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ORIGINAL PAPER

Geometrical analysis of stemless shoulder arthroplasty: a radiological study of seventy TESS total shoulder prostheses

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Abstract
Purpose The aim of this study was to investigate the ability of a stemless shoulder prosthesis to restore shoulder anatomy in relation to premorbid anatomy.
Methods This prospective study was performed between May 2007 and December 2013. The inclusion criteria were patients with primary osteoarthritis (OA) who had undergone stemless total anatomic shoulder arthroplasty. Radiographic measurements were done on anteroposterior X-ray views of the glenohumeral joint.
Results Sixty-nine patients (70 shoulders) were included in the study. The mean difference between premorbid centre of rotation (COR) and post-operative COR was 1±2 mm (range −3 to 5.8 mm). The mean difference between premorbid humeral head height (HH) and post-operative HH was −1±3 mm (range −9.7 to 8.5 mm). The mean difference between premorbid neck-shaft angle (NSA) and post-operative NSA was −3±12° (range −26 to 20°).
Conclusions Stemless implants could be of help to reconstruct the shoulder anatomy. This study 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 humeral head inclination and ensure correct head size.

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Keywords Stemless shoulder arthroplasty · TESS stemless prosthesis · Total shoulder arthroplasty · Shoulder anatomy · Shoulder radiology

Introduction

Results after shoulder arthroplasty have evolved steadily in recent years. More attention has been given to anatomical reconstruction in order to improve the functional results and implant longevity [1]. Variability of shoulder anatomy makes it a challenge for the surgeon to restore the premorbid anatomy [2]. Since its introduction by Neer in the early 1950s, the shoulder prosthesis has been improved to address the challenges in anatomical reconstruction of the soulder.

The first improvements in the original Neer prosthesis, which had only one head size, were in the early 1970s, leading to two different head sizes. In order to give the surgeon more possibility to reconstruct the shoulder anatomy, the second-generation prosthesis was developed. This incorporated the concept of modularity [3]. Further anatomic studies that showed the complexity of shoulder anatomy contributed to the development of a third-generation prosthesis with an adaptability concept. This newer design gave more flexibility in inclination and humeral offset in addition to a humeral head and stem that can be altered [1]. The humeral stem has also evolved, including in shape, method of fixation and length. Stem-related complications, such as intra-operative humeral fracture, loosening, stress shielding and periprosthetic fracture, are well known in the literature [4]. The concept of stemless shoulder implants was introduced in 2004 in France [5, 6]. The aim was to avoid stem-related complications, to preserve bone stock and to reproduce individual anatomy. Anatomical restoration after shoulder arthroplasty can generally be assessed in two ways:

either by comparing anatomy of the operated shoulder with the contralateral side or with its premorbid anatomy [7, 8].

The aim of this study was to investigate the ability of stemless shoulder prosthesis to restore shoulder anatomy in relation to premorbid anatomy. Our hypothesis was that the stemless shoulder prosthesis would meet the required anatomical restoration within acceptable limits.

Materials and methods

This prospective study was performed between May 2007 and December 2013. During that period, 216 shoulders were given an anatomic or reversed Total Evolutive Shoulder System (TESS; Biomet, Warsaw, IN, USA) implants for pain after osteoarthritis (OA), cuff-tear arthropathy (CTA), fractures, revision (due to failure of other implants) or rheumatoid arthritis (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. The implants used were a metaphyseally fixed uncemented humeral head implant with a cemented glenoid component of the same type (TESS). The operations were done by three shoulder surgeons.

During the study period, 81 patients (83 shoulders) were recruited. Twelve patients (13 shoulders) were excluded: (4 revisions, 5 post-traumatic OA and 4 due to bad image quality); thus, 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. The study was performed according to the Declaration of Helsinki, and the protocol was approved by the local Ethics Committee at Umea University (2012-201-31 M).

Surgical procedure

Pre-operative planning and templating were done on digital radiographs with anteroposterior (AP) and lateral views. The final choice of using a stemless implant was determined intraoperatively depending on bone quality. All patients were operated in the beach-chair position under general anaesthesia after interscalene block. The anterosuperior approach, according to Mackenzie, was used in all patients [9]. A small resection of the anteroinferior edge of the acromion was used to facilitate exposure. Biceps tenotomy was done in all cases but tenodesis only in patients with slender overarms. The subscapularis tendon was elevated from the lesser tuberosity. After dislocation of the humeral head, osteophytes were removed with a rongeur for visualisation of rotator cuff insertion and anatomical neck. The size of the humeral head was determined when choosing the appropriate HH guide. The cutting guide was held parallel to the anatomical neck. This adjusted the inclination and head version automatically. The HH cut was directed by the guide. The size of the corolla broach was chosen using a humeral sizing template. After glenoid preparation, a pegged polyethylene glenoid component was cemented in place. The metaphyseal fixation, i.e. the corolla implant, was introduced after broach removal, and a trial head was tested. There were six trial symmetrical and six asymmetrical head sizes available (41, 43, 45, 48, 50, 52). Several factors determine the appropriate choice of head size: size of the head cut, range of motion (ROM) and translation of the HH on the glenoid, which should be <50 %. In all nonstemmed 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 intracutaneous sutures. Patients were allowed to start exercises directly after the operation under the supervision of a physiotherapist. External rotation was restricted to 20° in the first four weeks. The post-operative follow-up plan comprised an operative wound check after two weeks, three and 12 months and then yearly to monitor clinical and radiographic outcome.

Radiographic examination

All radiographs were obtained using a computerised radiography system (Siemens, Erlangen, Germany). Pre-operative radiographs were performed within six weeks before surgery, while post-operative radiographs were taken on the second day post-operatively. Radiographic measurements were taken on AP X-ray views of the glenohumeral joint (Grashey view), and pre- and post-operative X-rays were performed according to a standardised protocol, as below. The AP view was taken under fluoroscopic control with the patient in a standing position and the shoulder in neutral position. The patient was turned posteriorly 35–45°, such that the plane of the scapula was parallel to the digital plate. The beam was directed tangentially to the glenohumeral joint. A 30-mm spherical marker was used to estimate the magnification factor.

Radiographic measurements

The images were digitally acquired, and measurements were performed using the Picture Archiving and Communication System (PACS) (Impax: Agfa, Antwerp, Belgium). One independent observer carried out all radiographic measurements.

Pre-operative measurements

Premorbid humeral head anatomy was estimated by a best-fit-circle method according to previous studies [7, 8]. 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. 1a).

The anatomic neck was defined as the best-fit line created by placing two markers: superolateral (at the junction of the greater tuberosity and articular surface) and inferomedial (junction of the calcar and the articular surface) (Fig. 1a). The centre of rotation (COR) was then identified from the circle, and the distance to the anatomical neck was calculated in millimetres (Fig. 1a). HH is defined as the perpendicular linear distance from the anatomic neck to the apex of the circle (Fig. 1b). 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, which was defined by a proximal and distal point in the centre of the intramedullary canal [8, 10] (Fig. 1c).

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 (cut level, lower margin of the prosthetic head) (Fig. 2a). Deviation of post-operative COR >3 mm from the normal anatomy was considered as being clinically significant [7].

HH was measured from the anatomical neck to the top of the prosthetic HH (Fig. 2b). Deviation of post-operative HH >5 mm from the normal anatomy was considered clinically significant [11]. NSA was measured in the same manner as pre-operatively (Fig 2c). Shoulders with post-operative NSA <130° were considered as varus [12]. We excluded shoulders that already had pre-operative NSA <130° from the varus group.

Statistics

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

Fig. 1 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**)

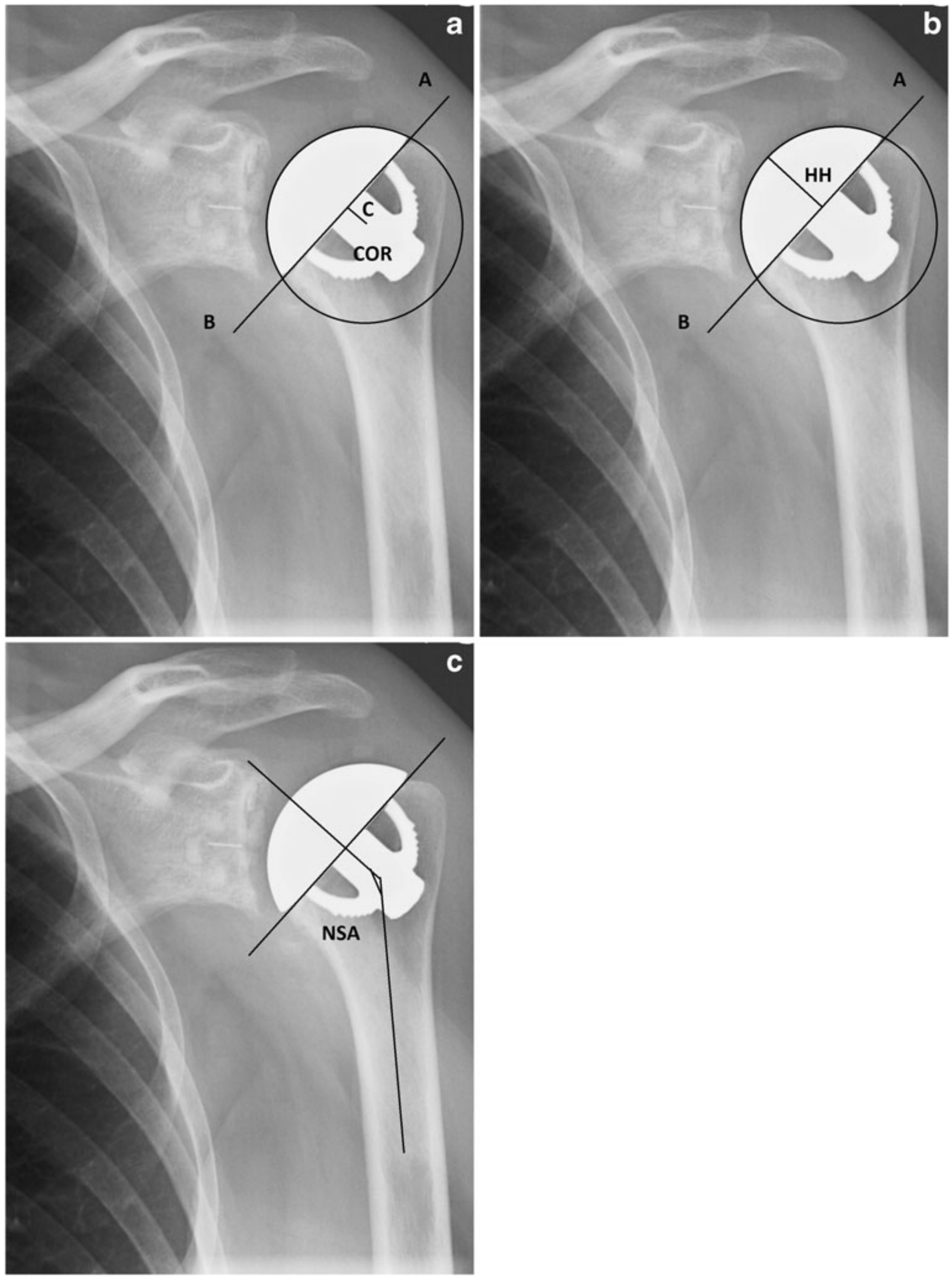

Fig. 2 Post-operative radiographic measurements. The centre of rotation (COR) identified by fitting a circle to the curvature of the humeral head prosthesis, and the distance to the lower margin of the prosthetic head was calculated in millimetres. (**a**). Humeral head height (HH) measured from the lower margin of the prosthetic head to the top of the prosthetic humeral head (**b**). Neck-shaft angle (NSA) and glenohumeral offset (GH) were measured in the same way as pre-operatively (**c**, **d**)

calculate the correlation between premorbid and post-operative parameters (COR, HH and NSA).

Results

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 post-operative 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. 3) (Table. 1).

Discussion

Anatomic restoration of the shoulder joint is a main goal in shoulder arthroplasty. Malpositioning of the prosthetic head may cause impingement to the coracoacromial arch and rotator cuff damage [13]. Factors that affect post-operative ROM, pain and prosthetic durability are multifactorial. Some of these parameters can be controlled by the surgeon through choice of appropriate component size and design [12]. It is unclear how much of the normal anatomy needs to be re-established [14, 15]. Because of the great individual variation in shoulder anatomy, it is a challenge to design implants that fit most anatomical variations [10, 16].

Stemless prosthesis with total elimination of the humeral stem and total reliance on metaphyseal fixation was introduced in France in 2004 (TESS, Biomet). The goals were to avoid stem-related complications (e.g. periprosthetic fractures) and preserve bone stock [5, 6]. Stemless implants should provide other potential benefits, including the ability to perform anatomic reconstruction regardless of the posterior offset of the proximal humerus [4, 17]. 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. A contraindication to the use of a stemless HH is acute proximal humeral fractures because stable fixation of the head may be compromised [18, 19].

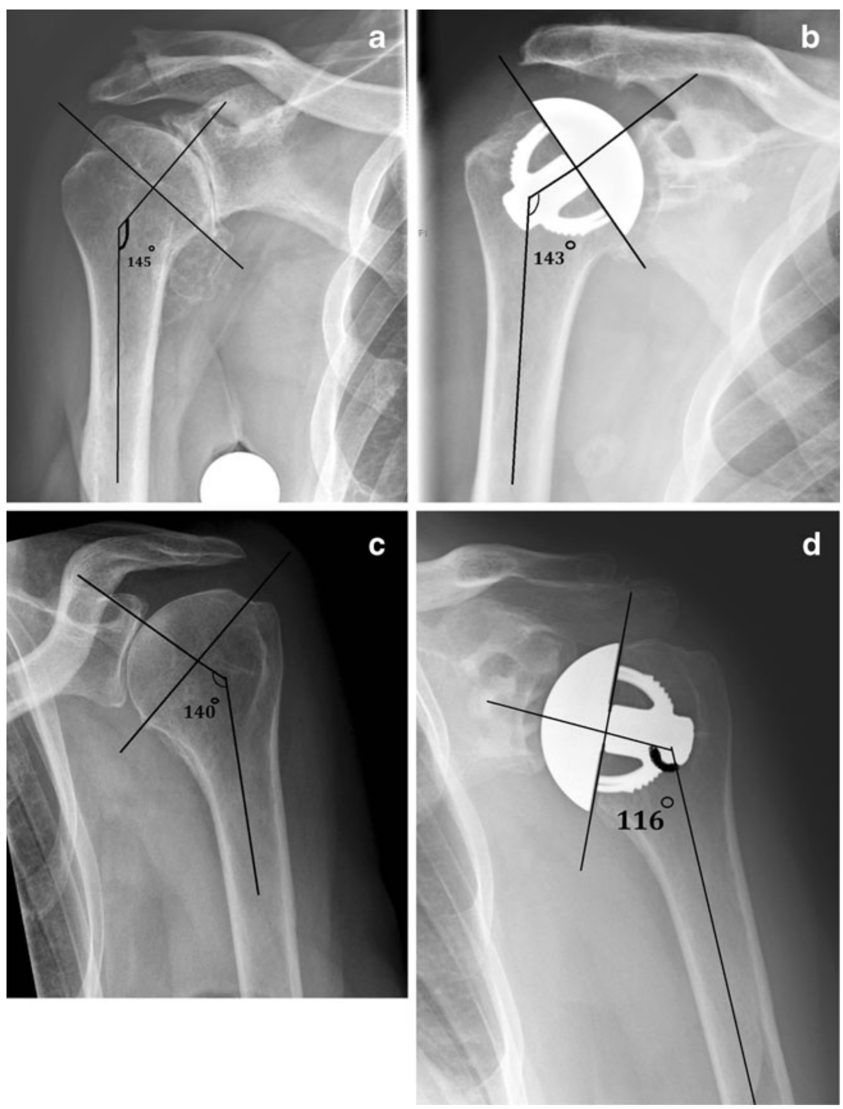

Fig. 3 Neck-shaft angle (NSA) reconstruction. In order to reconstruct the shoulder as closely as possible to the premorbid anatomy, identifying the appropriate bone-cut angle is critical (**a**, **b**). Failure to identify the correct osteotomy plane causes placement of the implant in varus (**c**, **d**)

Table. 1 Radiological measurements in shoulders before and after total shoulder replacement (n=70)

	Premorbid anatomy*	Post-operative anatomy*	Difference between premorbid anatomy and post-operative anatomy *	Pearson's correlation (r)
1. COR	6±2 mm	7±2 mm	1±2 mm	0.3
2. HH	20±3 mm	19±2 mm	−1±3 mm	0.20
3. NSA	133±6°	130±11°	−3±12°	0.10

COR distance between centre of rotation and anatomical neck, *HH* humeral head height, *NSA* neck-shaft angle, *GH* glenohumeral offset

* Mean±standard deviation (SD)

It is often difficult to accurately assess the correct size of the premorbid HH because the articular surface is generally deformed from the arthritic process. Youderian et al. demonstrated that premorbid HH size and COR in the arthritic shoulder can be accurately predicted from preserved nonarticular bony landmarks by a best-fit sphere or circle fitted to the proximal humerus [8]. The inter- and intra-observer reliability was assessed, both on computed tomography and X-ray, and the method was both reliable and reproducible.

In this study we investigated the ability of a stemless prosthesis to restore the premorbid proximal humerus anatomy using the best-fit-circle method. Pearl et al. considered the COR to be the most important parameter to reconstruct [14]. Several studies have shown that 2.5- to 5-mm malpositioning of the HH can affect shoulder ROM, rotator cuff moment arm and glenoid longevity [11, 14, 20]. We considered a 3-mm deviation from the premorbid COR to be clinically significant, as proposed by Alolabi et al. [7]. In this study, the difference was within 3 mm in 82 % of cases. Pearl et al. reported values of 14.7 mm and 2.1 mm difference in COR relative to the pre-operative side for second- and third-generation prostheses, respectively [15]. Irlenbusch et al. reported a 4-mm difference

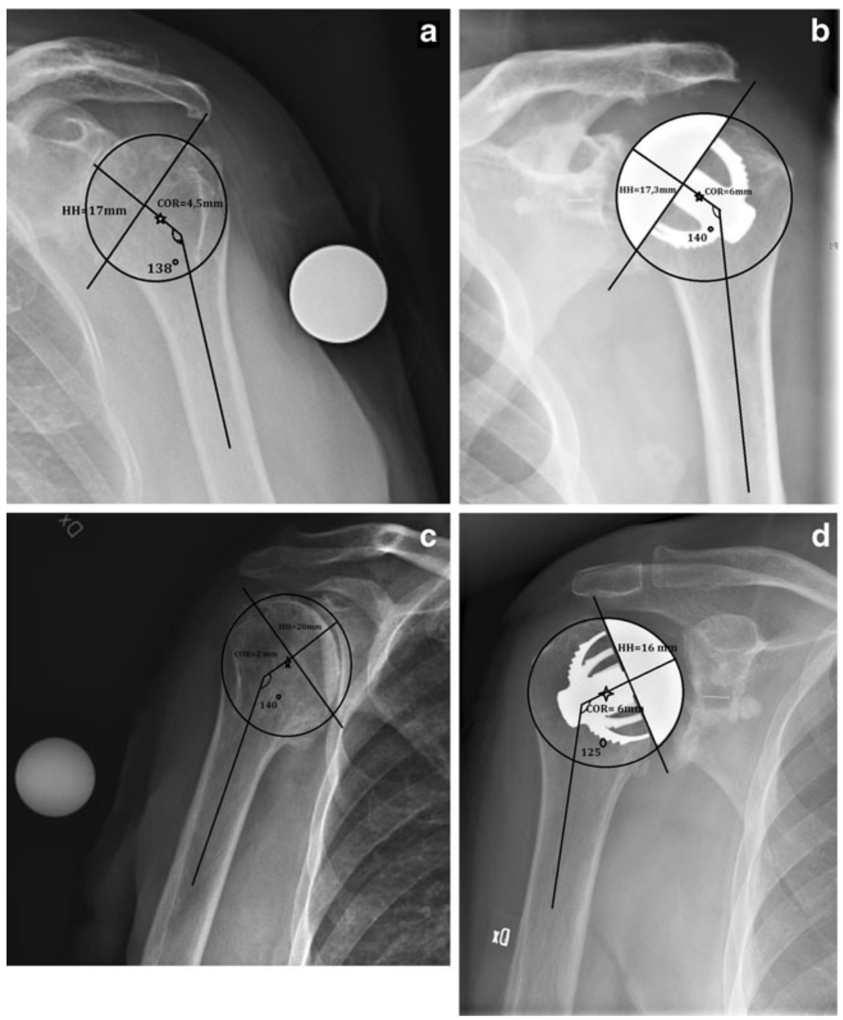

Fig. 4 Premorbid shoulder anatomy reconstruction. The stemless humeral prosthesis seemed to reproduce shoulder anatomy by correct orientation and height of the humeral osteotomy (**a**, **b**). Identification of anatomical landmarks for osteotomy on an arthritic humeral head can be difficult, and this may lead to incorrect cut level with failure to restore shoulder anatomy (**c**, **d**)

in COR in relation to the contralateral side in adjustable shoulder prosthesis [21].

Pre-operative diagnosis and the degree of humeral head deformity could affect the strategy to reconstruct COR. When the head is severely deformed and flattened, as in secondary OA, the COR shifts laterally compared with primary OA where the head is less deformed, making the technical demands in these conditions variable [21, 22]. Similarly HH is of paramount importance. In this study, post-operative HH was 19±2 mm, which was less than pre-operative values but were close to results of other studies [23, 24, 2]. Iannotti et al. studied the glenohumeral relationships in 140 shoulders, 96 measurements were made in the shoulders of cadavera and 44 on magnetic resonance imaging (MRI) studies of living patients, and HH was 19±2.4 mm (range 15–24 mm) [23]. Robertson et al. studied proximal humeral anatomy in 60 cadaveric humeri using 3D CT; mean HH was 19±2 mm (range 15–24 mm) [2]. Harryman et al. showed that a deviaton of ≥5 mm of the HH from pre-operative measurement can decrease ROM [11]. We had 8/70(11 %) shoulders with post-operative HH difference >5 mm.

NSA was 133±6° pre-operatively compared with 130±11° post-operatively. There were 25/70 (36 %) shoulders with post-operative NSA <130°, which shows a tendency to put the prosthesis in varus. NSA has a wide range of variation, as shown by other studies [23, 25]. Takase et al. studied NSA in 519 shoulders, and it ranged from 130° to 152°, with a mean of 140.5°± 4.0° [12]. Pre-operative NSA can affect the surgeon's plan during humeral osteotomy. In the varus group, the recommended starting point for osteotomy is at the superolateral point of the neck plane, thereby not violating the rotator cuff insertion site. In the valgus group, the recommended starting point for osteotomy is from the inferomedial point of the neck, thereby not violating the metaphyseal bone [26].

We used the Pearson correlation coefficient (r) to calculate the correlation between premorbid and post-operative parameters (COR, HH and NSA). According to Hornij, r values >0.75 represent excellent agreement, 0.4–0.75 fair to good agreement and <0.4 poor agreement [27]. 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 [28]. Others considered the value of 0.60 as a limit of acceptability for application in clinical practice [29]. In this paper, mean r values were used, leaving evaluation of the degree of their reliability and reproducibility to the judgment of the readers.

Our study shows that the stemless humeral prosthesis seemed to reproduce anatomy that was close to the normal glenohumeral joint. However, there was a tendency to place the implant in varus, meaning that positioning of the prosthesis can be improved. The surgeon influences positioning of the component by correct orientation and height of the humeral osteotomy. It is crucial to place the humeral guide in the correct position parallel to the anatomical neck and superiorly at the insertion of the supraspinatus tendon on the greater tuberosity. Identification of anatomical landmarks for osteotomy on an arthritic HH can be difficult, and this may lead to incorrect cut level with failure to restore shoulder anatomy (Fig. 4). Using the best-fit-circle method both pre-operatively and intra-operatively may help surgeons to choose the correct head size and position [8].

This study has some limitations. All measurements were done on plain X-ray, which could be subject to projection errors [30, 31]. To reduce this risk, we used a standardised protocol and excluded images (n=4) that did not meet our criteria. Also, COR location was measured in relation to the anatomical neck, and this is subject to variations between observers, as shown by other studies [17, 8]. In that study, only one independent observer did all measurements, as reliability and reproducibility was already assessed [8]. Furthermore, the influence of radiological parameters (COR, HH and NSA) on survival and functional results was beyond the scope of this study and therefore was not investigated. These limitations are counterbalanced by the strength of our study, which to our knowledge is the first to evaluate anatomical shoulder restoration using stemless prostheses. Also, we included an adequate number of shoulders operated using the same prosthesis and the same surgical approach.

Conclusion

Stemless, fixed metaphyseal implants have been developed to preserve bone stock and avoid stem-related complications. Stemless implants could be of help to reconstruct the shoulder anatomy. The simplicity of placing the implant could make it a more reproducible technique. This study 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. The surgical instruments and technique might require modifications to optimise the surgeon's ability to replicate normal anatomic parameters, allowing easier identification of the proper head-cut level.

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