



## Humeral head subluxation in Walch type B shoulders varies across imaging modalities



Bogdan A. Matache, MDCM, FRCSC<sup>a</sup>, Naser Alnusif, MD<sup>b</sup>, Jean Chaoui, PhD<sup>c</sup>, Gilles Walch, MD<sup>d</sup>, George S. Athwal, MD, FRCSC<sup>b,\*</sup>

<sup>a</sup> NYU Langone Health, New York, NY, USA

<sup>b</sup> Roth/McFarlane Hand & Upper Limb Centre, St. Joseph's Healthcare London, London, ON, Canada

<sup>c</sup> Imascap, Plouzané, France

<sup>d</sup> Centre Médical Santy, Lyon, France

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**Background:** The Walch type B pattern of glenohumeral osteoarthritis is characterized by posterior humeral head subluxation (PHHS). At present, it is unknown whether the percentage of subluxation measured on axillary radiographs is consistent with measurements on 2-dimensional (2D) axial or 3-dimensional (3D) volumetric computed tomography (CT). The purpose of this study was to evaluate PHHS across imaging modalities (radiographs, 2D CT, and 3D CT).

**Methods:** A cohort of 30 patients with Walch type B shoulders underwent radiography and standardized CT scans. The cohort comprised 10 type B1, 10 type B2, and 10 type B3 glenoids. PHHS was measured using the scapulohumeral subluxation method on axillary radiographs and 2D CT. On 3D CT, PHHS was measured volumetrically. PHHS was statistically compared between imaging modalities, with  $P \leq .05$  considered significant.

**Results:** The mean PHHS value for the entire group was  $69\% \pm 24\%$  on radiographs,  $65\% \pm 23\%$  with 2D CT, and  $74\% \pm 24\%$  with 3D volumetric CT. PHHS as measured on complete axillary radiographs was not significantly different than that measured on 2D CT ( $P = .941$ ). Additionally, PHHS on 3D volumetric CT was 9.5% greater than that on 2D CT ( $P < .001$ ). There were no significant differences in PHHS between the type B1, B2, and B3 groups with 2D or 3D CT measurement techniques ( $P > .102$ ).

**Conclusion:** Significant differences in PHHS were found between measurement techniques ( $P < .035$ ). A 9.5% difference in PHHS between 2D and 3D CT can be mostly accounted for by the linear (2D) vs. volumetric (3D) measurement techniques (a linear 80% PHHS value is mathematically equivalent to a volumetric PHHS value of 89.6%). Surgeons should be aware that subluxation values and therefore thresholds vary across different imaging modalities and measurement techniques.

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Glenoid deformity in shoulder osteoarthritis (OA) is commonly described by the Walch classification.<sup>24</sup> The Walch type B pattern is characterized by posterior humeral head subluxation (PHHS) and is correlated with worse clinical outcomes after total shoulder arthroplasty (TSA).<sup>3,10,12</sup> The type B pattern of OA is believed to begin with PHHS (B1) and progresses to posteroinferior glenoid bone loss, resulting in a biconcave (B2) deformity that may further erode into a mono-concave and severely retroverted (B3) glenoid.<sup>5</sup>

This study was approved by the investigational review board at St. Joseph's Health Care London.

\* Corresponding author: George S. Athwal, MD, FRCSC, Roth/McFarlane Hand and Upper Limb Centre, St Joseph's Health Care London, 268 Grosvenor St, London, ON, Canada, N6A 4L6.

E-mail address: [gathwal@hotmail.com](mailto:gathwal@hotmail.com) (G.S. Athwal).

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PHHS is a risk factor for failure of glenoid polyethylene components due to eccentric loading, which can lead to loosening over time.<sup>3,6,10,12,20,21</sup> In their series of patients with type B2 glenoids treated with TSA, Walch et al<sup>25</sup> demonstrated that 60% of post-operative dislocations occurred when PHHS was  $\geq 80\%$ . As such, they suggested a PHHS threshold value of 80% for anatomic TSA, and when values surpassed the 80% threshold, they recommended reverse shoulder arthroplasty (RSA).<sup>17</sup> The etiology of PHHS is unknown at present and is likely multifactorial. One factor that has been identified is that type B glenoids have greater pre-morbid retroversion that may predispose patients to subluxation.<sup>14</sup> Another identified association with subluxation is that patients with type B glenoids have more horizontal acromions. It is theorized that a more vertical acromion provides a restraint to PHHS; therefore, the more horizontal acromion found in type B glenoids

allows for greater posterior subluxation.<sup>16</sup> However, PHHS can also be present in patients with physiological humeral version and glenoid version, suggesting that there may be other contributing factors.<sup>1,9</sup>

The literature has shown that 2-dimensional (2D) computed tomography (CT) is more accurate than radiographs at evaluating PHHS.<sup>15</sup> Recently, 3-dimensional (3D) CT has gained increased popularity given its increased precision over 2D CT, its ease of interpretation, and the ability to preoperatively plan cases using commercially available templating software.<sup>22,26</sup> At present, there is limited literature comparing percentage values of PHHS between imaging modalities, such as radiographs, 2D CT, and 3D CT. An understanding of the relationships between the imaging modalities and PHHS is important as it will allow comparisons of the present literature with the historical literature using radiographic measurements. As such, the purpose of this study was to compare PHHS percentages calculated from axillary radiographs, 2D CT, and 3D CT in patients with Walch type B glenoids. Our hypothesis was that there would be statistically significant differences in PHHS between radiographic, 2D CT, and 3D CT measurements.

## Materials and methods

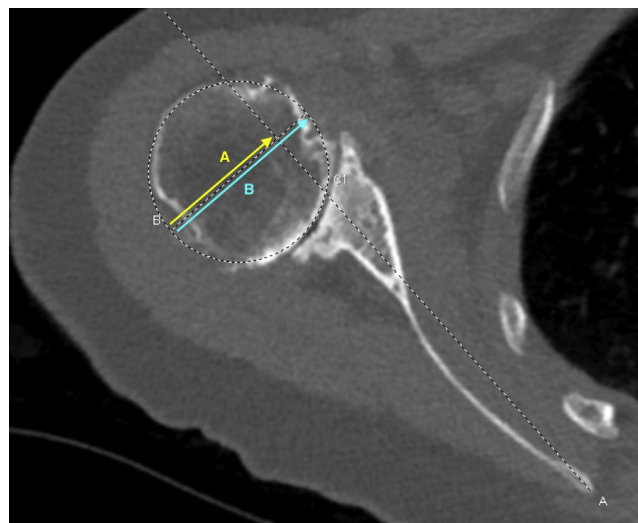
### Patient demographic characteristics and selection

We conducted a retrospective review of prospective patients who underwent either TSA or RSA between 2018 and 2019 for primary glenohumeral OA. Revision procedures were excluded. Per our institutional protocol, all shoulder arthroplasty patients underwent shoulder CT scanning prior to surgery. The 30-patient study group consisted of 10 type B1, 10 type B2, and 10 type B3 patients. Patients were subclassified into B types by the senior author (G.S.A.). Patients with Walch type A, C, and D glenoid deformities were excluded.

Radiographic assessment included preoperative axillary radiography, axial CT, and 3D CT modalities. Two fellowship-trained shoulder surgeons (B.A.M. and N.A.) independently measured the percentages of PHHS on the axillary radiographs and axial 2D CT scans for each patient. Measurements were obtained using the scapulohumeral subluxation method (Fig. 1).<sup>4</sup> In cases in which the medial scapular border was incompletely visualized on the radiographs, a best-estimate Friedman line was drawn.<sup>8</sup> For the 2D CT measurements, the axial slice immediately inferior to the tip of the coracoid, which corresponds to the approximate middle of the glenoid, was used to determine PHHS by a standardized method.<sup>17</sup> In brief, this consisted of drawing a best-fit circle on the humeral head and calculating the percentage of the humeral head posterior to the scapular axis line at the widest portion of the circle. PHHS on 3D CT was measured volumetrically and calculated automatically using surgical templating software (Blueprint; Wright, Memphis, TN, USA).

### Statistical analysis

The mean subluxation percentage values obtained from the different imaging modalities were compared using the paired-samples *t* test. To determine if there was a difference in PHHS between the different imaging modalities, we compared PHHS values between axillary radiographs and 2D CT scans, between axillary radiographs and 3D CT scans, and between 2D CT and 3D CT scans.  $P \leq .05$  was considered statistically significant. Reliability between raters' single measures was determined using the intraclass correlation coefficient (ICC) and a 2-way mixed-effects model with the confidence interval set at 95%, in which person effects are random



**Figure 1** Scapulohumeral subluxation method for calculating posterior humeral head subluxation. A best-fit circle is drawn on the humeral head, followed by a perpendicular tangent to the Friedman line at the location of maximal humeral head width; the percentage of posterior humeral head subluxation is obtained by dividing distance A by distance B.

and measure effects are mixed. Statistical analyses were performed with SPSS Statistics (version 23.0; IBM, Armonk, NY, USA).

## Results

### Study group

The study group consisted of a total of 30 patients (30 shoulders), with 10 type B1, 10 type B2, and 10 type B3 patients. Seventy-three percent of patients were men, and the average age of the patient cohort was 68 years (range, 49–90 years). There were no significant differences in sex or age between the Walch B subtypes ( $P > .104$ ).

### Radiographic subluxation

Assessment of the quality of axillary radiographs showed that 12 of 30 (40%) included the medial scapular border within the field of view whereas 18 of 30 (60%) excluded the medial border. The average radiographic PHHS value in all 30 patients was 69% (range, 45%–92%). The mean radiographic PHHS value was 62% in the type B1 group, 73% in the type B2 group, and 72% in the in the type B3 group. A comparison of the radiographic PHHS values between the Walch subtypes found that the type B2 group had significantly more subluxation than the type B1 group ( $P = .005$ ); however, there were no significant differences between the type B1 and B3 groups or between the type B2 and B3 groups ( $P > .067$ ). The measurement of axillary radiographic PHHS demonstrated good reliability for single measures between raters (ICC, 0.79).

### Subluxation on 2D CT

PHHS averaged 65% (range, 52%–88%) on the 2D CT scans using the scapulohumeral subluxation method. The mean 2D CT PHHS value was 61% in the type B1 group, 67% in the type B2 group, and 66% in the type B3 group. A comparison between the Walch types identified that there was no significant difference in PHHS between the type B1, B2, and B3 groups ( $P > .102$ ). The measurement of 2D CT

PHHS demonstrated excellent reliability for single measures between raters (ICC, 0.94).

*Subluxation on 3D CT*

The average PHHS value on the 3D CT scans using the volumetric calculation method in the templating software was 74% (range, 59%-99%). The mean 3D CT PHHS value was 70% in the type B1 group, 76% in the type B2 group, and 78% in the type B3 group. There were no significant differences in subluxation between the different B types ( $P > .199$ ). The ICC of the computer software system was excellent, at 1.0.

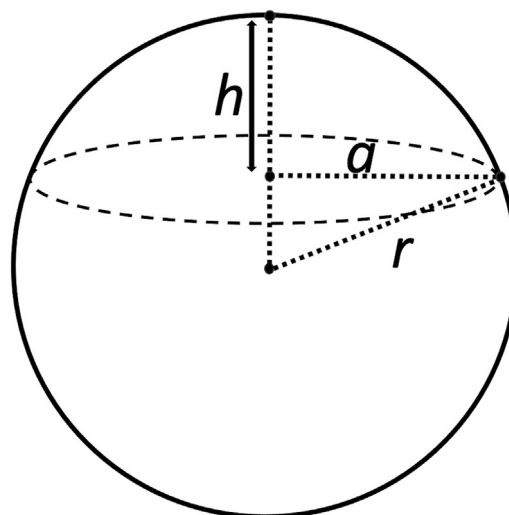
*Statistical correlations*

The percentage of PHHS measured from the complete set of 30 axillary radiographs was a mean of 4% more than that calculated from the 2D axial CT scans ( $P = .035$ ) and 6% less than that calculated by the 3D CT volumetric method ( $P = .011$ ). However, when axillary radiographs that had incomplete visualization of the medial scapular border were excluded from the analysis, there was no significant difference in PHHS as compared with the 2D axial CT scans ( $P = .941$ ). When the linear 2D axial CT measurement of PHHS was compared with the 3D CT volumetric measurement, the 3D CT percentage value was 9.5% greater ( $P < .001$ ).

**Discussion**

This study showed several major findings, including that PHHS determined by 3D CT volumetric measurement is significantly greater than that measured on axillary radiographs and 2D CT scans, that the majority of axillary radiographs exclude the medial scapular border, and that there is no significant difference in PHHS when complete axillary radiographs (medial scapular border included) are compared with 2D CT scans. These findings supported our hypothesis that there would be a statistically significant difference in PHHS between 2D CT and 3D CT scans and between radiographs and 3D CT scans but refuted our hypothesis that there would be a statistically significant difference in PHHS between radiographs and 2D CT scans.

A threshold value of 80% for PHHS has traditionally been used as a relative indication to perform an RSA instead of a TSA in patients with glenohumeral OA. Walch et al<sup>25</sup> reviewed 92 anatomic TSAs at a mean follow-up of 77 months and demonstrated that a PHHS value  $\geq 80\%$  was associated with an increased risk of dislocation and glenoid component loosening. This value was obtained using 2D CT measurements. PHHS on 2D CT is commonly measured using the technique defined by Badet et al<sup>1</sup> and Walch et al<sup>24</sup> that involves calculating the percentage of humeral head offset from the glenoid axis line relative to the maximal humeral head width on the midglenoid axial slice.<sup>1,24</sup> This technique has since been improved on to account for glenoid erosion by using the scapular axis line instead of the glenoid axis and drawing a best-fit circle on the humeral head instead of using its width.<sup>4,18</sup> In contrast, PHHS on 3D CT is often automatically measured using 3D templating software. Recent literature has shown that 3D CT imaging is more accurate and reliable than 2D CT for measuring glenohumeral parameters.<sup>2,7,11,19,22,23</sup> Many surgeons currently rely on preoperative 3D templating software to generate measurements of glenoid version, inclination, and subluxation, and they use these values to help guide surgical treatment. However, it is important for surgeons to be aware that these values vary within and across the different imaging modalities.<sup>4,13</sup> Jaxsens et al<sup>13</sup> compared 2D and 3D CT-based PHHS values in 151 normal shoulders and showed that 2D CT underestimated PHHS by 2.9% compared with 3D CT. They



**Figure 2** Formula for calculating 3-dimensional volumetric posterior humeral head subluxation;  $a$  is the scapular axis line,  $h$  is the distance between the scapular axis line and the most posterior portion of the humeral head, and  $r$  is the radius.

postulated that this occurred because of a difference in the plane of measurement between the 2 modalities. Our findings support the fact that PHHS is greater using 3D CT for measurement compared with 2D CT, with a mean 9.5% difference. The following formula is used to calculate 3D volumetric PHHS (in which  $r$  is radius,  $h$  is height, and  $d$  is diameter) (Fig. 2):

$$3D\ PHHS = \frac{\text{Volume of subluxated portion}}{\text{Volume of humeral head}} = [\pi h^2(3r - h)]/3$$

$$\text{Volume of subluxated portion} = \frac{\pi h^2(3r - h)}{3}$$

$$\text{Volume of humeral head} = \frac{4\pi r^3}{3}$$

According to this mathematical equation, a 2D linear PHHS value of 80% is equal to a 3D volumetric subluxation value of 89.6%. Therefore, although scapular orientation may play a minor role in the 2D and 3D differences, the mean 9.5% difference in PHHS between 2D and 3D measurements that we observed in our study can almost entirely be explained by the fact that one is a linear measurement whereas the other is a volumetric measurement. Furthermore, when one is deciding whether to perform an RSA instead of a TSA in a patient with glenohumeral OA, a threshold of 89.6%, rounded to 90%, should be considered instead of 80% when using 3D volumetric measurement. Additionally, historical studies with axillary and 2D CT measurements of PHHS are still applicable with 3D planning as long as a correction factor of 10% is used.

Our study has several limitations. First, the study was underpowered to demonstrate any statistically significant differences between Walch B subtypes. The purpose of this study was to determine whether there were differences in PHHS between the different imaging techniques, rather than between B subtypes. Second, the volumetric measurement technique used the Blueprint templating software program, and a comparison to other commercially available products was not performed. It is conceivable that other volumetric software programs may result in different values; however, the volumetric equation is a mathematical formula and has limited variability. In general, if variability in volumetric subluxation does occur, it will more likely be related

to the sphere fitting of the humeral head or the automated diameter selection. Third, we did not exclude patients with axillary radiographs that failed to adequately visualize the medial scapular border. Instead, we used a best-estimate Friedman line to measure scapulohumeral subluxation. As a result, inaccuracies in the reporting of percentage subluxation obtained from this imaging modality may be present. However, we purposely chose to include these patients to highlight the fact that, despite using a standardized imaging technique, there exist significant inconsistencies in the quality of axillary radiographs. Overall, obtaining a complete axillary radiograph with visualization of the medial scapular border is technically difficult. Our results show, however, that if a best-estimate Friedman line is used on an incomplete axillary radiograph, the PHHS value is slightly overestimated. Additionally, a good axillary radiograph with inclusion of the medial scapular border produces a PHHS value that is not substantially different than that on 2D CT.

## Conclusion

Significant differences in PHHS were found between measurement techniques ( $P < .035$ ). We also determined that obtaining a complete axillary radiograph with visualization of the medial scapular border is technically challenging. On axillary radiographs with visualization of the medial scapular border, PHHS was not substantially different than that on 2D CT. Additionally, a significant difference in PHHS was identified between the 2D and 3D CT measurement techniques. This mean difference of 9.5% in PHHS can be partially accounted for by the linear (2D) vs. volumetric (3D) measurement techniques. For example, a linear (2D) PHHS value of 80% is mathematically equivalent to a volumetric (3D) PHHS value of 89.6%. As such, when translating 2D threshold values to 3D volumetric values, a correction factor of approximately 10% should be used. Overall, it is important for surgeons to be aware that subluxation values and thresholds vary across the different imaging modalities.

## Disclaimer

The authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

## References

- Badet R, Boileau P, Noel E, Walch G. Arthrography and computed arthrography study of seventy patients with primary glenohumeral osteoarthritis. *Rev Rhum Engl Ed* 1995;62:555–62.
- Beuckelaers E, Jaxsens M, Van Tongel A, De Wilde LF. Three-dimensional computed tomography scan evaluation of the pattern of erosion in type B glenoids. *J Shoulder Elbow Surg* 2014;23:109–16. <https://doi.org/10.1016/j.jse.2013.04.009>.
- Boileau P, Avidor C, Krishnan SG, Walch G, Kempf JF, Mole D. Cemented polyethylene versus uncemented metal-backed glenoid components in total shoulder arthroplasty: a prospective, double-blind, randomized study. *J Shoulder Elbow Surg* 2002;11:351–9. <https://doi.org/10.1067/mse.2002.125807>.
- Bouacida S, Gauci MO, Coulet B, Lazerges C, Cyteval C, Boileau P, et al. Interest in the glenoid hull method for analyzing humeral subluxation in primary glenohumeral osteoarthritis. *J Shoulder Elbow Surg* 2017;26:1128–36. <https://doi.org/10.1016/j.jse.2017.01.027>.
- Chan K, Knowles NK, Chaoui J, Gauci MO, Ferreira LM, Walch G, et al. Characterization of the Walch B3 glenoid in primary osteoarthritis. *J Shoulder Elbow Surg* 2017;26:909–14. <https://doi.org/10.1016/j.jse.2016.10.003>.
- Collins D, Tencer A, Sidles J, Matsen F III. Edge displacement and deformation of glenoid components in response to eccentric loading. The effect of preparation of the glenoid bone. *J Bone Joint Surg Am* 1992;74:501–7.
- De Wilde LF, Verstraeten T, Speeckaert W, Karelse A. Reliability of the glenoid plane. *J Shoulder Elbow Surg* 2010;19:414–22. <https://doi.org/10.1016/j.jse.2009.08.009>.
- Friedman RJ, Hawthorne KB, Genz BM. The use of computerized tomography in the measurement of glenoid version. *J Bone Joint Surg Am* 1992;74:1032–7.
- Gerber C, Costouros JG, Sukthankar A, Fucentese SF. Static posterior humeral head subluxation and total shoulder arthroplasty. *J Shoulder Elbow Surg* 2009;18:505–10. <https://doi.org/10.1016/j.jse.2009.03.003>.
- Ho JC, Sabesan VJ, Iannotti JP. Glenoid component retroversion is associated with osteolysis. *J Bone Joint Surg Am* 2013;95:e82. <https://doi.org/10.2106/JBJS.L.00336>.
- Hoenecke HR Jr, Hermida JC, Flores-Hernandez C, D'Lima DD. Accuracy of CT-based measurements of glenoid version for total shoulder arthroplasty. *J Shoulder Elbow Surg* 2010;19:166–71. <https://doi.org/10.1016/j.jse.2009.08.009>.
- Iannotti JP, Norris TR. Influence of preoperative factors on outcome of shoulder arthroplasty for glenohumeral osteoarthritis. *J Bone Joint Surg Am* 2003;85-a:251–8. <https://doi.org/10.2106/0004623-200302000-00011>.
- Jaxsens M, Van Tongel A, Willemot LB, Mueller AM, Valderrabano V, De Wilde L. Accuracy of the glenohumeral subluxation index in nonpathologic shoulders. *J Shoulder Elbow Surg* 2015;24:541–6. <https://doi.org/10.1016/j.jse.2014.07.021>.
- Knowles NK, Ferreira LM, Athwal GS. Premorbid retroversion is significantly greater in type B2 glenoids. *J Shoulder Elbow Surg* 2016;25:1064–8. <https://doi.org/10.1016/j.jse.2015.11.002>.
- Mehta MP, Vogel LA, Shiu BB, Dennis ER, Petkovic D, Levine WN, et al. Determining glenoid component version after total shoulder arthroplasty. *J Shoulder Elbow Surg* 2018;27:1588–95. <https://doi.org/10.1016/j.jse.2018.03.003>.
- Meyer DC, Riedo S, Eckers F, Carpeggiani G, Jentsch T, Gerber C. Small anteroposterior inclination of the acromion is a predictor for posterior glenohumeral erosion (B2 or C). *J Shoulder Elbow Surg* 2019;28:22–7. <https://doi.org/10.1016/j.jse.2018.05.041>.
- Mizuno N, Denard PJ, Raiss P, Walch G. Reverse total shoulder arthroplasty for primary glenohumeral osteoarthritis in patients with a biconcave glenoid. *J Bone Joint Surg Am* 2013;95:1297–304. <https://doi.org/10.2106/JBJS.L.00820>.
- Rouleau DM, Kidder JF, Pons-Villanueva J, Dynamidis S, Defranco M, Walch G. Glenoid version: how to measure it? Validity of different methods in two-dimensional computed tomography scans. *J Shoulder Elbow Surg* 2010;19:1230–7. <https://doi.org/10.1016/j.jse.2010.01.027>.
- Scalise JJ, Codsí MJ, Bryan J, Brems JJ, Iannotti JP. The influence of three-dimensional computed tomography images of the shoulder in preoperative planning for total shoulder arthroplasty. *J Bone Joint Surg Am* 2008;90:2438–45. <https://doi.org/10.2106/JBJS.G.01341>.
- Stone KD, Grabowski JJ, Cofield RH, Morrey BF, An KN. Stress analyses of glenoid components in total shoulder arthroplasty. *J Shoulder Elbow Surg* 1999;8:151–8.
- Swieszkowski W, Bednarski P, Prendergast PJ. Contact stresses in the glenoid component in total shoulder arthroplasty. *Proc Inst Mech Eng H* 2003;217:49–57. <https://doi.org/10.1243/095441103762597737>.
- Terrier A, Ston J, Farron A. Importance of a three-dimensional measure of humeral head subluxation in osteoarthritic shoulders. *J Shoulder Elbow Surg* 2015;24:295–301. <https://doi.org/10.1016/j.jse.2014.05.027>.
- Verstraeten TR, Deschepper E, Jaxsens M, Walravens S, De Coninck B, De Wilde LF. Operative guidelines for the reconstruction of the native glenoid plane: an anatomic three-dimensional computed tomography-scan reconstruction study. *J Shoulder Elbow Surg* 2012;21:1565–72. <https://doi.org/10.1016/j.jse.2011.10.030>.
- Walch G, Boulahia A, Boileau P, Kempf JF. Primary glenohumeral osteoarthritis: clinical and radiographic classification. The Aequalis Group. *Acta Orthop Belg* 1998;64(Suppl 2):46–52.
- Walch G, Moraga C, Young A, Castellanos-Rosas J. Results of anatomic non-constrained prosthesis in primary osteoarthritis with biconcave glenoid. *J Shoulder Elbow Surg* 2012;21:1526–33. <https://doi.org/10.1016/j.jse.2011.11.030>.
- Werner BS, Hudek R, Burkhart KJ, Gohlke F. The influence of three-dimensional planning on decision-making in total shoulder arthroplasty. *J Shoulder Elbow Surg* 2017;26:1477–83. <https://doi.org/10.1016/j.jse.2017.01.006>.