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ORIGINAL PAPER

Variability of medial and posterior offset in patients with fourth-generation stemmed shoulder arthroplasty

Ulrich Irlenbusch · Alexander Berth · Georges Blatter · Peter Zenz

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Abstract

Purpose Most anthropometric data on the proximal humerus has been obtained from deceased healthy individuals with no deformities. Endoprostheses are implanted for primary and secondary osteoarthritis, rheumatoid arthritis, humeral-head necrosis, fracture sequelae and other humeral-head deformities. This indicates that pathologicoanatomical variability may be greater than previously assumed. We therefore investigated a group of patients with typical shoulder replacement diagnoses, including posttraumatic and rheumatic deformities.

Material and methods One hundred and twenty-two patients with a double eccentrically adjustable shaft endoprosthesis served as a specific dimension gauge to determine in vivo the individual humeral-head rotation centres from the position of the adjustable prosthesis taper and the eccentric head.

Results All prosthesis heads were positioned eccentrically. The entire adjustment range of the prosthesis of 12 mm medial/lateral and 6 mm dorsal/ventral was required. Mean values for effective offset were 5.84 mm mediolaterally [standard deviation (SD) 1.95, minimum +2, maximum +11] and 1.71 mm anteroposteriorly (SD 1.71, minimum −3, maximum 3 mm), averaging 5.16 mm (SD 1.76, minimum +2, maximum + 10). The posterior offset averaged 1.85 mm (SD 1.85, minimum −1, maximum + 6 mm).

Conclusions In summary, variability of the combined medial and dorsal offset of the humeral-head rotational centre determined in patients with typical underlying diagnoses in shoulder replacement was not greater than that recorded in the literature for healthy deceased patients. The range of deviation is substantial and shows the need for an adjustable prosthetic system.

U. Irlenbusch (✉)
Department of Orthopaedic Surgery, Marienstift Arnstadt, Orthopaedic Surgery,
Arnstadt, Germany
e-mail: ulrich.irlenbusch@web.de

A. Berth
Department of Orthopaedic Surgery,
Otto-von-Guericke-University,
Magdeburg, Germany

G. Blatter
Rosenberg Clinic,
Heiden, Switzerland

P. Zenz
Otto Wagner Hospital,
Vienna, Austria

Introduction

The anatomy of the proximal humerus shows substantial individual variation. This applies to inclination and retroversion of the articular surface and to displacement of the centre of rotation medially and dorsally [1, 5, 11, 14, 16, 17]. When implanting a shoulder endoprosthesis, it is therefore difficult to restore the normal anatomy precisely, and the use of advanced technology may be required. However, numerous authors consider that this is necessary, as any deviation from the anatomical geometry, e.g. incorrectly adjusted setting of the joint plane or the centre of rotation, will result in impaired joint kinematics leading to an unsatisfactory outcome [2–4, 9, 12, 13, 15, 18, 20, 21]. Precise knowledge of anatomical variability is an absolute prerequisite to obtaining optimal results. Studies on the variability of the proximal humerus anatomy cited most often were conducted on human corpses with no pathological conditions [1, 5, 10, 11]. Other authors do not provide detailed information about their patient populations or sample materials [6, 16, 17].

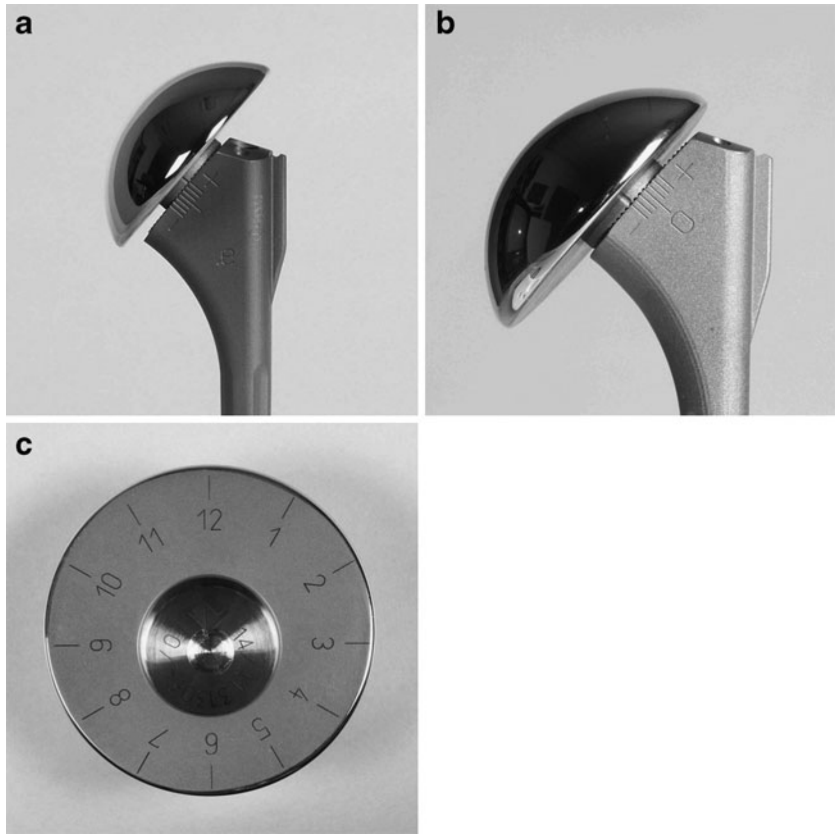

Fig. 1 **a**–**c** Principle of the double-eccentric head adjustability of the Affinis prosthesis (Mathys Ltd, Bettlach, Switzerland): **a**, **b** maximal lateral and medial head position resulting from displacement of the cone and the maximal eccentric head position; **c** eccentric humeral head

Endoprostheses are implanted to treat primary and secondary osteoarthritis, rheumatic changes, humeral-head necrosis, fracture sequelae and other humeral-head deformities. We therefore think that it is important to differentiate between the offset measured on 278 macerated specimens of an anatomical collection after exclusion of deformities [5] based on 56 shoulder joints of 39 cadavers [1] or based on living patients, reflecting the characteristic range of abnormalities that are typical indications for shoulder prosthesis implantation. The pathoanatomical variability may be greater, with implications for the development and choice of suitable implants and appropriate surgical techniques.

We therefore examined the rates of pathoanatomical changes of the proximal humerus in a group of patients who received a shoulder endoprosthesis. The study also included patients whose joints showed severe deformity following injury, inflammatory and other changes. In this way, the entire range of proximal humerus variability was covered.

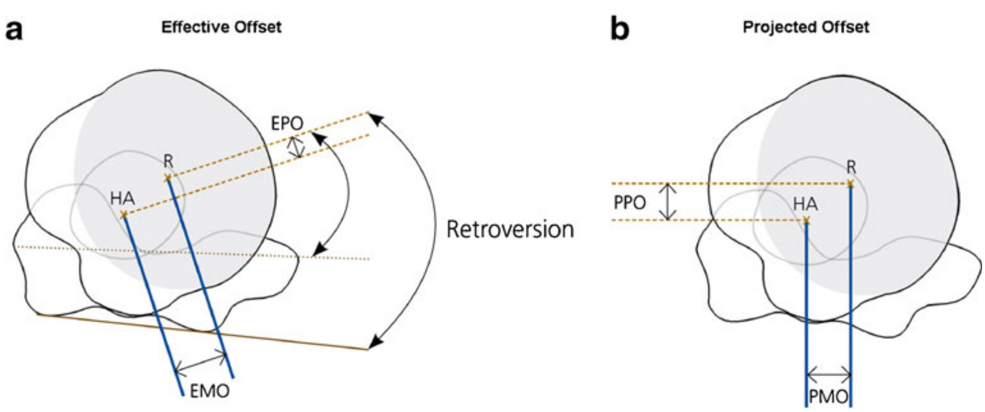

Fig. 2 **a** Effective offset: position of the humeral-head rotation centre in relation to stem axis on the retrotorsion level (mediolateral offset) or at right-angled to it (anteroposterior offset); **b** projected offset: projection of the humeral rotation centre onto frontal (medial offset) and sagittal (dorsal offset) planes. *R* rotation centre, *HA* humeral axis, *EMO* effective medial offset, *EPO* effective posterior offset, *PMO* projected medial offset, *PPO* projected posterior offset

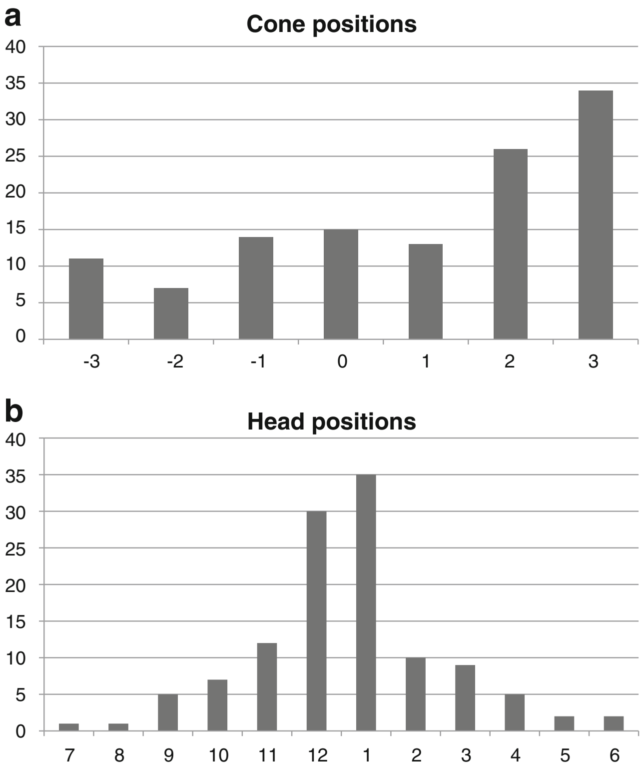

Fig. 3 **a** Cone positions (+3 to +1 = lateral, −1 to −3 = medial to the prosthesis centre); **b**) head positions (12 o'clock = lateral to the prosthesis centre, directed to the lateral fin; 6 o'clock = medial to the prosthesis centre)

Material and methods

One hundred and twenty-two consecutive cases of endoprosthesis implantation in 41 male and 81 female patients were studied. The average age was 68.1 years standard deviation (SD) 11.2]. The right side was operated upon in 72 cases and the left in 50. Uncemented prostheses were inserted in 57 cases and cemented in 65. There were 17 total prostheses and 105 hemiprostheses. Implantation was performed for the following indications: 60 primary and 17 posttraumatic osteoarthritis, 14 rheumatoid arthritis, 19 fracture sequelae and 12 other diseases (including six aseptic-head necroses).

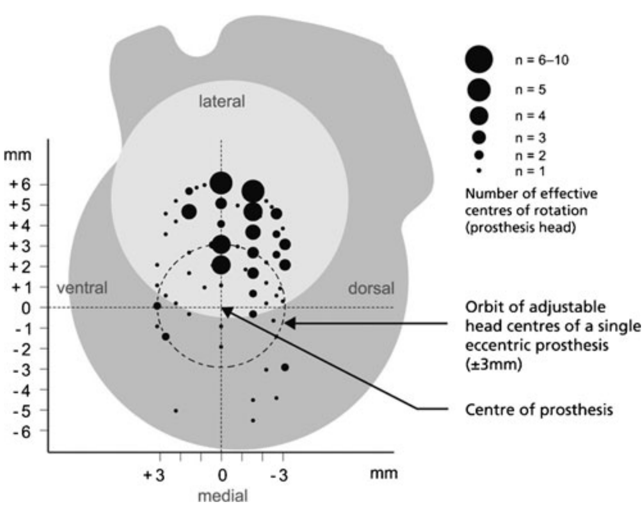

Fig. 4 Projection of rotation centres to the osteotomy level. The calculation resulted from the position of the prosthesis cone and the head eccentre, n=122. Graph not true to scale

Evaluation method

We used the Affinis shoulder endoprosthesis (Mathys Ltd. Bettlach, Switzerland) as a specific dimension gauge. The prosthesis allows an eccentric head positioning, i.e. it has a movable taper and an eccentric head (Fig. 1a–c). This results in a mediolateral adjustability of ±6 mm (12 mm) and an anterior-posterior adjustability of ±3 mm (6 mm). The prosthetic heads are available in eight sizes, ranging from 39 to 53 mm in diameter and 13 to 20 mm in height. Functionally, the combination of a movable taper and an eccentric head represents a double excentre. Therefore, the head position can be freely adjusted within this range and is not fixed to an orbit. The range of possible adjustments offered by this prosthesis covers almost the entire range of variability of medial and dorsal offset reported by Boileau and Walch respectively Hertel et al. [1, 5]. We therefore think that use of the prosthesis as a gauge by which to determine the centres of rotation of the humeri is justified.

From the position of the movable prosthesis cone and the eccentric head position, rotation centres of the humeral heads were determined using a trigonometric function. From the calculated value, the effective and projected offsets were established because both approaches are reported in the literature:

1. Effective offset: Position of the humerus rotation point in relation to stem axis on the level of retroversion (mediolateral offset) or at a right angle (anteroposterior offset) to it (Fig. 2a).

Table 1 Combined offset (millimetres), total group, n=122

Total group		No.	Median	Standard deviation
Effective offset	Mediolateral	122	5.84	1.95
	Anteroposterior	122	0.95	1.71
Projected offset	Medial	122	5.16	1.76
	Posterior	122	2.66	1.85

Effective offset adjustment of humeral-head rotation centres to the retrotorsion level (mediolateral offset) and right-angled to it (anteroposterior offset); *projected offset* variability of humeral-head rotation centres with projection front and sagittal

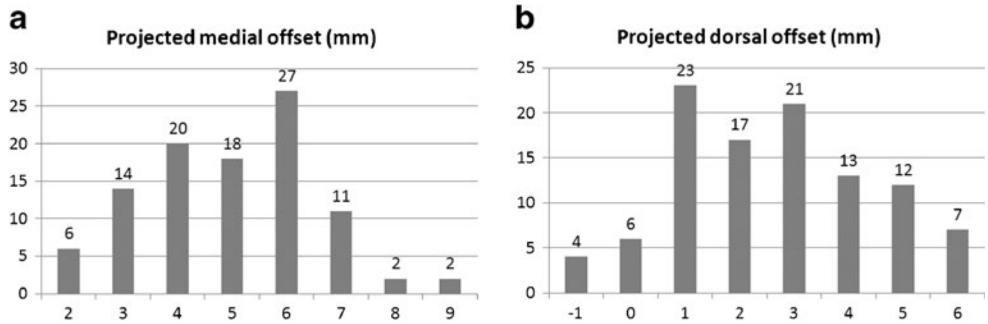

Fig. 5 **a** Projected medial offset, n=122; **b** Projected posterior offset, n=122 (please compare with Fig. 2)

2. Projected offset: Projection of the humerus rotation point to the frontal (medial offset) or sagittal (dorsal offset) plane (Fig. 2b).

Statistical methods

Mean values, SDs, and maximum and minimum values for the effective and projected offsets were calculated and presented in a chart. Finally, a statistical comparison of the offset variability between patients with fracture sequelae and patients with humeral heads not deformed by trauma was performed. Group means were compared using the Student t test. The level of significance was set at p=0.05, two-sided. For statistical analyses, including data management, SAS software, version 9.1.3, was used (SAS Institute, Cary, NC, U.S.A.).

Results

All prosthesis heads were positioned eccentrically. We noticed that it was necessary to make use of the entire range of adjustability provided by the prosthesis. The positions of the movable cone (±3 mm) and head (1–12 o'clock) in the individual settings were recorded (Fig. 3a, b).

From the combination of the cone and head position, the centres of the heads (centres of the measurement gauge) were extrapolated using a trigonometric function. These correspond to the centres of rotation projected onto the osteotomy level (Fig. 4). In other words, these many different fulcrums resulting from the various anatomical conditions had to be reconstructed. Consequently, the prosthetic heads were not placed in these positions randomly but based on the respective anatomy.

After the rotation centres had been determined, the effective and projected offsets were calculated. On the retrotorsion level (effective offset, Table 1), we found an average movement of humeral-head rotation centre in relation to the stem axis towards the posterior of 0.95 (−3.0 to 3.0) mm and towards the medial of 5.84 (+2 to +11) mm. As expected, projection of the rotation centres to the frontal and sagittal planes showed aberrant values (Table 1). The projected medial offset was 5.16 (+2 to +10) mm and dorsal offset 2.66 (−1 to +6) mm, respectively. To enable comparison with the data available in the literature, a chart was plotted for the projected offset only (Fig. 5).

In line with our question of whether inclusion of marked posttraumatic and other deformities in a study leads to increased variability compared with studies based on healthy human specimens, the combined offset was calculated separately for patients with abnormal fracture healing (fracture sequelae, n=19, Table 2) and the remainder of the group (n=103). For the projected posterior offset, there was hardly any measurable difference (2.84/2.62 mm; p=0.635, not significant), and for the medial offset, there

Table 2 Combined offset (millimetres); comparison of fracture sequelae (n=19) with the remainder of the group (n=103):

	Direction	No.	Median	Standard deviation
Fracture sequelae				
Effective offset	Mediolateral	19	6.21	1.81
	Anteroposterior	19	1.00	1.94
Projected offset	Medial	19	5.42	1.61
	Posterior	19	2.84	2.09
Osteoarthritis, Rheumatoid arthritis, Avascular necrosis				
Effective offset	Mediolateral	103	5.77	1.97
	Anterioposterior	103	0.94	1.68
Projected offset	Medial	103	5.12	1.78
	Posterior	103	2.62	1.82

Effective offset adjustment of humeral-head rotation centres to the retrotorsion level (mediolateral offset) and right-angled to it (anteroposterior offset); *projected offset* variability of humeral-head rotation centres with projection front and sagittal

Table 3 Comparison of combined projected offset in various studies (for explanations, see text)

Author	No.	Diagnosis	Medial offset medial/lateral (mm)		Posterior offset anterior/posterior (mm)	
			Mean	Min./Max.	Mean	Min./Max.
Boileau and Walch 1999 [1]	39 (56)	No deformity	6.9	2.9–10.8	2.6	−0.8 to +6.1
Hertel et al. 2002 [5]	278	No deformity	6.0	1.7–11.5	1.4	−3 to +5.3
Jeong et al. 2009 [10]	36	No deformity	5.6	1.7–9.5	−0.25	−2.0 to 2.7
McPherson et al. 1997 [11]	93	No deformity	1.9	±1.7	7.6	±3.2
Pearl 2005 [15]	–	–	–	4–14	–	−2 to +10
Roberts et al. 1991 [17]	29	–	–	–	4.7	0–11
Our study	122	Pathologic deformities	5.16	+2–+10	2.66	−1 to +6

was only a slight difference (5.2/5.12 mm; p=0.49, not significant).

Discussion

The in vivo results of our study show a wide variability of medial and dorsal offsets (Table 1). When comparing the results of previous studies by Boileau and Walch and Hertel et al. [1, 5] with those of this study, it is striking to see that their results are almost identical to the averages of the projected offset (Table 3). Even the distribution of values is very similar (Figs. 5 and 6). The consistency between the two graphs is surprising given the entirely different patient population and investigation material and the completely different methods of measurement. For example, Boileau and Walch derived their values from assessing 56 shoulder joints of 39 cadaver specimens. Following surface scanning and digitalisation of the measurements, digitalised representations of the examined humeri were created and then used to determine the relevant parameters [1]. In contrast, Hertel et al. examined 278 humeri from anatomical collections using standardised radiographic evaluation in two planes, along with additional visual marking of defined landmarks on the specimens [5]. In both studies, specimens with deformities were excluded. The patient population of our study, in contrast, consisted of patients typically needing endoprosthesis implantation, and we performed our investigations in vivo using various gauges (the adjustable heads of the Affinis prosthesis of various sizes were used for this purpose).

It is also of special interest to note that no significant difference was found between the offset variability among patients with fracture sequelae and patients with almost intact anatomy (Table 2). Consequently, the anatomical variability of the proximal humerus in the studied patient sample did not—or only insignificantly—exceed the values reported in the literature, despite the inclusion of patients with deformities. We expected this study to reveal more significant differences. Comparison of our results with those reported in the literature was hampered by the fact that previous studies did not differentiate between effective and dorsal offset, even though the difference between the two projections is significant. Some published information is contradictory in this respect. For example, in the Boileau and Walch article, the offset described in their "Methods" section is presented at the retroversion level, or perpendicular to the retroversion level, which we define as an

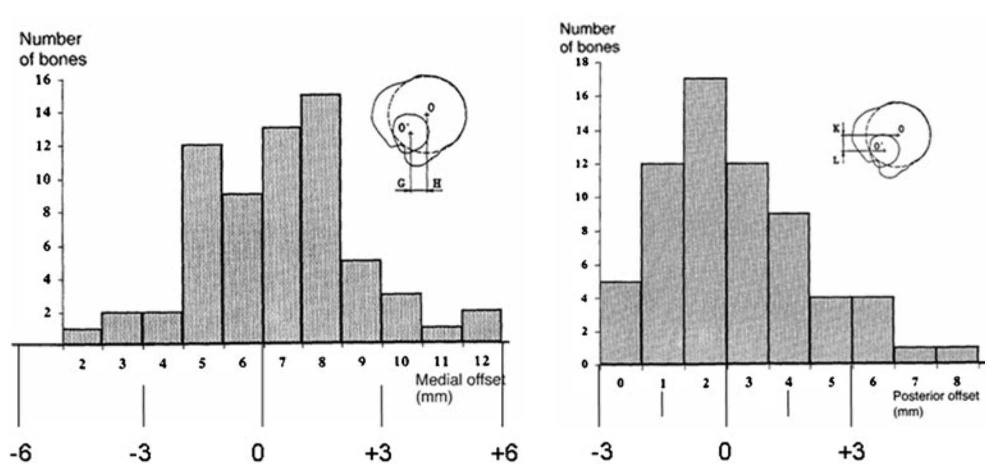

Fig. 6 Projection of the rotation centres onto the frontal and sagittal planes according to Boileau and Walch: mediolateral offset is almost double the anteroposterior offset [1]. The *lower row* of numbers gives the adjustable area of the Affinis prosthesis of ±6 mm and ±3 mm

"effective offset" [1]. However, from the graphs included in the diagrams in their "Results" section, it can be concluded that they show the projected offset (Fig. 6). In the other publications listed in Table 3, either the description of the methods used or the arrangements of the measurements indicate that the projected offset was used. For this reason, comparison is exclusively based on this parameter.

Study limitations

From a methodological perspective, we need to discuss whether measurement accuracy was sufficient. According to Nyffeler and Gerber, replacement of the resected humeral head with a prosthetic head of the same height, diameter and eccentricity leads to restoration of the head's anatomical centre [13]. This hypothesis is based on the assumption that the humerus head and the prosthesis resemble a sphere or a spherical segment. However, this only holds true in about 90% of cases; therefore, some compromises must be made with regards accuracy [19]. In our measuring arrangement, adjustment of the head size is ensured by a graded selection of eight sizes of prosthetic heads, whereas eccentricity restoration is ensured by the ability to freely position the head in relation to the stem because of the double eccenter. In addition, measurement accuracy depends on precise centring of the prosthetic stem within the humerus. Here again, some compromises must be made regarding the precision of the measurement, as we rely solely on the prosthesis as a gauge. However, as it was not our aim to record the combined offset in relation to the stem precisely but, rather, to assess its variability, we think these inaccuracies can be overlooked. A problem would only arise if the adjustment range of the prosthesis were smaller than the anatomical variability. However, there was no evidence of that being the case (Table 1).

We were able to verify in another study the accuracy of anatomical restoration with the prosthesis model used in this investigation [7]. The study showed that rotation centre restoration can be achieved with significantly more precision than with older, nonadjustable prostheses (Neer II, among others). The midterm clinical outcomes achieved with this prosthesis are similar to those reported in the literature for other modern prostheses; some parameters are even markedly superior [8].

Another critical point may arise when estimating the centre of rotation in severe deformities of the humeral head (e.g., after avascular necrosis or aseptic necrosis due to humeral-head fractures). These pathologies may lead to a three-dimensional deformity of the humeral head so that the centre of rotation is not necessarily on the resection plane. In cases of complex deformities, a flattened humeral head often occurs, and therefore, the centre of rotation may be located more laterally. This variable could not be considered in our work.

Conclusion

Variability of the combined medial and dorsal offset of the rotation centre of the humeral head determined in patients with conditions typically treated by shoulder replacement was not greater than that reported in the literature for healthy deceased patients. However, the greater overall variability of the humeral-head centres indicates the importance of an adjustable prosthesis system. By optimal adjustment to the complicated anatomy of the proximal humerus, modern prostheses allow extensive anatomical restoration and also accommodation for massive deformities. Marked false positioning (so-called mushroom heads), which was sometimes unavoidable in older prosthesis models, was not seen in our patients.

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Conflict of interest Independent statistical analysis was supported by Mathys Ltd., Bettlach, Switzerland. UI received consultant payments from Mathys.

Ethics standard The study protocol was reviewed and approved by the ethics committee of St. Gallen, Switzerland; the institutional review board of the Marienstift Arnstadt/ Germany; the ethics committee of the Town of Vienna; and the ethics board of the Rosenberg Clinic, Heiden. All patients were informed preoperatively and provided written informed consent to participate in this study.

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