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Replication of the rotational center of the humeral head with second-generation stemmed prostheses

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Objective: Reconstruction of the anatomy of the proximal humerus is an indispensible prerequisite to achieve good clinical results and long-term prosthesis stability. Modern, adjustable prostheses have greater flexibility of inclination, retrotorsion, as well as medial and dorsal offset, in comparison to older prostheses. Such improvements are expected to allow for more accurate reconstruction of the anatomical condition, such as targeted reconstruction of the primary and the secondary rotational centers.

Methods: The reconstruction of the humeral rotational center was assessed in 48 second-generation prostheses. All reconstructions were compared by radiographic parameters with the pre-operative state and the operated opposite side.

Results: The positions of the new rotational centers after arthroplasty were not close to those of pre-operative and healthy opposite side's radiographs. No characteristic change in the position of the humeral head, or of its rotational center was detected.

Conclusion: Second-generation prostheses can only provide a limited reconstruction of the original anatomy in shoulder hemiarthroplasty. In contrast, the modern third- and fourth-generation modular prostheses with variable inclination are more potent in replicating the original shoulder anatomy with its primary and secondary rotational centers.

Key words: Anatomic rotational center; shoulder prosthesis; shoulder reconstruction.

Accurate shoulder endoprosthesis implantation is made difficult by the individual variation of the proximal humerus anatomy. There is a wide variation regarding inclination, retrotorsion, as well as medial and dorsal offsets of the rotational center in relation to the shaft axis.[1-6] Therefore, many authors emphasize the importance of precise anatomical restoration during implantation of a shoulder endoprosthesis for an optimum post-operative joint function.[1,7-15] In rare cases, these demands are more specific and the restoration of the normal rotational center is the primary goal.[5]

Current literature, however, does not indicate whether restoration of the original anatomical condition (of the primary rotational center) or the adaptation of the prosthesis to the altered anatomy of the affected joint (the secondary center of rotation) is strived for. During shoulder arthroplasty, it should be decided either to correct the deformities or to adapt the reconstruction to the pathological deformity. There are considerable differences between the two approaches. For example, a lateral displacement of the humeral head center in relation to shaft axis (functionally causing a medial displacement of the rotational center) can be observed after the flattening of the humeral head (Figs. 1a and b). The correction of the deformity would lateralize the rotational center. As opposed to the example above, Fig. 1c shows

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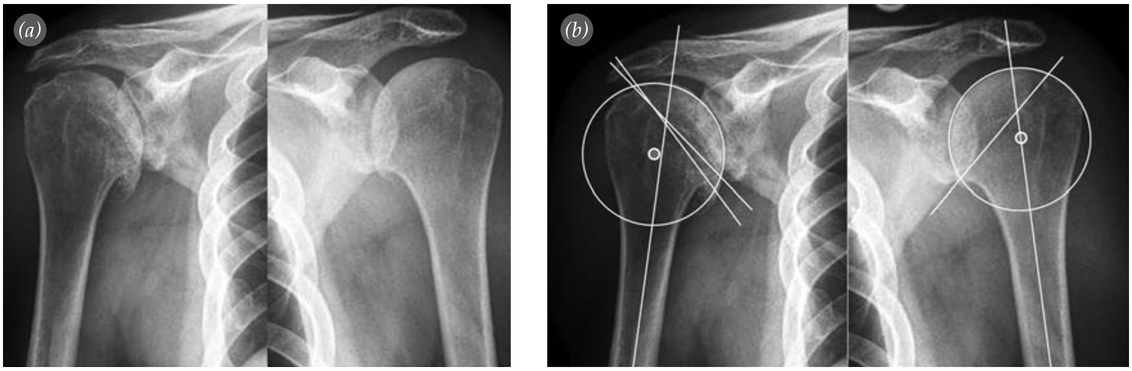


Fig. 1. **(a)** Deformation of the right shoulder in a patient with primary osteoarthritis. Compare with the healthy opposite side. **(b)** The flattened humeral head within the intact glenoid causes a lateral shift of the humeral head center in relation to the shaft axis, but causing a medial displacement of the center of rotation in relation to the glenoid. The inclination of the osteotomy plane is difficult to define, but this is of no influence on the rotational centre if it is performed in the demonstrated way. If the lateral level of the osteotomy is the same (exactly at the anatomical neck) in all cases, a lower osteotomy angle would provoke an additional lateral displacement of the rotational centre. **(c)** Primary osteoarthritis of the shoulder with no substantial deformity of the humeral head or glenoid.

a primary osteoarthritis of the shoulder joint with no significant deformation of the humeral head.

Modern third- and fourth-generation prostheses can be adapted to both original and pathologically altered anatomies. In contrast, older, non-adjustable prostheses of the second generation do not allow for flexible adaptation (Fig. 2). Adjustment can only be achieved, for example, by implanting prosthesis with a thin shaft in a varus or valgus position, laterally or medially, higher or lower. Additionally, second generation prostheses allow to change the size of the head. Consequently, adjustment is more difficult and cannot be achieved with the same precision as in modern, adjustable prostheses.

We hypothesized that these adjustment difficulties should alter the post-operative rotational center compared to the pre-operative position and the healthy, contralateral side. We hypothesized that conventional first and second-generation prostheses (without the possibility of adjusting the inclination and the eccentricity of the humeral head) would not create a rotational center similar to either the rotational center of the pre-operative or opposite side.

Patients and methods

The research was reviewed and approved by the review board of the Marienstift Arnstadt, Germany.

Radiographs from 48 consecutive patients were evaluated in a retrospective analysis. In all cases, second-generation prostheses were implanted between 1994 and 2001. Surgery was performed for primary osteoarthritis (n=11), post-traumatic osteoarthritis (n=10), malunited fractures (n=16), rheumatoid arthritis (n=9) and avascular humeral

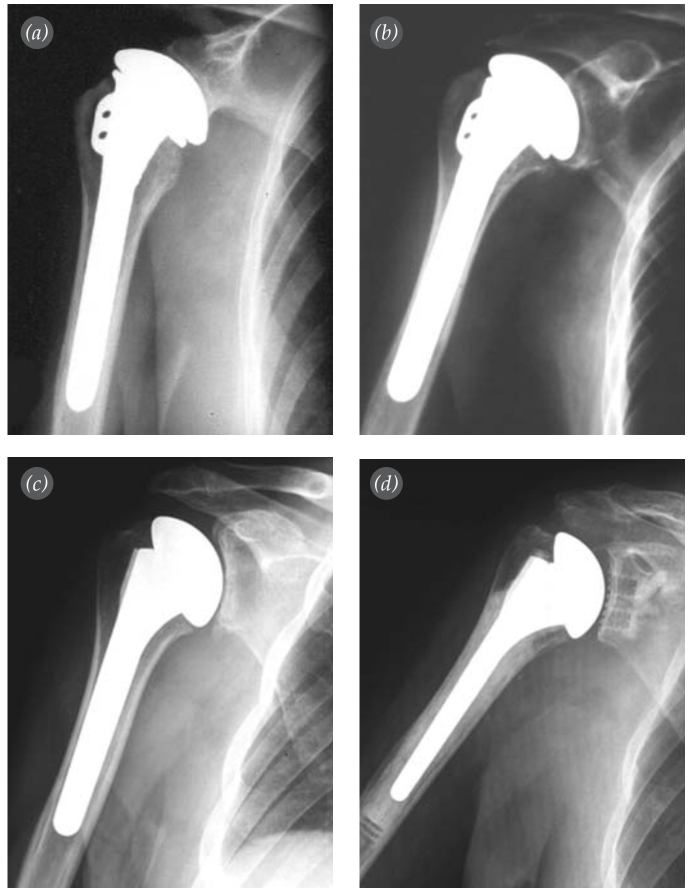


Fig. 2. Comparison of adaptation with 2nd generation (Neer II, Kirschner) and 4th generation (Affinis, Mathys Ltd, Bettlach, Schweiz) prostheses: **(a, b)** In 2nd generation implants optimal adaption is not always possible. **(c, d)** Fourth generation prosthesis allow nearly exact adjustment in most cases.

head necrosis (n=2). In these 48 patients, 44 Neer II (Kirschner), 2 Bio-Modular (Biomet) and 2 Cofield (Smith and Nephew) prostheses had been implanted.

Anteroposterior radiographs of the damaged and healthy sides were taken before surgery. Additional radiographs, i.e. exclusively for study purposes, did not have to be taken. As this was a retrospective analysis, axillary views were available in a limited number of cases and the rotational center could only be determined in the frontal plane of the shoulder.

All prostheses were implanted by the same surgeon. Evaluations were performed by an independent examiner.

Figs. 3a-c show the parameters describing the humeral anatomy as defined by various authors.[2,4,12,13,16-20] The humeral head center was determined by a transparent template, on which circles of different diameters were drawn. Various parameters are dependent on each other. As some points of reference were not clear in every radiograph, some dependent parameters were intentionally used, e.g. DCR (distance coracoid/center of rotation) and DGR (distance glenoid/center of rotation) (Fig. 3c). To define DCR, a clear identification of the coracoid process was required, on which a vertical line was set. In the case of DGR, clear identification of the superior and inferior glenoid poles was necessary, through which a reference line was drawn. It was usually possible to measure at least one parameter, but not always possible to obtain both.

Statistical methods

All parameters were measured in metric units. The conventional alpha-error rate of 5% was applied throughout. Possible cumulative errors were not adjusted. Pre- vs. post-operative value and opposite side vs. post-operative value were compared with either a one- or two-sided paired t-test, respectively.

Results

Both the parameters describing the reconstruction of the humeral geometry and those characterizing the center of the humeral head in relation to the glenoid, revealed non-specific changes after surgery.

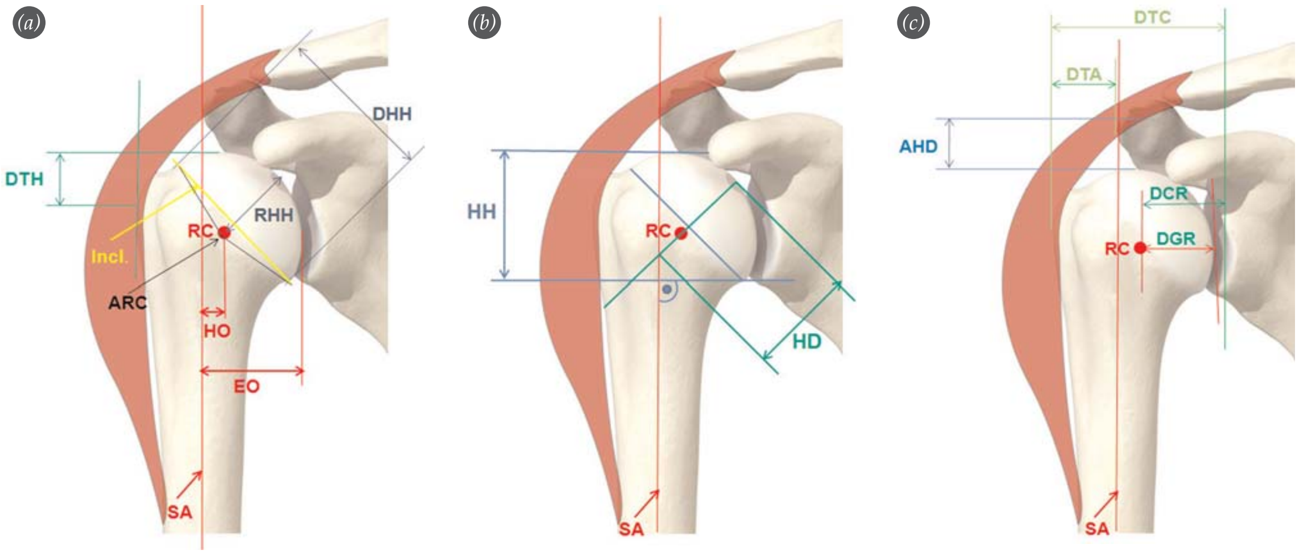


Fig. 3. Radiograph parameters: **(a, b)** Parameters used to define the bony geometry of the humeral head. **(c)** Parameters used to define the characteristics (centralization) of humeral head center. AHD: acromio-humerale distance, ARC: articular surface arc, DCR: distance coracoid/ rotational centre, DGR: distance glenoid/ rotational centre, DHH: diameter of humerus head, DTA: distance tuberculum majus/acromion, DTC: distance tuberculum majus/coracoid, DTH: distance tuberculum majus/top of humerus head, EO: effective offset, HD: depth of humerus head, HH: height of humerus head, HO: humerus offset, Incl: inclination angle, RC: rotational center, RHH: radius of humerus head, SA: shaft axis. [Color figure can be viewed in the online issue, which is available at www.aott.org.tr]

This means that the parameters characterizing the humeral geometry does not exhibit any characteristic changes in the post-operative assessment (Table 1). However, individual values differ sometimes significantly from the pre-operative initial values and others from those of the healthy opposite side. Fig. 4 clearly illustrates these conditions. For example, the post-operative value of EO is approximately in the middle between the pre-operative initial value and the value of the opposite side; HD approaches to the opposite side but strongly differs from the pre-operative value; ARC clearly deviates from both values. The value of the distance between the *Tuberculum majus* and the humeral head height (DTH) differ both from the preoperative side as well as from the healthy side.

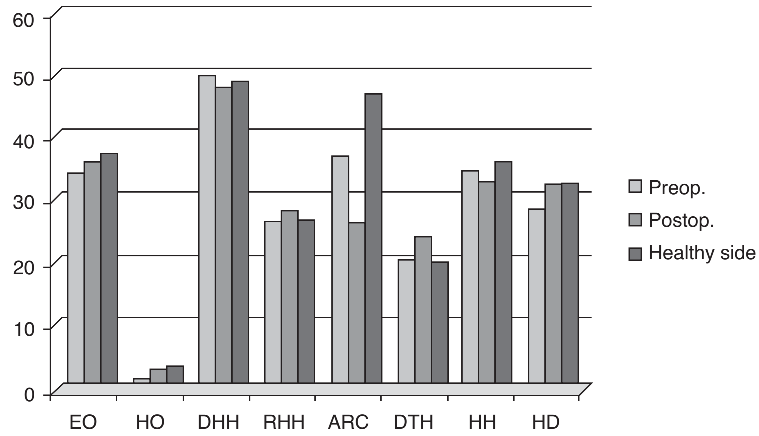
The center of the humeral head in relation to the glenoid showed the same tendency (Table 2). The changes are uncharacteristic; a clear tendency to one or the other side is not evident. Fig. 5 clearly illustrates this situation. The "distance between the

Table 1. Radiological parameters for specification of humeral geometry.

Parameter	Preop. (mm)	SD	Postop. (mm)	SD	Opposite side (mm)	SD	P Pre/post	P Post/opposite side
EO	34.83	12.71	36.68	10.91	38.14	8.63	0.5050	0.2210
HO	1.62	4.24	3.53	3.43	4.14	2.62	*0.0001*	0.2800
DHH	50.38	6.29	48.51	5.80	49.64	8.36	0.2000	0.1780
RHH	27.28	3.49	28.81	5.29	27.25	3.51	*0.0380*	0.3550
ARC	137.55	18.17	127.04	16.36	147.64	14.00	0.1360	*0.0001*
DTH	20.93	3.81	24.74	6.98	20.67	6.06	*0.0001*	*0.0360*
HH	35.24	5.02	33.19	5.93	36.68	5.03	0.1300	*0.0000*
HD	29.00	6.18	33.02	6.47	33.14	6.27	*0.0000*	0.2170

Radiological parameters for specification of humeral geometry in 48 shoulder prostheses of 2nd generation. EO: effective offset, HO: humerus offset, DHH: diameter of humerus head, RHH: radius of humerus head, ARC: articular surface arc, DTH: distance tuberculum majus/top of humerus head, HH: height of humerus head, HD: depth of humerus head.

Fig. 4. Results of radiological parameters to define the bony geometry of the humeral head (2nd generation prostheses, n= 48; legends *see* Fig. 3).



Tuberculum majus and the coracoid" (parameter DTC) shows no change between pre- and post-operative states, but there is a difference to the opposite side (not significant). The parameter DGR shows a similar result. Significant differences between pre- and post-operative state were only demonstrated in parameters AHD and DTA; the remaining parameters showed no significant differences to the pre-operative values.

Discussion

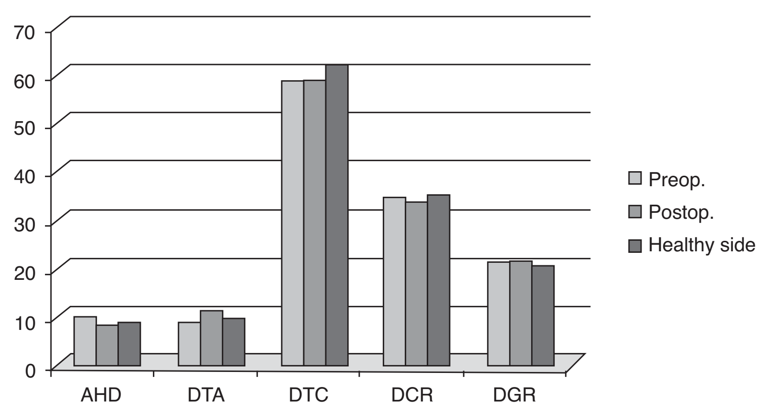
Implantation of a shoulder endoprosthesis should aim for the restoration of joint geometry as precisely as possible. This opinion is held by numerous authors.[1,7-14] However, because of the geometric variability of the proximal humerus, this may be difficult to achieve. Ideally, after the operation, these parameters should be similar to the healthy side, or the pre-operative situation. It was postulated in the

Table 2. Radiological parameters for specification of the centering of humeral head.

Parameter	Preop. (mm)	SD	Postop. (mm)	SD	Opposite side (mm)	SD	P Pre/post	P Post/opposite side
AHD	10.20	5.36	8.49	5.58	9.18	2.76	*0.013*	0.956
DTA	9.07	10.60	11.46	10.74	9.71	6.36	*0.037*	0.316
DTC	59.00	11.91	59.00	11.55	62.93	8.80	0.467	0.064
DCR	35.17	9.49	33.91	8.93	35.50	5.24	0.289	0.314
DGR	21.53	6.36	21.57	5.52	20.64	4.75	0.978	0.422

Radiological parameters for specification of the centering of humeral head in 48 shoulder prostheses of 2nd generation. AHD: acromio-humerale distance, DTA: distance tuberculum majus/acromion, DTC: distance tuberculum majus/coracoid, DCR: distance coracoid/ rotational centre, DGR: distance glenoid/ rotational center.

Fig. 5. Results of radiological parameters to define the centralization of the humeral head (2nd generation prostheses, n= 48; legends *see* Fig. 3).



introduction that this aim can only be achieved to a limited extent or not at all with older, non-adjustable prostheses. It can be expected that following implantation of a second-generation prosthesis the values will not show characteristic changes, i.e. they will either approach the values of the healthy side or of the pre-operative situation. In fact, an inconsistent change of the parameters in one or the other direction is likely.

The post-operative changes of humeral head geometry largely support this hypothesis. After surgery, the individual parameters exhibit uncharacteristic and inconsistent changes. It cannot be determined whether they are similar to the pre-operative or the opposite side's values. It can be observed that in some cases the difference to the opposite side is reduced (e.g. EO, HO, HD); in other cases, an increase can be noticed (e.g. ARC, HH). This is also reflected in the irregular distribution of the significant changes.

It is interesting to note that the post-operative value of EO compared to the pre-operative value and the opposite side value is only 1.85 mm and 1.46 mm, respectively. The corresponding differences for the HO are 1.91 and 0.61 mm (Table 1 and Fig. 4). Thus, the center of rotation is within the range of 4 mm, which is the maximum range of tolerance defined by various authors.[5,21] In contrast to our study, Pearl at al. found that the rotational center in second-generation prostheses deviated from the original position by 14.7 mm.[12,13] This deviation in third-generation prostheses was only 2.1 mm.[5,13,22] However, it was not clear whether they compared the post-operative state with the pre-operative state or with the opposite side.

We found clear differences in other parameters, e.g. the ARC. In relation to the pre-operative value, a difference of 10.51° and of 20.6° to the opposite side was found. Pearl et al. suggested the deviation should be no more than 30° from the "original value".[12,13] Beyond these deviations, worse clinical results may be expected.[5] Both of our results fall within this limit. Also in this case, it was not clear whether Pearl et al. compared the post-operative state with the pre-operative state or with the healthy opposite side. Nevertheless, our deviation result of 20.6° compared to the healthy side seemed relatively large. In another study, our working group found a deviation of only 4.64° using the same technique with fourth-generation prostheses.[23]

The changes predicted in the initial hypotheses are also observed in the parameters describing the center of the humeral head in relation to the glenoid. Aside from the reconstruction of the anatomy of the humeral head, there are several other factors influencing the position of the humeral head in relation to the glenoid, e.g. the condition of the rotator cuff or contracture of the joint capsule. Similarly, while AHD and DTA significantly differed from the pre-operative values (Table 2 and Fig. 5), there was no clear tendency in the direction of this displacement.

In spite of uncharacteristic and inconsistent deviations, the average differences was remarkably low (especially the deviation of the EO and the HO). Consequently, the anatomical condition can also be largely restored using conventional prostheses. This corresponds to the results published by Ianotti et al., using a computer simulation of CT-scans and 3-D-reconstruction of 36 cadaveric humeri, they compared the adaptation possibilities of conventional prostheses and prostheses with variable angles.[18] It was found that a satisfactory reconstruction is also possible using conventional prostheses by choosing different osteotomy planes (according to a varus or valgus shaft position) and different head sizes. However, this could be achieved more easily and with better results by means of modern prostheses with variable inclination and eccentric adjustability of the head position.[3,9,15] The medial and dorsal offset was the parameter with the most difficult restorability.

These observations are consistent with the findings of many authors, who observed more adaptive capabilities with third- or fourth-generation prostheses than the conventional first- or second-generation ones. It remains to be seen if better adaptation leads to longer prosthesis stability.[5,12] However, it has been clearly verified that the range of motion can be optimized and the risk of subacromial impingement reduced.[10,11,20,21] Exact reconstruction of the rotational center is also important to maintain the normal function of the rotator muscles.[10,11] This leads to a reduction of the eccentric load on the glenoid.[7] The focus of the adaptation should be the reconstruction of the combined offset. A prosthesis with double-eccentric head adjustment facilitates this process.[2,3,9] Early clinical results and experimental analysis support the functional advantage of modern third- and fourth-generation prostheses.[24]

Some authors have concluded that modular shaft prostheses do not offer superior reconstruction of the anatomy compared to conventional models.[25-27] However, these studies grouped together a variety of implant models from second- to fourth-generation under the term ‘modular prostheses’ which featured a broad range of possibilities in terms of adjustment. Their study included several prostheses including; simple shaft prostheses with variably selectable head (second-generation), prostheses with variable inclination and simple-eccentric head adjustment, and prostheses with fixed inclination and double-eccentric head adjustment (third- and fourth-generation). Therefore, the statements of the above-mentioned authors should be interpreted with caution.

Conclusion

Our results have shown that neither a targeted reconstruction of the primary anatomical condition nor an adaptation to the existing anatomical condition can be achieved by means of second-generation prostheses, but the average deviations are within an acceptable range. However, in individual cases, extreme positions can be observed at times and the results correspond to the initially formulated hypothesis.

In contrast, adjustable modern shaft prostheses allow for a considerably better reconstruction of the anatomical condition. When choosing prosthesis with variable inclination and osteotomy without resection gauge along the anatomical neck, adaptation to the existing secondary anatomical conditions can be achieved. When using a saw gauge and prosthesis with fixed inclination, adaptation to the primary anatomy is possible. Extreme deviations, as seen with first- and second-generation prostheses, do not occur any longer.

Since various biomechanical studies have pointed out that exact anatomical positioning is crucial for range of motion, rotator cuff function, mechanical glenoid stress, and the lifetime of the prosthesis, all available technical resources should be used to achieve the best possible restoration of the anatomy.

Conflicts of Interest: No conflicts declared.

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