] However, it came with several drawbacks including prosthetic instability, deficient internal and external rotation, aesthetic complaints owing to loss of shoulder contour, scapular impingement and stress fractures.[2] All of these can be attributed completely or partially to the medialisation and distalisation of the humerus and the centre of rotation.

One option to lateralise the glenoid component is Bony Increased Offset Reverse Shoulder Arthroplasty (BIO-RSA).[3] Some studies report improved rotation with BIO-RSA compared to non-lateralised RSA.[4,5] However, this procedure is promising but also more technically challenging, prone to specific compilations and costly compared to regular RSA.[6]

Increasing the size of the glenoid component has also been proposed to further reduce the rate of scapular notching and improve rotational range of motion (ROM) by lateralising the humerus without changing the centre of rotation, and by increasing the inferior overhang. Previous studies have reported lower rates of scapular notching and greater rotational and elevation ROM in patients with a larger glenoid component.[4–6] However, other studies did not replicate these results.[5,7]

To our knowledge, no prior studies have been published directly comparing these two groups. To address the gaps and contradictions in the literature, this study aims to compare the ROM of BIO-RSA using a 38-millimetre (mm) component with regular RSA using a 42-mm glenoid component in a matched retrospective series using the Delta Xtend reverse shoulder prosthesis (DePuy Synthes, Warsaw, United States) with a 155° neck-shaft angle design. The secondary aims are to compare patient-reported and radiographic outcomes, such as scapular notching.

Methods

Patient selection

After approval from the institutional review board, all consecutive primary RSA procedures performed between January 2015 and December 2021 were identified. Because all consecutive patients were identified, no power calculation was performed. Inclusion and exclusion criteria are reported in Table 1.

Table 1. Inclusion & exclusion criteria

Inclusion	Exclusion
1. RSA using Delta Xtend* model	1. Deceased patients
2A. Regular RSA + size 42 glenosphere or 2B. BIO-RSA + size 38 glenosphere	2. Language barrier with regards to the researchers (speaking English, French, Italian, German, Dutch, and Spanish)
	3. No contact information
	4. Bone graft used for glenoid bone loss or glenoid defects (instead of lateralisation)
	5. Augmented or lateralised prosthesis designs
	6. Pre-operative nerve palsies or neurological defects

BIO-RSA: bony increased offset reverse shoulder arthroplasty, RSA: reverse shoulder arthroplasty. *Depuy Synthes, Warsaw, United States

All patients with a BIO-RSA and a size 38 glenosphere (BIO-RSA 38 group) were matched with patients with a regular RSA and a size 42 glenosphere (RSA 42 group) with a 1:1 ratio. Patients were matched based on sex, age, body mass index (BMI), and the indication for RSA using optimal pair matching. The mean and maximum distances in propensity score between the pairs were reported. The matched patients were contacted for a follow-up visit. In case patients were unable to visit the hospital, questionnaires were completed via telephone. The minimum follow-up for inclusion was set at 1 year, on the basis of a previous study that reports no change in ROM and patient reported outcome measures (PROMs) between the 1- and 2-year follow-up periods.[8]

Variables

A revision was defined as any unplanned surgical procedure to the ipsilateral glenohumeral joint related to the arthroplasty. A complication was defined as any unforeseen medical problem caused by the RSA procedure which negatively influences the outcome temporarily or permanently.[9]

The following questionnaires were completed: subjective shoulder value (SSV),[10] Constant score,[11] American Shoulder and Elbow Surgeons (ASES),[12] activities of daily living which require internal rotation (ADLIR),[13,14] activities of daily living which require external rotation (ADLER),[15] and a visual analogue scale (VAS) for pain.

Radiographic outcomes

On the most recent radiographic imaging lateralisation, distalisation, inferior overhang, scapular notching, heterotopic bone formation, radiolucency, stress shielding, bone graft healing and viability, and potential other complications were assessed independently assessed by two authors

in a standardised fashion described in Additional file 1: Table S1.[3,16–24] All assessments were then discussed with the senior author to reach consensus between the three assessors. For the angle and distance measurements, three authors including the senior author independently performed the measurements, and the mean result was calculated.

Statistics

The improvement from pre- to postoperative measurements was compared using paired Wilcoxon signed-rank tests. For the comparisons between the two groups (BIO-RSA 38 versus RSA 42), unpaired tests were used. This was chosen over paired tests owing to the potential differences in response rate between the groups leading to unequal group sizes, the overall small cohort, and limited population to draw from for patient matching leading to minimal dependence between matched cases.[25,26] Chi-squared or Fisher exact tests were used for binary categorical variables and *T*-tests or Mann-Whitney *U* tests were used for continues variables.

For the radiological assessment, reliability between the first two authors analysing the radiographs was assessed using the interclass correlation (ICC) for the angle measurements and Cohen's Kappa (*k*) for the grades. An ICC of less than 0.50 was considered poor reliability, between 0.5 and 0.75 moderate reliability, between 0.75 and 0.9 good reliability, and greater than 0.9 was considered excellent reliability. A Cohen's Kappa of less than 0.20 was considered a slight agreement, between 0.21 and 0.40 fair, between 0.41 and 0.60 moderate, between 0.61 and 0.80 substantial, and between 0.81 and 1.00 was considered almost perfect agreement.[27]

To correct for multiple testing, *p*-values were adjusted using a Benjamini-Hochberg procedure. An adjusted *p*-value lower than 0.05 was considered statistically significant. A post-hoc power calculation was performed for the primary outcomes (rotational range of motion) using 0.05 as the significance level, a resulting power of > 0.80 was considered sufficient. Statistical analysis was performed using R version 4.2.1 (R Foundation for Statistical Computing, Vienna, Austria).

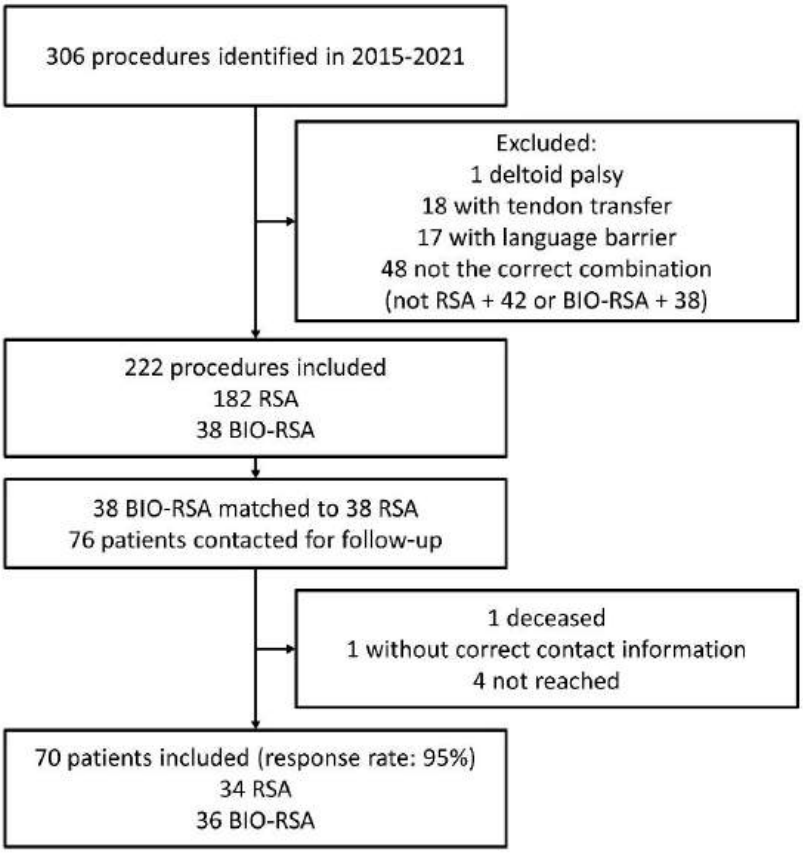
Surgical technique

In all cases a Delta Xtend prosthesis was used (DePuy Synthes, Raynham, USA) with a high-mobility polyethylene insert size 3. A deltopectoral approach was used for all BIO-RSA cases and an anterosuperior approach for all RSA cases. For BIO-RSA cases, a bone graft of approximately 1 centimetre in width was used, harvested from the resected humeral head when possible. In cases of BIO-RSA the glenoid baseplate construct was angled 10° inferior, in RSA cases an inclination angle of 0° was aimed for. The subscapularis tendon was either absent or detached in all cases without subsequent repair.

Results

After inclusion (Figure 1) 38 BIO-RSAs with a glenosphere size 38 were matched to 38 regular RSAs with a glenosphere size 42. The median distance in propensity scores between the matched pairs was 0.27 and the maximum distance 0.58. Of the 76 matched patients, 74 could be contacted and 70 were included (response rate: 95%). In total, five patients had a bilateral prosthesis but there were no cases in which both shoulders were included in the study. The post-hoc power calculation resulted in a statistical power of > 0.99 for the primary outcomes (rotational range of motion).

Figure 1: Inclusion flowchart



Flowchart showing the inclusion, exclusion, matching, and follow-up including the number of patients for each step in the process.

Study cohort

The mean age at the time of primary surgery in the cohort was 72 (*SD* 8) and the majority of patients were female (44/70, 63%). The follow-up was longer in the RSA 42 group (3.7 years; interquartile range (IQR): 2.2-5.4 versus 2.3 years; *IQR* 2.1-2.5, $p = 0.0126$). The other patient characteristics did not differ between the groups after correction of the *p*-values (Table 2).

Table 2. Patient characteristics

	BIO-RSA 38 (n=36)	RSA 42 (n=34)	p-value	adjusted p-value
Female, n (%)	22 (61)	22 (65)	[A]0.756	1.000
Age, mean years (SD)	70 (8)	73 (7)	[B]**0.0424**	0.806
BMI, mean kg/m^2 (SD)	26 (4)	26 (4)	[B]0.990	1.000
Diagnosis, n (%)			[C]0.912	1.000
Osteoarthritis	13 (36)	14 (41)		
Cuff tear arthropathy	12 (33)	9 (26)		
Irreparable cuff tear	10 (28)	10 (29)		
Acute fracture	1 (3)	1 (3)		
ASA classification, n (%)			[A]0.938	1.000
I	8 (24)	15 (42)		
II	21 (62)	15 (42)		
III	5 (15)	6 (17)		
Comorbidities, n (%)				
Diabetes	3 (8)	2 (6)	[C]1.000	1.000
Cardiological	20 (56)	18 (53)	[A]0.826	1.000
Thyroid disease	5 (14)	4 (12)	[C]1.000	1.000
Gastroenterological	4 (11)	4 (12)	[C]1.000	1.000
Respiratory	0 (0)	3 (9)	[C]0.109	1.000
Urological	4 (11)	3 (9)	[C]1.000	1.000
Neurological	1 (3)	5 (14)	[C]0.199	1.000
Psychological	2 (6)	1 (3)	[C]0.609	1.000
Oncological	0 (0)	1 (3)	[C]0.486	1.000
Smoking, n (%)	5 (14)	3 (9)	[C]0.711	1.000
Dominant side operated, n (%)	12 (52)	7 (32)	[A]0.167	1.000
Previous surgery, n (%)	12 (33)	6 (18)	[A]0.133	1.000
Rotator cuff	11 (31)	3 (9)	[A]**0.0231**	0.462
Latarjet	1 (3)	2 (6)	[C]0.609	1.000
Other	1 (3)	1 (3)	[C]1.000	1.000
Follow-up time, median years (IQR)	2.3 (2.1-2.5)	3.7 (2.2-5.4)	[D]**0.0006**	**0.0126**

BMI: body mass index, BIO-RSA: Bony increased offset reverse shoulder arthroplasty, RSA: reverse shoulder arthroplasty, SD: standard deviation. [A]chi-square, [B]t-test, [C]Fisher exact test, [D]Mann-Whitney U test

An acromioplasty was more commonly performed in the RSA 42 group (32/34; 94% versus 25/36; 69%, $p = 0.0399$). The other treatment characteristics did not differ between the two groups (Table 3).

Table 3. Treatment characteristics

	BIO-RSA 38 (n=36)	RSA 42 (n=34)	p-value	adjusted p-value
Acromioplasty, n (%)	25 (69)	32 (94)	[A]**0.00798**	**0.0399**
Humerus size, median (IQR)	10 (10-11)	10 (10-11)	[D]0.707	0.707
Cemented humerus, n (%)	0 (0)	3 (9)	[C]0.109	0.327
Retroversion, median ° (IQR)	30 (30-30)	30 (30-30)	[D]0.588	0.707
Locking screws, n (%)			[A]0.069	0.276
2/4	0 (0)	17 (50)		
0/4	36 (100)	17 (50)		
Graft donor, n (%)				
Humeral head	34 (94)			
Iliac crest	1 (3)			
Allograft	1 (3)			

BIO-RSA: bony increased offset reverse shoulder arthroplasty, IQR: interquartile range, RSA: reverse shoulder arthroplasty
[A]chi-square, [B]t-test, [C]Fisher exact test, [D]Mann-Whitney U test

Information on pre-operative assessments was available in 67 patients (96%). There was no difference between the groups in pre-operative PROMs and ROM ($p > 0.260$; Table 4).

Table 4. Pre-operative measurements

median (IQR)	BIO-RSA 38 (n=36)	RSA 42 (n=34)	p-value	adjusted p-value
Subjective Shoulder Value (0-100)	30 (30-50)	40 (30-48)	0.554	0.554
VAS pain (0-10)	6 (5-7)	7 (5-7)	0.348	0.554
Anterior elevation, °	90 (70-130)	105 (80-137)	0.547	0.554
External rotation, °	10 (-4-30)	20 (10-44)	0.065	0.260
Internal rotation, level reached	buttock (hip-L3)	L3 (buttock-T12)	0.059	0.260

BIO-RSA: bony increased offset reverse shoulder arthroplasty, IQR: interquartile range, RSA: reverse shoulder arthroplasty, VAS: visual analogue scale

Patient-reported outcomes

PROM results at final follow-up were available in 67 patients (96%). The SSV and pain score at final follow-up improved significantly compared to the pre-operative measurements ($p < 0.001$), the other PROMs were not recorded pre-operatively. There were no differences between the two groups in PROMs at the final follow-up or the amount of improvement between pre-operative measurements and the final follow-up ($p = 0.961$, Table 5).

Table 5. Patient-reported and clinical outcomes

	BIO-RSA 38 (n=36)	RSA 42 (n=34)	p-value	adjusted p-value
At final follow-up				
Subjective Shoulder Value (0-100), median (IQR)	80 (70-91)	80 (60-90)	[D]0.488	0.961
VAS pain (0-10), median (IQR)	1 (0-2)	1 (0-3)	[D]0.615	0.961
Constant score, mean (SD)	62 (17)	65 (23)	[B]0.699	0.961
ASES score, median (IQR)	82 (75-90)	82 (67-92)	[D]0.790	0.961
ADLIR score, median (IQR)	84 (78-88)	86 (77-95)	[D]0.370	0.961
ADLER score, median (IQR)	29 (28-30)	29 (21-30)	[D]0.290	0.961
Anterior elevation, median ° (IQR)	160 (134-170)	150 (115-160)	[D]0.365	0.961
Abduction, median ° (IQR)	150 (115-170)	140 (88-160)	[D]0.564	0.961
External rotation, median ° (IQR)	40 (20-49)	30 (20-45)	[D]0.676	0.961
External rotation in abduction, median ° (IQR)	75 (60-80)	70 (45-90)	[D]0.961	0.961
Internal rotation, median level reached (IQR)	L1 (L5-T12)	L4 (buttock-T12)	[D]0.380	0.961
Improvement from pre-operative to final follow-up				
Subjective Shoulder Value (0-100), mean Δ (SD)	44.6 (24.8)	31.0 (29.0)	[B]0.197	0.961
VAS pain (0-10), mean Δ (SD)	-4.7 (3.2)	-4.2 (2.2)	[B]0.607	0.961
Anterior elevation, mean Δ° (SD)	38.4 (55.9)	29.0 (52.4)	[B]0.578	0.961
External rotation, mean Δ° (SD)	21.1 (32.1)	2.9 (27.6)	[B]0.070	0.961
Internal rotation, mean Δ* (SD)	4.7 (5.3)	-1.4 (5.3)	**[B]0.00220**	**0.0352**

BIO-RSA: bony increased offset reverse shoulder arthroplasty, IQR: interquartile range, RSA: reverse shoulder arthroplasty, SD: standard deviation, VAS: visual analogue scale. *Improvement measured in number of anatomic landmarks (such as one vertebra) surpassed superiorly compared to the pre-operative level reached
[B]t-test, [D]Mann-Whitney U test

Clinical outcomes

Information on clinical outcomes was available in 52 patients (74%). Postoperatively, there were no cases with an external rotation lag sign or Hornblower sign. All ROM measurements in the total

cohort improved significantly compared to pre-operative measurements ($p < 0.0132$), except for internal rotation ($p = 0.052$). There were no differences between the two groups in ROM at the final follow-up ($p = 1.000$). The level reached in internal rotation improved by more anatomical landmarks in the BIO-RSA 38 group (Δ4.7, *SD* Δ5.3 versus Δ-1.4, *SD* Δ5.3, $p = 0.0352$, Table 5).

Radiographic outcomes

Radiographs were available in 45 patients (59%). The interobserver reliability between the first to assessors was good for the lateralisation shoulder angle (LSA; ICC: 0.851, 95% confidence interval (CI): 0.457-0.942) and for the inferior overhang (ICC: 0.769, 95%CI: 0.600-0.873), and was excellent for the distalisation shoulder angle (DSA; ICC: 0.911, 95%CI: 0.842-0.951). The reliability was poor for the radiological grading of scapular notching ($k = 0.425$), glenoid lucencies ($k = 0.161$) humeral lucencies ($k = 0.474$), ossification ($k = 0.353$), and for the assessment of graft healing ($k = 0.068$). The reliability was moderate for the assessment of graft viability ($k = 0.644$), zones of humeral lucencies ($k = 0.581$) and stress shielding ($k = 0.536$).

None of the components were considered at risk of loosening (notching grade IV, radiolucencies grade III or IV, or radiolucencies in more than three zones). Of the 25 patients with a BIO-RSA and available radiographs, the graft was considered viable in 21 cases (84%) and healed in 23 cases (92%). The inferior overhang was greater in the RSA 42 group (4.91 mm; *SD* 1.84 versus 2.96 mm; *SD* 1.80, $p = 0.02186$). The other radiographic measurements and outcomes did not significantly differ between the two groups ($p > 0.485$, Table 6).

Table 6. Radiographic measurements and outcomes

	BIO-RSA 38 (n=25)	RSA 42 (n=20)	p-value	adjusted p-value
Lateralisation angle, mean ° (SD)	82.7 (8.2)	82.8 (8.0)	[B]0.738	1.000
Distalisation angle, mean ° (SD)	52.1 (8.1)	57.6 (9.4)	**[B]0.04846**	0.436
Lateralisation/distalisation, median (IQR)	1.62 (1.40-1.71)	1.42 (1.21-1.77)	[D]0.178	1.000
Inferior overhang, mean mm (SD)	2.96 (1.80)	4.91 (1.84)	**[B]0.002186**	**0.02186**
Notching, n (%)			[C]0.853	1.000
None	18 (75)	16 (80)		
Grade I	5 (21)	3 (15)		
Grade II	1 (5)	1 (4)		
Glenoid: lucency grade, n (%)			[C]0.708	1.000
None	23 (96)	19 (95)		
Grade I	0 (0)	1 (5)		
Grade II	1 (4)	0 (0)		
Humerus: lucencies, median n of zones (IQR)	0 (0-1)	0 (0-0)	[D]0.155	1.000
Humerus: highest grade of lucencies, n (%)			[C]0.233	1.000
None	18 (72)	18 (90)		
Grade I	4 (16)	0 (0)		
Grade II	2 (8)	2 (10)		
Grade III	1 (4)	0 (0)		
Ossification grade, n (%)			[C]0.492	1.000
None	18 (72)	16 (80)		
Grade I	5 (20)	3 (15)		
Grade II	2 (8)	0 (0)		
Grade III	0 (0)	1 (5)		
Stress shielding, n (%)	3 (12)	2 (10)	[C]1.000	1.000
Graft healed, n (%)	23 (92)			
Graft viable, n (%)	21 (84)			

BIO-RSA: bony increased offset reverse shoulder arthroplasty, mm: millimetres, RSA: reverse shoulder arthroplasty
[A]chi-square, [B]t-test, [C]Fisher exact test, [D]Mann-Whitney U test

Complications

Three unfavourable events occurred: one patient in the BIO-RSA 38 group suffered a peri-prosthetic fracture of the humeral diaphysis which healed successfully with conservative treatment. One patient in the RSA 42 group underwent a single-stage revision replacing all

components 6 months after the primary RSA owing to a periprosthetic joint infection. One patient in the BIO-RSA 38 group underwent a revision owing to aseptic loosening of the glenoid 3 years after the primary RSA, in which the glenoid components were replaced and the glenoid was reconstructed with a bone graft from the iliac crest.

Discussion

The current study aimed to compare the outcomes of RSA using a larger (size 42) glenosphere with BIO-RSA using a regular glenosphere (size 38), using a Delta Xtend prosthesis for both groups, designed as an inlay prosthesis with a 155° neck-shaft angle. At the final follow-up, there was no difference in post-operative ROM and PROMs between the groups. The level reached in internal rotation increased by a greater amount in the BIO-RSA 38 group (p=0.0352). However, although not statistically significant, internal rotation trended towards lower preoperative values in the BIO-RSA 38 group. Furthermore, the clinical relevance of this difference is questionable. Similarly, external rotation improved markedly in the BIO-RSA group but was inferior preoperatively in this group. Both differences were not statistically significant. Apart from a greater inferior overhang in the RSA 42 group, there were no differences in radiographic measurements or outcomes. These results suggest that using a larger glenosphere size is a feasible alternative for lateralising RSA.

Range of motion

Previous studies have found glenoid lateralisation to be associated with postoperative range of motion, alongside preoperative shoulder function, preoperative status of the rotator cuff, surgical approach and implant design.[28–30] To our knowledge, there are no previous studies directly comparing BIO-RSA with a regular glenosphere size to RSA using a larger glenosphere size. The literature comparing BIO-RSA with regular RSA, regardless of glenosphere size, is contradictory. Only a few studies report improved rotational ROM, which did not seem to translate to superior PROM results.[31–33] Similarly, literature comparing ROM between glenosphere sizes is sparse and contradictory. Some studies report superior ROM, which does not translate to superior PROM results.[5–7,34] Our results suggest that the benefit in terms or rotational ROM when using a BIO-RSA instead of a regular RSA is matched by the benefit of using a larger glenosphere.

The increase in lateralisation when using a size 42 glenosphere, which is currently the largest commercially available glenosphere for this implant model, instead of a size 38 is minimal (2 mm) compared to the increase in lateralisation when opting for BIO-RSA (1 cm). In the current study, the poly-ethylene insert was the same size for both groups. The increased lateralisation in BIO-RSA leads to greater muscle tension, which is beneficial for movement. Despite the minimal lateralisation, using a larger glenosphere also leads to increased wrapping of the surrounding muscles around the prosthesis, which also increases muscle tension. In contrast to BIO-RSA, the larger glenosphere also does not change the centre of rotation, thereby maintaining the positive

effect on the deltoid moment arm that is inherent to the medialised centre of rotation in RSA. Nevertheless, increasing the size of the glenosphere also increases the dynamic anteroposterior span of the prosthesis, leading to an increased rotational arc of the humerus. This results in a more anterior position of the humerus in internal rotation, which may cause an anterior conflict between the greater tuberosity and the conjoint tendon-coracoid complex, potentially limiting internal rotation. Using BIO-RSA with a standard glenosphere does not increase the diameter of the rotational arc, potentially avoiding an anterior conflict. Further biomechanical studies are required to confirm the dynamic changes caused by increasing the glenosphere size.

Previous studies focus on objective ROM measured in clinic. However, for daily activities requiring rotational motion, more complex movements are necessary than internal or external rotation alone, such as adequate abduction and extension.[35] A previous study confirmed this discordance between objective and patient-reported range of motion.[36] To assess functional internal and external rotation in tasks of daily living the ADLIR and ADLER questionnaires were used in this study. Satisfactory results were achieved in our cohort of patients undergoing RSA and BIO-RSA (median ADLIR 84/100 and median ADLER 29/30) and no difference was observed between the two groups.

Radiographic parameters

Implant positioning was assessed on radiographs using the LSA, DSA, and inferior overhang. Interestingly, the angles did not differ significantly between the groups, despite inherent differences in implant positioning. A possible explanation may be the inaccuracy of these measurements on plain radiographs: the angle is highly dependent on the angle in which the radiograph is taken and the position of the arm. Furthermore, the inferior overhang was significantly lower in the BIO-RSA 38 group (p=0.02186). However, the overhang is measured using lines drawn parallel to the central peg of the glenoid. In contrast to regular RSA, the glenoid component is placed in about 10° inferior inclination when using a BIO-RSA technique as described by Boileau et al.[37] This results in a lower measurement than the true inferior overhang.

In the current cohort, the rate of scapular notching did not differ between the two groups (p = 1.000). To our knowledge, there are no previous studies comparing radiographic outcomes between BIO-RSA and regular RSA using a larger glenosphere. However, two previous studies comparing BIO-RSA with regular RSA regardless of glenosphere size found a higher rate of notching in the RSA group (75% versus 40% and 68% versus 33%, $p < 0.028$).[33,38] When a larger glenoid component is placed in the same position, more inferior overhang is created, potentially decreasing the rate of notching. One previous randomised study found a significant reduction in scapular notching rate using a larger glenoid component; 49% in patients receiving a 38-mm component, and 12% with a 42-mm component.[4]

Costs

BIO-RSA using an autograft from the humeral head is more economical compared to other lateralisation techniques, such as using an allograft or an augmented baseplate.[39] However, the added operative time and specific operative tools required for this procedure still lead to increased costs compared to regular RSA, while opting for a larger glenosphere does not increase the time or costs of the procedure. We hypothesize that regular RSA using a larger glenosphere is more cost-effective than BIO-RSA.

Limitations

First, patients were identified retrospectively, which may lead to a selection bias owing to the factors influencing the decision to perform RSA or BIO-RSA. To address this shortcoming, patients were matched to create more comparable groups. Despite including age as a matching parameter, the age differed significantly between the groups, this may indicate that the RSA cohort was too small to achieve optimal matching. There was also a significant difference in follow-up time between the groups. This reflects current practice as BIO-RSA is becoming increasingly popular in recent years. We intentionally selected a large time window to include a large cohort, which benefits the matching accuracy. The difference in follow-up time may be a source of bias, however, a previous study found no significant changes in results after 1 year, which was the minimum follow-up in this study.[8] Furthermore, the approach differed between the groups (the anterosuperior approach was used for regular RSA and the deltopectoral approach for BIO-RSA); however, the approach did not influence outcomes in previous studies.[40,41] Second, bone graft healing and viability, and implant positioning is best assessed on computed tomography (CT) scans instead of radiographs. However, CT scans were not available in all patients. To maintain methodological consistency, we opted to assess these factors on radiographs in all patients. Last, the current cohort is too small to compare rare complications and revisions between the two groups.

Conclusion

At a minimum of 1 year follow-up, there was no difference in range of motion when comparing BIO-RSA with a size 38 glenosphere to RSA with a size 42 glenosphere. Similarly, no differences were found in patient-reported and radiographic results, apart from a smaller inferior overhang in the BIO-RSA group. However, prospective, randomised studies are required to confirm the findings, as well as including different prosthesis designs. Besides the similar clinical results found in this study, increasing the glenosphere size is less technically demanding and time consuming compared to BIO-RSA, less costly, and does not have technique-specific complications such as graft non-union and resorption. These findings suggest that using a larger glenosphere size is a feasible and simple alternative to BIO-RSA for lateralising RSA. The conclusions of this study may

also add perspective for manufacturers to pursue development and research towards larger (i.e. 44-46 mm) glenospheres.

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Chapter 7

Functional and Radiographic Outcomes of Reverse Shoulder Arthroplasty with a Minimum Follow-up of 10 Years.

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Part II

Abstract

Background

The use of reverse shoulder arthroplasty (RSA) is becoming increasingly prevalent. However, few studies have been published reporting the long-term outcomes of RSA. This study aims to report the clinical, radiographic, and patient-reported outcomes of the Delta Xtend reverse shoulder prosthesis, performed by a single surgeon and with a minimum follow-up of 10 years.

Methods

All RSA procedures performed between 2005 and 2012 were identified. Patients were contacted and invited for a follow-up visit including clinical assessment, radiographs, and patient-reported outcome measures. Patients with a follow-up of less than 10 years were excluded. The revision-free implant survival was calculated at 10 years. Between 2005 and 2012, 119 procedures in 116 patients meeting inclusion criteria were identified. Of these patients, 35 were deceased before reaching the 10-year follow-up and 23 could not be reached. In total, 63 RSAs could be included in 61 patients (response rate: 75%). The median follow-up was 11.7 years (interquartile range [IQR]: 10.5-13.2).

Results

Of the 61 patients, 7 patients underwent a revision after a median of 3 years (IQR: 0.2-9.8) during the total follow-up period. The 10-year implant survival was 94% (95% confidence interval: 84-98). At final follow-up, the median anterior elevation was 135° (IQR: 130°-160°), the median abduction was 120° (IQR: 100°-135°), and the median level reached with internal rotation was L5 (IQR: sacrum-L5). The median Auto-Constant score was 68 (IQR: 53-78), the median Subjective Shoulder Value was 80 (IQR: 70-93), and the median pain score was 0.2/10 (IQR: 0-2). In total, radiographs could be obtained in 25 patients (40%). Scapular notching occurred in 10 patients (40%), which was classified as Sirveaux-Nerot grade IV in 3 patients (12%). Ossification occurred in 10 patients (40%), and stress shielding in 2 patients (8%). Radiolucencies were observed around the humeral component in 24 patients (96%) and around the glenoid component in 13 patients (52%).

Conclusion

The long-term results of RSA with a Delta Xtend prosthesis are favourable, with long-term improvement in range of motion and patient-reported outcome measures, and a satisfactory implant survival rate. Interestingly, the radiographical analysis showed high prevalence of signs associated with loosening, which did not seem to translate to high complication rates or inferior results.

Introduction

Reverse shoulder arthroplasty (RSA) is used for an increasing range of indications including cuff tear arthropathy, irreparable cuff tears, primary osteoarthritis with an insufficient cuff or bone stock, and complex proximal humerus fractures. In the two decades since the introduction of the RSA design by Grammont, technical improvements have led to increasingly favourable outcomes.[1] Current RSA designs result in good range of motion (ROM), patient-reported outcome measures (PROMs), and overall low complications on short-term outcomes.[2]

However, few studies have reported detailed long-term outcomes of RSA. To our knowledge, only three studies have reported outcomes after RSA with a minimum follow-up of 10 years,[3–5] and 1 study reported outcomes after 15 years.[6] These studies report favourable functional and patient-reported outcomes, which remain stable at long-term follow-up.[3–6] Only in 1 out of four studies the Constant score and anterior elevation decreased from mid- to long-term follow-up,[5] in the other three studies the significant functional improvements after RSA did not decrease after 10 years.[3,4,6]

Despite cohorts in the four studies with a minimum follow-up of 10 years ranging from 22 to 93 patients, radiographic analysis was only available in relevant numbers in 1 study; Bacle et al. assessed radiographs of 64 RSAs after 10 years and found scapular notching in 74% of cases.[5] Other studies reporting radiographic outcomes at mid- to long-term follow-up report similar results with scapular notching rates ranging from 68 to 94%, [5,7] and grade III or IV notching in 42% of cases.[8] A previous meta-analysis found that patients with scapular notching had significantly worse clinical outcomes and reduced ROM compared to patients without scapular notching.[9,10] Previous studies have also shown that notching is influenced by glenoid component positioning; inferior overhang reduces rates of notching.[11,12] The preferred placement of the glenoid component may vary between surgeons, resulting in different rates of notching.

Furthermore, there is an incongruence in the literature regarding the long-term survival rate of RSA; the reported survival rates vary between 82% and 93% after at least 10 years.[3,5,6,13,14] The number at risk at this time point was low in all studies. The survival rate is also highly dependent on implant design and fixation techniques that are used, which are highly variable between studies. With regard to the Delta Xtend prosthesis specifically, a 97% survival rate has been reported after 8 years, but no survival analysis is available after 10 years.[15]

Another point of discussion is the decision to repair the subscapularis tendon, leave it detached, or use a subscapularis-sparing approach. Previous short- to mid-term studies comparing subscapularis tendon repair with leaving the subscapularis tendon detached report conflicting results in terms of ROM and patient-reported outcomes.[16–18] To our knowledge, long-term data are lacking; none of the four studies with a minimum follow-up of 10 years mention whether the subscapularis tendon was spared, repaired, or left detached.[3–6]

To address these gaps and inconsistencies in the literature, this study aims to assess the functional, patient-reported, and radiographic outcomes of RSA using the Delta Xtend prosthesis performed by a single surgeon using a standardized technique (including ensuring an inferior overhang of the glenosphere and systematically not repairing the subscapularis tendon) at a minimum follow-up of 10 years.

Materials and methods

For this case series, RSA procedures using the Delta Xtend prosthesis (DePuy Synthes, Raynham, United States of America) performed by the senior author between 2005 and 2012 were identified. Patients were contacted and invited for a follow-up visit including clinical assessment, radiographs and PROMs. If patients were unable to visit the hospital, questionnaires were completed by telephone. All patients in which contact was established after 10 years and the presence or absence of a revision could be confirmed were considered eligible, regardless of the completeness of the outcome parameters. Patients with a follow-up of fewer than 10 years were excluded.

Surgical technique

In all cases, the following procedures were performed. The Delta Xtend prosthesis was used, which is based on the original Grammont design.[1] A superolateral approach was used unless pre-operative evaluation of imaging indicated that an inferior extension of the incision might become necessary, for example, to remove inferior osteophytes. The subscapularis was tenotomized without reattachment when it was still present. An intramedullary guide at 30° of retroversion and neck-shaft angle (NSA) of 155° was used to determine the level of the humeral cut enabling the humeral component placement, which is different from the anatomical NSA of 135°. Due to the inlay design of the glenoid baseplate, this does not create unwanted distalization of the humerus. The metaglene was positioned at the inferior edge of the glenoid. In general, a size 42 glenosphere was used to achieve sufficient inferior overhang, a size 38 glenosphere was used exceptionally in small female patients. A 'high mobility' polyethylene component was used, which decreases the risk of impingement and increases the ROM.

Patient-reported and clinical outcome measures

At the final follow-up, the Auto-Constant score, the Subjective Shoulder Value (SSV), and a visual analogue scale (VAS) for pain were completed.[19] A previous study has shown an excellent correlation between the self-reported Auto-Constant and the Constant score assessed by a physician.[20] Furthermore, the ROM was measured during the follow-up visit by at least two physicians; 1 fellowship-trained shoulder surgeon and 1 orthopaedic surgeon in fellowship. In case patients were unable to visit the hospital for follow-up, self-reported ROM for anterior

elevation, abduction, and external and internal rotation was assessed in a standardized fashion using example videos recorded by the researchers which were sent to the patient to imitate for the patient to properly demonstrate and record their ROM. Two previous studies found that self-assessed ROM was accurate in the majority of cases (>85%).[21,22]

Radiographic outcomes

On the most recent radiographic imaging, lateralization, distalization, scapular notching, heterotopic bone formation, radiolucency, stress shielding, and potential other complications were independently measured and graded by two authors in a standardized fashion. For the angles, the mean of the two measurements was taken as the definitive measurement. For the other assessments, all radiographs were discussed with the senior author and consensus was reached. Lateralization and distalization were measured using the angles described by Boutsiadis et al.[23] Scapular notching was graded according to the Sirveaux-Nerot classification.[24] Based on a previous study reporting all cases of glenoid component loosening occurring in patients with grade IV notching and none in grade I-III, glenoid components with grade IV notching were considered at risk of loosening.[25] Heterotopic bone formation was graded according to a modified Brooker classification.[26,27] Radiolucency occurring between the implanted material and bone interface was assessed and graded according to Schoch et al.[28] Glenoid and humeral components with grade four or five radiolucent lines or the presence of radiolucency in more than three zones around the humeral component as described by Gruen et al. were considered at risk of loosening.[29–34] Stress shielding was defined as described by Melis et al. as the presence of medial and lateral cortical bone narrowing associated with osteopenia, condensation lines around the tip of the stem, and a spot weld between the cortical bone and the stem.[30] The presence of other complications, such as fractures, bone cysts, malalignment or material failure, was also assessed.[27]

Statistical analysis

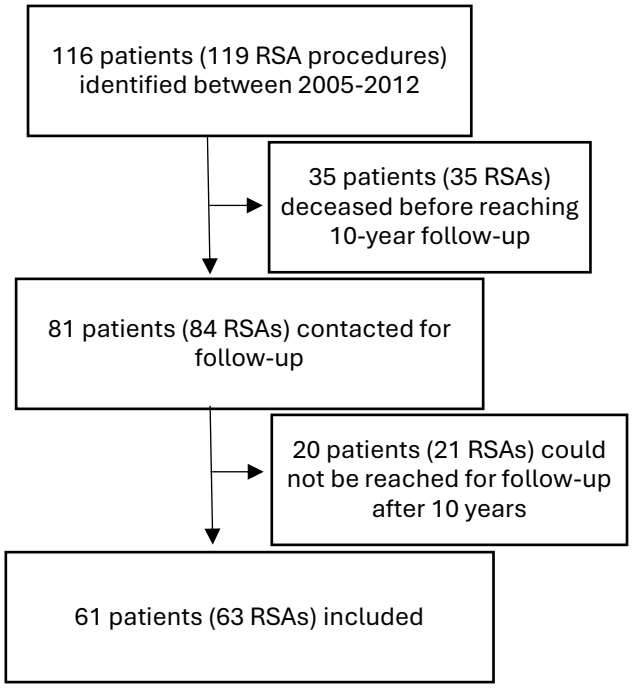
Categorical data were represented with numbers and proportions. For numerical data, normality was assessed using histograms and the Shapiro-Wilk test. Normally distributed data were represented by means and standard deviations, and abnormally distributed data by medians and interquartile ranges (IQRs). The revision-free implant survival was calculated at the 10-year follow-up, using a revision for any cause as the event and the time until revision or final follow-up as the survival time. Patients that were deceased before reaching 10-year follow-up or could not be contacted were censored. For the radiological assessment, reliability between the first two authors analysing the radiographs was assessed using the interclass correlation (ICC) for the angle measurements and Cohen's Kappa (k) for the grades. An ICC of less than 0.50 was considered poor reliability, between 0.5 and 0.75 moderate reliability, between 0.75 and 0.9 good reliability, and greater than 0.9 was considered excellent reliability. A Cohen's Kappa of less than 0.20 was considered a slight agreement, between 0.21 and 0.40 fair, between 0.41 and 0.60 moderate, between 0.61 and 0.80 substantial, and between 0.81 and 1.00 was considered almost perfect

agreement. Pre-operative PROM scores and ROM were compared with the outcomes at the final follow-up using paired t-tests. A *P* value lower than 0.05 was considered statistically significant. Statistical analysis was performed using R version 4.0.5 (R Foundation for Statistical Computing, Vienna, Austria) and R studio (RStudio Public-benefit corporation, Boston, United States of America).

Study cohort

Between 2005 and 2012, 119 RSA procedures (116 patients) by a single surgeon using the Delta Xtend prosthesis were identified and patients were contacted for follow-up. In total, 61 patients with 63 RSAs could be included (response rate: 75%; Figure 1). The median follow-up was 11.7 years (IQR: 10.5-13.2). The median age at the time of the primary RSA in the cohort was 73 (IQR: 69-76) and the majority of patients were female (n=44, 69%). Cuff tear arthropathy was the most common indication for RSA (n=28, 44%; Table I).

Figure 1: Inclusion flowchart



Flowchart showing the inclusion and follow-up process including the number of patients in each step. (RSA: Reverse Shoulder Arthroplasty)

Table I. Description of cohort			
Female, n (%)	44 (69)	Dominant side operated, n (%)	34 (55)
Age, median (IQR)	73 (69-76)	Approach, n (%)	
Diagnosis, n (%)		Superolateral	58 (92)
Cuff tear arthropathy	28 (44)	Deltopectoral	5 (8)
Revision	2 (3)	Acromioplasty, n (%)	27 (43)
Rheumatoid arthritis	2 (3)	Cemented humerus, n (%)	4 (6)
Acute fracture	1 (2)	Retaining cup, n (%)	4 (6)
Fracture sequelae	2 (3)	Retroversion, median (IQR)	20 (13-30)
Cuff arthropathy	2 (3)	Glenosphere size 42, n (%)	59 (92)
Primary osteoarthritis, other or unknown	26 (42)	Subscapularis detached (without reinsertion) or absent	63 (100)
IQR: interquartile range			

Pre-operative measurements

Pre-operatively, the median Constant score was 25 (IQR: 17-35), the median VAS for pain was 7 (IQR: 3-7) and the ROM was limited in all patients (Table II).

Table II. Pre-operative measurements (n=36)	
	median (IQR)
Constant score	25 (17-35)
VAS pain (0-10)	7 (3-7)
Anterior elevation	70° (45°-79°)
Abduction	68° (45°-75°)
External rotation	10° (0°-20°)
Internal rotation level reached	Sacrum (buttock-L5)
IQR: interquartile range, VAS: visual analogue scale	

Results

Complications and revisions

In total, 10 complications occurred (16%), of which seven (11%) required a revision after a median of 3 years (IQR: 0.2-9.8). Notably, there were no cases with acromial fractures. The majority of revisions occurred either shortly after the primary surgery or after more than 10 years. The 10-year implant survival was 94% (95% confidence interval: 84-97). One patient underwent a revision for a peri-prosthetic fracture elsewhere and the exact date of the revision was unknown, this patient

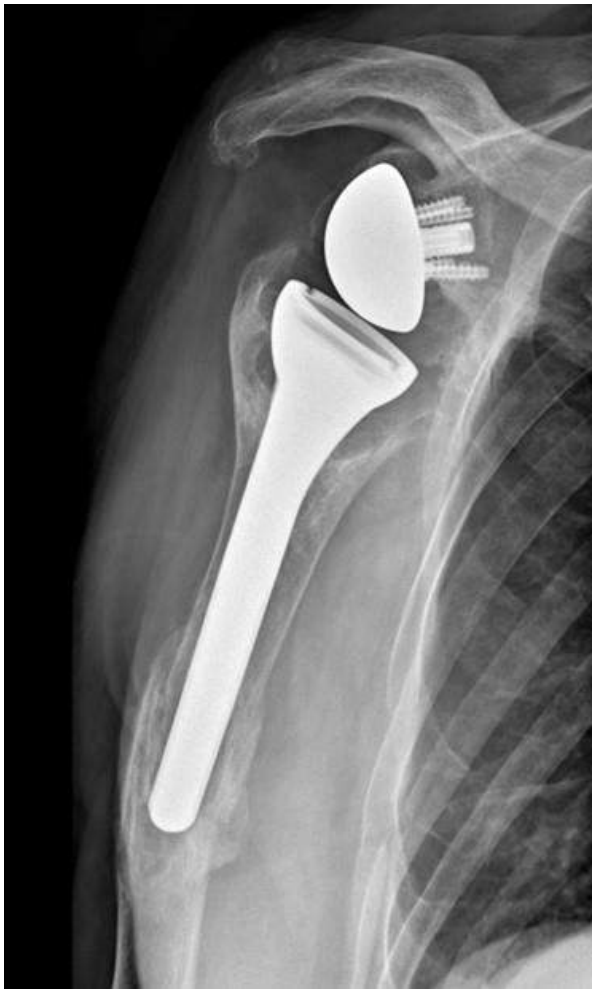
was censored in the survival analysis. One case of peri-prosthetic infection was treated with a two-stage revision (Table III). There were no cases that required a secondary revision. Three complications were treated conservatively: 1 peri-prosthetic fracture, 1 axillary nerve injury leading to deltoid paralysis and 1 plexus injury. The former healed with conservative treatment (Figure 2) and the latter resolved completely after two years, the patient with a deltoid paralysis remained symptomatic but opted for conservative treatment.

Table III. Revision characteristics

Case	Sex	Age at RSA	Reason for revision	Years to revision	Procedure	Components revised
1	Male	65	Peri-prosthetic fracture		ORIF	None
2	Male	66	Instability	0.2	Revision	PE
3	Male	69	Instability	0.0	Revision	PE
4	Male	72	Instability	0.3	Revision	Humeral, PE
5	Female	75	Loosening	11.5	Revision	All
6	Female	75	Luxation	11.2	Reduction under anaesthesia	None
7	Male	69	Infection	5.7	Two-stage revision	All

ORIF: Open reduction and internal fixation, PE: polyethylene

Figure 2: Example of a peri-prosthetic fracture and grade III notching



Anteroposterior radiograph of a Delta Xtend prosthesis in situ 13.1 years post-operatively showing a peri-prosthetic fracture at the distal end of the humeral stem which was treated conservatively and grade III scapular notching.

Patient-reported and clinical outcome measures

PROMs were collected in 48 patients (79%). At the final follow-up, the median Auto-Constant score was 68 (IQR: 53-78), the median SSV was 80 (IQR: 70-93), and the median VAS for pain was 0.2 (IQR: 0-2). Internal rotation did not differ significantly from pre-operative measurement to the

final follow-up (p = .144). All other ROM measurements and patient-reported outcomes showed significant long-term improvement compared to the pre-operative measurements (p < .001; Table IV).

Table IV. Patient-reported outcomes

	At final follow-up (n=47), median (IQR)	Improvement from pre-operative to final follow-up (n=26), median (IQR)	*p-value
Auto-Constant score	68 (53-78)	42 (32-52)	**<0.001**
Subjective Shoulder Value	80 (70-93)		
VAS pain (0-10)	0.2 (0-2)	-7 (-7--3)	**<0.001**
Anterior elevation	135° (131°-160°)	75° (58°-98°)	**<0.001**
Abduction, median (IQR)	120° (100°-135°)	45° (28°-80°)	**<0.001**
External rotation, median (IQR)	20° (10°-43°)		
Internal rotation, median level reached (IQR)	L5 (sacrum-L5)	1/5 of total range (-1/5-2/5)	0.144

IQR: interquartile range, VAS: visual analogue scale. *Comparison of the scores pre-operatively and at final follow-up using a paired t-test

Table V. Radiographic outcomes (n=25)

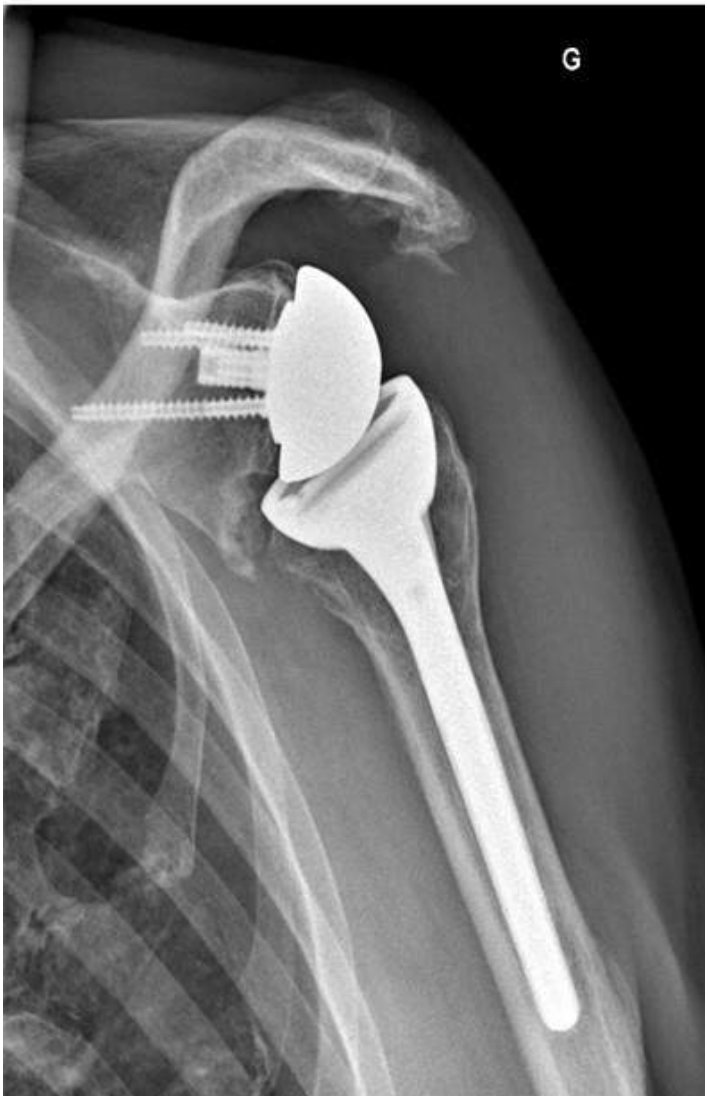
Lateralization angle, median (IQR)	78 (76-82)	Humerus: zones with lucencies, median (IQR)	2 (1-2)
Distalization angle, median (IQR)	51 (45-54)	Humerus: highest grade of lucencies, n (%)	
Notching, n (%)		None	1 (4)
None	15 (60)	Grade I	14 (56)
Grade I	2 (8)	Grade II	3 (12)
Grade II	4 (16)	Grade III	3 (12)
Grade III	1 (4)	Grade IV	1 (4)
Grade IV	3 (12)	Grade V	3 (12)
Glenoid: lucency grade, n (%)		Humerus: at risk of loosening, n (%)	4 (16)
None	12 (48)	Ossification grade, n (%)	
Grade I	9 (36)	None	15 (60)
Grade II	2 (8)	Grade I	6 (24)
Grade III	0 (0)	Grade II	0 (0)
Grade IV	0 (0)	Grade III	4 (16)
Grade V	2 (8)	Stress shielding, n (%)	2 (8)
Glenoid: at risk of loosening, n (%)	4 (16)		

Radiographic outcomes

In total, radiographs could be obtained in 25 patients (40%). The interobserver reliability between the first two authors was poor for the distalization angle (ICC = 0.36) and moderate for the lateralization angle (ICC = 0.57). The agreement was moderate for ossification (k = 0.52), and slight for scapular notching (k = 0.16), the number of zones around the humeral component with radiolucencies (k=-0.01), the grade of radiolucencies around the humeral component (k = 0.07), the grade of radiolucencies around the glenoid (k = 0.14), and the presence of stress shielding (k = -0.03). All radiographs were discussed with the senior author and the definitive assessment is reported.

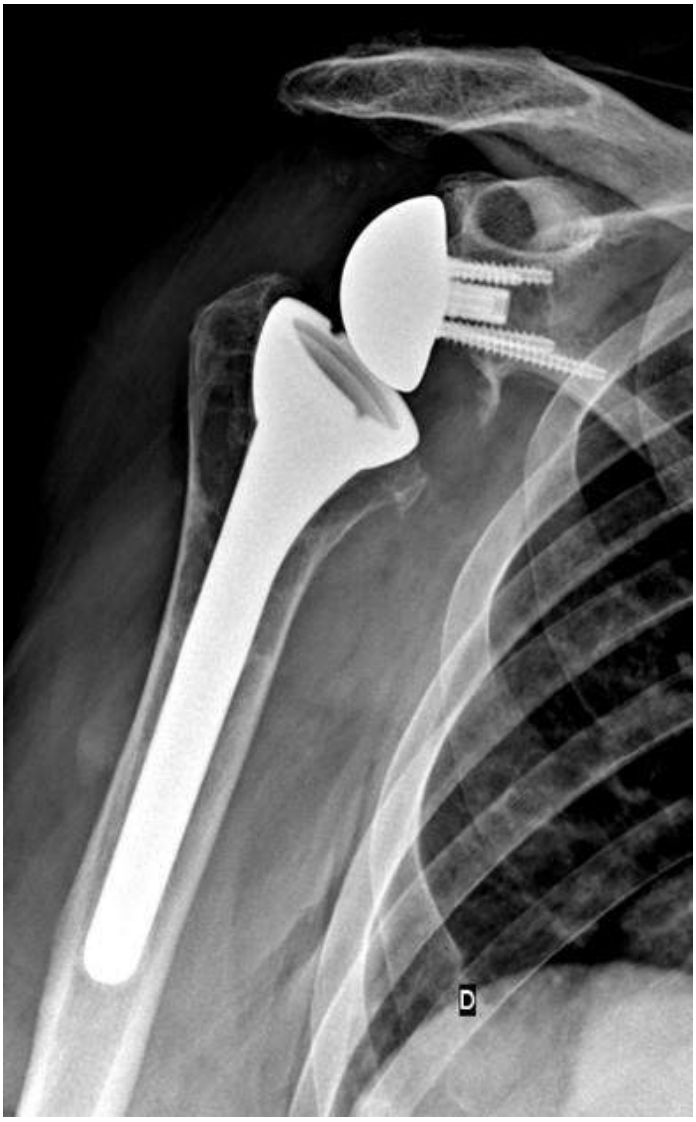
Scapular notching occurred in 10 patients (40%), which was classified as grade IV in 3 patients (12%). The glenoid component was considered at risk of loosening (notching grade IV or radiolucency grade IV or V) in 4 patients (16%). Ossification occurred in 10 patients (40%; Figure 3), and stress shielding in 2 patients (8%). Radiolucencies around the humeral component occurred in 24 patients (96%), 4 humeral components (16%; Figure 4) were considered at risk of loosening due to the grade or amount of radiolucency (grade IV or V, or radiolucencies occurring in >3 zones). Radiolucencies around the glenoid component occurred in 13 patients (52%; Table V).

Figure 3: Example of grade III ossification.



Anteroposterior radiograph of a Delta Xtend prosthesis in situ 10 years post-operatively, showing grade III ossification between the humerus and glenoid.

Figure 4: Example of grade IV radiolucencies and grade IV scapular notching



Anteroposterior radiograph of a Delta Xtend prosthesis in situ 13.1 years post-operatively, showing grade IV radiolucencies and grade IV scapular notching, potentially caused by an insufficient inferior overhang due to a high position of the metaglene.

Discussion

This study aimed to report the outcomes of RSA with a minimum follow-up of 10 years, performed by a single surgeon using the Delta Xtend prosthesis and a standardized technique. During the total follow-up period, seven patients (11%) required a revision. The 10-year revision-free survival rate was 94%. Furthermore, the long-term results show satisfactory PROM results and a long-term improvement in ROM. The radiographical analysis showed a high prevalence of signs associated with worse outcomes and complications such as loosening. Scapular notching occurred in 40% of cases, and at least some degree of radiolucencies around the humeral component was found in 96% and around the glenoid component in 52%. However, the radiographical findings did not translate to inferior functional results or high complication rates.

Radiographic outcomes

In the current cohort, the rate of scapular notching was high, but lower in comparison to other long-term reports using similar prosthesis models. Scapular notching occurred in 40% of cases, which was classified as grade III or IV in 16%. Conversely, Bacle et al. found scapular notching in 73% of cases after 10 years, 30% of which were graded III or IV.[5] Previous mid- to long-term studies of RSA report similarly high rates of scapular notching, ranging between 68 to 94%. [5,7] This is markedly higher than our long-term findings (40%). The discrepancy in scapular notching may be explained by the placement of the glenoid component. Previous research has shown that inferior overhang and a large glenosphere size reduce rates of notching.[11,12,35,36] The senior author responsible for all surgeries in our cohort routinely created an inferior overhang of 5-10 millimetres by adjusting the glenoid baseplate placement and glenosphere size accordingly, using a size 42 in most cases. This is an important aspect when placing RSA, as a high degree of notching may lead to loosening or breaking out of the component. A previous meta-analysis also found that patients with scapular notching had significantly worse clinical outcomes and reduced ROM compared to patients without scapular notching.[9,10]

Besides component placement and surgical technique, several factors related to the implant design are of influence on the development of scapular notching, such as size, shape, humeral NSA, lateralization, and bearing properties. More recent, short-term studies have highlighted several important aspects of implant design which may reduce the rate of scapular notching.[37] Previous studies have found lower rates of notching in lateralized prosthesis designs.[38–41] Similarly, bony increased offset RSA decreases the rate of scapular notching.[42] Furthermore, the humeral NSA may be of influence; a systematic review of 38 studies with 2222 shoulders reported a higher rate of scapular nothing with an NSA of 155° compared to a prosthesis with an NSA of 135° and a lateralized glenosphere.[43] Another design option is an inverted bearing RSA (a poly-ethylene glenosphere and metal humeral component).[44] This implant design leads to a distinct type of scapular notching which appears to be less severe and solely mechanical, differing from notching enhanced by poly-ethylene-induced osteolysis.[45,46] In a previous study this type of notching

caused by the metal component (present in 35% of cases) did not lead to inferior clinical results.[45] However, comparative studies and long-term results of inverted bearing RSA are still lacking. These studies show that several innovations in implant design may decrease the rate of scapular notching, and lead to a lower rate of scapular notching than found in the current cohort. However, long-term results are required to confirm these results. Furthermore, it is difficult to distinguish exactly which aspect of the prosthesis is responsible for the reduction in notching rates as most studies compare two types of prosthesis which differ in multiple aspects of the design.

Ossification occurred in 10 patients (40%) in the current cohort. To our knowledge, there are no studies with a minimum follow-up of 10 years reporting the presence or absence of ossification. Mid- to long-term studies report rates of ossification ranging from 18% to 75%,[30,47–52] and are inconclusive with regards to the association between ossification and adverse clinical outcomes.[47,50] Further studies are required to clarify the definition and role of ossification after reverse shoulder arthroplasty.

This study demonstrates a relatively high rate of radiolucencies on radiographic assessment 10 years after RSA. Radiolucent lines are a sign of progressive destruction of peri-prosthetic bone, caused by implant micro-motion, poly-ethylene wear and aspects of implant design and positioning,[12,53,54] resulting in an inflammatory cascade and bone resorption.[55] Radiolucent lines have been linked to implant loosening and failure.[53,56] In the current cohort, at least some degree of radiolucencies around the humeral component was found in 96% of patients and 16% of humeral components were considered at risk of loosening due to the grade of radiolucency and the number of zones affected. Radiolucencies were reported around the glenoid component in 52% of patients, 16% were considered at risk of loosening. In contrast to our results, the rate of radiolucency was lower in 1 study with radiographical assessment after 10 years; radiolucent lines around the glenoid component occurred in 5% and radiolucent lines around the humeral component in at least 3 zones (considered at risk of loosening) were seen in 12%.[5] This discrepancy may be explained by the subjectivity in radiographic assessment, as demonstrated by the low agreement between the first two assessors in our study when determining the grades and zones of radiolucency. However, the high grade of radiolucencies combined with a low revision rate in both studies also suggest radiographic findings currently causing the component to be considered at risk of loosening may have to be re-evaluated for long-term results. Current methods of assessing and grading radiolucency and risk of loosening seem to be inaccurate and highly dependent on the assessor; further studies are required to develop more objective methods.

Functional outcomes

The outcomes of the current cohort are comparable to previous studies with a minimum follow-up of 10 years after RSA demonstrating significant improvement in functional outcomes and ROM. The median Auto-Constant score was 68, which is comparable to mean scores of 55 and 58 reported in the literature. The median SSV in the current cohort was 80%, similar to 1 previous study which reported a mean SSV of 78% after 15 years.[6] These studies confirm our findings that

the improvement in patient-reported functional outcomes after RSA is sustained at a long-term follow-up. Only 1 study reported a significant decrease in anterior elevation and constant score between the mid- and long-term follow-up periods.[5] In the current study with a median follow-up was 11.7 years, 11% of cases required a revision. The 10-year implant survival rate in this study (94%) is comparable with previous studies reporting the 10-year survival ranging from 82% to 93%.[3,5,6,13,14] The survival rate of 94% is also comparable to a previously published survival rate of the Delta Xtend prosthesis of 97% at 8 years, demonstrating no clear decrease in survival from 8 to 10 years follow-up.[15]

Despite the high degree of positive radiographic findings in the current study, the revision rate remains low, and the functional outcomes are favourable. This discrepancy may be caused by the lack of objective grading methods for radiographic outcomes, which is demonstrated by low interobserver agreement statistics in the current study (ICC ≤ 0.57 and k ≤ 0.52). However, all assessments were discussed, and consensus was reached with the senior author. Furthermore, previous studies seem to report similar results; high rates of concerning radiographic findings, but positive results.[5,6] Another potential explanation could be the decreasing patient expectations and activity with age. It is possible that older patients put less strain on their shoulder and simultaneously tend to respond more positively on questionnaires due to lower expectations and less demanding daily activities. Unfortunately, due to the low numbers, we were unable to statistically test the association between radiographic findings and outcome variables. Future studies could aim to identify which objective radiographic outcomes influence long-term functional outcomes and complications. In addition, future cohort studies may evaluate influence of patient characteristics such as age on PROM results.

Subscapularis tendon

In the current cohort, the subscapularis tendon was routinely detached and not repaired. A commonly voiced concern for leaving the subscapularis tendon off is a deficient internal rotation and increased instability and dislocation rates. In total, 4 revisions (6%) were performed for these reasons; 3 for instability and 1 for a dislocation. This is comparable to previous studies with a minimum follow-up of 10 years reporting revisions for recurrent instability or dislocation ranging from 4 to 14%.[3,4,6] One study reporting internal rotation after a minimum of 10 years reported a median level of internal rotation reaching the sacrum without mentioning handling of the subscapularis tendon.[5] In the current study, the median level reached in internal rotation was L5, suggesting that not repairing the subscapularis tendon leads to a range of internal rotation which is comparable to the literature. Previous short-term studies report contradicting results on the role of the subscapularis, and there is no conclusive evidence that leaving the subscapularis tendon detached leads to a decrease in functional or objective internal rotation.[16–18,57,58] This is supported by a biomechanical analysis demonstrating that the pectoralis major is the main internal rotator after RSA.[59,60] In addition, the limitation in internal rotation after RSA implantation may be related to a conflict between the implants and the bone rather than musculature, for which the most

influencing factor is the positioning of the implants.[61] We hypothesise from a biomechanical point of view that the altered mechanics of the shoulder after implantation of a RSA may allow for the deltoid and other muscles to replace the function of the subscapularis muscle, and that the importance of the subscapularis muscle after RSA may be limited. Furthermore, leaving the subscapularis tendon detached may even prevent a potential restriction in external rotation and abduction caused by increased tension on the repaired subscapularis tendon when lateralizing and distalizing the proximal humerus compared to the anatomical situation. A previous study has also shown significantly increased ROM in abduction when not repairing the subscapularis tendon.[16] However, the current study does not include a control group and future long-term comparative studies are required to further investigate the role of the subscapularis muscle.

Limitations

The results of this study must be interpreted in light of its limitations. First, the high degree of missing data and loss to follow-up may introduce a bias in this study. In addition, 35 patients were deceased before reaching the 10-year follow-up, creating a competing risk with revision surgery and potentially introducing a bias favouring healthier patients. However, this is inherent to studies with a long-term follow-up in an elderly population and reflects daily practice. Despite the long follow-up, we were able to achieve a response rate of 75%. However, it is possible that complications occurred in the 25% of patients that did not respond, which are not taken into account. Furthermore, not all patients were able to visit the hospital for a radiograph. We attempted to minimize bias by obtaining PROMs and ROM outcomes in those patients that were unable to visit the hospital. Second, for most radiographic analyses, the agreement between the first two assessors was poor. However, all radiographs were discussed with the senior author and consensus was reached in order to obtain the most objective measurement possible. Nonetheless, the assessment of radiographs and discussion between authors remains subject to bias. Third, only revisions performed at our centre could be assessed, it is possible that those patients that were lost to follow-up or deceased underwent a revision elsewhere, resulting in an underestimation of the revision rate. Similarly, this may also apply to the rate of complications, which is also low in the current cohort. This limitation is inherent to a single-centre study with a long follow-up. Last, the single-centre, single-surgeon, single-technique, and single-prosthesis study design results in a high homogeneity and internal validity of the data. However, this decreases the external applicability of the results.

Conclusion

RSA results in a long-term improvement of functional outcomes and ROM after a minimum of 10 years. The 10-year implant survival rate was 94%. High rates of radiolucency are reported, which do not seem to translate to inferior outcomes or complication rates. The lower rate of scapular notching (40%) in comparison to the literature may be related to the amount inferior overhang of

the glenoid component. Leaving the subscapularis tendon detached did not result in high rates of instability or poor internal rotation relative to the available long-term literature. However, this topic is still debated, and no consensus has yet been reached. Future studies could focus on clarifying the role of the subscapularis muscle and the relationship between radiographic findings and clinical long-term outcomes.

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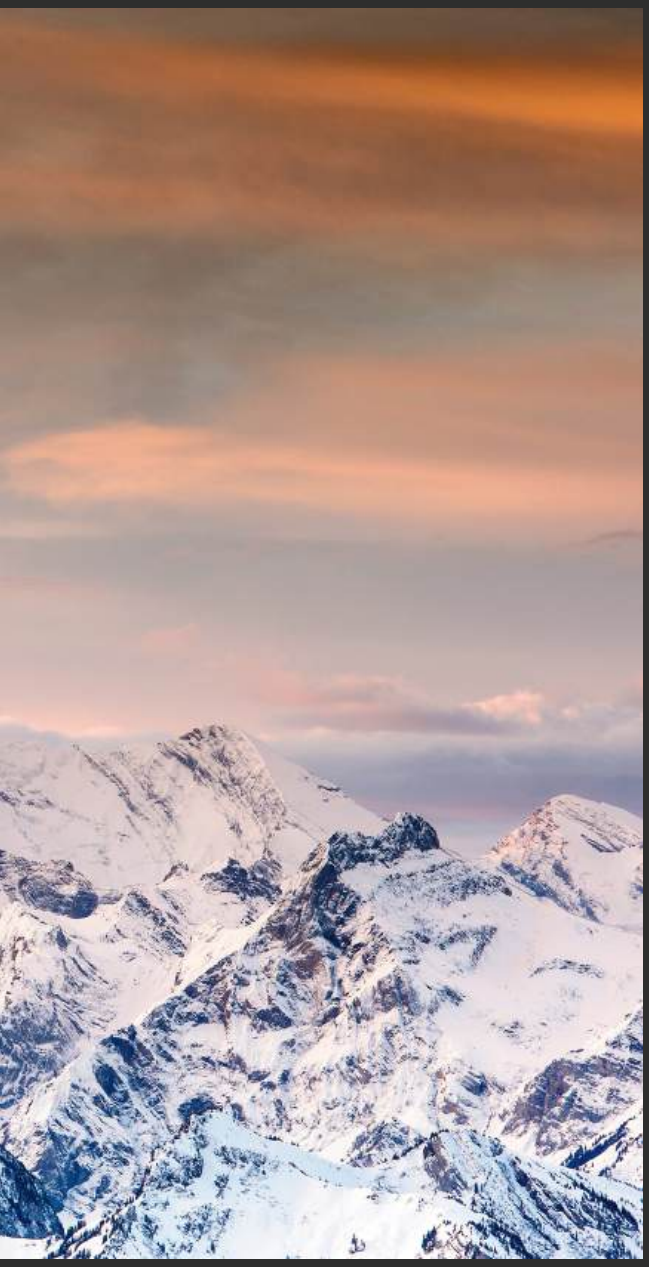
Part III

General discussion and summary



Chapter 8

General Discussion

Part III

This thesis aimed to assess and optimise the outcomes of total elbow and reverse total shoulder arthroplasty. Current trends in indications for total shoulder and elbow arthroplasty are assessed, a simplification of the follow-up is proposed, the relation between volume and outcome is analysed, several techniques aimed at optimising the outcomes are compared, and long-term results are reported. This section presents a critical appraisal of the main findings in light of existing literature, with an emphasis on how these insights contribute to ongoing clinical debates. Conclusions that may impact decision-making in clinical practice and directions for future research are presented in the form of *key insights* at the end of this section.

Trends in current indications

For both total shoulder and elbow arthroplasty, the range of indications is broadening. Due to the continuous development of prosthetic designs, techniques, and alternative treatment options, a shift in indications is observed.

For total elbow arthroplasty, rheumatoid arthritis is becoming less common as an indication and traumatic indications, such as acute fractures and posttraumatic sequelae, are becoming more common (**chapter 2**). Several underlying mechanisms can be appraised. Although the results of total elbow arthroplasty for rheumatoid arthritis are suboptimal, with acceptable patient-reported outcomes but relatively high complication rates,[1] this decreasing trend in the use of total elbow arthroplasty for rheumatoid arthritis is not necessarily due to the limited success of total elbow arthroplasty. Instead, the non-surgical treatment options for rheumatoid arthritis have expanded with increasing success. Similarly, the increase in traumatic indications should not be attributed to the success of total elbow arthroplasty in these cases. The alternatives in elderly patients with complex intra-articular distal humerus fractures, such as open reduction and internal fixation, have proven to result in unpredictable and often unsatisfactory results.[2,3] The optimal choice of treatment in these cases remains a topic of debate.

For reverse total shoulder arthroplasty, the most common indications in the Netherlands are highlighted in **chapter 5** but an accurate overview of global trends is currently lacking. Previous literature has shown that the proportion of reverse total shoulder arthroplasties is increasing compared to hemi- and anatomic shoulder arthroplasty.[4] The growing preference for reverse total shoulder arthroplasty may stem from its favourable functional outcomes, but it also reflects concerns regarding the long-term integrity of the rotator cuff, particularly in elderly patients, which may lead to a growing tendency in favour of reverse rather than anatomic total shoulder arthroplasty in cases of primary osteoarthritis. Furthermore, increased success with muscle advancement for previously considered 'irreparable' rotator cuff tears may have led to a decrease in arthroplasties performed for rotator cuff tears alone.[5] Similar to total elbow arthroplasty, cases of complex proximal humerus fractures remain a topic of debate.[6]

Follow-up

In **chapter 3**, a simplification of the follow-up after elbow arthroplasty is proposed using one single question (the Subjective Elbow Value), which showed a significant, moderate correlation with traditional patient-reported outcome measures.

In contrast to the elbow, a simplification of the follow-up metrics is already widely adopted for shoulder arthroplasty. The Subjective Shoulder Value is commonly used for monitoring patients after shoulder arthroplasty, for research purposes, and is also used in **chapter 6** and **chapter 7**.[7] However, the Subjective Shoulder Value is often used alongside other patient-reported outcome questionnaires, nullifying the advantage of a Single Assessment Numeric Evaluation. The Subjective Shoulder Value is currently not used as a stand-alone metric.

These results suggest that the follow-up after total shoulder and elbow arthroplasty may be simplified to two or more *key* questions focussing on function and pain during activity rather than several longer questionnaires. This simplification may streamline postoperative monitoring by decreasing the burden on patients and healthcare costs while maintaining clinical validity.

However, factors other than pathology or intervention influencing patient-reported outcomes after upper extremity arthroplasty should also be considered. Patient-reported outcome measures, whether in the form of questionnaires or a single question, are often considered an objective measure of the result of an intervention. However, a growing body of evidence shows that many more factors are of influence.[8] Previous studies have shown that psychological factors, such as depression, resilience, pain catastrophising, and kinesiophobia may influence patient-reported outcomes in orthopaedic conditions.[9–14] For example, a previous study in shoulder arthroplasty showed a strong correlation between mental health scores and postoperative pain and function, suggesting that mental health plays an important role in the outcome after upper extremity arthroplasty.[12] In light of these results, the pathology and the intervention should not be considered the sole driver of variation in patient-reported outcomes and satisfaction. The correlation between mental health status and functional outcomes likely works both ways. Not only does (pre-existing) mental health status influence patient-reported outcomes, but poor elbow function may also influence overall mental health. Some studies have already validated simplified versions of mental health questionnaires containing only two questions. For example, shortened assessments exist for depression (PHQ-2),[15] anxiety (GAD-2),[16] and pain self-efficacy (PSEQ-2).[17] A previous study found that a PSEQ-2 below 10 was associated with worse patient-reported outcomes, degree of functional limitation, and severity of pain in patients with upper extremity pathology.[11] Mental health should be an integral part of the evaluation of upper extremity arthroplasty and a focus of future research. Potentially, one or more questions may be added to the set of *key* questions for the follow-up of total elbow arthroplasty focusing on the mental health component.

Optimising outcomes

Many of the current techniques and practices influence the outcomes of total elbow and shoulder arthroplasty. However, the literature to date is inconclusive on many of these topics. In this thesis, three of the most prominent topics of debate have been chosen: the association between volume and outcome, the surgical approach, and the method of increasing offset in reverse total shoulder arthroplasty.

Volume

For both total shoulder and elbow arthroplasty, specific expertise is required. However, procedures are performed at many different centres in the Netherlands and the number of high-volume centres is limited.

Primary total elbow arthroplasty in the Netherlands is performed in 24 different centres (**chapter 4**). Of these centres, only one is considered high-volume (>18 procedures per year), performing 20 procedures per year on average. Treatment in a high-volume centre was not correlated with a higher revision rate. However, the population treated at the single high-volume centre differed from the rest of the cohort. The high-volume centre treated more younger, male patients with traumatic indications and previous surgeries, which are factors that may lead to a higher risk of revision. Furthermore, these factors, combined with the higher level of expertise at this centre may influence decision-making in favour of a revision surgery rather than non-operative treatment of a complication after arthroplasty. The absence of a revision does not directly imply a successful arthroplasty, and patient-reported outcomes, pain scores, or range of motion are not collected in the registry used for **chapter 4**. In other literature, a relationship is found between hospital volume and complication rate. Previous studies report lower complication rates with a centre-volume of more than 20 cases per year or a surgeon-volume of more than 10 cases per year.[18,19]

Reverse total shoulder arthroplasty is performed at 82 different centres in the Netherlands (**chapter 5**). Only 11% of patients are treated at one of the two high-volume centres (>53 procedures per year). In a previous study, an annual surgeon-volume of 30 reverse total shoulder arthroplasties or more was associated with a 26% decreased odds of revision within two years.[20] Similar to total elbow arthroplasty, patient demographics differ between high- and low-volume centres for reverse total shoulder arthroplasty.[21,22] **Chapter 5** also shows that surgeons in high- or low-volume centres prefer different surgical approaches, prosthetic designs, and sizes. Although the association between centre-volume and outcome was not the main aim of this study and surgeon-volume was not specifically assessed, the centre-volume was a confounding factor in one of three regression analyses and the prosthesis model in all three regression analyses. Consequently, the demographics, prosthetic design, and surgical approach may be potential

confounding factors, complicating the assessment of the association between volume and outcome.

Considering the specific expertise required for total shoulder and elbow arthroplasty and the correlation between hospital volume and complication rate for both arthroplasties in the previous literature, centralisation of total shoulder and elbow arthroplasty in a handful of high-volume centres may be the solution. Some considerations are essential to this goal. For example, the previously discussed complex fractures of the distal or proximal humerus may present at any hospital providing trauma care. For adequate and unbiased decision-making in these cases, it is important for (orthopaedic) surgeons treating shoulder or elbow trauma to have a centre in their network that is available for referral to perform primary arthroplasty or open reduction and fixation with the option of intra-operative conversion to arthroplasty if necessary. Low-threshold consultation and referral to these centres should be the standard.

Surgical approach

Several different surgical approaches are used for total shoulder and elbow arthroplasty, with each approach having specific advantages and disadvantages. Therefore, an informed decision for the right technique may aid in optimising the outcomes after total shoulder and elbow arthroplasty.

For total elbow arthroplasty, the posterior approach is most commonly used in the Netherlands (95%), using a technique leaving the triceps intact in most cases (42%), followed by triceps detachment (35%), and a triceps-split technique (5%; **chapter 4**). Previous literature has shown that detachment of the triceps is associated with triceps insufficiency and inferior function, potentially due to the necessity of applying a cast postoperatively when detaching the triceps.[23] A triceps-sparing approach avoids these issues. However, due to the relatively limited exposure of the joint surface in a triceps-sparing approach, concerns have been raised about the positioning of the implant, which may affect functional results and complications rates.[24] Future, prospective studies are required to compare the approaches, including an assessment of implant positioning.[25]

Regarding the two most common surgical approaches used for reverse total shoulder arthroplasty (the deltopectoral and the anterosuperior approach), the deltopectoral approach is used most often (54% versus 46%; **chapter 5**). When correcting for confounding factors, no difference is found in the revision rate between the two surgical approaches. This means that the choice of approach can be made based on other factors. Each approach comes with specific advantages and disadvantages. For example, the deltopectoral approach can be extended distally, which can be helpful to remove inferior osteophytes or to address a humeral shaft fracture, but requires detachment of the subscapularis tendon.[26] The anterosuperior approach provides a more direct view of the glenoid surface which facilitates accurate glenoid baseplate positioning and provides easier exposure of posterior structures, but requires splitting the deltoid muscle.[27] Currently, the choice of approach is based chiefly on surgeon preference. This is demonstrated in

chapter 5, revealing a preference for one of the two approaches in most centres, with high-volume centres preferring the anterosuperior approach. For high-volume surgeons, it may be feasible to use both approaches regularly and make the decision on a case-by-case basis. However, for lower-volume surgeons, this may prove challenging. Therefore, it may be more preferable to choose one approach. The deltopectoral approach should be preferred in this case, as it is used for a wider range of procedures outside arthroplasty.

Increasing offset in reverse total shoulder arthroplasty

The method to increase the offset in reverse total shoulder arthroplasty is an important consideration in optimising the outcomes. Many different techniques are used, however, these are not recorded in detail in the national registry, and an accurate overview of the current techniques is lacking. In **chapter 6**, using a bonegraft to increase offset (BIO-RSA) is compared to performing a regular reverse total shoulder arthroplasty with a larger glenosphere size; a glenosphere with a diameter of 42 millimeters instead of 38, which is the median diameter of all glenosphere components used in the Netherlands (**chapter 5**). Range of motion and patient-reported outcomes were similar between the groups, suggesting that using a larger glenosphere is a feasible alternative to using a bonegraft. This potentially decreases the operative time, costs, and risk of complications related to using a bonegraft. To our knowledge, this is the first study directly comparing reverse shoulder arthroplasty using bonegraft to using a larger glenosphere. Previous literature comparing a bonegraft with regular reverse total shoulder arthroplasty without taking into account glenosphere size is contradictory. Some studies report improved rotational range of motion when using a bonegraft, which did not seem to translate to superior patient-reported results.[28–30] Similarly, literature comparing range of motion between different glenosphere sizes is sparse and contradictory. Some studies report superior range of motion with increased glenosphere size, which also does not translate to superior patient-reported results.[31–34] As a result, the clinical relevance of the improvements in range of motion is questionable. Our results suggest that the benefit of using a bonegraft is matched by using a larger glenosphere. However, the comparison was made in a matched retrospective cohort, resulting in a potential indication bias. Furthermore, alternative options for increasing offset in reverse total shoulder arthroplasty, such as design alterations increasing offset and metal augmentation, should also be compared to current techniques.

Long-term results

For evidence-based decision-making in total shoulder or elbow arthroplasty, the longevity of the implant and the long-term results are an important consideration.

The 5-year revision-free implant survival of total elbow arthroplasty in the Netherlands is 91% (**chapter 4**), which is slightly lower than the 5-year survival of reverse total shoulder

arthroplasty (95%, **chapter 5**). The most common reason for revision after total elbow arthroplasty was aseptic loosening (34%), followed by an infection (23%) and elbow instability (23%), and polyethylene wear (14%) and a periprosthetic fracture (14%; **chapter 4**). This is similar to previous literature, reporting aseptic loosening as the most common reason for revision.[35] It remains unclear why the implant survival of total elbow arthroplasty, with loosening as the main driver, remains limited. Some suggestions can be extracted from the results of **chapter 4**; a higher body mass index and male sex were associated with a higher chance of revision, suggesting that increased loadbearing and functional demands play a role. Furthermore, polyethylene wear over time is a concern following total elbow arthroplasty but is not consistently recognised as such. Polyethylene wear may lead to instability or loosening due to the inflammatory cascade initiated by released particles from the worn polyethylene components in the joint. Specifically in linked designs, the repetitive strain on the bushings or hinge system makes the implant susceptible to wear. A portion of revision cases attributed to aseptic loosening or instability may have been primarily caused by implant wear as an underlying mechanism, although the clinical relevance of this mechanism is questionable. The shift towards semi-constrained and unlinked implant designs and accompanying improvement in implant survival also suggest that valgus-varus and rotational forces play a role in loosening. This is supported by previous studies, which suggest torsional, asymmetrical and gravitational forces are major drivers in implant wear and loosening.[36–38] For these reasons, a lifetime limit of lifting a maximum of 1 to 5 kilograms with the operated arm is advised in some practices to prevent implant wear and loosening. However, this recommendation is debated. There is no consensus on the optimal postoperative restrictions; in a survey of European elbow specialists, 60% of respondents indicated that they recommend a lifelong restriction for “heavy physical activities with the elbow”, while others recommended avoiding rotational forces or did not provide any restrictions.[39] Furthermore, the biomechanical background behind these restrictions is questionable; one biomechanical study showed that forces during some activities of daily living could, in theory, lead to permanent deformation of the prosthetic material, even after the instruction to lift no more than 1 kilogram.[40] Furthermore, the practical feasibility of many restrictions remains questionable. There is currently no conclusive evidence as to which type and amount of strain is acceptable.

Despite advances in implant design for total elbow arthroplasty and various postoperative restrictions, the durability of novel implant models remains suboptimal (**chapter 4**). The limited implant survival of total elbow arthroplasty is a concern, leading to alternative treatment options being preferred in many cases, specifically in younger patients. In some cases of moderate osteoarthritis, arthroscopic debridement can be considered as an alternative. However, this is unfeasible in more severe cases. In cases of complex distal humerus fractures, several surgical options exist. In a randomized study comparing internal fixation with arthroplasty in elderly patients with complex distal humerus fractures, the patient-reported outcomes were superior in the arthroplasty group in the short-term, but no significant differences were found in the long-term.[2,3] Both treatment options include a risk of complications, potentially requiring a revision. Reoperation rates were high in both groups (arthroplasty: 12%, fixation: 27%, p=0.2).[2,3]

However, it should be considered that a revision after fixation is generally less complex than revising a total elbow arthroplasty. Furthermore, the mean age in this study was 77 years. Total elbow arthroplasty also comes with several downsides in comparison to an attempt at reconstructing the native joint, such as the previously discussed postoperative restrictions. Therefore, arthroplasty for fractures should be reserved for the elderly population with low functional demands. In younger patients, an attempt to reconstruct the native joint is advised. Another alternative in these cases is elbow hemiarthroplasty, where the distal humerus is replaced, but the native ulna is preserved. A recent randomised controlled trial comparing total and hemiarthroplasty for distal humerus fractures reported similar results in terms of range of motion, patient-reported outcomes, and adverse events with a minimum follow-up of 2 years.[41] Similar results were found in a previous meta-analysis.[42] These results suggest that elbow hemiarthroplasty is a valuable alternative to total elbow arthroplasty in these cases, potentially resulting in a lower complication rate. Studies reporting mid- to long-term survival after elbow hemiarthroplasty are sparse. One study from the Australian National Joint Registry reported slightly higher revision rates after total elbow arthroplasty at nine years post-operatively: 11.9% after total elbow arthroplasty and 9.7% after hemiarthroplasty.[43] 2.4% of all hemiarthroplasty cases were converted to total elbow arthroplasty.[43] Aseptic loosening was more common as a reason for revision in total elbow arthroplasty, whereas instability was the most common reason for revision after hemiarthroplasty.[43] Aseptic loosening is a more significant concern in younger patients, probably due to higher functional demands and longer life expectancy. Therefore, hemiarthroplasty could be considered in younger patients, for whom the distal humerus fracture is considered irreparable.

In contrast to total elbow arthroplasty, the implant survival of reverse total shoulder arthroplasty is relatively favourable (**chapter 4** and **chapter 7**). In **chapter 7** an implant survival of 94% after 10 years is reported. Similar results are reported in the literature, with 10-year implant survival rates ranging from 82% to 93%.[44–48] **Chapter 7** also reveals that most revision surgeries occur in the first year after primary surgery (instability, infection) or after 10 years (aseptic loosening, peri-prosthetic fracture). In the Netherlands, an infection is the most common reason for revision (35%), followed by aseptic loosening (25%) and instability (25%; **chapter 5**). These data suggest that many revision cases cannot directly be attributed to implant failure but rather the implantation and sizing (instability) or peri-prosthetic issues (infection, peri-prosthetic fracture). Despite promising long-term results, alternative treatments must be considered in cases where shoulder arthroplasty is potentially indicated. Few surgical alternatives exist for the two most common indications for reverse total shoulder arthroplasty (cuff tear arthropathy and primary osteoarthritis with an insufficient rotator cuff; **chapter 5**). However, conservative treatment based on physical and pharmacological therapies may prove beneficial in many cases.[49] An attempt to manage cuff tear arthropathy and osteoarthritis conservatively should be made, specifically in younger patients. In older patients or severe cases, reverse total shoulder arthroplasty is a suitable option. Some studies propose arthroscopic management for glenohumeral osteoarthritis in younger patients.[50] However, the literature is sparse and contradictory. A recent systematic review

reports improvements in pain and patient-reported outcome scores, but conversion rates to arthroplasty ranging from 4% to 42% with follow-up periods ranging between 1 and 4 years.[50] Reverse total shoulder arthroplasty is also commonly used for acute fractures (**chapter 5**). For an acute fracture with two parts, open reduction and internal fixation is the mainstay treatment. Reverse total shoulder arthroplasty can be considered for more complex fractures, such as 3- and 4-part, heavily comminuted, head-split, or heavily displaced fractures. Contrasting results are reported in the literature, with most studies reporting similar outcomes but lower revision and complication rates after arthroplasty.[51,52] In a previous meta-analysis comparing reverse total shoulder arthroplasty to open reduction and internal fixation, arthroplasty resulted in better forward flexion and patient-reported outcome scores, equal abduction, less external rotation, and increased complications but fewer revision surgeries.[53] The authors recommend reverse total shoulder arthroplasty in patients older than 65 years with a complex fracture. An attempt at reconstructing the native joint should be made in younger patients. Reverse shoulder arthroplasty results in satisfactory patient-reported outcomes and a long-term improvement in range of motion (**chapter 7**), including internal rotation, which is a commonly voiced concern in reverse total shoulder arthroplasty. Previous studies report similar results.[44–48] In addition, the radiographical analysis in **chapter 7** reveals a high prevalence of radiographic signs associated with complications such as loosening. Scapular notching occurred in 40% of cases, and at least some degree of radiolucencies around the humeral component was found in 96% and around the glenoid component in 52%. However, the radiographical findings were not accompanied by high complication rates or inferior functional results. These results suggest that the correlation between radiographic signs and aseptic loosening may not be as strong as previously assumed. This also supports the low observed implant-related complication rate. When weighing reverse total shoulder arthroplasty against alternative options, the positive functional results and favourable long-term survival despite radiographic findings strengthen the argument in favour of reverse total shoulder arthroplasty, specifically in older patients with lower functional demands.

Limitations and biases

The findings and conclusions in this thesis must be interpreted in light of the biases and limitations of the included studies.

Three chapters (**2**, **4**, and **5**) consist of studies performed using data from national arthroplasty registries. In **chapter 2**, a review is performed using all publicly available data reported by national registries worldwide. While this method effectively reduces publication bias and increases external validity, the interpretation is limited by the availability, completeness and accuracy of the data. Only few national registries publish annual reports, and the detail provided in the reports is limited. Furthermore, many registries do not record total elbow arthroplasties. In the Netherlands, shoulder and elbow arthroplasties were added to the registry in 2014, limiting the

long-term follow-up. For **chapter 4** and **chapter 5**, a database was provided by the Dutch National Arthroplasty Registry (LROI). Although this increases the accuracy and reliability of the data compared to extracting data from annual reports, the quality and completeness of the data are still dependent on healthcare providers reporting to the registry. Reporting to the national registry is not strictly obligatory, but widely encouraged and an important quality metric during hospital audits. The completeness is routinely monitored and was 86% for **chapter 4** and 89% for **chapter 5**. An increasing trend in completeness is observed in recent years. Another important limitation to consider in registry studies is the lack of functional results and patient-reported outcomes. Only revisions in which at least one component is replaced are included in the registry; complications that do not lead to a revision are not recorded. Although patient-reported outcome measures have recently been added to the registry, completeness is still too low for a reliable analysis. No radiographic outcomes are currently collected in the registry. Despite the limited detail and potential reporting bias, registry data remains a useful tool for obtaining a large cohort, allowing for the assessment of rare complications and thorough statistical methods by correcting for confounding factors. This is especially relevant in rare procedures such as total elbow arthroplasty. Furthermore, at the cost of decreased internal validity, the generalisability of the results is an advantage.

Chapter 3, **chapter 6**, and **chapter 7** consist of retrospectively identified cohorts, with or without the prospective collection of follow-up data. These studies are subject to selection and indication bias. For example, in **chapter 6**, patients that underwent reverse total shoulder arthroplasty using a bonegraft to increase offset were matched to patients with a larger glenosphere. Matching was performed using Optimal Pair Matching based on several factors. However, it is probable that many more considerations went into the treatment choice for these patients. In addition, there were some notable differences between the matched groups, such as follow-up time and the used surgical approach. However, these factors did not influence the results in previous studies.[54–56] To confirm the results of these studies, the hypothesis must be tested in a prospective, randomised study design. For **chapter 7**, the retrospective inclusion is less of an issue, as this reflects current practice, and no specific comparison is made. In contrast to **chapter 4**, **chapter 5**, and other registry-based studies, **chapter 7** is a single-centre, single-surgeon study using the same prosthetic design and techniques. This results in high homogeneity and internal validity but decreases the external applicability of the results. It is also important to consider that in **chapter 7**, analysis was performed according to the 'intention-to-treat' method, meaning that the functional results of revised implants were also taken into consideration. Furthermore, in contrast to registry-based studies, **chapter 7** also reports functional results and complications that do not result in a revision. As a result, a more complete overview of the long-term results after reverse total shoulder arthroplasty is provided. However, despite this study reporting on one of the largest cohorts with a minimum 10-year follow-up in the literature, the relatively small sample size remains a limitation. It is not feasible to perform detailed statistical analyses, for example, to correlate the radiographic findings with clinical outcomes. Larger studies, such as multi-centre or international collaborations, are required for this aim.

In **chapter 3**, a retrospective analysis is performed correlating the Subjective Elbow Value to commonly used patient-reported outcome measures. Due to the recent introduction of the Subjective Elbow Value, the follow-up and completeness of the study are limited. This study also does not assess measurement reliability, such as floor and ceiling effects, test-retest reliability, and measurement precision. Furthermore, a strong correlation with traditional outcome measures is not the primary purpose of Subjective Elbow Value. To assess the practical use of the follow-up metric, it must be tested for the primary aims of patient-reported outcome measures: reliability in evaluating results and early identification of potential complications.

Future perspectives

Due to the broadening range of indications, the increasing popularity of reverse total shoulder arthroplasty compared to other types of shoulder arthroplasty, and the aging population, the overall number of procedures of total elbow and reverse total shoulder arthroplasty are expected to continue to increase. The observed trends in the indications and techniques in total shoulder and elbow are expected to continue to develop. A global overview of current practice based on national registry data rather than single-institution studies, assessing trends and comparing geographic regions is provided for total elbow arthroplasty in **chapter 2**, but is missing for shoulder arthroplasty. This is important for predicting the future burden on healthcare systems and could be an aim of future studies.

The detail, homogeneity, and accessibility of registry data could also be improved. If more national registries would include shoulder and elbow arthroplasty and regularly publish reports, this would provide a more accurate and complete overview of current practice, facilitating future studies and the formation of new hypotheses. Patient-reported outcomes could also be integrated into registries in the future. In the Netherlands, the first step in this process is taken, but currently completeness is too low for a reliable assessment of patient-reported outcomes. Collaboration between national registries may aid in studying rare procedures, such as total elbow arthroplasty, and the assessment of uncommon complications. An example of an international collaboration between national registries is the Nordic Arthroplasty Registry Association (NARA), in which registries from Norway, Denmark, Sweden and Finland work together.[57] Unfortunately, the pooling of different registry databases leads to a loss in detail. This could be improved by standardising the variables that are collected. In implementing patient-reported outcomes into registries and facilitating collaboration between registries, the Subjective Elbow Value may be a helpful tool.

Further steps could also be made to optimise the follow-up after total shoulder and elbow arthroplasty. The results of **chapter 3** suggest that the follow-up after total shoulder and elbow arthroplasty may be simplified to two or more *key* questions focussing on function and pain during activity rather than several longer questionnaires. Future studies may investigate the

reliability and practical use of the Subjective Elbow Value, besides the correlation with currently used patient-reported outcome measures. First, floor and ceiling effects, test-retest reliability, and measurement precision, could be assessed. Furthermore, the accuracy in the early detection of complications could be investigated. For the shoulder, the Subjective Shoulder Value has already been widely implemented. However, it is not used as a stand-alone metric, nullifying the advantages of a Single Assessment Numeric Evaluation. The feasibility of using the Subjective Shoulder Value as a stand-alone metric could be evaluated. Additionally, mental health components should be integral to the evaluation of upper extremity arthroplasty. However, to date, it is unclear which mental health metrics and domains are most relevant. Aiming to simplify the follow-up after total shoulder and elbow arthroplasty while maintaining only the most important aspects, relevant simplified or single-question mental health assessments can be identified. Potentially, one or more questions may be added to the set of *key* questions for the follow-up of total shoulder and elbow arthroplasty focussing on the mental health component. The set of *key* questions, consisting of simplified or single-question assessments addressing the main relevant domains: function, pain during activity, and mental health, could be assessed in future studies investigating the reliability, validity, and feasibility of implementation.

There is room for improvement in the distribution of case volume and expertise in upper extremity arthroplasty. In **chapter 4** and **chapter 5**, it was revealed that total shoulder and elbow arthroplasty is performed at many different centres. Using cut-off values based on previous literature, only one centre performing total elbow arthroplasty and two centres performing reverse total shoulder arthroplasty in the Netherlands were considered high-volume centres. Considering the specific expertise required for total shoulder and elbow arthroplasty and the relationship between hospital volume and complication rate in the literature, total shoulder and elbow arthroplasty should be concentrated in a handful of high-volume centres, where a surgeon-volume of more than 10 total elbow arthroplasties or more than 30 reverse total shoulder arthroplasties per year can be achieved. Another advantage of concentrating reverse total shoulder arthroplasty in high-volume centres is that it is feasible to use both surgical approaches, deciding which technique to use on a case-by-case basis, as discussed in **chapter 5**. For adequate and unbiased decision-making, low-threshold and consultation with a centre performing total shoulder or elbow arthroplasty should be the standard. Future projects may aim to assess the practical feasibility of the concentration of shoulder and elbow arthroplasty care in high-volume centres.

With regards to the current techniques used in reverse shoulder arthroplasty, further research may aid in optimising evidence-based decision-making when deciding between techniques, such as the surgical approach and method of increasing offset. In **chapter 5** and **chapter 6**, no difference was found in outcomes when comparing the surgical approach and method of increasing offset, which may influence the decision-making process for these techniques in practice. However, **chapter 5** only compared the revision rate at a minimum follow-up of 5 years. The registry data used for this study does not include clinical or radiographic outcomes, or complications that do not lead to a revision. In contrast, **chapter 6** assesses

functional and radiographic outcomes, but the cohort is too small to statistically compare complication rates, and the follow-up is relatively short. Furthermore, both studies are retrospective, and many factors influence the decision to use one of the two techniques. Therefore, a future study may aim to compare the functional and radiographic outcomes between the two approaches, preferably in a prospective, randomised design. Similarly, a larger study with a longer follow-up is required to compare the complication rate between techniques used to increase offset in reverse total shoulder arthroplasty, and a prospective, randomised study could compare the functional and radiographic results with a lower risk of bias. Although these study designs may aid in providing evidence for the superiority of one of the techniques, non-superiority may also be the conclusion. After a complete comparison with an adequate sample size is performed, the focus of future research may be shifted to other domains. For example, future studies may address other methods to increase offset that are not included in **chapter 6**, taking into account cost and complication risk.

The long-term results of upper extremity arthroplasty should be taken into account when considering total elbow or reverse shoulder arthroplasty. The suboptimal long-term results after total elbow arthroplasty and the relatively favourable results after reverse shoulder arthroplasty influence the choice between arthroplasty and alternative (surgical) options. However, future studies may address some remaining gaps. For example, little data is available on the long-term functional results of total elbow arthroplasty. Regarding reverse total shoulder arthroplasty, future studies may investigate the association between radiographic findings and long-term outcomes.

Conclusions

This thesis aims to assess and optimise the outcomes after total shoulder and elbow arthroplasty.

First, current practice is addressed. The most common indication for total elbow arthroplasty in the Netherlands is rheumatoid arthritis (33%), followed by posttraumatic sequelae (28%). The most common indication for reverse total shoulder arthroplasty in the Netherlands is cuff tear arthropathy (35%), followed by primary osteoarthritis (29%). The range of indications for arthroplasty is broadening for both joints due to the continuous development of techniques, implant designs, and alternative treatment options. For total elbow arthroplasty, the posterior surgical approach is most commonly used (95%). For reverse total shoulder arthroplasty, the deltopectoral approach is used most often (54%). In the Netherlands, primary total elbow arthroplasty is performed in 24 different centres and primary reverse total shoulder arthroplasty in 82 different centres.

A novel method to simplify the follow-up after elbow arthroplasty is proposed: a Single Assessment Numeric Evaluation, the Subjective Elbow Value. The Subjective Elbow Value showed a significant, moderate correlation with traditional patient-reported outcome measures. A Single

Assessment Numeric Evaluation is already widely adopted for the shoulder but often used alongside other patient-reported outcomes, nullifying the advantages of using a single question. Further research is required to simplify the follow-up of total shoulder and elbow arthroplasty, potentially resulting in a set of *key* questions that can replace lengthy questionnaires.

Three main topics of debate are addressed, aiming to optimise the outcome after upper extremity arthroplasty. For total elbow arthroplasty, the centre-volume was not correlated with revision rate. However, the population differed between high- and low-volume centres, and previous literature found higher complication rates for low-volume surgeons for both the elbow and the shoulder. Considering the high number of centres at which total shoulder or elbow arthroplasty is performed in the Netherlands, a step towards centralisation of upper extremity arthroplasty may prove to be beneficial in the future. For reverse total shoulder arthroplasty, no difference in revision rates is found when comparing the two main surgical approaches (deltopectoral and anterosuperior). Due to the specific advantages and disadvantages of each approach, high-volume surgeons may consider deciding which technique to use on a case-by-case basis. Future studies may focus on comparing functional and radiographic results between the two approaches in a prospective setting. Regarding the method of increasing offset in reverse total shoulder arthroplasty, functional and radiographic outcomes were similar when comparing a bonegraft with a larger glenosphere. These results suggest that using a larger glenosphere is a feasible alternative to increase offset, potentially decreasing costs and the risk of complications. However, this result must be confirmed in a prospective, randomised study.

In terms of long-term outcomes, the 5-year revision-free implant survival rate after total elbow arthroplasty in the Netherlands is 91%, which is slightly lower than the observed 95% survival after reverse total shoulder arthroplasty. At 10 years, the implant survival after reverse total shoulder arthroplasty remains favourable at 94% with patients demonstrating satisfactory functional results. Although a significant number of concerning radiographic findings were observed, these did not appear to translate to a high revision rate or negatively impact functional outcomes. Future studies could focus on evaluating the long-term outcomes of total elbow arthroplasty and analyse the correlation between radiographic findings and long-term results to better understand their potential impact on implant longevity.

Key insights

The range of indications for total shoulder and elbow arthroplasty is broadening, and the number of procedures is increasing.

The Subjective Elbow Value showed a significant, moderate correlation with traditional patient-reported outcome measures after total elbow arthroplasty and may be a feasible method to simplify the follow-up. For the shoulder, the Subjective Shoulder Value is already widely adopted, but not as a stand-alone metric.

In the Netherlands, primary total elbow arthroplasty is performed in 24 different centres and primary reverse total shoulder arthroplasty in 82 different centres. Considering the volume-outcome relationship in the literature, total shoulder and elbow arthroplasty should be concentrated in a handful of high-volume centres.

For reverse total shoulder arthroplasty, no difference was found in revision rate between the two most common surgical approaches (anterosuperior and deltopectoral). As a result, high-volume surgeons (>30 per year) may consider deciding the surgical approach on a case-by-case basis, whereas choosing the deltopectoral approach may be preferable for low-volume surgeons.

For the method of increasing offset in reverse shoulder arthroplasty, similar functional and radiographic outcomes were found when comparing using a bonegraft to using a larger glenosphere size, suggesting that using a larger glenosphere size may be a feasible alternative, potentially decreasing costs and complication risk.

The 5-year implant survival after total elbow arthroplasty is 91%. As a result, alternative surgical options should be given preference over total elbow arthroplasty where possible, specifically in younger patients.

The 10-year implant survival after reverse total shoulder arthroplasty is 94%, and the functional results at a minimum of 10 years follow-up are favourable. As a result, arthroplasty should be given preference over alternative surgical options in elderly patients.

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Chapter 9

Summary

Part III

Introduction

Adequate function of the upper extremity is essential for daily activities such as manual tasks and personal care and is important for quality of life. In severe or complex pathology of the shoulder and elbow, total joint arthroplasty may be required to restore function and relieve complaints. Since the introduction of total shoulder and elbow arthroplasty, the indications, surgical techniques, and implant designs have continuously evolved. Despite these advances, the clinical results and survival of total shoulder and elbow arthroplasty are not comparable to more common arthroplasties, such as hip replacements, which have been in use and continuously developed for a longer time. The field of upper extremity arthroplasty is rapidly advancing, but several issues remain disputed. To address these gaps in the current literature, this thesis aims to assess and optimise the outcomes of total elbow and reverse total shoulder arthroplasty. To this goal, the chapters in this thesis aim to assess current practice, optimise the follow-up and the results after total elbow and reverse total shoulder arthroplasty, and report long-term outcomes. The thesis is subdivided into two parts; **part 1** (chapters 2-4) focuses on total elbow arthroplasty, and **part 2** (chapters 5-7) discusses reverse total shoulder arthroplasty.

Part I: Elbow

To assess and optimise the outcomes of total shoulder and elbow arthroplasty, current practice in indications and used techniques must first be addressed. **Chapter 2** reveals that the indications for total elbow arthroplasty are shifting, with rheumatoid arthritis becoming less common while traumatic indications, such as acute fractures and posttraumatic sequelae, are gaining ground. However, this should not be directly attributed to the results of total elbow arthroplasty. Instead, the non-surgical treatment options for rheumatoid arthritis have expanded with increasing success. Currently, the most common indication for total elbow arthroplasty in the Netherlands is rheumatoid arthritis (33%), followed by posttraumatic sequelae (28%), primary osteoarthritis (21%), and an acute fracture (10%), and the posterior surgical approach is the most commonly used technique (95; **chapter 4**).

To assess the results after total shoulder and elbow arthroplasty and to compare different techniques, patient-reported outcomes are of paramount importance. However, there is a wide variety of current methods of collecting outcomes. Many different patient-reported outcome measure questionnaires are used, leading to questionnaire fatigue and poor comparability between studies. In **chapter 3**, a simplification of the follow-up after elbow arthroplasty is proposed using one single question, a Single Assessment Numeric Evaluation (the Subjective Elbow Value): '*How do you rate your elbow function on a scale from 0 to 10*?'. The Subjective Elbow Value showed a significant, moderate correlation with traditional patient-

reported outcome measures. Adding a question for pain during movement increased this correlation, whereas pain in rest was not of added value. These results suggest that the follow-up after total elbow arthroplasty may be simplified to two or more *key* questions focussing on function and pain during activity rather than several longer questionnaires.

Due to the relatively low volumes compared to arthroplasty of the lower extremity joints, expertise in total shoulder and elbow arthroplasty is generally more scattered. In the Netherlands, total elbow arthroplasty is performed at 24 different centres (**chapter 4**). Treatment in a high-volume centre was not correlated with a higher revision rate. However, the population treated at the single high-volume centre differed from the rest of the cohort. In other literature, a relationship between surgeon-volume and complication rate is found, reporting a higher risk of complications when surgeons perform less than 10 cases per year. Centralisation of total elbow arthroplasty in a handful of high-volume centres may aid in optimising the outcomes.

The long-term implant survival and functional results are important when deciding between arthroplasty and alternative (surgical) options. In **chapter 4,** a 5-year revision-free implant survival of 91% is reported after total elbow arthroplasty in the Netherlands. The most common reason for revision after total elbow arthroplasty was aseptic loosening (34%), followed by an infection (23%) and elbow instability (23%), polyethylene wear (14%) and a periprosthetic fracture (14%). Due to the suboptimal implant survival after total elbow arthroplasty, alternative surgical options should be given preference over total elbow arthroplasty where possible, specifically in younger patients.

Part II: Shoulder

For reverse total shoulder arthroplasty in the Netherlands, the most common indication is cuff tear arthropathy (35%), followed by primary osteoarthritis (29%), acute fracture (13%), posttraumatic sequelae (10%), and an irreparable cuff rupture (5%; **chapter 5**).

A Single Assessment Numeric Evaluation is already widely adopted in reverse total shoulder arthroplasty: the Subjective Shoulder Value. However, the metric is often used alongside other patient-reported outcomes, nullifying the advantages of using a single question. Future studies may focus on validating the Subjective Shoulder Value as a stand-alone metric.

Reverse total shoulder arthroplasty is performed in 82 centres in the Netherlands (**chapter 5**). In previous literature, a surgeon-volume lower than 30 procedures each year was associated with a higher risk of complications. Similar to total elbow arthroplasty, a step towards centralisation of reverse shoulder arthroplasty could be beneficial.

Of the two most common surgical approaches for reverse total shoulder arthroplasty (deltopectoral and anterosuperior), the deltopectoral approach is used most often (54% versus

46%; **chapter 5**). There is no difference in revision rate between the two approaches when correcting for confounding factors. Due to the specific advantages and disadvantages of each approach, high-volume surgeons may consider deciding which technique to use on a case-by-case basis, whereas for low-volume surgeons, mastering the deltopectoral approach may be preferable. Future studies may focus on comparing functional and radiographic results between the two approaches in a prospective setting.

In reverse total shoulder arthroplasty, the offset can be increased in several ways: by alterations to the implant design (such as an increased neck-shaft angle) or sizing (such as using a larger glenosphere size), by using a metal augmented baseplate, or by using a bonegraft (BIO-RSA). However, the literature on the different methods of increasing offset in reverse total shoulder arthroplasty is limited, and there is no evidence supporting the superiority of one of the techniques. In **chapter 6**, increasing offset using a bonegraft is compared to using a larger glenosphere. The functional and radiographic outcomes were similar. This suggests that using a larger glenosphere is a feasible alternative to increase offset, potentially decreasing costs and the risk of complications. However, this result must be confirmed in a prospective, randomised study.

For reverse total shoulder arthroplasty, studies reporting mid-term follow-up are promising. However, the literature on long-term outcomes is sparse. In **chapter 7**, a 10-year implant survival of 94% is found. Additionally, favourable functional results are reported after a minimum of 10 years. As a result, arthroplasty should be given preference over alternative surgical options in elderly patients. Furthermore, a high degree of concerning radiographic findings are observed, which do not seem to translate to a high revision rate or inferior functional outcomes. Future studies could assess the correlation between radiographic findings and functional results.

Conclusions

The range of indications for reverse total shoulder and elbow arthroplasty is broadening due to the continuous development of techniques, implant design, and alternative treatment options, alongside an overall increased volume of procedures. These developments highlight the need to optimise the follow-up and decision-making processes in reverse total shoulder and elbow arthroplasty. Actionable recommendations are made to streamline current practice: the follow-up may be simplified by using a Single Assessment Numeric Evaluation or a set of *key* questions instead of lengthy questionnaires, reverse total shoulder and elbow arthroplasty should be concentrated in a handful of high-volume centres, high-volume shoulder surgeons may consider deciding the surgical approach for reverse total shoulder arthroplasty on a case-by-case basis, using a larger glenosphere size in reverse total shoulder arthroplasty may be considered as a feasible alternative to increasing offset instead of using a bonegraft, and the reported long-term results should be taken into account when weighing reverse total shoulder or elbow arthroplasty against alternative treatment options. Future studies could focus on testing these hypotheses in a

prospective, randomised setting and further validation and implementation of the proposed adjustments in current practice.

Chapter 10

Dutch Summary

Part III

Inleiding

Een adequate functie van de bovenste extremiteit is essentieel voor dagelijkse activiteiten zoals handmatige taken en persoonlijke verzorging en is belangrijk voor de kwaliteit van leven. Bij ernstige of complexe aandoeningen van de schouder en elleboog kan een totale gewrichtsvervanging (prothese) nodig zijn om de functie te herstellen en klachten te verlichten. Sinds de introductie van totale schouder- en elleboogprothese zijn de indicaties, chirurgische technieken en het ontwerp van de implantaten voortdurend geëvolueerd. Ondanks deze adaptaties zijn de klinische resultaten en de levensduur van de totale schouder- en elleboogprothese niet vergelijkbaar met meer gebruikelijke gewrichtsvervangingen, zoals heupprotheses, die al langer in gebruik en ontwikkeling zijn. De prothesiologie van de bovenste extremiteit heeft zich snel ontwikkeld, maar er blijven verschillende vraagstukken onbeantwoord. Om deze lacunes in de huidige literatuur aan te pakken, richt dit proefschrift zich op het beoordelen en optimaliseren van de resultaten van totale elleboog- en reverse totale schouderprotheses. Het proefschrift is opgedeeld in twee delen: **deel 1** (hoofdstukken 2-4) richt zich op totale elleboogprotheses en **deel 2** (hoofdstukken 5-7) bespreekt reverse totale schouderprotheses.

Deel I: de Elleboog

Om de klinische resultaten van protheses van de schouder en elleboog verder te verbeteren moeten eerst de huidige werkwijzen en gebruikte technieken worden geïnventariseerd. **Hoofdstuk 2** toont aan dat de indicaties voor totale elleboogprotheses verschuiven, waarbij reumatoïde artritis minder vaak voorkomt als indicatie, terwijl traumatische indicaties, zoals acute fracturen en posttraumatische sequelae, toenemen. Dit kan worden toegeschreven aan de toegenomen succespercentages van niet-chirurgische behandelingen voor reumatoïde artritis. Momenteel is de meest voorkomende indicatie voor totale elleboogprotheses in Nederland reumatoïde artritis (33%), gevolgd door posttraumatische sequelae (28%), primaire artrose (21%) en een acute fractuur (10%). Bij al deze indicaties wordt de posterieure chirurgische benadering het vaakst toegepast (95%; **hoofdstuk 4**).

Om de resultaten van protheses van de schouder en elleboog te evalueren en verschillende technieken te vergelijken, zijn patiëntgerapporteerde uitkomsten van groot belang. Er is echter veel variatie in de huidige methoden voor het verzamelen van uitkomsten en is er in de dagelijkse praktijk sprake van zogenaamde ‘questionaire fatique’ bij patiënten. In **hoofdstuk 3** wordt een vereenvoudiging van de follow-up na elleboogprotheses voorgesteld door één enkele vraag te gebruiken, een Single Assessment Numeric Evaluation (de Subjective Elbow Value): 'Hoe beoordeelt u de functie van uw elleboog op een schaal van 0 tot 10?'. De Subjective Elbow Value

toonde een significante, middelmatige correlatie met traditionele patiëntgerapporteerde uitkomstmaten. Het toevoegen van een vraag over pijn tijdens beweging verhoogde deze correlatie, terwijl pijn in rust geen toegevoegde waarde had. Deze Single Assessment Numeric Evaluation zou het aantal vragen in de huidige vragenlijsten kunnen reduceren en bijdragen aan een hogere 'response rate' en reductie van de 'questonaire fatique'.

Door het relatief lage aantal ingrepen in vergelijking met gewrichtsvervangingen van de onderste extremiteiten, is de expertise in protheses van de schouder en elleboog beschikbaar in minder ziekenhuizen. In Nederland wordt totale elleboogprothese in 24 verschillende centra uitgevoerd in wisselende volumes. (**hoofdstuk 4**). Behandeling in een centrum met een hoog volume was niet gecorreleerd met een hogere kans op een revisie. In andere literatuur wordt echter wel een verband gevonden tussen volume en complicatierisico, waarbij een hoger risico op complicaties wordt gerapporteerd wanneer chirurgen minder dan 10 elleboogprotheses per jaar uitvoeren. Centralisatie van totale elleboogprotheses in een beperkt aantal hoog-volume centra kan bijdragen aan het optimaliseren van de resultaten.

Kennis van de overleving van een implantaat is belangrijk. De lange termijn overleving van het implantaat en de functionele resultaten zijn immers belangrijke overwegingen bij de keuze tussen een prothese en alternatieve (chirurgische) opties. In **hoofdstuk 4** wordt een revisievrije implantaatoverleving van 91% na vijf jaar gerapporteerd voor totale elleboogprotheses in Nederland. De meest voorkomende reden voor revisie na totale elleboogprotheses was aseptische loslating (34%), gevolgd door een infectie (23%), instabiliteit (23%), polyethyleen slijtage (14%) en een periprothetische fractuur (14%). Vanwege de suboptimale overleving na totale elleboogprotheses zouden alternatieve gewrichtssparende chirurgische opties de voorkeur moeten krijgen boven totale elleboogprotheses waar mogelijk, met name bij jongere patiënten.

Deel II: Schouder

Voor het plaatsen van reverse totale schouderprotheses in Nederland is de meest voorkomende indicatie cuff tear artropathie (35%), gevolgd door primaire artrose (29%), acute fracturen (13%), posttraumatische sequelae (10%) en een niet-reparabele cuffruptuur (5%; **hoofdstuk 5**).

In reverse totale schouderprotheses is een Single Assessment Numeric Evaluation al breed geïmplementeerd: de Subjective Shoulder Value. Echter, het meetinstrument wordt vaak gebruikt naast andere patiëntgerapporteerde uitkomsten, waardoor de voordelen van het gebruik van één enkele vraag tenietgedaan worden. Toekomstige studies kunnen zich richten op het valideren van de Subjective Shoulder Value als een op zichzelf staande meting.

Reverse totale schouderprotheses worden uitgevoerd in 82 centra in Nederland (**hoofdstuk 5**). In eerdere literatuur was een volume per chirurg van minder dan 30 ingrepen per

jaar geassocieerd met een hoger risico op complicaties. Net als bij totale elleboogprotheses kan een stap richting centralisatie van reverse schouderprotheses wenselijk zijn.

Van de twee meest gebruikelijke chirurgische benaderingen voor reverse totale schouderprotheses (de deltopectorale en de anterosuperieure benadering) wordt de deltopectorale benadering het vaakst toegepast (54% versus 46%; **hoofdstuk 5**). Na correctie voor confounders werd geen verschil gevonden tussen de twee benaderingen in het aantal revisies. Vanwege de specifieke voor- en nadelen van elke benadering kunnen chirurgen met een hoog volume overwegen om per geval te beslissen welke techniek te gebruiken, terwijl het voor chirurgen met een laag volume wellicht beter is om de deltopectorale benadering te beheersen. Toekomstige studies kunnen zich richten op het vergelijken van functionele en radiografische resultaten tussen de twee benaderingen in een prospectieve setting.

Bij de reverse totale schouderprothese kan de offset op verschillende manieren worden vergroot: door aanpassingen aan het implantaatontwerp (zoals een verhoogde neck-shaft angle), door de keuze van maten van de prothese (zoals het gebruik van een grotere glenosfeer), door een 'metal augmented baseplate' of door een 'botgraft' (BIO-RSA). De literatuur over de verschillende methoden om de offset in reverse totale schouderprotheses te verhogen is echter beperkt en er is geen bewijs dat de superioriteit van een van de technieken ondersteunt. In **hoofdstuk 6** wordt het vergroten van de offset met behulp van een bottransplantaat vergeleken met het gebruik van een grotere glenosfeer. De functionele en radiografische resultaten waren vergelijkbaar. Dit suggereert dat het gebruik van een grotere glenosfeer een potentieel alternatief is om de offset te vergroten, wat mogelijk de kosten en het risico op complicaties verlaagt. Deze resultaten moeten echter worden bevestigd in een prospectieve gerandomiseerde studie.

Voor reverse totale schouderprotheses zijn de studies die follow-up na gemiddelde termijn rapporteren veelbelovend, maar de literatuur over langetermijnresultaten is schaars. In **hoofdstuk 7** wordt een implantaatoverlevingspercentage van 94% na tien jaar gerapporteerd. Daarnaast worden gunstige functionele resultaten gerapporteerd na een minimum van 10 jaar. Als gevolg hiervan zou een prothese vaker de voorkeur moeten krijgen boven alternatieve chirurgische opties bij oudere patiënten. Bovendien worden er een hoog aantal verontrustende radiografische bevindingen waargenomen die blijkbaar niet leiden tot een hoger aantal revisies of inferieure functionele uitkomsten. Toekomstige studies kunnen zich richten op het beoordelen van de correlatie tussen radiografische bevindingen en functionele resultaten.

Conclusies

De indicaties voor protheses van de schouder en elleboog breiden zich uit door de continue ontwikkeling van technieken, implantaatontwerpen en alternatieve behandelingsopties, samen met een algemene toename van het volume aan operaties. Deze ontwikkelingen benadrukken de

noodzaak om de follow-up en besluitvormingsprocessen bij protheses van de schouder en elleboog te optimaliseren. Doelgerichte aanbevelingen worden gedaan om de huidige praktijk te stroomlijnen: de follow-up kan worden vereenvoudigd door gebruik te maken van een Single Assessment Numeric Evaluation of een set van *key* questions in plaats van lange vragenlijsten; protheses van de schouder en elleboog zouden geconcentreerd moeten worden in een kleiner aantal hoog-volume centra; hoog-volume schouderchirurgen kunnen overwegen om de chirurgische benadering voor reverse totale schouderprotheses per geval te bepalen; het gebruik van een grotere glenosfeer bij een reverse schouderprothese kan worden overwogen als een haalbaar alternatief om de offset te vergroten in plaats van een bottransplantaat en de gerapporteerde langetermijnresultaten moeten worden meegewogen bij het afwegen van een protheses tegen andere behandelingsmogelijkheden. Toekomstige studies kunnen zich richten op het bevestigen van deze hypotheses in een prospectieve, gerandomiseerde setting en het verder valideren en implementeren van de voorgestelde aanpassingen in de praktijk.

Addendum

Portfolio
Curriculum vitae
Acknowledgments

Portfolio

Publications included in this thesis (6)

2024

- Can a single question replace patient-reported outcomes in the follow-up of elbow arthroplasty? A validation study.
  ***AA Macken**, A Prkic, I Koenraadt-van Oost, GA Buijze, B The, D Eygendaal - Journal of Orthopaedics and Traumatology*
- Lateralising Reverse Shoulder arthroplasty using Bony Increased Offset (BIO-RSA) or Increasing Glenoid Component Diameter; comparison of clinical, radiographic, and patient reported outcomes in a matched cohort.
  ***AA Macken**, GA Buijze,, M Kimmeyer, T Hees, D Eygendaal, MPJ van den Bekerom, L Lafosse, T Lafosse - Journal of Orthopaedics and Traumatology*

2023

- Functional and radiographic outcomes of reverse shoulder arthroplasty with a minimum follow-up of 10 years.
  *T Lafosse[1], **AA Macken[1]**, G Lallemand, G Caruso, GA Buijze, L Lafosse – Journal of Shoulder and Elbow Surgery*
- Anterosuperior versus deltopectoral approach for primary reverse total shoulder arthroplasty: a study of 3,902 cases from the Dutch National Arthroplasty Registry with a minimum follow-up of five years.
  ***AA Macken**, A Haagmans-Suman, A Spekenbrink-Spooren, A van Noort, MPJ van den Bekerom, D Eygendaal, GA Buijze – The Bone and Joint Journal*

2022

- Implant survival of total elbow arthroplasty: analysis of 514 cases from the Dutch arthroplasty registry.
  ***AA Macken**, A Prkic, I Koenraadt-van Oost, B The, D Eygendaal - Bone and Joint Open*

2020

- Global trends in indications for total elbow arthroplasty: a review of national registries.
  ***AA Macken**, A Prkic, IF Kodde, J Lans, NC Chen, D Eygendaal - EFORT open review*

Publications outside of this thesis (16)

2024

- Evaluation Of A Novel Curved Intramedullary Button Versus Traditional Flat Button For Proximal Biceps Tenodesis: A Biomechanical Study
  *I Shirinskiy, **AA Macken**, P Caekebeke, D van Deurzen, G Tuijthof, T Alta, R Bleys, R Janssen, MPJ van den Bekerom – JSES International*
- Comparing Postoperative Proprioception of the Glenohumeral Joint Between the Open and the Arthroscopic Latarjet Procedure
  *G Lallemand, MN Soares, E Lante, **AA Macken**, A Kling, L Lafosse, GA Buijze, T Lafosse - Journal of Shoulder and Elbow Surgery*
- Latissimus Dorsi Transfer or Lower Trapezius Transfer: A treatment algorithm for irreparable posterosuperior rotator cuff tears - Muscles transfers in posterosuperior rotator cuff tears
  *M Kimmeyer, T Hees, L Allaart, R Nerot, **AA Macken**, GA Buijze, L Lafosse, T Lafosse - JSES International*
- Reverse shoulder arthroplasty with a 155° neck-shaft angle inlay implant design without reattachment of the subscapularis tendon results in satisfactory functional internal rotation and no instability: a cohort study.
  ***AA Macken**, WJ van der Poel, GA Buijze, JJ Beckers, D Eygendaal, L Lafosse, T Lafosse – Journal of Orthopaedics and Traumatology*
- Analysis of 516 cases of revision Total Elbow Arthroplasty from the Dutch Arthroplasty Registry: Centralization of care is the future.
  *A Al-Hamdani, **AA Macken**, A Prkic, B The, A Spekenbrink-Spooren, D Eygendaal – Seminars in Arthroplasty; JSES*

2023

- Correct positioning of the calcar screw leads to superior results in proximal humerus fractures treated with carbon-fibre-reinforced polyetheretherketone plate osteosynthesis with polyaxial locking screws.
  *M Kimmeyer, J Schmalzl, V Rentschler, C Schieffer, **AA Macken**, C Gerhardt, L Lehmann - Journal of Orthopaedics and Traumatology*
- Developing a machine learning algorithm to predict the probability of aseptic loosening of the glenoid component after anatomical total shoulder arthroplasty: protocol for a retrospective, multicentre study.
  ***AA Macken**, LC Macken, JHF Oosterhoff, P Boileau, GS Athwal, JN Doornberg, L Lafosse, T Lafosse, MPJ van den Bekerom, GA Buijze – BMJ Open*
- Biomodulating healing after arthroscopic rotator cuff repair: the protocol of a randomised proof of concept trial (BIOHACK).

*LJH Allaart, J Lech, **AA Macken**, A Kling, L Lafosse, T Lafosse, MPJ van den Bekerom, GA Buijze – BMJ Open*

2022

- Diagnosis, Treatment and Complications of Radial Head and Neck Fractures in the Paediatric Patient.
  ***AA Macken**, D Eygendaal, CJA van Bergen – World Journal of Orthopaedics*
- Pediatric Clavicle Fractures and Congenital Pseudarthrosis Unraveled
  *L van der Water, **AA Macken,** D Eygendaal, CJA van Bergen – Children*
- Soft tissue reconstruction after total elbow arthroplasty: a case series.
  ***AA Macken**, J Lans, S Miyamura, KR Eberlin, NC Chen – Clinics in Shoulder and Elbow*

2021

- Outcomes of Flexor Pollicis Longus Reconstruction after Volar Plating of Distal Radius Fractures.
  ***AA Macken**, J Lans, S Ozkan, JB Jupiter, NC Chen – Journal of Hand and Microsurgery*
- Influence of complications on the subjective and objective outcomes of total elbow arthroplasty.
  ***AA Macken**, A Prkic, N Vermeulen, I van Oost, K Koenraadt, B The, D Eygendaal – JSES international*
- A registry study on radial head arthroplasties in the Netherlands; indications, types and short-term survival.
  ***AA Macken,** A Prkic, I van Oost, K Koenraadt, AS Spooren, B The, D Eygendaal - Shoulder and Elbow*

2020

- Diagnosis and Treatment of Osteochondritis Dissecans of the Elbow.
  ***AA Macken**, CJA van Bergen, D Eygendaal, B The - Orthopaedics and Trauma*
- Surgery for Lower Extremity Symptomatic Neuroma: Long-term Outcomes.
  *N Anantavorasakul, J Lans, **AA Macken**, R Sood, NC Chen - Journal of Plastic, Reconstructive & Aesthetic Surgery*

Book chapters

- Implant design optimisation and classification – Reverse shoulder arthroplasty (in print)
- Tendon transfers around shoulder arthroplasty – Revision shoulder arthroplasty
- Osteochondritis dissecans of the elbow – Elbow work is teamwork

Portfolio activities

Total ECTS	Courses and conferences	Presentations	Teaching	Event organisation
60.2	30	15.7	7.5	7.0

Courses and conference attendance				
Course	**Year**	**Centre**	**Location**	**ECTS**
Essentials of Biostatistics	2019	Harvard medical school	Boston, USA	1
Applied Biostatistics using R	2019	Harvard medical school	Boston, USA	1
Jupiter Hand Forum	2019	Massachusetts General Hospital, Hand and Upper Extremity Service	Boston, USA	0.3
Smith Memoral Day	2019	Massachusetts General Hopsital, Hand and Upper Extremity Service	Boston, USA	0.3
AAHS congress	2020	AAHS	Fort Lauderdale, USA	0.6
Practical Biostatistics	2020	Amsterdam UMC doctoral school	Amsterdam, the Netherlands	1.1
Amphia Science Day	2020	Amphia Hospital	Breda, the Netherlands	0.3
EFORT congress	2021	EFORT	Online	0.9
Bioinformatics	2022	Amsterdam UMC doctoral school	Amsterdam, the Netherlands	1.1
ESSKA congress	2022	ESSKA	Paris, France	0.9
EFORT congress	2022	EFORT	Lisbon, Portugal	0.9
Conversation French B2/C1	2022	Alliance Française	Amsterdam, the Netherlands	1.5
Review of Mathematics and Introduction to Statistics	2022	Erasmus MC doctoral school	Rotterdam, the Netherlands	1.0
Data Visulisation and Storytelling	2022	GrowthTribe	Online	1.0
Scientific Integrity	2022	Erasmus MC doctoral school	Rotterdam, the Netherlands	0.3
NOV Autumn Congress	2022	NOV	Leeuwarden, the Netherlands	0.3

Biomedical Writing for PhD Candidates	2022	Erasmus MC doctoral school	Online	1.5
Stryker Advanced Shoulder Arthroscopy Course	2022	Alps Surgery Institute	Annecy, France	0.9
Johnson & Johnson Advanced Arthroscopy and Arthroplasy Course	2022	Alps Surgery Institute	Annecy, France	0.9
Johnson & Johnson Arthroscopic Latarjet Course	2022	Alps Surgery Institute	Annecy, France	0.9
SFA congress	2022	SFA	Toulouse, France	0.9
EFORT congress	2023	EFORT	Vienna, Austria	0.9
Annecy Live Surgery congress	2023	Alps Surgery Institute	Annecy, France	0.9
Job Doornberg symposium	2023	UMC Groningen	Groningen, the Netherlands	0.3
ICSES congress	2023	ICSES	Rome, Italy	1.2
VOCA congress	2023	VOCA	Amsterdam, the Netherlands	0.3
Stryker Advanced Shoulder Arthroplasty Course	2023	Alps Surgery Institute	Annecy, France	0.9
VEJOS workshops (3)	2024	VEJOS	The Netherlands	0.8
NOTS symposium winter injuries	2024	NOTS	Rotterdam, the Netherlands	0.1
Symposium: 10 years of shoulder fellowship	2024	Spaarne Gasthuis	Haarlem, the Netherlands	0.3
2nd Orthopaedic congress	2024	CUF Trinidade	Porto, Portugal	0.5
ESSKA congress	2024	ESSKA	Milan, Italy	1.5
SECEC congress	2024	SECEC-ESSSE	Munich, Germany	0.9
Flevoziekenhuis Orthopaedic Symposium	2024	Flevoziekenhuis	Almere, the Netherlands	0.3
Science Day	2025	Erasmus MC Department of Orthopaedics and Sport medicine	Rotterdam, the Netherlands	0.5

Presentations				
Event	**Year**	**Location**	**Activity**	**ECTS**
Smith Memorial Day	2019	Boston, USA	2 podium presentations	1.0
AAHS	2020	Fort Lauderdale, USA	2 poster presentations	1.0
Amphia Science Day	2020	Breda, the Netherlands	2 poster presentations	1.0
EFORT	2020	Online	1 poster presentation	0.5
SECEC	2020	Online	1 poster presentation	0.5
EFORT	2021	Online	1 poster & audio presentation	0.5
Amphia Science Day	2021	Breda, the Netherlands	1 poster presentation	0.5
Amphia Science Day	2022	Breda, the Netherlands	1 poster presentation	0.5
ESSKA	2022	Paris, France	1 podium presentation	0.5
EFORT	2022	Lisbon, Portugal	1 podium presentation	0.5
NOV autumn congress	2022	Leeuwarden, the Netherlands	1 podium presentation	0.5
Stryker Advanced Shoulder Arthroscopy Course	2022	Annecy, France	2 complex case presentations	1.0
Johnson & Johnson Advanced Arthroscopy and Arthroplasy Course	2022	Annecy, France	2 complex case presentations	1.0
Rome Revision Shoulder Arthroplasty Course	2023	Rome, Italy	1 co-authorship invited presentation	0.2
EFORT	2023	Vienna, Austria	1 podium & 2 poster presentations	1.5
ICSES	2023	Rome, Italy	1 podium & 3 poster presentations	2.0
Stryker Advanced Shoulder Arthroscopy Course	2023	Annecy, France	2 complex case presentations	1.0
2nd Orthopaedic congress CUF Trinidade	2024	Porto, Portugal	1 invited presentation	0.5

ESSKA congress	2024	Milan, Italy	1 podium & 1 poster presentation	1.0
Flevoziekenhuis Orthopaedic Symposium	2024	Almere, the Netherlands	1 invited presentation	0.5

Teaching

Type	Year	Location	Projects	Student	ECTS
Master Thesis Medicine	2022	Annecy, France	5-month Research Internship	Wouter van der Poel	3.5
Master Thesis Medicine	2023	Annecy, France	6-month Research Internship	Dries Boulidam	4.0

Event organisation

Event	Year	Centre	Location	Role	ECTS
Stryker Advanced Shoulder Arthroscopy Course	2022	Alps Surgery Institute	Annecy, France	Co-organiser: coordinating presentations	1.0
Johnson & Johnson Advanced Arthroscopy and Arthroplasy Course	2022	Alps Surgery Institute	Annecy, France	Co-organiser: coordinating presentations	1.0
Stryker Advanced Orthopaedic Sports Medicine Course	2023	Alps Surgery Institute	Annecy, France	Co-organiser: coordinating presentations	1.0
Annecy Live Surgery Congress	2023	Alps Surgery Institute	Annecy, France	Core organising committee: congress planning and organisation, case preparation, imaging preparation, on-site organisation.	3.0
Stryker Advanced Shoulder Arthroscopy Course	2023	Alps Surgery Institute	Annecy, France	Co-organiser: coordinating presentations	1.0

Parameters of esteem		
Grants		
Foundation	**Year**	**Grant**
KNAW	2020	Grant for congress visit
Stichting Michaël-van Vloten fonds	2022-2023	Research Grant
Erasmus Trustfonds	2022-2023	Research Grant
VSBfonds	2022-2023	Exchange Grant
Prins Bernhard Cultuurfonds	2022-2023	Crone-Haver Doeze Research Grant
Erasmus+	2022-2023	Internship Grant
Clinique Générale d'Annecy, Vivalto Santé	2022-2023	Institutional research support
Prizes		
EFORT	2022	Best Poster Award (co-author)

Other relevant experience	
Experience	**Year**
Observership Traumatology – Ganga Hospital, Coimbatore, India	2019
MD (ANIOS) – Orthopaedic department, Flevoziekenhuis, Almere	2023
Peer reviewer – Journal of Experimental Orthopaedics (JEO)	2024
Peer reviewer – Knee Surgery, Sports Traumatology, and Arthroscopy (KSSTA)	2024
Peer reviewer – Journal of Shoulder and Elbow Surgery (JSES)	2024
Observership Shoulder Surgery - Hospital SAMS, Lisbon, Portugal	2024
Observership Traumatology – Hospital Central da Praia, Cape Verde	2024
MD (ANIOS) – Orthopaedic department, Spaarne Gasthuis, Hoofddorp	2025

Curriculum vitae

Arno Alexander Macken was born on the 16th of July 1996 in Veghel, the Netherlands. He graduated from secondary school in 2014 (Gymnasium, Maurick college, Vught). His interest in the musculoskeletal system was first sparked by a career in rugby on an international level. During his school years, Arno represented the Netherlands in several European championships for national youth teams. After a year in Padova, Italy, pursuing his athletic career, he started his medical studies in Amsterdam in 2015 (Vrije Universiteit). In 2018, Arno won the national Ereklasse championship and made his debut for the Dutch national rugby team. During his studies, Arno completed internships in Belgium (VUB, Brussels), India (Ganga Hospital, Coimbatore), and the United States (MGH / Harvard, Boston). The latter consisted of a research internship at the Hand and Upper extremity service under the supervision of Dr. Neal Chen, with Prof. Denise Eygendaal as the Netherlands-based supervisor. This meant the start of his scientific career. During the remainder of his studies, he continued working in close collaboration with Prof. Eygendaal, laying the foundations for this PhD thesis. Arno concluded his medical studies in 2022. He continued his PhD with a research fellowship in Annecy with Dr. Geert Alexander Buijze, Dr. Thibault Lafosse, and Dr. Laurent Lafosse, where he worked on a wide variety of research projects and was involved in the organisation of international courses and congresses on shoulder surgery, including the 2023 Annecy Live Surgery course. In 2023, he started working as a resident not in training (ANIOS) at the Orthopaedic and Trauma department of Flevoziekenhuis, and currently works at the Orthopaedic department of Spaarne Gasthuis. Arno continues to be involved in various research projects in Annecy (ASI), Amsterdam (ASECE), Breda (Amphia), and Rotterdam (Erasmus MC), and aims to pursue the path toward becoming an orthopaedic surgeon.

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Word of thanks

This thesis is teamwork. It could not have been written without the help and support of a large group of people for which I am very grateful.

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