Total Shoulder Arthroplasty
Clinical and radiological studies on the implant positioning and fixation

Ph.D. Thesis in Orthopaedics by
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To my parents, Whose immeasurable sacrifices I have never forgotten- I thank you.

"I don't have any regrets. I consider myself really privileged to belong to medicine and do what I do. I would do it all again." ~ Magdi Yacoub
# Table of Contents

Abstract 1

Abstrakt på svenska (Abstract in Swedish) 3

List of papers 5

List of abbreviations 6

1. Introduction 7
   1.1 Historical background 7
   1.2 Anatomical and biomechanical rationale 10
   1.3 RSA 12
   1.4 Implant fixation 15
   1.5 Stemless shoulder arthroplasty 16
   1.6 Surgical approaches 18

2. Aim of the studies 20

3. Hypotheses of the studies 21

4. Material and methods 22

5. Results 40

6. Discussion 52

7. Conclusion 60

8. Implications for future research 61

9. Acknowledgements 62

10. References 64

11. Appendix 73

Reprinted studies I-V 76
Abstract

Shoulder arthroplasty surgery has shown remarkable progress during the last few decades. A number of factors affect postoperative range of motion, pain and prosthetic durability. Among these factors, the length of the lever arm and joint stability is the ones that can be altered by the selected prosthetic component. It is uncertain how much of the normal anatomy needs to be re-established. Stemless prostheses with total reliance on metaphyseal fixation were introduced in France in 2004 (TESS, Zimmer Biomet). The goals were to avoid stem-related complications. Stemless implants have other potential benefits, including the ability to restore shoulder anatomy.

The aims of this thesis were to:
(1) Investigate the functional outcome and radiological stability of stemless shoulder prostheses.
(2) Study the effect of prosthesis positioning in reverse shoulder arthroplasty on radiological and clinical outcome.
(3) Study the reliability of measurement of the lateral humeral offset (LHO) i.e. the distance between the medial edge of the base of the coracoid process to the most lateral point of the greater tubercle, using CT or X-ray.
(4) Study the ability of stemless shoulder prosthesis to restore shoulder anatomy.
(5) Clinical importance of LHO restoration in optimizing the functional outcome after shoulder arthroplasty.

Study I: This is a prospective cohort study of 49 patients with one of two versions of the TESS prosthesis (anatomic or reverse) with clinical and radiological follow-up ranging from 9–24 months. The TESS prosthesis showed short-term results that were comparable with other shoulder prosthetic systems.

Study II: This is a prospective comparative non-randomised study of 37 patients (40 shoulders) who underwent reverse shoulder arthroplasty (RSA) with a follow-up ranging from 15–66 months. We found a significant improvement in functional outcome and reduction of pain in both stemmed and stemless groups. Glenoid overhang influenced the occurrence of scapular notching (SN).
**Study III:** This is a radiological study showing that CT had a good reliability and reproducibility in estimating LHO.

**Study IV:** This is a prospective radiological study of 69 patients (70 shoulders) with primary osteoarthritis (OA) who had undergone stemless anatomical total shoulder arthroplasty (TSA). This study showed that stemless anatomical TSA could be useful in restoring shoulder anatomy.

**Study V:** This is a prospective study of 44 patients with OA who had undergone stemless anatomical TSA with a clinical and radiological follow up ranging from 12 – 50 months. Our study showed that LHO reconstruction close to the anatomy of a healthy contralateral shoulder improved shoulder function. Stemless anatomical TSA help to restore LHO. Increasing LHO may have a negative effect on shoulder function at three months but had no effect at 12 months.

**The main conclusions of this thesis are:**
1. TSA (anatomic and reverse) using stemless humeral components is reliable if bone quality is adequate. The complication rate is comparable with other shoulder prosthetic systems.
2. Glenoid overhang decreased complications in RSA.
3. LHO measurement on AP radiographs is less reliable and underestimates the distance when compared with CT.
4. Stemless TSA could be of help in reconstructing shoulder anatomy.
5. Shoulder reconstruction close to the anatomy of a healthy contralateral shoulder improves shoulder function.

**Keywords**
Total shoulder arthroplasty, reverse shoulder arthroplasty, stemless shoulder arthroplasty, TESS shoulder prosthesis, comprehensive shoulder prosthesis, scapular notching, arm lengthening, Quick DASH, lateral humeral offset, glenohumeral offset, shoulder anatomy, CT shoulder, shoulder anatomy reconstruction.
Abstrakt på svenska (Abstract in Swedish)


Syftet med denna avhandling var:
(1) Att undersöka radiologisk stabilitet av oskaftade axelproteser.
(2) Att studera effekten av protes placering vid omvänd axelarto prostik både radiologiska och kliniskt utfall.
(3) Att studera tillförlitlighet av mätningen av den laterala humeral offset (LHO), avståndet mellan processus coracoideus till laterala kanten av tuberkulum majus, med användning av CT eller röntgen.
(4) Att studera oskaftad axelprotes förmåga att återställa axelnsanatomi.
(5) Att studera den kliniska betydelsen av LHO återställning i för det funktionella resultatet efter axelarto prostik.

Studie I: Detta är en prospektiv kohortstudie av 49 patienter med en av de två versionerna av TESS (anatomisk eller omvänd) med klinisk och radiologisk uppföljning från 9-24 månader. TESS protes visade lovande resultat på kort sikt med komplikationer som var jämförbar med andra axelprotesystem.

Studie II: Detta är en prospektiv jämförande icke-randomiserad studie av 37 patienter (40 skuldror) som opererades med TESS omvänd axelarto prostik med en uppföljning från 15-66 månader. Vi fann en signifikant förbärmring av funktion och minskning av smärta i både skaftad och oskaftad grupper. Glenoid overhang bedöms påverka risken för scapular notching (SN).

Studie III: Detta är en radiologisk studie som visade att CT hade god tillförlitlighet och reproducerbarhet att mäta LHO.
**Studie IV:** Detta är en prospektiv radiologisk studie av 69 patienter (70 skuldror) med primär artros som hade genomgått oskaftad total anatomisk axelprotes. Denna studie visade att oskaftad axelprotes kan vara till hjälp att återställa axelnsanatomii.

**Studie V:** Detta är en prospektiv studie av 44 patienter med unilateral primär artros som hade genomgått oskaftad total axelprotes med en klinisk och radiologisk uppföljning från 12 - 50 månader. Vår studie visade att LHO rekonstruktion till den friska axeln förbättrar axelfunktion. Oskaftat implantat kan vara av hjälp till att återställa LHO. Ökad LHO kan ha en negativ effekt på axelnsfunktion vid tre månader, men denna effekt påvisade ej vid 12 månader.

**De viktigaste slutsatserna i denna avhandling är:**

1. Oskaftad total axel artroplastik (anatomisk och omvänd) är tillförlitlig om benkvalitén är god med komplikationer som var jämförbar med andra axelprotesystem.
2. Glenoid overhang minskar komplikationer vid omvänd axelartroplastik.
3. LHO mätningen på röntgen är mindre tillförlitlig och underskattar avståndet jämfört med CT.
4. Oskaftad axelprotes skulle kunna vara till hjälp för att rekonstruera axelnsanatomii.
5. Axel rekonstruktion inom anatomi till att efterlikna anatomi på den friska kontralateralaxeln förbättrar axelfunktion.
LIST OF PAPERS

This thesis is based on the following papers, which are indicated in the text by their Roman numerals (Studies I-V).

I. Results of the Total Evolutive Shoulder System (TESS): a single-centre study of 56 consecutive patients.
Kadum B, Mafi N, Norberg S, Sayed-Noor AS.

II. Clinical and radiological outcome of the Total Evolutive Shoulder System (TESS®) reverse shoulder arthroplasty: a prospective comparative non-randomised study.
Kadum B, Mukka S, Englund E, Sayed-Noor A, Sjödén G.

III. Radiologic assessment of glenohumeral relationship: reliability and reproducibility of lateral humeral offset.
Kadum B, Sayed-Noor AS, Perisynakis N, Baea S, Sjödén G.

IV. Geometrical analysis of stemless shoulder arthroplasty: a radiological study of seventy TESS total shoulder prostheses.
Kadum B, Hassany H, Wadsten M, Sayed-Noor A, Sjödén G.
Int Orthop. 2015 Aug 11.

V. Association of lateral humeral offset with functional outcome in total shoulder arthroplasty: a study on 44 stemless implants
Kadum B, Khoschnau S, Wahlström P, Sjödén G, Sayed-Noor A
In manuscript
LIST OF ABBREVIATIONS

AS  Anterosuperior
COR  Center of rotation
CT  Computerized tomography
CTA  Cuff tear arthropathy
DASH  Disabilities of the arm, shoulder and hand score
DP  Deltopectoral
GH  Gleno-humeral
EQ-5D  EuroQol index
HRQoL  Health-related quality of life
ICC  Intra-class correlation coefficient
NSA  Neck shaft angle
OA  Osteoarthritis
RA  Rheumatoid arthritis
RCo  Reversed corolla
ROM  Range of motion
RSA  Reverse shoulder arthroplasty
SBI  Scapular bone impression
SD  Standard deviation
SN  Scapular notching
TESS  Total Evolutive Shoulder System
TSA  Total shoulder arthroplasty
VAS  Visual analogue scale
1. INTRODUCTION

1.1 Historical background

Pioneers of shoulder arthroplasty

Jules Emil Péan performed the first shoulder replacement in March 11, 1893, at the Hospital International in Paris, preceding the first prosthetic hip joint replacement by 26 years. The patient was a 37 year old baker who had tuberculosis of the shoulder joint. The patient had refused amputation, so Péan was left only with the possibility of excising the infected tissue and inserting a prosthesis. The prosthesis was designed and constructed by Dr. J. Porter Michaels, a Parisian dentist. The prosthesis was made of platinum for the humeral shaft and rubber for the head of the humerus. The intervention was not a complete success since Péan had to remove the artificial joint after two years due to a persistent tubercular infection (Lugli 1978). However, in his original report Péan refers to the work of Themistocles Gluck as being the inspiration for his shoulder prosthesis (Bankes et al 1995). Gluck designed a number of shoulder replacements, including a simple prosthesis consisting of an ivory humeral component, which articulated by hooking on to an ivory eye screwed into the glenoid. He also developed more complex hinge and ball and socket joints using ivory and cadaveric bone (Gluck 1891). However, he did not describe the results of these operations or state definitively that they were performed in living human beings (Eynon-Lewis et al 1995).

In the 1930s and 1940s Baron and Judet used an acrylic prosthesis to replace the proximal humerus. These prostheses failed due to material indurability. Frederick Krueger in 1950 performed the first modern shoulder arthroplasty using a Vitallium prosthesis. This was used to treat a patient with avascular necrosis (Fealy et al 2008).

Charles S. Neer introduced the concept of using prosthesis for treatment of proximal humerus fractures in the early 1950s. His clinical series was first published in the Journal of Bone and Joint Surgery in 1953 (Neer et al 1953). The success that he made with Neer I marked the beginning of shoulder arthroplasty, becoming part of mainstream treatment in orthopedic surgery.
Evolution of the design of shoulder prostheses

Neer designed his humeral prosthesis in 1951 for treatment of four-part fracture dislocation of the proximal humerus. The prosthesis was monoblock with one press fit stem and head size. The stem had additional holes in the upper lateral flange in order to stabilize the tuberosities. Further development resulted in 5 different stem sizes.

Neer and Averil, in the early 1970s designed fully constrained or fixed fulcrum prosthesis. The prosthesis consisted of a ball and socket. The indication for using this prosthesis was treating severe shoulder OA and CTA and was basically a salvage procedure because of a high failure rate.

Neer further developed his original Neer I prosthesis in 1974. The prosthesis constituted of a monoblock humeral component, with 2 different humeral head sizes, and a keeled polyethylene glenoid component (Fig.1).

![Image of Neer I prosthesis](Reproduced from: OrthopaedicLIST.com collection with permission.) Original image courtesy of Dr. Dr. Ralph Coonrad, retired Professor of Orthopaedic Surgery at Duke University Medical Center.

**Fig.1** Neer further developed his original Neer I prosthesis in 1974. The prosthesis constituted of monoblock humeral component and a keeled polyethylene glenoid component. (Reproduced from: OrthopaedicLIST.com collection with permission.) Original image courtesy of Dr. Dr. Ralph Coonrad, retired Professor of Orthopaedic Surgery at Duke University Medical Center.
These designs showed good results in the treatment of shoulder OA in terms of improving pain and function (Neer 1974). The Neer II prosthesis was the first complete unconstrained shoulder arthroplasty and marked the birth of modern day TSA. Neer continued to use the Neer II prosthesis until his retirement in 1990.

A flurry of activity began in the 1970s with the creation of new shoulder prosthesis designs. The designs were basically divided into three types: a fully-constrained prosthesis, a semi-constrained design and a non-constrained prosthesis. Various constrained prostheses were developed but most of the systems were abandoned because of high complication rates.

The second generation of unconstrained shoulder arthroplasty adopted the concept of modularity. The humeral component was split into two parts, a stem and a head, connected by a morse taper. This new generation of prosthesis tried to better address the challenges in shoulder anatomy and to make it more feasible to reconstruct the anatomy (Moeckel et al 1992). Anatomic studies in the late 1980s lead to further development in implant design and appearance of a third generation. The newer designs attempted to give the surgeon more feasibility to adapt the prosthesis to the individual anatomy. This new generation of humeral components is commonly referred to as adaptable and modular.

The Aequalis prosthesis which was developed by Walch and Boileau was one of the earlier prosthesis of this kind. The humeral component of the prosthesis was made of three parts (stem, neck and head). The stem was of 3 diameters and 2 different lengths. The head was of 7 different sizes with additionally 4 neck angles. The glenoid polyethylene component was available in three different sizes in order to fit different humeral sizes. This allowed greater flexibility, creating a more anatomical implant for each individual patient (Walch et al 1999).
1.2 Anatomical and biomechanical rationale

Shoulder anatomy consideration

Normal shoulder anatomy varies considerably among different individuals as well as in the left and right shoulders of the same individual (Pearl et al 2005, Moeckel et al 1992). The neck is inclined relative to the humeral shaft (NSA) by 130-150°. The head is retroverted with a highly variable angle which ranges from 0° to 55°. COR of the humeral head is displaced by 6 mm medially (medial offset) and 3-5 mm posteriorly (posterior offset), relative to the axis of the humeral shaft (Severt et al 1993, Pearl et al 1995). In addition, the offset of the humerus in relation to the glenoid may vary in three dimensions, and the radius of curvature ranges from 20 to 30 mm (Pearl et al 1995, Pearl et al 2005). All of these variations should be considered when an arthroplasty is performed because changes in any of these parameters adversely affect the biomechanics of the shoulder.

TSA biomechanics consideration

TSA can basically be divided into total arthroplasty or hemi-arthroplasty depending on whether a glenoid component is involved. TSA is subdivided into three groups depending on the degree of stability: unconstrained, semiconstrained or fully constrained. The classification can be further subdivided according to degree of constraint and conformity of the articular surface into:

a) low constraint and low conformity
b) low constraint and high conformity
c) high constraint and low conformity
and d) high constraint and high conformity (Severt et al 1993, Zadeh et al 1998).

Success in shoulder arthroplasty is dependent on a number of factors. Reproducing normal GH anatomy and biomechanical environment is an important factor (Severt et al 1993). Several factors should be considered by the surgeon in order to restore the anatomy. The surgeon must ensure accurate soft tissue tensioning by deciding on accurate alignments and choosing the right size of the components. Humeral head version is critical and most shoulder arthroplasty systems recommend 20 to 30 degree retroversion. The top of the humeral component should protrude above the tuberosity to avoid impingement. Larger humeral head size improves stability but increases soft tissue tensioning which reduces the range of motion. One of the tests that can be done by the surgeon to determine the humeral head height is testing the displacement of the humeral head relative to the glenoid. It should not be displaced downward more than 50%. 

10
Displacement more than this means the prosthesis is too low, while the opposite means the prosthesis is too high with increased risk of subacromial impingement (Pearl et al 1995).
1.3 RSA

**Historical backgrounds**

Although successful results had been achieved using the Neer II TSA in treatment of shoulder OA, these unconstrained prostheses had higher failure rates in treatment of cuff deficient arthritis. CTA was first termed by Neer as a massive rotator cuff tear associated with proximal humeral head migration and secondary arthritic changes in the glenoid (Jazayeri et al 2011). The first RSA was designed in the early 1970s by Neer (Mark I). The prosthesis is composed of a large spherical glenoid implant with a neck to stabilize the humerus. The prosthesis had a high failure rate and poor functional outcome due to the absence of cuff function. The prosthesis was further modified (Mark II) with a smaller glenosphere in order to permit rotator cuff reconstruction and decrease superior impingement. The new prosthesis was abandoned because of a high glenoid loosening rate. Further development led to Mark III, which allowed axial rotation between the humeral stem and the diaphysis in order to limit constraint and improve range of motion. Unfortunately this new design was also unsuccessful and in 1974 Neer abandoned it. After that, many designs were developed but all resulted in catastrophic failure of the glenoid implants (Grammont et al 1987, Jazayeri et al 2011).

**Grammont RSA**

Attempts to design a RSA continued to fail until 1985, when a French surgeon, Paul Grammont, revolutionized RSA with his concept of medialising and distalizing the COR. Grammont used a neckless glenoid component (glenosphere). By putting the COR within the glenoid, the shearing force was transformed into a compressive force at the glenoid- bone interface. Another mechanical advantage by medialising and distalizing the COR is increasing the lever arm of the deltoid muscle and so more fibers are recruited for abduction (Fig.2), (Grammont et al 1987, Boileau et al 2006). The Grammont RSA was composed of an inverted polyethylene humeral stem and a cemented glenosphere. Further modifications in the original Grammont design led to the DELTA prosthesis in 1991. The new design was composed of a glenosphere which was screwed onto a glenoid base plate that had a central peg. This type of fixation was unsuccessful due to early loosening and further modification led to a second generation with a morse taper design. A third generation appeared in 1994 which further modified the humeral component into a stem which was screwed onto the metaphyseo-epiphyseal block (Nyffeler et al 2005, Edwards et al 2012).
Fig. 2 COR and position of the humerus and the deltoitd muscle with the arm at the side (A) and in abduction (B) in normal shoulder anatomy. C and D, RSA medializes the center of rotation, distalizes the humerus, and elongates the deltoitd. The lever arm of the deltoitd muscle (dotted line) is lengthened so that for any given angular displacement of the humerus, shortening of the deltoitd is greater than in total shoulder arthroplasty. (Reproduced from: Gerber C, Pennington SD, Nyffeler RW. Reverse total shoulder arthroplasty. J Am Acad Orthop Surg. 2009 May; 17(5): 284-95. © 2009 by the American Academy of Orthopaedic Surgeons. With permission.)

Complications of RSA

The main complications of RSA are: SN, periprosthetic infection, instability, acromion stress fracture, mechanical failure and brachial plexus neuropathy.

Medialising the COR is not without biomechanical disadvantages. One possible mechanical disadvantage may be insufficient tensioning of external rotators which may lead to weakness in external rotation. Another potential problem is that the concave humeral component can glide
medially over the edge of the convex glenoid component in adduction position. This repetitive contact can lead to bone loss under the inferior aspect of the glenoid and SN development. The incidence of this phenomenon is variable in the literature and up to 96% has been reported (Levigne et al 2008). The clinical significance of SN is still unclear although glenoid components failure and polyethylene wear have been reported as possible consequences. To avoid or decrease the incidence of SN, a number of technical modifications in component positioning have been suggested. These recommendations have included: inferior glenoid component position, a larger glenosphere, a lateralized COR, tilting the glenoid component 10 degrees inferiorly and a varus humeral cut. However, the best way to avoid scapular notching is still debatable (Simovitch et al 2007, Levigne et al 2008, Edwards 2012).

Putting the humerus more distally with subsequent arm lengthening can be another source of complication. Excessive lengthening can lead to high deltoid muscle tension with increasing risk of acromion stress fracture and neuropathy. On the other hand, inadequate deltoid tensioning can lead to instability (Lädermann et al 2014).

The large subacromial dead space with formation of a hematoma can be a possible source of infection. Periprosthetic infection has been reported in up to 5.1% of primary RSA (Jazayeri R et al 2011).
1. 4 Implant fixation

**Humeral component fixation**

Humeral stems can be used both in uncemented press-fit or cemented fashion. A cemented prosthesis is recommended where there is risk of implant subsidence like fracture, RA and osteoporosis. To enhance biological fixation, hydroxyapatite coatings have been added by some manufacturers. Regardless of the mode of fixation, aseptic loosening remains remarkably uncommon (Cofield 1994).

**Glenoid component fixation**

Glenoid fixation remains the weakest link in TSA. The revision rate for the glenoid component is 3.2% compared with 1.8% for the humeral component (Torchia et al 1997). A cemented glenoid component has been shown to be an effective treatment for glenohumeral arthritis. Radiolucent lines and potential for glenoid loosening remain a major concern. Most cemented glenoid components with lucent lines are present from the immediate postoperative period and do not progress (Blevins et al 1997). These concerns resulted in development of metal-backed, bone-ingrowth prostheses which potentially could offer a more stable fixation. Another potential benefit is the ability to convert an anatomical TSA to a RSA, in cases of revision due to rotator cuff failure, without compromising the fixation of the glenoid baseplate component (Rodosky et al 1996). Unfortunately, the results of metal-backed components in anatomical TSA have been associated with a higher revision rate (Boileau et al 2002, Clitherow et al 2014).
1.5 Stemless shoulder arthroplasty

Background

Complications related to the humeral stem account for 10-20\% of postoperative complications (Zumstein 2011). The reported complications in the literature that are related to insertion of a stemmed prosthesis can be divided into intraoperative complications (malpositioning, false route, periprosthetic fracture) or postoperative complications (loosening, migration, disassembly, peri-prosthetic fracture, stem fracture). In the presence of a long stem elbow prosthesis it is difficult or sometimes even impossible to implant a humeral stem. Increasing stress increases the risk of fracture when there is an ipsilateral elbow prosthesis. When revision of a stemmed implant is necessary, the removal of well fixed implant can be a challenge and can lead to bone damage (Sahota et al 2014). With the aim of reducing stem related complications, many designs of prosthesis have progressively shortened the humeral stem. Stemless arthroplasty, with complete humeral stem elimination and reliance on metaphyseal fixation, was first introduced in 2004 (Churchill RS 2014).

Types of stemless prosthesis

There are two different types of stemless prosthesis; one obtained by impaction of a fin system and in the other implants system, cage screw fixation is used. In sclerotic bone the cage screw system seems to be advantageous whereas impaction using the fin system seems to be preferable in osteoporotic bone and in conditions with defects of the bone. Because of the small number of cases and short period of observation at the present time, none of the implant systems show a decisive superiority. A total number of almost 10,000 stemless implants have been used in shoulder arthroplasty since 2004 (Petriccioli et al 2015).

Today, at least five stemless shoulder implants are available on the worldwide market:

1. TESS (Zimmer Biomet), the world’s first stemless shoulder arthroplasty system, first implanted in Europe in 2004 that evolved into the Comprehensive shoulder system (Zimmer Biomet). The TESS is a 3-component system based on a 6-armed corolla metaphyseal component that is porous coated for improved bone fixation (Fig.3). The corolla component is impaction implanted into the metaphyseal bone, followed by the screw-in insertion of a male Morse taper. The humeral head has a corresponding female Morse taper. The Nano uses the same basic features of the TESS with the added ability to convert to a reverse configuration.
The Nano system is similar in that the 6-armed corolla is impaction implanted. One major difference between the TESS and the Nano, however, is that the Nano has a female Morse taper within the corolla and a corresponding male Morse taper on the humeral head (Churchill 2014, Petriccioli et al 2015).

Fig.3 The TESS is a 3-component system based on a 6-armed corolla metaphyseal component that is porous coated for improved bone fixation (This figure is the property of Zimmer Biomet Inc or its affiliates, which have granted their permission for usage only on this publication and solely for educational and scientific purposes).

2. Eclipse stemless shoulder arthroplasty (Arthrex, Naples, FL, USA), which was first introduced in Europe in 2005.
3. Affinis stemless arthroplasty (Mathys, Bettlach, Switzerland), introduced in 2009.
4. Simpliciti by Tournier available only for the European market, since 2010.
5. Sidus stemless shoulder system (Zimmer, Warsaw, IN, USA) which was recently introduced.

**Indications and contraindications**

The indications for an anatomical stemless TSA are the same as conventional anatomical TSA i.e. OA, RA, post-traumatic OA or osteonecrosis that is not amenable to non-surgical treatment. The contraindications for stemless shoulder prosthesis include proximal humeral fractures and inadequate bone stock (Huguet et al 2010, Berth 2013).
1. 6 Surgical approaches

The questions concerning any surgical approach are its utility, advantages, and disadvantages. The two most common approaches in implanting shoulder prostheses are the deltopectoral (DP) and antero-superior (AS) approaches. The choice between the DP and AS approach depends primarily on the experience of the surgeon. Secondarily, it is guided by the indication and analysis of the advantages and disadvantages of both techniques.

**AS approach**

The main advantages of the AS approach are simplicity, ease of axial preparation of the humerus, quality of the frontal exposure of the glenoid, and preservation of the subscapularis tendon. The main drawback of the AS approach is the potential risk of weakening of the anterior deltoid due to either mechanical stretching by retractors or direct damage to the axillary nerve which lies in the lower part of the incision (Molé et al 2007). Many authors consider the AS approach for treatment of complex fractures of the proximal humerus because, in addition to the quality of exposure from the proximal humerus to the glenoid, it offers the advantages of better conditions of release and fixation of the greater tuberosity when compared to the DP approach (Bufquin et al 2007). AS is the preferable approach when implanting a reverse prosthesis by many surgeons because of better visualization of the glenoid surface which enhances the precision and accuracy of component positioning (Valenti et al 2008). Nonetheless, some surgeons continue to use the deltopectoral approach when doing RSA.

**DP approach**

The main advantages of the deltopectoral approach are the preservation of the deltoid muscle, exposure of the lower pole of the glenoid to facilitate glenoid implant positioning, possibility of inferior extension to control the proximal humerus, and ability to perform a latissimus dorsi transfer (Boileau et al 2008). The main drawbacks of the DP approach are the interruption of the continuity of the subscapularis tendon (the main anterior stabilizer), need for an extended capsular release (which is a factor for instability), lack of control of posterior cuff and in glenoid screwing. The two approaches were compared in a multicenter study of the French Society of Trauma and Orthopaedic Surgery, which reported on 527 primary RSA with a follow-up of more than 2 years in 11 European specialist centers. The authors found that the AS was associated with less instability and comparable risk for scapular notching and periprosthetic fractures. Outcome was
similar between the two approaches. However, loosening tended to occur more often with the anterosuperior approach (Molé et al 2007).
2. Aims of the studies

The general aim of this thesis was to report the functional and radiological outcome of TSA in relation to anatomical placement and implant stability.

The specific aims of these studies were:

**Study I**
The primary aim was to assess the functional outcome after TESS shoulder arthroplasty. The secondary aim was to investigate the radiological stability of stemless shoulder prostheses.

**Study II**
The primary aim was to report the functional outcome after RSA. The secondary aim was to evaluate the effect of glenoid component positioning on occurrence of SN, to address the effect of arm lengthening on shoulder function and to assess the radiological stability of the humeral component.

**Study III**
The aim of the study was to evaluate the reliability and reproducibility of LHO measurements on plain radiographs in comparison to CT.

**Study IV**
The aim of this study was to investigate the ability of stemless shoulder prosthesis to restore proximal humerus anatomy in relation to premorbid anatomy.

**Study V**
The primary aim was to assess the importance of LHO restoration in optimising the functional outcome after anatomical TSA. The secondary aim was to investigate the ability of stemless implants in restoration of LHO.
3. Hypotheses of the studies

Study I
The functional and radiological outcome after TESS shoulder arthroplasty is comparable with other shoulder prosthetic systems. Stemless shoulder prostheses have a good radiological stability.

Study II
RSA provides a reliable treatment option and prosthesis component position affects the rate of occurrence of SN.

Study III
CT is more reliable than X-ray in estimating LHO.

Study IV
The use of stemless shoulder prostheses results in acceptable restoration of shoulder anatomy.

Study V
LHO restoration within accepted anatomical limits improves postoperative function.
4. Material and methods

Ethics

All studies were conducted according to the Helsinki declaration and were approved by the Ethics Committee of Umeå University. All patients gave their informed consent to participate.

Study I

During the study period 56 consecutive patients were included who underwent shoulder arthroplasty with one version of TESS (Zimmer Biomet) at the Orthopaedic department at Sundsvall Teaching Hospital, Sweden between October 2007 and December 2009. There was no age limits for inclusion.

Before the operation, the patient’s functional impairment was evaluated by Quick DASH index, while the affection of health status was evaluated by EQ-5D self report questionnaire, including a 10 cm VAS for the level of life quality. Preoperative radiographic evaluation was obtained by anteroposterior, axillary and lateral views. When indicated, MRI was performed to evaluate the rotator cuff. Regardless of the version of shoulder prosthesis implanted, the AS approach according to Mackenzie was used in all patients. Postoperative radiographic and clinical assessment was evaluated in the same way as preoperatively. For the postoperative rehabilitation, patients are allowed to start exercises directly after the operation under the supervision of a physiotherapist. Patients operated with anatomical TSA were instructed to avoid external rotation more than 20 degrees for 4 weeks while patients with RSA were instructed to avoid extension against resistance for 4 weeks. Six weeks postoperatively, the patients were allowed to use their arms as tolerated. The postoperative follow-up plan included: a 2 weeks visit to check the operative wound, a 3 and 12 months visit to check the clinical and radiographic outcome and an additional visit in September 2010 to check the clinical and radiographic outcome as a final control for this study.

We compared the results in fracture patients (3 and 4 fragments proximal humeral fractures) with sex- and age-matched OA patients from the same cohort. Reports of the ROM before and after the operation were not documented in a standardized way and therefore were not included in this study.
Quick DASH score

The DASH score is a region-specific outcome instrument developed as a measure of upper extremity disability and symptoms (Hudak et al 1996). We used the 11-item Quick DASH, which has been developed from the original 30-item DASH. The Quick DASH has been shown to have similar precision as the original DASH and can replace it with similar precision in upper extremity disorders (Gummesson et al 2006). The items are used to calculate a score ranging from 0 (no disability) to 100 (most severe disability). The Swedish version of DASH has been shown to have good reliability, validity and responsiveness (Atroshi et al 2000).

EQ-5D score

The EQ-5D, the health status component of the Euro-Qol assessment (EuroQol Group, Rotterdam, The Netherlands), is a non-disease-specific instrument for describing and evaluating HRQOL. The EuroQol instrument has been designed for self-completion by the respondent. There are four components of the instrument: description of the respondent’s own health (EQ-5D), rating of own health by means of the EuroQol thermometer, evaluation of a standard set of health states, and background information about the respondent. The respondents describe their own health state on five dimensions -mobility, self-care, usual activities, pain/discomfort, and anxiety/depression. One of three levels is chosen for each dimension and thus the resulting health state can be defined by a five-digit number (EuroQol Group 1990). The reliability and validity of the EQ-5D has been evaluated in different patient populations including the Swedish population and it was concluded that there was good evidence for the validity, reliability, and responsiveness of the EQ-5D (Brooks 1991). It was demonstrated that the EQ-5D had good internal and external responsiveness in patients with shoulder injuries and can therefore be recommended for use as an outcome measure for evaluating the HRQOL in both clinical studies and health-care assessments (Olerud et al 2011).

Radiographic views

For accuracy and reproducibility, a true AP X-ray view of the glenohumeral joint was obtained under the following conditions:

The AP view was taken with the patient erect with the arm by the trunk in neutral position and with the palm facing forward. All examinations were made under fluoroscopy control in order to obtain views without overlap of the glenoid and humeral head (Takase et al 2004). All views included the whole scapula and the space between scapula and spine in order to give
optimum exposure. A 30 mm spherical marker placed lateral to the greater tubercle was used to control magnification. All radiographs were obtained on a computerised radiography system (Siemens, Erlangen, Germany). The images were digitally acquired using the Picture Archiving and Communication System (PACS) (Impax: Agfa, Antwerp, Belgium).

**Surgical approach:**

We used the AS approach, regardless of the version of TESS implanted, according to Mackenzie (Burgess et al 2009). The anatomical details are described below.

1. **Anatomical landmarks**

   The acromion is rectangular. Its bony dorsum and lateral border are easy to palpate on the outer aspect of the shoulder.

2. **Incision**

   The longitudinal skin incision runs from just posterior to the acromioclavicular joint down the lateral aspect of the arm for about 7-9 cm.

3. **Superficial surgical dissection**

   There is no true internervous plane. The fibers of the anterior deltoid muscle are split longitudinally from the acromion about 5 cm downward. To decrease the accidental extension and axillary nerve injury, a suture at the inferior border was occasionally used. The deltoid muscle was detached at its origin on the anterior part of the acromion. The axillary nerve leaves the posterior wall of the axilla by penetrating the quadrangular space. Then it winds around the humerus with the posterior circumflex artery. The nerve enters the deltoid muscle posteriorly from its deep surface, about 7 cm below the tip of the acromion (Stanley Hoppenfeld 2009).

4. **Deep surgical dissection**

   The lateral aspect of the upper humerus and its attached rotator cuff lie directly under the deltoid muscle and subacromial bursa. An acromioplasty was regularly performed. After further excision of the bursa, the cuff was evaluated. The rotator interval was divided longitudinally and the subscapularis muscle detached at its insertion. If the tendon of the long portion of the
biceps was still present, its intra-articular portion was resected and a tenodesis was sometimes performed. The inferior aspect of the capsule was released along the humeral neck while the shoulder was progressively externally rotated to approximately 80° to 90°. Proximally directed force on the elbow while the arm is in extension allowed the humeral head to luxate superiorly and the humerus was prepared for prosthesis. Any osteophyte on the glenoid rim was removed to improve exposure of the glenoid.

Surgical technique:

Three general orthopaedic surgeons with a special interest in shoulder surgery operated on the patients. All patients were given 2g cloxacillin preoperatively, followed by 2 additional doses during the first 24 hours. General anaesthesia with interscalene blockade was used. The patient lies in the beach chair position with a 40-60° tilt of the chest position in a theatre with laminar airflow. A sandbag or other form of support was placed under the medial edge of the scapula to facilitate exposure. The arm was placed on an armrest and was draped free.

1. Anatomical TSA

After dislocation of the humeral head, osteophytes were removed with a ronguer for visualisation of rotator cuff insertion and anatomical neck. The cutting guide was held parallel to the anatomical neck. This adjusted the inclination and head version automatically. The final decision as to whether a stemmed or stemless humeral implant would be used was made intraoperatively depending on bone quality and stability of the humeral component. We chose the stemmed version if primary stability of the humeral implants could not be achieved. If it was planned implant the stemmed version then the medullary canal was prepared. If a stemless version was considered appropriate then corolla preparation proceeded. The size of the corolla broach was chosen using a humeral sizing template. Preparation of the glenoid begins with an assessment of wear and loss of bone stock. The surgeon then completes glenoid exposure, labrum resection, and peripheral capsular release. The inferior labrum is carefully released with a knife while maintaining contact with the bony rim and avoiding electric cautery, considering the proximity of the axillary nerve, which is not visualized. This allows the positioning of a hooked retractor that presses the humeral epiphysis, which is protected by its trial prosthesis. Once the glenoid implant was in place, the humerus again was subluxated superiorly and anteriorly. The metaphyseal fixation, i.e. the corolla implant, was
introduced after broach removal, and a trial head was tested. There were six symmetrical and six asymmetrical head sizes available (41, 43, 45, 48, 50, 52 mm). Several factors determine the appropriate choice of head size: size of the head cut, range of motion (ROM) and translation of the humeral head on the glenoid, which should be <50 %. In all anatomical TESS implants, a symmetrical head was chosen. After reducing the joint, the subscapularis was reinserted back into the lesser tuberosity, and the deltoid was reattached to the acromion using osteosutures. The skin was closed using intracutaneus sutures.

2. RSA

The design of the TESS RSA prosthesis is based on Grammont’s concept. For the glenoid, an asymmetric reamer increased the height of the central portion to improve osteointegration and preserved the peripheral rim to optimize the stability of the baseplate. The glenosphere (sized 36 or 41 mm in diameter) is made of cobalt-chrome and is bolted to a glenoid baseplate fixed by 4 screws. The humeral stemless cup has been developed from the anatomic corolla. The RCO is made of cobalt-chrome with a titanium plasma spray and hydroxyapatite coating. It has six anti-rotational wings to optimize the rotational stability and is available in 4 sizes. The bone cut is done with the help of a cutting guide with an angulation of 150 degrees. A pin was centred on the bone resection using a template and a humeral reamer was centered on the resected humeral cut. The RCO was retroverted by 20 degrees and was press fitted without cement. If bone quality was deemed to be inadequate, a stem of adequate diameter was inserted after prereaming of the medullary canal. The polyethylene component is prevented from dislocating by a ring-lock system. Trial humeral inserts were tested and the final polyethylene insert was impacted. After testing the amplitude and stability, the subscapularis muscle was reattached to the lesser tuberosity.

Statistical analysis

SPSS version 16 (SPSS, Chicago, IL, USA) was used for the statistical analysis. The Student’s paired t test was used to compare the Quick DASH, EQ-5D and VAS for life quality before and after the operation. A p value\(0.05\) was considered statistically significant.
Study II

The study period was between October 2007–January 2012 at Sundsvall teaching hospital. The inclusion criteria were: 1. All patients with CTA, primary OA with rotator cuff dysfunction, RA and proximal humeral fracture sequelae who had undergone TESS RSA (Zimmer Biomet), both stemmed and stemless at Sundsvall Hospital, Sweden during the study period 2. Intact cognitive function (no diagnosis of dementia, with the patient being lucid and fully oriented). 3. No previous neurological disorder that affects the operated side. There was no age limits for inclusion.

Functional impairment was evaluated by the Quick DASH index, the EQ-5D score was used for the estimation of quality of life and global VAS for evaluation of overall health status. Pre- and post-operative active ROM was measured by visual estimation in degrees of abduction and flexion, while internal rotation was measured as the ability to reach behind the back. VAS was used for assessing pain.

The VAS pain is a continuous scale comprised of a 100 mm line, anchored by 2 verbal descriptors, one for each symptom extreme. For pain intensity, the scale is most commonly anchored by “no pain” (score of 0) and “pain as bad as it could be” or “worst imaginable pain” (score of 100), (Huskisson et al 1974, Jensen et al 1986).

Radiographic assessment with anteroposterior (AP), axillary and lateral scapular radiographs was performed pre- and post-operatively by standardised views at three months and then annually.

SN was assessed on the latest radiograph using the AP view according to Sirveaux (Sirveaux 1997). Grade 1 indicated a notch limited to the scapular pillar, grade 2 reached the inferior screw of the baseplate, grade 3 extended beyond the inferior screw and grade 4 reached the central peg of the baseplate.

Glenoid loosening was defined as radiolucencies under the baseplate or around the peg or screws, screw breakage or glenoid migration.

The peg-glenoid rim distance was measured as the distance from the uppermost border of the central peg to the inferior glenoid margin on post-operative AP radiographs (Fig.3 a) (Simovitch et al 2007).

Glenoid component craniocaudal positioning Two horizontal lines were drawn, one from the inferior margin of the glenoid sphere parallel to another line which was drawn from the inferior
The distance between the two lines was calculated and values more than 0 mm were regarded as overhang (Fig. 3 b) (Nyffeler et al 2005).

Glenoid component inclination was described as the angle between the baseplate and a horizontal line drawn from the upper margin of the glenoid. An inferior tilt was defined as an angle measuring more than 90°; a superior tilt was under 90°, while 90° was considered neutral (Fig. 3 c) (Lévine et al 2011).

**Fig. 3** a The peg-glenoid rim distance (PGRD) was measured as the distance from the uppermost border of the central peg to the inferior glenoid margin on the post-operative AP radiograph. b The craniocaudal glenoid component position was measured by drawing two horizontal lines, one from the inferior margin of the glenoid sphere parallel to another line which was drawn from the inferior margin of the glenoid. The distance between the two lines was calculated and values more than 0 mm were regarded as overhang. c Glenoid baseplate inclination was described as the angle between the baseplate and a horizontal line drawn from the upper margin of the glenoid.
Arm length measurement was performed using a computed tomography (CT) scout view showing both arms from the acromion to the elbow joint. Three lines were defined on the CT scanogram for making the measurements: the distal humeral line, the longitudinal axis of the humerus and the acromial line (Fig. 4). Arm length was calculated as the distance from the undersurface of the acromion to the elbow joint line. Arm lengthening was calculated as the difference in arm length between the operated and contralateral arm. A positive number indicated arm lengthening of the operated shoulder, while a negative number was considered as a shortening.

Fig. 4 Arm lengthening was assessed using a CT scout view showing both arms from the acromion to the elbow joint. Three lines were defined for making the measurements: the distal humeral line (D), the longitudinal axis of the humerus (H) and the acromial line (A). Arm length was defined as the length of the longitudinal axis line from the acromial line to the distal humeral line.
**Statistical analysis**

Statistics were obtained using SPSS for Windows statistical program release 21 (SPSS Inc., Chicago, IL, USA). The Wilcoxon signed rank test was used to compare pre- and post-operative values of Quick DASH, EQ-5D, VAS pain and ROM. The Mann-Whitney test was used to compare inclination and overhang between categories of glenoid notching. The Spearman correlation was used to evaluate relations between arm lengthening and outcome. Kruskal-Wallis analysis of variance (ANOVA) was used to evaluate relations between notching and glenoid loosening. Values for continuous data are presented as median (min., max.). The statistical significance level was designated at P<0.05.
Study III

This prospective study was performed at Sundsvall Teaching Hospital, Sweden between May 2011 and January 2013. A power analysis for 4 observers and a minimum value of 0.7 for the interclass correlation coefficient (ICC) indicated that 22 shoulders were required. Thus, 26 consecutive patients that underwent anatomical TESS TSA (Zimmer Biomet) were included in order to provide a safe margin of error.

Inclusion criteria were primary OA of the shoulder and scheduled to have anatomical TSA. Patients with previous shoulder surgery were excluded as well as those with secondary OA such as posttraumatic OA or CTA. The 4 observers were two shoulder surgeons, one orthopaedic resident and one radiologist. The four observers had access to written instructions and illustrations of LHO measurements and they independently examined all radiographs and CT scans. After 6 weeks and blinded to their results, each observer repeated the same measurements.

Plain radiograph measurements

LHO was evaluated by measuring the distance between the medial edge of the base coracoid process and the most lateral point of the greater tubercle in AP X-ray view (Fig. 5).

CT measurements

CT imaging was done with the patient in supine position and the arms by the side with palms facing upward (anatomical position). Both shoulders were included in the axial CT sections. LHO was measured in the axial section by measuring the distance between the medial edge of the base of the coracoid process to the most lateral point of the greater tubercle, (LHO, CT) (Fig. 6).

Statistical analysis

The ICC (with 95 % CI) was used to evaluate the interobserver reliability and intraobserver reproducibility of the obtained measures while paired t-tests were used to compare their means. For ICC the value of 0.00–0.20 was considered slight, 0.21–0.40 was considered fair, 0.41–0.60 was considered moderate, 0.61–0.80 was considered substantial and 0.81–1.00 was considered excellent (Landis 1977). The distributions of variables were tested for normality using the Shapiro–Wilk test (Shapiro et al 1965). Correlation between LHO (X-ray) and LHO
(CT) measurements were analysed using Bland–Altman plots (Bland et al 1986). A scatter plot with linear regression was performed to relate corresponding measurements. Statistical analysis was carried out using SPSS for Windows version 20.0 (SPSS Inc., Chicago, Illinois) and statistical significance was set at p<0.05.

**Fig. 5** LHO measured in the A-P view as the distance (c) between the medial edge of the base of coracoid process (a) to the most lateral point of the greater tubercle (b).
Fig. 6 (LHO, CT) measured in axial CT section as the distance between the medial edge of the base of coracoid process (A) to the most lateral point of the greater tubercle (B).
Study IV

This prospective study was performed between May 2007 and December 2013 at Sundsvall teaching hospital. During that period, 216 shoulders were given an anatomic TSA or RSA TESS (Zimmer Biomet) implant for pain after OA, CTA, fractures, revision (due to failure of other implants) or RA. Inclusion criteria were patients with primary OA who had undergone stemless total anatomic shoulder arthroplasty. Patients with post-traumatic OA, inflammatory arthropathies, bone-stock insufficiency, revision, previous surgeries or stemmed humeral implants were excluded.

Radiographic parameters

Pre-operative measurements:

Premorbid humeral head anatomy was estimated by a best-fit circle method according to previous studies (Alolabi et al 2014, Youderian et al 2014). A circle was mapped in the AP view and matched to three preserved nonarticular bone landmarks: the lateral cortex below the flare of the greater tuberosity, the medial footprint of the rotator cuff on the greater tuberosity and the medial calcar at the inflection point where the calcar meets the articular surface (Fig. 7a). COR was then identified from the circle and the distance to the anatomical neck was calculated in millimetres (Fig. 7a).

Humeral head height (HH) is defined as the perpendicular linear distance from the anatomic neck to the apex of the circle (Fig. 7b).

NSA was measured as the angle between a line perpendicular to the anatomical neck and the long axis of the humeral diaphysis, which was defined by a proximal and distal point in the centre of the intramedullary canal (Fig. 7c).

Post-operative measurements:

COR was identified by placing a circle fitted to the curvature of the HH prosthesis. The anatomical neck was supposed to be the same as that identified during surgery (lower margin of the prosthetic head). Deviation of post-operative COR >3 mm from the normal anatomy was considered as being clinically significant (Alolabi et al 2014). HH was measured from the anatomical neck to the top of the prosthetic HH. Deviation of postoperative HH >5 mm from the normal anatomy was considered clinically significant (Harryman et al 1995). NSA was measured in the same manner as pre-
operatively. Shoulders with post-operative NSA <130° were considered as varus (Takase et al 2002). We excluded shoulders that already had pre-operative NSA <130° from the varus group.

**Statistical analysis**

Data was tested for normality with the Shapiro–Wilk test. Descriptive statistics are reported as means, standard deviations (SD) and ranges for continuous data. We used the Pearson correlation coefficient (r) to calculate the correlation between premorbid and postoperative parameters (COR, HH and NSA).
Fig. 7 Pre-operative radiographic measurements. Premorbid humeral head anatomy was measured by a best-fit circle in the anteroposterior (AP) view. Asterisks represent nonarticular landmarks. The anatomic neck was defined as the line between point A and point B. The centre of rotation (COR) was then identified and the distance to the anatomical neck calculated in millimetres (a). Humeral head height (HH) is defined as the perpendicular linear distance from the anatomic neck to the apex of the circle (b). Neck-shaft angle (NSA) was measured as the angle between a line perpendicular to the anatomical neck and the long axis of the humeral diaphysis (c). Glenohumeral offset (GH) was measured as the transverse distance between the glenoid and the lateral cortex of the greater tubercle (d).
Study V

This prospective study was performed between May 2011 and August 2014 at Sundsvall teaching hospital, Sundsvall, Sweden. All patients with symptomatic unilateral primary OA scheduled for stemless anatomical TSA were considered for inclusion. Patients with previous shoulder surgery, cognitive impairment or neurological disorder were excluded.

Functional measurements

Within 6 weeks preoperatively, functional impairment was measured by the Quick DASH score, quality of life by EQ-5D, a measure of health status using the VAS scale component of EQ-5D, pain both at rest and exertion using a VAS scale and active ROM.

Postoperatively, the patients were assessed with the same functional parameters at 3 months, 12 months and then once annually. One independent observer performed all functional measurement to ensure objectivity.

CT measurements

CT imaging was done in the same way as in study III. Preoperative CT was done within 6 weeks before surgery and used to rule out the presence of any osteoarthritic changes in the contralateral shoulder and therefore to confirm the diagnosis of unilateral OA. The postoperative CT was done at three months follow-up to measure the LHO bilaterally.

LHO was measured in the same way as in study III. LHO was measured for the contralateral healthy shoulder, (LHO contra), while LHO for the operated shoulder, (LHO op) (Fig.7). The difference between LHO op and LHO contra, (LHO post), was calculated and a positive value was obtained when the LHO op was longer than the contralateral side, whereas a negative value indicated the opposite.
Fig. 7 LHO of the operated shoulder, (LHO op), was measured in the axial CT section as the distance between the medial edge of the base of coracoid process (A) to the most lateral point of the greater tubercle (B).

**Type of stemless implants**

All patients were treated with stemless implants, either the Total Evolutive Shoulder System (TESS), or its second generation, Nano comprehensive system (Zimmer Biomet).

**Statistical analysis**

To calculate the required sample size, a priori power analysis was performed using G*Power software (Faul et al 2009) based on comparing the means of the primary outcome Quick DASH index in each group. With a power of 0.80 and a significance level (alpha) of 0.05, a minimum of 32 patients were needed to detect a clinically significant 10 points difference (SD 20) in Quick DASH index. The distributions of variables were tested for normality using the Shapiro–Wilk test (Shapiro et al 1965).

The intraclass-correlation coefficient ICC (with 95 % CI) was used to evaluate the correlation between LHO op and LHO contra. For ICC a value of 0.00–0.20 was considered slight, 0.21–0.40 was considered fair, 0.41–0.60 was considered moderate, 0.61–0.80 was considered substantial and 0.81–1.00 was considered excellent (Landis et al 1977). The Wilcoxon signed rank test was used to compare pre- and post-operative values of Quick DASH, EQ-5D, VAS health status, VAS pain and ROM. The correlation between LHO postoperative changes and
functional parameters was calculated by linear regression analysis. Statistical analysis was carried out using SPSS for Windows version 20.0 (SPSS Inc., Chicago, Illinois) and statistical significance was set at $p = 0.05$. 
5. Results

Study I

Patient flow and baseline data

Forty-nine patients were available with a mean follow-up 14 months (range 9–24 months). There were 36 females and 13 males with ages at operation ranging between 50 and 83 years (mean 71). The right side was operated in 27 patients and the left side in 22 patients. There were 30 patients with OA (19 with good cuff function and 11 with cuff dysfunction), 9 with RA (6 with cuff dysfunction and 3 with good cuff function) and 10 with proximal humerus fracture sequelae (6 with good cuff and 4 with cuff dysfunction).

Type of implants and operation indications

There were 28 anatomical TSA and 21 RSA. There were 39 stemless shoulder prostheses (22 anatomical TSA and 17 RSA) and 10 stemmed (6 anatomical TSA and 4 RSA). The shoulder disorders that were operated on using stemless TSA (n= 22) were as follows:
1. OA (n=19).
2. RA (n=3).

The shoulder disorders that were operated on using stemless RSA were as follows:
1. OA with cuff dysfunction (n=11).
2. RA with cuff dysfunction (n=6).

Cemented stemmed prosthesis, both anatomical and RSA, were used only in fracture patients. Patients with malunion or non-union proximal humerus fracture with cuff dysfunction received cemented stemmed RSA while those with fracture sequelae with intact cuff received anatomical TSA.

Patient outcome measurements

All functional parameters (Quick DASH, EQ-5D and VAS for life quality) were significantly improved (Table. 1). None of the patients operated on using reverse TESS (n = 21) showed radiolucencies or scapular notching during the study period. There were no radiolucencies around any stemless prosthesis (n=39). The outcome in fracture patients was compared with age- and sex-matched patients operated for primary/ posttraumatic osteoarthritis with the same TESS version from the same cohort. We found that the Quick DASH index was worse in
fracture patients (43, SD 18) compared to osteoarthritis patients (28, SD 26). However, this difference did not reach a statistical significance (p = 0.08).

Table. 1 pre- and postoperative functional outcome for all patients (n= 49)

<table>
<thead>
<tr>
<th></th>
<th>Preoperative (Mean, SD)</th>
<th>Postoperative (Mean, SD)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quick DASH</td>
<td>56 ± 25</td>
<td>34 ± 22</td>
<td>0.001</td>
</tr>
<tr>
<td>EQ-5D</td>
<td>0.36 ± 0.30</td>
<td>0.73 ± 0.23</td>
<td>0.001</td>
</tr>
<tr>
<td>VAS for life quality</td>
<td>39 ± 23</td>
<td>66 ± 22</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Complications and re-operations

1. Two patients had superficial wound infections treated with soft tissue debridement and antibiotics
2. One patient with rheumatoid arthritis operated on using stemless RSA had antero-posterior instability secondary to malpositioned glenosphere.
3. One patient with posttraumatic arthritis operated on using stemless RSA had early dislocation secondary to displacement of RCo, treated with revision to stemmed RSA.
4. One patient operated on using RSA had an intraoperative fracture of the glenoid cavity
5. One patient operated on using RSA for proximal humeral fracture showed dissociation between the stem and metaphyseal corolla.
Study II

Patient flow and baseline data

The study group comprised 37 patients (23 women and 14 men; mean age at surgery 72.0 years; age range 60–88 years). In total 40 shoulders were operated on. The mean duration of follow-up was 39 months (range 15–66 months). Indications were CTA (n=14), primary OA with rotator cuff dysfunction (n= 10), RA (n=7) and proximal humeral fracture sequelae (n=9).

Three patients died during the study from causes unrelated to the surgery at 20, 35 and 40 months post-operatively. For these patients, results were obtained from their last follow-up.

Type of implants and operation indications

There were 37 patients (40 shoulders) who underwent TESS RSA. There were 16 stemless and 24-stemmed.

The shoulder disorders that were operated on using stemmed RSA (n=24) were as follows:
1. CTA (n= 7).
2. OA with cuff dysfunction (n= 5).
3. RA (n= 3).
4. Proximal humeral fracture sequelae (n= 9).

Cemented stemmed RSA prostheses were used only in fracture patients.

The shoulder disorders that were operated on using stemless RSA (n= 16) were as follows:
1. CTA (n= 7).
2. OA (n=5).
3. RA (n=5).

Patient outcome measurements

There was a marked improvement in shoulder function, quality of life and reduction of pain for both stemmed and stemless versions and for all included diagnoses (Table. 2).

When we looked at the stemmed and stemless RSA in arthritis patients (i.e. no fracture patients included), we found the two groups to be comparable except that more women received stemmed implants (< 0.05). At radiological follow-up we found no signs of humeral implant loosening except for one stemmed shoulder where thin zones of resorption of the proximal humerus were detected.
Table 2: Preoperative and post-operative values of EQ-5D, Quick DASH score, pain and ROM for all patients.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Preoperative</th>
<th>Post-operative</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. QuickDASH</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>68 (4.5–93.2)</td>
<td>30 (2.5–86.4)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Stemless</td>
<td>67 (38.6–88.6)</td>
<td>29 (4.5–86.4)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Stemmed</td>
<td>56 (4.5–55)</td>
<td>35 (5–80)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>2. EQ-5D</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>0.60 (0.11–1.00)</td>
<td>0.81 (0.18–1)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Stemless</td>
<td>0.49 (0.18–0.77)</td>
<td>0.74 (0.3–1)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Stemmed</td>
<td>0.43 (0.17–0.80)</td>
<td>0.73 (0.4–1)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>3. VAS pain at rest</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>35 (0–80)</td>
<td>0 (0–20)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Stemless</td>
<td>30 (10–80)</td>
<td>10 (0–20)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Stemmed</td>
<td>35 (15–60)</td>
<td>0 (0–15)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>4. VAS pain at activity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>60 (30–90)</td>
<td>10 (0–30)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Stemless</td>
<td>65 (40–80)</td>
<td>10 (0–20)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Stemmed</td>
<td>70 (50–75)</td>
<td>15 (0–20)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>5. Abduction</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>30 (10–80)</td>
<td>100 (50–170)</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Stemless</td>
<td>30 (10–60)</td>
<td>110 (60–170)</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Stemmed</td>
<td>40 (20–80)</td>
<td>90 (70–160)</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>6. Forward elevation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>50 (10–80)</td>
<td>100 (40–170)</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Stemless</td>
<td>50 (10–80)</td>
<td>110 (80–170)</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Stemmed</td>
<td>45 (20–80)</td>
<td>90 (60–160)</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>7. Internal rotation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>Sacrum (trochanter L5)</td>
<td>L3 (trochanter L1)</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Stemless</td>
<td>Sacrum (trochanter L5)</td>
<td>L3 (trochanter L2)</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Stemmed</td>
<td>Sacrum (trochanter L5)</td>
<td>L4 (sacrum L1)</td>
<td>&lt;0.05</td>
</tr>
</tbody>
</table>
Radiological parameters and clinical correlation

SN

SN was seen in 12 shoulders. Seven shoulders had SBI already on the first post-operative X ray (day one to four). In the remaining five shoulders, SN appeared at a mean of seven months (range 3 to 12 months). Patients with CTA had more SBI than other diagnoses (five of seven) \( P<0.01 \). Three of the four baseplate loosenings occurred concurrent with grade 1 SN. However, SN was not correlated with glenoid loosening and did not affect final ROM or reported quality of life.

Glenoid component positioning

The inclination of the glenoid baseplate was 93° (range 80–105°). No correlation was observed between inclination and SN. The mean glenoid overhang was 1.3 mm (range 5–6 mm). With no overhang there was a higher incidence of SN (10 of 12 shoulders; \( P<0.001 \)). The peg-glenoid rim distance was 20 mm (range 15–28 mm). The peg-glenoid distance correlated with SN. When the distance was more than 20 mm, SN was evident in 9/12 shoulders, while 3/12 occurred when the distance was less than 20 mm (\( P<0.01 \)).

Arm lengthening

The lengthening of the upper extremity was 16 mm (range 0–32 mm). We compared those with arm lengthening 15 mm or less (15 shoulders) to those with lengthening over 15 mm (12 shoulders). Those with arm lengthening more than 15 mm showed greater improvement in EQ-5D (preoperative mean = 0.41 vs 0.80 post-operatively) as compared with the others (preoperative mean = 0.51 vs 0.66 postoperatively; \( P<0.05 \)). However, lengthening did not correlate with degree of post-operative pain, ROM, Quick DASH or SN.

Complications and re-operations

Of the 16 stemless implants, two prostheses were revised at three and four days post-operatively due to corolla displacement. There were two RSA dislocations in two patients with fracture sequelae. These were treated with exchange of the polyethylene insert. Also, four glenoid loosenings were revised with exchange of the baseplate.
Study III

Patient flow and baseline data

Fifteen females and 11 males were recruited into the study. The mean age was 70 years (range 54–83). Ten patients had OA on the right side, 8 on the left side and 8 had bilateral OA. Preoperative CT of 26 patients (52 shoulders) and X-ray of 34 shoulders were available for examination.

Radiological parameters

The interobserver reliability of LHO (CT) measurements among the four observers was excellent (0.93) while LHO (X-ray) was moderate (0.48). The intraobserver reproducibility of LHO (X-ray) was variable among the observers. It was excellent for observers 1 and 4 while it was moderate and fair for observers 2 and 3, respectively. The intraobserver reliability was excellent for LHO (CT) for all four observers. A Bland–Altman plot was used for the analysis of correlation between LHO (CT) and LHO (X-ray). Disagreement in assessment of LHO between CT and X-ray was within 5 mm. The mean LHO (X-ray) was significantly lower than the mean LHO (CT) (p = 0.001, paired sample t-test) with a mean difference of 5.0 mm (95 % CI 2.3–7.1).
Study IV

Patient flow and baseline data

69 patients (70 shoulders) were available for the study. The patients (33 men and 36 women) had a mean age of 69 years (range 52–88 years) at time of the surgery.

Type of implants and operation indications

Patients with primary OA who had undergone stemless anatomical TESS TSA (Zimmer Biomet) were included in the study.

Radiological parameters

COR

The mean difference between premorbid and post-operative COR was 1±2 mm (range −3 to 5.8 mm). There were 13/70 (19 %) shoulders with increased post-operative COR >3 mm (3.9±0.5 mm).

HH

The mean difference between premorbid and post-operative HH was −1±3 mm (range −9.7 to 8.5 mm). There were 8/70 (11 %) shoulders with a post-operative HH difference >5 mm. Of the eight, six had decreased post-operative HH >5 mm (range −9.7 to −5.7 mm) and two had increased postoperative HH >5 mm.

NSA

The mean difference between premorbid and post-operative NSA was −3±12° (range −26 to 20°). There were 25/70 (36 %) shoulders with post-operative NSA <130° (Fig. 8) (Table. 3).
Table. 3 Radiological measurements in shoulders before and after total shoulder replacement (n=70).
* Mean ± standard deviation (SD)

<table>
<thead>
<tr>
<th></th>
<th>Premorbid anatomy*</th>
<th>Post-operative anatomy*</th>
<th>Difference between premorbid anatomy and post-operative anatomy *</th>
<th>Pearson’s correlation (r)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. COR</td>
<td>6 ± 2 mm</td>
<td>7 ± 2 mm</td>
<td>1 ± 2 mm</td>
<td>0.3</td>
</tr>
<tr>
<td>2. HH</td>
<td>20 ± 3 mm</td>
<td>19 ± 2 mm</td>
<td>−1 ± 3 mm</td>
<td>0.20</td>
</tr>
<tr>
<td>3. NSA</td>
<td>133 ± 6°</td>
<td>130 ± 11°</td>
<td>−3 ± 12°</td>
<td>0.10</td>
</tr>
</tbody>
</table>

Fig. 8 NSA reconstruction. In order to reconstruct the shoulder as closely as possible to the premorbid anatomy, identifying the appropriate bone-cut angle is critical (a, b). Failure to identify the correct osteotomy plane causes placement of the implant in varus (c, d)
Study V

Patient flow and baseline data

Forty-four patients with a minimum follow up of 12 months (range 12 – 50 months) were available for the study. The patients (22 men and 22 women) had a mean age of 69 years (range 52 to 82) at time of the surgery.

Type of implants and operation indications

Forty-four patients with primary OA who had undergone stemless total anatomic shoulder arthroplasty were included in the study. There were 20 TESS and 24 Comprehensive stemless implants (Zimmer Biomet).

Radiological parameters

LHO

The mean difference between LHO contra and LHO op was 1.3 mm ± 4.6. Deviation of LHO op of more than 5 mm from LHO contra was considered as being clinically significant (Mechlenburg 2013). There were 36/44 (82%) patients whose LHO ops were restored within 5 mm from LHO contra (mean 0 mm ± SD 3.8) and 8/44 (18%) patients who had more than 5 mm (mean 7.5 mm ± SD 1.85). There were 26/44 (59%) patients with LHO op > 0 mm (mean 4.4 mm ± SD 2.5), and 18/44 (41%) patients with LHO ≤ 0 (mean − 3 mm ± SD 2.8). The correlation between (LHO contra) and (LHO op) was substantial (ICC 0.8, CI 95% 0.62 - 0.87, P = 0.001).

Functional outcome

All functional measures showed significant improvement (Table.3). We compared values of functional parameters at the three follow-up occasions: 3 months, 12 months and at last follow-up visit in order to investigate whether the shoulder function would be different. All parameters showed significant improvement at 3 and 12 months post-surgery but not after 12 months follow-up (Table. 4).
Correlation between LHO post and Quick DASH

LHO post was correlated with Quick DASH at 3 months (Pearson correlation = 0.36, P = 0.01) in which lengthening of LHO showed a tendency for increasing Quick DASH i.e. worsening shoulder function (coefficient =1.09). LHO post showed no correlation with Quick DASH at 12 months (Pearson correlation = −0.01, P = 0.49).

Correlation between LHO post and VAS pain

LHO post was correlated with VAS pain (at rest) at 3 months (Pearson correlation= 0.30, P =0.03) in which lengthening of LHO showed tendency for increasing pain at rest (coefficient=0.65) but not at 12 months (Pearson correlation = −0.18, P = 0.12).
LHO post was correlated with VAS pain (at exertion) at 3 months (Pearson correlation= 0.34, 95%, P = 0.01) in which lengthening of LHO showed tendency for increasing pain at exertion (coefficient=1.68) but not at 12 months (Pearson correlation = −0.01, p = 0.47).

Correlation between LHO post and other functional outcome measures

There was no correlation between LHO post and other outcome measures (EQ-5D, VAS health, ROM) at either 3 or 12 months follow-up. Age and gender did not correlate with any of the functional outcome measures.
Table. 3 Preoperative and post-operative values of Quick DASH, EQ-5D score, VAS global health, VAS pain and ROM for the entire series. f-u follow-up, SD standard deviation, P₁ value p value at three months vs preoperative values, P₂ value p value at last follow-up vs preoperative values.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Preoperative</th>
<th>3 months follow-up</th>
<th>P₁ value</th>
<th>Last follow-up</th>
<th>P₂ value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Quick DASH</td>
<td>56.6 (SD 16)</td>
<td>20.6 (SD 14)</td>
<td>0.001</td>
<td>8.7 (SD 9)</td>
<td>0.001</td>
</tr>
<tr>
<td>2. EQ-5D</td>
<td>0.49 (SD 0.21)</td>
<td>0.82 (SD 0.20)</td>
<td>0.01</td>
<td>0.84 (SD 0.23)</td>
<td>0.001</td>
</tr>
<tr>
<td>3. VAS global health</td>
<td>55 (SD 17)</td>
<td>77 (SD 16)</td>
<td>0.03</td>
<td>86 (SD 13)</td>
<td>0.01</td>
</tr>
<tr>
<td>4. VAS pain at rest</td>
<td>33 (SD 21)</td>
<td>3 (SD 10)</td>
<td>0.001</td>
<td>0.0 (SD 2)</td>
<td>0.001</td>
</tr>
<tr>
<td>5. VAS pain at exertion</td>
<td>71 (SD 17)</td>
<td>18 (SD 23)</td>
<td>0.001</td>
<td>5 (SD 7)</td>
<td>0.001</td>
</tr>
<tr>
<td>6. Abduction</td>
<td>60 (SD 22)</td>
<td>98 (SD 46)</td>
<td>0.001</td>
<td>130 (SD 46)</td>
<td>0.001</td>
</tr>
<tr>
<td>7. Flexion</td>
<td>80 (SD 27)</td>
<td>110 (SD 41)</td>
<td>0.001</td>
<td>145 (SD 38)</td>
<td>0.001</td>
</tr>
<tr>
<td>8. Internal rotation</td>
<td>12 (SD 12)</td>
<td>25 (SD 20)</td>
<td>0.001</td>
<td>40 (SD 26)</td>
<td>0.001</td>
</tr>
<tr>
<td>9. External rotation</td>
<td>14 (SD 13)</td>
<td>50 (SD 24)</td>
<td>0.001</td>
<td>55 (SD 23)</td>
<td>0.001</td>
</tr>
</tbody>
</table>
Table 4 There was no significant improvement of functional parameters after 1 year.
SD standard deviation

P¹ value p value of the difference between 3 months and 12 months values.
P² value p value of the difference between 12 months and 24 months values.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>3 m follow-up</th>
<th>12 m follow-up</th>
<th>Last follow-up</th>
<th>P¹ value</th>
<th>P² value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Quick DASH</td>
<td>20.6 (SD 14)</td>
<td>11.2 (SD 11)</td>
<td>8.7 (SD 9)</td>
<td>0.03</td>
<td>0.07</td>
</tr>
<tr>
<td>2. EQ-5D</td>
<td>0.82 (SD 0.20)</td>
<td>0.84 (SD 0.23)</td>
<td>0.88 (SD 0.15)</td>
<td>0.04</td>
<td>0.6</td>
</tr>
<tr>
<td>3. VAS global health</td>
<td>77 (SD 16)</td>
<td>84 (SD 12)</td>
<td>86 (SD 13)</td>
<td>0.01</td>
<td>0.9</td>
</tr>
<tr>
<td>4. VAS pain at rest</td>
<td>3 (SD 10)</td>
<td>0 (SD 0.6)</td>
<td>0 (SD 2)</td>
<td>0.02</td>
<td>0.7</td>
</tr>
<tr>
<td>5. VAS pain at exertion</td>
<td>18 (SD 23)</td>
<td>6 (SD 11)</td>
<td>2 (SD 7)</td>
<td>0.001</td>
<td>0.4</td>
</tr>
<tr>
<td>6. Abduction</td>
<td>98 (SD 46)</td>
<td>128 (SD 46)</td>
<td>130 (SD 43)</td>
<td>0.001</td>
<td>0.07</td>
</tr>
<tr>
<td>7. Flexion</td>
<td>110 (SD 41)</td>
<td>139 (SD 38)</td>
<td>145 (SD 35)</td>
<td>0.001</td>
<td>0.06</td>
</tr>
<tr>
<td>8. Internal rotation</td>
<td>25 (SD 20)</td>
<td>39 (SD 26)</td>
<td>40 (SD 23)</td>
<td>0.001</td>
<td>0.4</td>
</tr>
<tr>
<td>9. External rotation</td>
<td>50 (SD 24)</td>
<td>57 (SD 23)</td>
<td>55 (SD 23)</td>
<td>0.005</td>
<td>0.22</td>
</tr>
</tbody>
</table>
6. Discussion

Stemless prostheses with total elimination of the humeral stem and total reliance on metaphyseal fixation were developed to decrease shaft-related complications, e.g. periprosthetic fracture and bone loss (Huguet et al 2010). The great individual variation in shoulder anatomy makes it a challenge to design implants that fit most anatomical variations (Pearl et al 2002, Iannotti et al 2005). The factors that affect pain range of motion, stability and wear rate after shoulder reconstruction are multifactorial. For instance, the length of the lever arm of the deltoid and rotator cuff muscles and tension of the soft tissue are both important and can be adjusted by proper component position and size selection (Iannotti et al 1998, Takase et al 2004). Stemless implants should provide other potential benefits, including the ability to restore shoulder anatomy regardless of the posterior offset of the proximal humerus (Sassoon et al 2013, Churchill et al 2014). This thesis evaluated the implication of the type of implant fixation and positioning of prosthesis on both clinical and radiological outcome.

Evaluation of the type of implant fixation

In studies I and II, we reported clinical and radiological results using the TSA and RSA (TESS, Zimmer Biomet) shoulder system, both stemless and stemmed, for various shoulder disorders. Both stemmed and nonstemmed implants showed improvement in clinical outcome with no sign of radiological loosening after stemless implantation. In contrast, there were zones around one stemmed implant. We did not find a specific diagnosis where the use of stemless implants was mandatory. Instead the decision to use stemmed or stemless humeral implants depends on bone quality and judgment of the stability achieved during the initial preparation of the proximal humerus. In fracture surgery we recommend that only stemmed implants should be used since implant-bone stability is not expected in osteoporotic bone. We chose to cement the stems in the fracture group to secure the fixation of the prosthesis and to maintain the proximal humeral length. We used the anterosuperior surgical approach in all cases. We experienced no technical difficulty with this approach and had no axillary nerve injury.

We had two patients in the stemless group with early instability secondary to a malpositioned or displaced corolla component. This can be the effect of limited surgical technical experience, limited operative exposure or poor bone quality. We reported also in the first study, a complication in the fracture group with dissociation between the metaphyseal corolla and the stem. The presence of an unhealed humeral neck fracture might have applied excessive
rotational forces on the humeral component leading to mechanical failure in the coupling between the corolla and the stem.

The first study on TESS implants was in 2010 from the TESS group. The authors reported the results of 63 TESS implants with a minimum follow-up of three years. A good clinical and radiological outcome was achieved with no evidence of subsidence or loosening (Huguet et al 2010). In the first report regarding the Eclipse stemless implant, the authors concluded that it is possible to implant the prosthesis without a stem (Schoch et al 2011). Another study compared clinical and radiological outcomes of three different prosthetic designs: the Neer II system, the Bigliani-Flatow, and TESS stemless prosthesis. The authors concluded that TESS implants resulted in significant functional improvement and the results were comparable to other stemmed prosthesis (Razmjou et al. 2013). In a prospective randomized trial that compared the stemless TESS and stemmed implants, the authors found that the functional improvement and radiological stability of the stemless shoulder prosthesis were comparable with those provided by a standard anatomical shoulder prosthesis (Berth 2013). Brunner et al. in 2012 presented the results obtained in 233 patients treated with the Arthrex Eclipse stemless prosthesis for various indications. In this study the Eclipse prosthesis showed a secure bony fixation and no evidence of loosening.

We had two dislocations after fracture sequelae who had undergone RSA; both of them had proximal humeral bone loss. Boshali et al. found that glenohumeral instability was the second leading cause of complications associated with total shoulder arthroplasty, with a reported prevalence of 4% and accounting for 30% of all complications. Malpositioning of the prosthetic components, inadequate tensioning of the periprosthetic soft tissues, bone defects and rupture of the subscapularis tendon are some of the underlying factors (Boshali et al 2006). The above mentioned complications took place early in the study period and the authors think that this is most probably due to the learning curve of the procedure. Kempton et al. reported that 30–40 cases are needed as a learning curve to improve the rate of early complications associated with reverse shoulder replacement (Kempton et al 2011). The complications encountered in our studies are comparable to that reported by other authors using other shoulder prosthesis systems (Boshali et al 2006, Chin et al 2006, Farng et al 2011).

Despite the early good results obtained with the use of stemless anatomical implants, the use of stemless reverse prostheses is still limited. This could be due to greater forces on the implant because the joint constraint leads to increased forces at the bone interfaces and hence possible failure of bone fixation.

Ballas et al in 2013 studied 56 stemless TESS RSA with a mean follow-up period of 58 months.
There was a significant functional improvement in all parameters and the results were comparable to conventional prostheses with a stem. They had only one revision surgery due to early instability, no humeral loosening and 5 cases (9%) of scapular notching. This study showed the possibility of safely implanting a stemless humeral cup for reverse shoulder arthroplasty.

Teissier et al in 2015 reported the results of 105 stemless TESS RSA with a minimum follow-up period of 24 months. There was neither radiographic evidence of nor glenoid nor humeral component. SN occurred in 17 cases (19%) which was higher than their first published series which had only 9%. The authors explained this as being due to the larger sample size.

Von Engelhardt et al recently published a report of 67 patients (56 stemless, 11 stemmed) with a mean follow-up of 17.5 months. The study showed again a significant functional improvement with no loosening of the non-stemmed humeral component in the CTA group. On the other hand one loosening was observed in the revision group. The SN rate was 13.4% in this series. Three patients were revised immediately after surgery because of an intraoperative malpositioning of one humeral component and 2 glenoid components.

A number of developments in prosthetic design occurred after the early reports, to prevent the reported complications, like:

A. Downsizing the size of corolla, which decreased intraoperative periprosthetic fracture.

B. Development of the fracture system (stem) into a monoblock to overcome the weak link between the corolla and the shaft

C. Improvement of the fixation of the glenosphere into the base plate to avoid early dissociation and an increase in the number of fixation screws from 2 to 4.

D. Obliteration of the metal backed glenoid component from the anatomical system because of increased incidence of polyethylene wear.

Study I and II might have a number of limitations. The sample size was probably relatively small. However, all consecutive patients were operated upon using the same implant and approach. This is the usual situation in middle sized county hospitals with general orthopaedic surgeons interested in shoulder surgery, i.e. a situation resembling most of the hospitals around the world.

In spite of the relatively short follow-up period, these studies reported the early results after surgery which have special importance when evaluating a new prosthesis. This will provide surgeons with valuable information on how to improve their early results of the operation.

The absence of control of the range of shoulder movements in study I is another limitation. At the time of writing the first report there was discussion within the authors group about using
goniometry as a standard method to increase the precision. The included patients were measured by visual estimation, therefore, we chose not to include this part in our report despite its importance. After a thorough discussion within our research group, consulting other researchers within the same field and doing a literature review, we concluded that visual estimation is an acceptable method. It has good inter- and intrarater reliability as shown by many studies (Riddle et al 1987, Williams et al 1990, Hayes et al 2001). Therefore, we decided to continue measuring ROM by visual estimation and included this important measurement of shoulder function evaluation in the other reports.

Although a standardised positioning protocol was used in obtaining AP radiographs, the method for obtaining the radiographs remains a source of bias as both arm rotation and positioning of the scapula depend on the judgment of the technician.

In spite of mentioned limitations, there were a number of strengths. These studies, reports results of a stemless version of both anatomical TSA and RSA, where the available data in the literature is still sparse. The studies showed the importance of the learning curve as a possible way to avoid early complications especially in the accurate assessment of suitable bone quality that permits implantation of a stemless implant. This will hopefully encourage further research on the development of an objective tool that assesses bone quality. Rehabilitation was standardised and all patients were followed up prospectively.

**Evaluation of the implication of the positioning of the prosthesis in RSA**

In study II, we studied the positioning of the glenoid components in RSA and its radiological and clinical correlation. We found SN in 30 % of our patients. However, SN did not influence the clinical or the radiological outcome. The incidence of SN is variable in the literature, ranging from 0 to 96 %, and increases with longer follow-up (Nyffeler et al 2005, Simovitch et al 2007, Lévine et al 2011). In the first study, we did not observe SN. This could be explained by the smaller sample size (21 RSA) and shorter follow-up (mean 14 months), hence we recommended in the first study further investigations with repeated clinical and radiological controls. Another possible explanation is that SN was not well identifiable to the authors at the time of writing the first study.

The underlying cause, clinical significance and ways to avoid notching are still under debate (Nyffeler et al 2005, Simovitch et al 2007). We found that glenoid overhang decreases SN. This finding is consistent with several studies that found that it is a critical factor in order to avoid SN (Sirveaux et al 1997, de Wilde et al 2010). We found also a peg-glenoid distance less than 20
mm significantly decreased SN which is consistent with Simovitch et al. (Simovitch et al 2007, De Biase et al 2013).

We did not find any correlation between glenoid inclination and SN. However, this could be due to the small number of patients with inclination over 10° from neutral. There are divergent findings about the effect of inferior inclination on the incidence of SN. Some deny its effect (Kempton et al 2011, Edwards et al 2012), while others report decreased (Gutiérrez et al 2007, Gutiérrez et al 2011) or increased incidence of SN (Simovitch et al 2007).

We also noticed that some patients already had SBI on the post-operative X-ray that later developed into SN. A possible explanation could be the use of the anterosuperior approach. This approach necessitates retractors to be placed under the glenoid rim to dislocate the humerus downwards creating deformative forces on the scapular edge. Other possible explanations cannot be excluded, e.g. the forward scapular rotation in the early post-operative period or a prominent anatomical notch of the circumflex scapular vessels.

In the same study, we reported the effect of arm lengthening on radiological and clinical outcome. We found that arm lengthening improved the quality of life, but we were unable to note effects on function, ROM or pain. This is in accordance with previous reports that found that arm lengthening could influence the outcome (Lädermann et al 2012, Lädermann et al 2014).

**Evaluation of the implication of the prosthesis positioning on LHO in stemless anatomical TSA**

One important radiological parameter is LHO as shown by many studies that its reconstruction is an important element in achieving efficient shoulder function (Takase et al 2004). Iannotti et al. measured LHO offset as the distance between the coracoid base to the most lateral part of the greater tubercle and showed that it correlated both with the size of the humeral head and the moment arm of the deltoid and rotator muscles (Iannotti et al 1992, Iannotti et al 1998). It is still unclear how much restoration of the LHO is needed, and whether this restoration would affect the prosthetic long-term survival (Pearl et al 2002, Pearl et al 2009). Takase et al studied LHO offset in AP radiography and showed also that it is related to other parameters like humeral head diameter, radius of curvature of the humeral head and the distance between the acromion and the greater tubercle (Takase et al 2004).
Plain radiographs are routinely used for preoperative templating and postoperative evaluation. However, despite their availability, easy interpretation, low cost and low radiation exposure, plain radiographs have limited accuracy compared to CT scans (Ho et al 2013).

In study III we evaluated reliability of LHO performed on both AP radiographs and axial CT of the shoulder in patients with primary OA. The interobserver reliability using AP radiography was moderate while the intraobserver reproducibility was variable among the observers. A possible explanation is the variable experience among the observers. Another possible explanation is the difficulty in finding the same point on the medial border of the coracoid process among the observers.

Thomas et al. studied reliability of LHO in plain radiography using the same standardised protocol that we used in our study. They found it to be unreliable with a tendency of observers to disagree on the medial/ lateral location of the base of the coracoid (Thomas et al 2005).

We found excellent inter- and intraobserver agreement of the CT measurements among all 4 observers. The correlation between CT and X-ray in measuring LHO was moderate with a significant underestimation of LHO on AP radiographs with a mean difference of 5 mm. This indicates that CT is more precise in identifying the base of the coracoid process than plain radiographs and thus is the recommended method for measuring LHO. Differences in the estimation between CT and X-ray could be also explained by the measurements having been done in different planes, i.e. coronal and sagittal. Possibly also the patient positioning could have a role, being prone in CT and erect in X-ray examinations. Deladerrière et al analysed the geometry of 42 resurfacing shoulder implants using CT. They used a modified method to measure LHO on axial CT scans. The study showed that CT was a reliable way to identify these two points and of measuring LHO (Deladerrière et al 2012).

In Study V we evaluated the ability of stemless implants to restore LHO and its correlation with functional results. In order to assess the ability of an implant to restore shoulder anatomy, we chose to use the contralateral healthy shoulder in the axial CT, as a reference in our measurements.

The correlation between LHO contra and LHO op was substantial (ICC 0.8, CI 95% 0.62 - 0.87, P = 0.001). This supports the hypothesis that stemless implants could restore the linear glenohumeral relationship, LHO, close to the normal anatomy.

Variation of the LHO op from the LHO contra > 5 mm was considered as being clinically significant (Mechlenburg 2013). There were 8/44 (18%) of patients with > 5 mm (mean 6.8 mm ± SD 2).
Regarding the postoperative outcome, all included measures showed significant improvement compared with the preoperative state, regardless of LHO. This improvement was not detectable after 12 months postoperatively. Therefore, the authors think that 12 months follow-up is adequate to make a reasonable evaluation of the postoperative outcome. The LHO was correlated at three months with Quick DASH (Pearson correlation = 0.36, P = 0.12), VAS pain (at rest) (Pearson correlation = 0.33, P = 0.05) and VAS pain (at exertion) (Pearson correlation = 0.33, P = 0.05), where increased LHO op negatively affected these measures. No correlation at 12 months was found. The LHO showed no correlation with any of the other outcome measures (EQ-5D, VAS health status, ROM) during the follow-up period.

One possible explanation for this negative effect of increased LHO is soft-tissue over-tensioning of the newly operated shoulder joint, especially if the joint had excessive long lasting narrowing of the joint space and capsule tightening secondary to OA. Differences in the laxity of the joint capsule among patients might also affect the degree of association between the LHO increment and the outcome measures. Gradual adaptation of the soft-tissue to the new postoperative LHO after the first 3 months can explain the lack of association between the LHO increment and the outcome measures at 12 months follow-up. The LHO seemed not to affect quality of life, health status or ROM at any time during the first year postoperatively.

Evaluation of the implication of the prosthesis positioning on proximal humeral anatomy in stemless anatomical TSA

In study IV we investigated the ability of a stemless prosthesis to restore the premorbid proximal humerus anatomy using the best-fit-circle method (Youderian et al. 2014). COR is considered by many studies to be an important parameter to reconstruct (Pearl et al 2009). We considered a 3-mm deviation from the premorbid COR to be clinically significant, as proposed by (Alolabi et al 2014). In our study, the difference was within 3 mm in 82 % of cases.

HH is similarly of paramount importance. In our study, post-operative HH was 19±2 mm, which was less than pre-operative values but close to results of other studies (Iannotti JP et al 1992, Nyffeler RW et al 2004, Nyffeler RW et al 2005). Deviation of ≥5mm of the HH from the pre-operative measurement was considered of clinical importance as shown by other studies (Harryman DT et al 1995). We had 8/70(11 %) shoulders with postoperative HH difference >5 mm.
NSA was 133±6° pre-operatively compared with 130±11° post-operatively. There were 25/70 (36 %) shoulders with postoperative NSA <130°, which shows a tendency to put the prosthesis in varus. NSA has a wide range of variation, as shown by other studies (Iannotti JP et al 1992, Boileau P et al 1997). Takase et al. studied NSA in 519 shoulders, and it ranged from 130° to 152°, with a mean of 140.5°± 4.0° (Takase et al 2002).

We used the Pearson correlation coefficient (r) to calculate the correlation between premorbid and post-operative parameters (COR, HH and NSA). According to Hornij et al , r values >0.75 represent excellent agreement, 0.4–0.75 fair to good agreement and <0.4 poor agreement. Rheault et al. used criteria recommended by Landis and Koch (0.00–0.20 slight agreement, 0.21–0.40 fair agreement, 0.41–0.60 moderate agreement, 0.61–0.80 substantial agreement, 0.81–1.00 excellent agreement. Lindell et al considered the value of 0.60 as a limit of acceptability for application in clinical practice. In this paper, mean r values were used, leaving evaluation of the degree of their reliability and reproducibility to the judgment of the readers.

These studies (III, IV and V) have some limitations. The use of CT can be associated with high cost and radiation dose. We included only patients with primary OA. In secondary OA, many cases have flattening of the humeral head causing a medial shift of the rotational centre in relation to the glenoid, and hence decreasing LHO with soft-tissue contracture. The technical demands for shoulder anatomy restoration also differ considerably in both groups. For these reasons, we chose to exclude patients with secondary OA in order to have a homogenous group. This can be considered as a limitation since the results of these studies cannot be applied to patients with secondary OA.

In spite of these limitations there were also strengths like:

The CT measurements have a proven reliability and reproducibility and it was used in measuring LHO instead of plain radiographs. To our knowledge, these are the first studies designed to investigate the ability of stemless implants to restore LHO and proximal humerus anatomy using the same prosthesis and the same surgical approach.
7. Conclusion

1. The results of stemless shoulder prostheses are promising with a complication rate that is comparable with other shoulder prosthetic systems with the advantage of bone stock preservation and avoidance of stem-related complications. Long-term follow-up is required to confirm the results of this innovative system in the long run.

2. The anterosuperior approach can adequately be used for the implantation of different versions of shoulder prostheses.

3. RSA can successfully treat different shoulder problems. Glenoid overhang can reduce SN and arm lengthening has positive effects on outcome. Our method of arm lengthening measurement needs further studies to ensure validity.

4. LHO measurement on AP radiographs is less reliable and underestimates the distance when compared with CT. Also, CT is a reliable tool to measure LHO supporting its use in preoperative planning. Outcome measures were improved regardless of the LHO. At 3 months follow-up, increased LHO had negative effect on shoulder function and gave more shoulder pain at rest and exertion but did not affect quality of life, health status or ROM. At 12 months follow-up, LHO had no relation with the outcome measures. Further studies are warranted to investigate the influence of LHO on long-term prosthetic survival.

5. Stemless implants could restore the shoulder anatomy in an acceptable manner. This thesis shows that there are some challenges to be addressed when attempting to ensure optimal implant positioning. The critical step is to determine the correct level of bone cut to avoid varus or valgus HH inclination and version. Surgical instruments and technique may require modifications to optimise the surgeon’s ability to replicate normal anatomic parameters, allowing easier identification of the proper head-cut level.
8. Implications for future research

**Future research on stemless implants**
To investigate remodelling characteristics and bone quality at the prosthetic-bone interface in stemless implants and correlate it to functional outcome and implant survival.

**Future research on shoulder anatomy restoration**
To investigate the other factors that could play a role in shoulder anatomy restoration such as the type of approach, BMI, type of diagnosis e.g. secondary OA.

**Future research on RSA**
To study the reliability and reproducibility of our method of measuring arm lengthening in CT in comparison to methods in the literature.
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10. References

A


B


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P


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R


S


T


V


11. Appendix:

A. EQ5D

Markera, genom att kryssa i en ruta i varje nedanstående grupp (så här ☐), vilket påstående som bäst beskriver Ditt hälsotillstånd i dag.

Rörlighet
- Jag går utan svårigheter
- Jag kan gå men med viss svårighet
- Jag är sängliggande

Hygien
- Jag behöver ingen hjälp med min dagliga hygien, mat eller påklädning
- Jag har vissa problem att tvätta eller klä mig själv
- Jag kan inte tvätta eller klä mig själv

Huvudsakliga aktiviteter (t ex arbete, studier, hushållssysslor, familje- och fritidsaktiviteter)
- Jag klarar av mina huvudsakliga aktiviteter
- Jag har vissa problem med att klara av mina huvudsakliga aktiviteter
- Jag klarar inte av mina huvudsakliga aktiviteter

Smärtor/besvär
- Jag har varken smärtor eller besvär
- Jag har måttliga smärtor eller besvär
- Jag har svåra smärtor eller besvär

Oro/nedstämdhet
- Jag är inte orolig eller nedstämd
- Jag är orolig eller nedstämd i viss utsträckning
- Jag är i högsta grad orolig eller nedstämd
Till hjälp för att avgöra hur bra eller dåligt ett hälsotillstånd är, finns den termometer-liknande skalan till höger. På denna har Ditt bästa tänkbara hälsotillstånd markerats med 100 och Ditt sämsta tänkbara hälsotillstånd med 0.

Vi vill att Du på denna skala markerar hur bra eller dåligt Ditt hälsotillstånd är, som Du själv bedömer det. Gör detta genom att dra en linje från nedanstående ruta till den punkt på skalan som markerar hur bra eller dåligt Ditt nuvarande hälsotillstånd är.
**B. Quick DASH**

Hälsoenkät (arm/axel/hand)


<table>
<thead>
<tr>
<th>Fråga</th>
<th>Ingen svårighet</th>
<th>Viss svårighet</th>
<th>Måttlig svårighet</th>
<th>Stor svårighet</th>
<th>Omöjligt att göra</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Öppna en ny burk eller hårt sittande lock</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>2. Utföra tunga hushållssysslor (t ex tvätta golv, putsa fönster, hänga tvätt)</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>3. Bära matkassar eller portfölj</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>4. Tvätta Din rygg</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>5. Använda en kniv för att skära upp maten</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>6. Fritidsaktiviteter där Du rör armen fritt (t ex spela badminton, simma, gympa)</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>

7. **Under den senaste veckan**, i vilken utsträckning har Dina arm-, axel- eller handproblem stört Ditt vanliga umgänge med anhöriga, vänner, grannar eller andra?

- ☐ Inte alls
- ☐ Lite
- ☐ Måttligt
- ☐ Mycket
- ☐ Väldigt mycket

8. **Under den senaste veckan**, i vilken utsträckning har Dina arm-, axel- eller handproblem stört Ditt vanliga arbete eller andra dagliga aktiviteter?

- ☐ Inte alls
- ☐ Lite
- ☐ Måttligt
- ☐ Mycket
- ☐ Väldigt mycket

Ange svårighetsgraden på Dina symtom **den senaste veckan**:

<table>
<thead>
<tr>
<th>Fråga</th>
<th>Ingen</th>
<th>Lätt</th>
<th>Måttlig</th>
<th>Svår</th>
<th>Mycket svår</th>
</tr>
</thead>
<tbody>
<tr>
<td>9. Värk/smärta i arm, axel eller hand</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>10. Stickningar (sockerfrickskänsla) i arm, axel eller hand</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>

11. Har Du haft svårt att sova, **under den senaste veckan**, på grund av värk/smärta i arm, axel eller hand?

- ☐ Inte alls
- ☐ Viss svårighet
- ☐ Måttlig svårighet
- ☐ Stor svårighet
- ☐ Mycket stor svårighet

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QuickDASH - Grainnecon/Atrafio 2005