Determination of humeral inclination in stemless shoulder arthroplasty using plain radiographs

Sascha Beck,[1] Robert J. Martin,[2] Theodor Patsalis,[3] Manuel Burggraf,[1] André Busch,[1] Stefan Landgraeber,[4] Wegner Alexander[1]

[1]Department of Orthopaedics and Trauma Surgery, University Hospital Essen, University of Duisburg-Essen, Essen; [2]Faculty of Mathematics, University of Duisburg-Essen, Essen; [3]Department of Shoulder, Elbow, Hand and Foot Surgery, St. Josef Hospital, Wuppertal; [4]Department for Orthopaedics and Orthopaedic Surgery, Saarland University Medical Center and Saarland University Faculty of Medicine, Hamburg, Germany

Abstract

Plain radiographs of the shoulder are routinely used to assess implant orientation after shoulder arthroplasty. Recently, humeral inclination has come into focus especially in reverse stemless shoulder arthroplasty. But, in X-ray projections not exactly parallel to the base of the humeral component, the humeral inclination angle cannot be determined precisely. Therefore, we established a mathematical algorithm to calculate the humeral neck shaft angle and counterchecked the formula using plain radiographs of a sawbone model containing a humeral head prosthesis. With increasing angles of retroversion, the base of the humeral component forms an ellipse in plain radiographs. Knowing the width and length of the ellipse as well as the inclination angle in a plain radiograph, the exact inclination angle can be determined using the equation reported below. Thus, independent from the viewing angle or angle of retroversion, the inclination angle of a stemless humeral head implant can be estimated with an accuracy of ±1.5-degree deviation. The algorithm proposed may be the basis for further research on the impact of humeral inclination in stemless shoulder arthroplasty.

Introduction

In the last decade total shoulder arthroplasty (TSA) has undergone a vast evolution. Meanwhile most companies provide stemless implants for anatomic TSA, several companies even offer stemless implants for reverse shoulder arthroplasty (RSA). Stemless components enable restoration of proximal humeral anatomy independent on humeral shaft orientation. Thus, center of rotation, inclination, retroversion and offset can be reproduced more accurately.[1-3] In anatomic TSA, malpositioning of both the humeral and glenoid components adversely affect the range of motion, kinematics, and stability of the shoulder. Therefore, TSA should adapt to the individual's anatomy and pathology to reconstruct the shoulder to mimic natural anatomy and function.[4,5]

In RSA humeral inclination can be adjusted as required when using stemless implants. Inclination of the humeral component is of special interest in reverse total shoulder arthroplasty. A high angle of humeral inclination is associated with an increased rate of scapular notching,[6] whereas a low humeral neck shaft angle has been found to be associated with an improvement in range of motion in onlay reverse shoulder arthroplasty.[7] Plain radiographs of the shoulder are routinely used to assess implant orientation after TSA. In plain radiographs humeral inclination can only be measured accurately if the x-ray beam (viewing angle) is exactly parallel to the retroversion angle of the humeral component. In standard antero-posterior x-ray projections of the shoulder this is rarely the case. When viewing the humeral head component in a non-orthograde manner, the base of an anatomical implant as well as the cup of a reverse humeral implant form an ellipse (Figure 1).

In these projections the base of the humeral component is not parallel to the viewing angle, making it difficult to determine the exact humeral inclination.

The purpose of this paper is to describe a simple and precise method of measuring the humeral inclination angle in standard plain radiographs of the shoulder.

Materials and Methods

Theoretical mathematical deliberations were undertaken for determination of the humeral neck shaft angle (humeral inclination) when looking at a prosthetic humeral head implant at an angle. The angle θ between the orthogonal plane of the head component base (circle) and the viewing direction is given by

$$\theta = \arccos\left(\frac{a}{b}\right), \qquad (1)$$

where a and b denote the radii of the minor and major axes of the projected ellipse. An equivalent formula was previously given by McLaren[8] for the angle β between the bounding plane of the hemisphere and the viewing axis (Figure 2). Consider an orthogonal coordinate basis $\{e_1, e_2, e_3\}$ with the unit vectors e_1 and e_3 pointing in distal direction of the humerus and in the viewing direction, with the unit vector e_2 chosen to comply with the right-hand rule. Let x denote the unit vector in direction orthogonal to the plane of the prosthetic head's base. Then the inclination is the angle α between x and e_1, as visualized in Figure 3.

In terms of corresponding spherical coordinates, the azimuth φ of x is the projected angle between the base of the humeral component and the humerus pointing in distal direction, which is the apparent inclination measured in the radiograph, whereas the polar angle of x is exactly the angle θ between the viewing axis and the joint axis computed in (1). In particular, the first component x_1 of the unit vector x is given by $x = \sin(\theta)\cos(\varphi)$. Since $x = e_1 = x_1$ for the dot product between x and the basis vector e_1,

Correspondence: Sascha Beck, Department of Orthopaedics and Trauma Surgery, University Hospital Essen, University of Duisburg-Essen, Hufelandstrasse 55, 45147 Essen, Germany.
E-mail: sascha.beck@uk-essen.de

Key words: Humeral inclination, humeral neck shaft angle, stemless, total shoulder arthroplasty, reverse shoulder arthroplasty.

Acknowledgements: We thank Sebastian Blex, Institute of Diagnostic and Interventional Radiology and Neuroradiology, Essen University Hospital, for his technical support. Moreover, we would like to thank Mathys AG, Bettlach, Switzerland, especially Hans Vaegler for providing the sawbone model.

Contributions: the authors contributed equally.

Conflict of interest: the authors declare no potential conflict of interest.

Funding: We acknowledge support by the Open Access Publication Fund of the University of Duisburg-Essen.

Received for publication: 5 June 2019.
Accepted for publication: 19 August 2019.

Orthopedic Reviews 2019;11:8194
doi:10.4081/or.2019.8194

$$\cos(\alpha) = \cos(\angle(x, e_1)) = x \cdot e_1 = x_1 =$$
$$\sin(\theta)\cos(\varphi) = \sin\left(\arccos\left(\frac{a}{b}\right)\right)\cos(\varphi)$$
$$= \sqrt{1 - \left(\frac{a}{b}\right)^2} \cdot \cos(\varphi).$$

Thus, the inclination α is given by

$$\alpha = \arccos\left(\sqrt{1 - \left(\frac{a}{b}\right)^2} \cdot \cos(\varphi)\right). \quad (2)$$

If the x-ray beam is perpendicular to the humeral shaft axis, the above formula (2) can be applied to calculate the inclination of a prosthetic humeral component on plain radiographs.

The accuracy of the theoretical calculation of humeral inclination was counterchecked by a radiographic model of the humerus. A sawbone model of a left humerus was used for the radiographic study. The humeral head of the sawbone was resected and a stemless humeral head prosthesis was inserted at the at the anatomical neck (Affinis short, Mathys AG, Bettlach, Switzerland). The sawbone model was installed on a tray using the distal part of the humeral canal for fixation. A wooden peg was positioned onto the distal humerus serving as a pointer for measuring rotation, parallel to the retroversion of the implant (Figure 4). The plane parallel to the humeral cut was determined under fluoroscopic control, when the base of the humeral head implant projected as a line. This position was defined as 0 degrees. Starting at 0

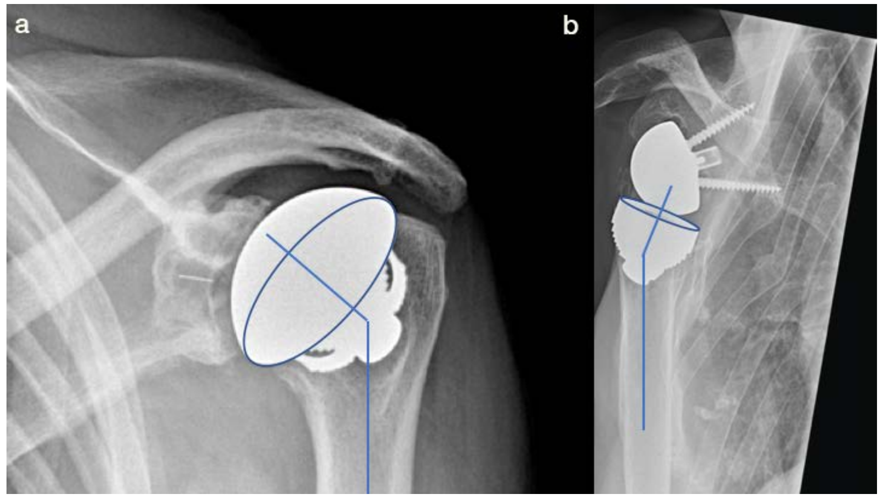

Figure 1. Anteroposterior radiographic views of stemless total shoulder implants. The bases of the humeral components form an ellipse, current humeral inclination, (a) anatomical (b) reverse Total Evolutive Shoulder System (TESS), Biomet, Warsaw, IN, USA

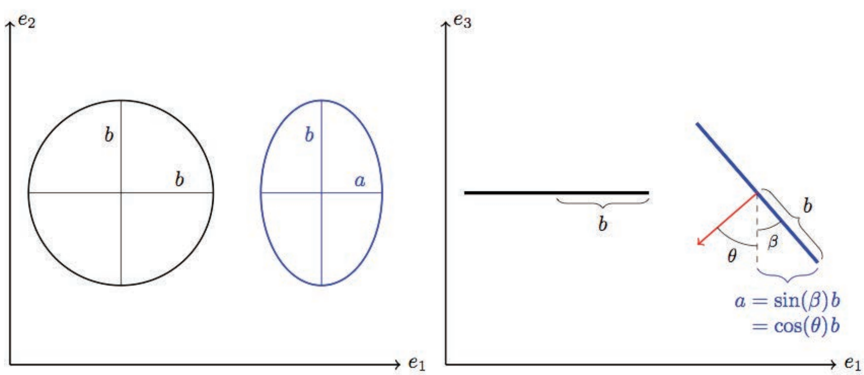

Figure 2. Two differently oriented circles with radius b, observed from different directions.

Table 1. Aberration of calculated inclination angle (CIA) using the formula in (3) from real inclination angle (RIA).

Retroversion angle	Width of ellipse (a)	Length of ellipse (b)	Measured inclination angle (MIA)	Real inclination angle (RIA)	Calculated inclination angle (CIA)	Aberration from real inclination angle
0	0	7.94	129.6	129.6	-	-
5	0.56	7.84	129.7	129.6	129.57	-0.02
10	1.29	7.84	130.0	129.6	129.35	-0.25
15	2.12	7.99	130.4	129.6	128.67	-0.93
20	2.60	7.93	131.0	129.6	128.30	-1.30
25	3.02	8.00	131.4	129.6	127.76	-1.84
30	3.49	7.97	133.3	129.6	128.07	-1.53
35	3.98	7.93	134.7	129.6	127.47	-2.13
40	4.36	7.95	137.7	129.6	128.21	-1.39
45	4.68	7.93	139.9	129.6	128.13	-1.47
50	4.82	7.93	140.2	129.6	127.59	-2.01
55	5.10	7.93	141.8	129.6	127.00	-2.60
60	5.28	7.95	145.6	129.6	128.09	-1.51
65	5.46	7.95	149.3	129.6	128.68	-0.92
70	5.64	7.87	158.0	129.6	130.30	+0.70

degrees, x-rays of the sawbone model were taken with increasing angles of retroversion. An x-ray was taken every 5 degrees between 0 and 70 degrees of retroversion.

Results

At 0 degrees of retroversion the 'real inclination angle' (RIA) of the sawbone model measured 129.6 degrees. With increasing angle of retroversion, the base of the humeral head prosthesis projected as an ellipse on plain radiographs (Figure 4). The ellipse with its two axes was delineated in each x-ray projection. Humeral inclination was measured using one axis perpendicular to the base of the ellipse and the other axis parallel to the humeral shaft. The angle formed between the two axes was named 'measured inclination angle' (MIA). With increasing angles of retroversion, the ellipse gained in width, whereas the length did not significantly change. With higher angles of retroversion, the MIA was found to increase up to 158.0 degrees at 70 degrees of retroversion (Table 1).

Knowing the width *a* and *b,* length of the projected ellipse as well as the MIA (φ), the RIA could be calculated using the following formula:

$$\arccos\left(\sqrt{1-\left(\frac{a}{b}\right)^2}\cdot\cos(\varphi)\right). \qquad (3)$$

Discussion

Plain radiographs of the shoulder are routinely used to assess implant positioning in total shoulder arthroplasty, but measuring humeral inclination may be inaccurate due to projectional error. This poses a real challenge when stemless humeral implants are used, which enable placement of the humeral component independent from the humeral shaft axis. In contrast to stemmed humeral implants the surgeon is now free to choose inclination of the humeral implant.[1,9-14] The described method for measuring anteversion of an acetabular cup from standard anteroposterior radiographs[15-17] could not be easily transferred to the shoulder, since the base of the humeral component forming an ellipse is affected in two planes when the humeral head is rotated.

In our study, we demonstrate that the measured humeral inclination angle depends on the viewing- and retroversion angle of the implant on x-rays and the estimated value erroneously increases with advancing retroversion angle. We observed, that the apparent humeral inclination, as measured on plain radiographs, corresponds to the true humeral inclination when humeral retroversion does not exceed 25 degrees. Humeral inclination only increased from 129.6 degrees in neutral rotation to 131.4 degrees at 25 degrees of retroversion.

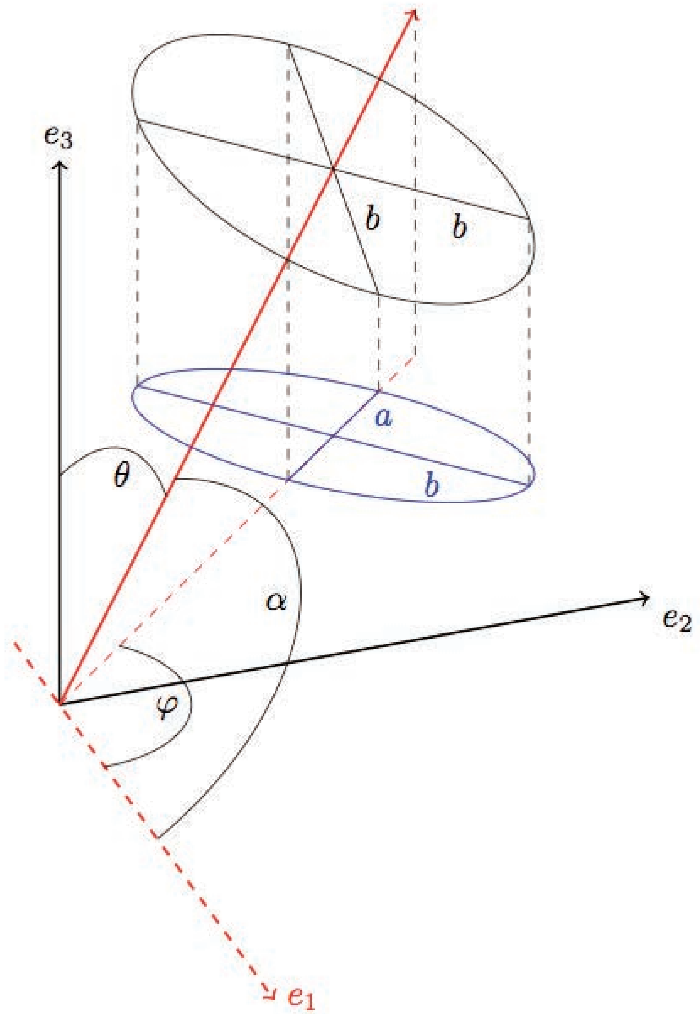

Figure 3. Spherical coordinates used to compute the inclination *a*, showing the azimuth *φ* and the polar angle *θ* as well as the head's circular base and its projection to the viewing plane.

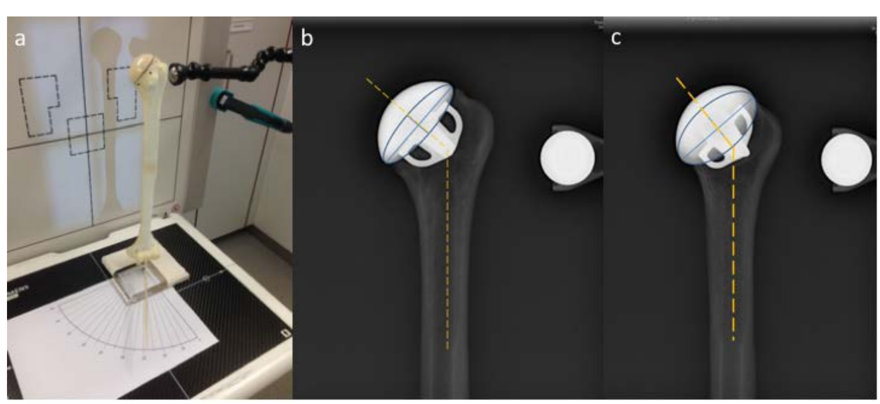

Figure 4. a) Radiographic setup: sawbone with Affinis short humeral head replacement installed on a tray with a pointer for measurement of rotation. b) Anteroposterior radiographs of the sawbone in 20 degrees (b) and 45 degrees of retroversion (c). The base of the prosthetic component projects as an ellipse (blue), orange dotted lines demonstrate measured humeral inclination (MIA).

Variability amounted to less than 2 degrees and could also be due to inaccuracy when measuring humeral inclination. However, for exact determination of humeral inclination on plain radiographs, an algorithm is required which generates the real inclination angle (RIA) independent of the viewing angle/retroversion angle. With varying angles, the base of the humeral component forms an ellipse with two axes. Knowing the minor and major axes of the ellipse as well as measuring humeral inclination (MIA), the real inclination angle (RIA) can be calculated accurately. In our sawbone model the calculated inclination angle (CIA) varied between 127.00 and 130.30 degrees. Thus, the maximum aberration of the CIA from the RIA was 2.6 degrees. This variation can be attributed to inaccuracy when determining the axes of the ellipse and the MIA. With the formula given (3) the mean deviation of the CIA was less than 1.5 degrees (1.32±0.71 degrees).

Our algorithm was counterchecked using an anatomical humeral head prosthesis. The basis for calculating the real inclination angle consists of measuring the apparent humeral inclination and the axes of the ellipse in plain radiographs. These principles do not only apply to anatomical humeral head components, but also for reverse implants since the base of a reverse implant also forms an ellipse with increasing angles of retroversion (Figure 1).

Thus, using the algorithm introduced, the inclination angle of the humeral component in anatomic and reverse shoulder arthroplasty can be determined precisely.

Our algorithm may be the basis for further research on the effect of humeral inclination in stemless shoulder arthroplasty.

Limitations

We are aware that it is not possible to distinguish retroversion from anteversion of the humeral head prosthesis in plain radiographs. Nevertheless, assuming correct patient positioning and x-ray projection as well as correct implant positioning anteversion is very unlikely since anatomical studies showed that humeral head retroversion averages around 30 degrees.[18,19] Furthermore, differentiation of retroversion *vs*. anteversion has no adverse effect on the calculated inclination angle.

Conclusions

The mathematical algorithm introduced (3) can serve as an important tool for precise determination of humeral inclination in stemless shoulder arthroplasty. Independent from the viewing angle or angle of retroversion the humeral neck shaft angle can be calculated ±1.5-degree deviation.

References

1. Beck S, Beck V, Wegner A, et al. Long-term survivorship of stemless anatomical shoulder replacement. Int Orthop 2018. DOI 10.1007/s00264-018-3779-0
2. Boileau P, Walch G. The three-dimensional geometry of the proximal humerus. Implications for surgical technique and prosthetic design. J Bone Joint Surg Br 1997;79:857-65.
3. Maier MW, Lauer S, Klotz MC, et al. Are there differences between stemless and conventional stemmed shoulder prostheses in the treatment of glenohumeral osteoarthritis? BMC Musculoskelet Disord 2015;16:275.
4. Iannotti JP, Spencer EE, Winter U, et al. Prosthetic positioning in total shoulder arthroplasty. J Shoulder Elbow Surg 2005;14:111S-21S.
5. Iannotti JP, Lippitt SB, Williams GR Jr. Variation in neck-shaft angle: influence in prosthetic design. Am J Orthop (Belle Mead NJ) 2007;36:9-14.
6. Erickson BJ, Frank RM, Harris JD, et al. The influence of humeral head inclination in reverse total shoulder arthroplasty: a systematic review. J Shoulder Elbow Surg 2015:24:988-93.
7. Werner BS, Chaoui J, Walch G. The influence of humeral neck shaft angle and glenoid lateralization on range of motion in reverse shoulder arthroplasty. J Shoulder Elbow Surg 2017;26:1726-31.
8. McLaren RH. Prosthetic hip angulation. Radiology 1973;107:705-6.
9. Ballas R, Beguin L. Results of a stemless reverse shoulder prosthesis at more than 58 months mean without loosening. J Shoulder Elbow Surg 2013;22:e1-6.
10. Churchill RS, Athwal GS. Stemless shoulder arthroplasty-current results and designs. Curr Rev Musculoskelet Med 2016;9:10-6.
11. Hawi N, Magosch P, Tauber M, et al. Nine-year outcome after anatomic stemless shoulder prosthesis: clinical and radiologic results. J Shoulder Elbow Surg 2017;26:1609-15.
12. Kadum B, Mafi N, Norberg S, Sayed-Noor AS. Results of the Total Evolutive Shoulder System (TESS): a single-centre study of 56 consecutive patients. Arch Orthop Trauma Surg 2011;131:1623-9.
13. Moroder P, Ernstbrunner L, Zweiger C, et al. Short to mid-term results of stemless reverse shoulder arthroplasty in a selected patient population compared to a matched control group with stem. Int Orthop 2016;40:2115-20.
14. Teissier P, Teissier J, Kouyoumdjian P, Asencio G. The TESS reverse shoulder arthroplasty without a stem in the treatment of cuff-deficient shoulder conditions: clinical and radiographic results. J Shoulder Elbow Surg 2015;24:45-51.
15. Ackland MK, Bourne WB, Uhthoff HK. Anteversion of the acetabular cup. Measurement of angle after total hip replacement. J Bone Joint Surg Br 1986;68:409-13.
16. Marx A, von Knoch M, Pfortner J, et al. Misinterpretation of cup anteversion in total hip arthroplasty using planar radiography. Arch Orthop Trauma Surg 2006;126:487-92.
17. Nomura T, Naito M, Nakamura Y, et al. An analysis of the best method for evaluating anteversion of the acetabular component after total hip replacement on plain radiographs. Bone Joint J 2014;96B:597-603.
18. Gracitelli ME, Duarte FA, Toffoli RP, et al. Shoulder arthroplasty in osteoarthritis: correlation between function and radiographic parameters. Acta Ortop Bras 2013;21:98-102.
19. Kronberg M, Brostrom LA, Soderlund V. Retroversion of the humeral head in the normal shoulder and its relationship to the normal range of motion. Clin Orthop Relat Res 1990:113-117