

Intrinsic Inclination of Glenoid Components for Anatomic Total Shoulder Arthroplasty: A Virtual, Comparative Analysis of Contemporary Implant Systems

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Background: Glenoid inclination influences glenohumeral biomechanics. Superior inclination has been associated with superior humeral head migration and the rocking-horse phenomenon in anatomic total shoulder arthroplasty (aTSA). While surgical correction of glenoid inclination has been extensively investigated, it remains unknown whether commercially available glenoid components incorporate intrinsic inclination as a design characteristic.

Purpose: To quantify the intrinsic inclination of contemporary glenoid components used in aTSA.

Methods: A cross-sectional three-dimensional geometric analysis was performed using a manufacturer-independent preoperative planning platform. All commercially available anatomic glenoid components contained within the mediCAD® 3D Shoulder implant library were evaluated. Glenoid component inclination was measured in the central coronal plane as the angle between the articular surface and the vertical reference plane of the virtual three-dimensional environment using a standardized measurement protocol. Additionally, implant height was measured for the available sizes of each system. Measurements were performed independently by two observers, and intra- and interobserver reliability was assessed using the intraclass correlation coefficient (ICC).

Results: A total of 111 glenoid components representing 26 implant systems from 14 manufacturers were analyzed. The intra- and interobserver reliability for the inclination parameter was excellent (ICC = 0.89–0.99). Twenty of the 26 systems (76.9%) demonstrated neutral intrinsic inclination (0°), whereas six systems (23.1%) exhibited non-neutral inclination ranging from +1.9° (superior inclination) to –4.4° (inferior inclination). Within individual implant systems, inclination showed only minor variation across component sizes.

Conclusion: Contemporary glenoid component designs differ only slightly in intrinsic inclination, as most systems exhibit a neutral (0°) inclination. Given the usual superior native glenoid inclination in osteoarthritic shoulders, neutral implant geometry alone may not always achieve the desired postoperative orientation without corrective reaming.

What this study adds: This study provides a systematic characterization of virtual intrinsic inclination across contemporary glenoid components used in aTSA, demonstrating that most systems exhibit neutral inclination, while a minority incorporate measurable superior or inferior inclination.

Potential impacts on research, practice, or policy: Awareness of implant-specific intrinsic inclination may inform preoperative planning and component positioning in aTSA and should be considered when interpreting glenoid component orientation across different implant systems.

Study Design and Level of Evidence: Basic Science Study; Implant Geometry Analysis

Keywords: Anatomic total shoulder arthroplasty; Glenoid; Inclination; Glenohumeral; Osteoarthritis

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Introduction

Anatomic total shoulder arthroplasty (aTSA) is an established treatment for patients with end-stage glenohumeral osteoarthritis and an intact rotator cuff, providing reliable pain relief, restoration of function, and satisfying long-term survivorship.[1][2][3] Despite these favorable outcomes, glenoid-sided complications remain a significant concern and continue to be a leading cause of revision surgery.[4][5] Among all failure mechanisms, glenoid component loosening remains one of the most frequent complications and has been reported to account for up to 63% of revisions following aTSA.[3][6][7]

The pathogenesis of glenoid loosening is multifactorial but is commonly attributed to the “rocking-horse phenomenon,” originally described by Franklin et al.[8] Repetitive eccentric loading of the humeral head on the glenoid component generates alternating compressive and tensile stresses at the bone–implant interface, resulting in progressive micromotion, radiolucent line formation, loss of fixation, and eventual implant failure.[9] Previous studies have associated superior glenoid inclination with superior humeral head migration, increased eccentric loading, and unfavorable implant-bone interface stresses.[10][11]

On the other hand, rotator cuff insufficiency, for which superior humeral head migration is widely regarded as an indirect radiographic marker,[12][13][14] accounts for approximately 32.4% of revision procedures requiring conversion from anatomic to reverse total shoulder arthroplasty (rTSA) and has, in turn, been associated with superior glenoid inclination.[15][16][17]

The clinical relevance of glenoid inclination is further indicated by observations that osteoarthritic shoulders frequently demonstrate increased superior inclination compared with non-pathologic shoulders and that glenoid inclination tends to increase with age.[4][18] In aTSA, restoration of the premorbid glenoid orientation and center of rotation is of utmost importance. While abnormalities in glenoid version can be addressed using eccentric reaming or augmented glenoid components, [19][20] correction of glenoid inclination is typically achieved through reaming alone.[21]

Although this technique improves implant orientation in the axial plane, it requires removal of native glenoid bone, thereby reducing the structural support available for implant fixation, which may compromise the mechanical environment of the glenoid component, increase the risk of fixation pegs or keels violating the cortical vault, and result in joint-line medialization, potentially altering rotator cuff biomechanics. [13][22][23]

Loewen et al.[24] recently demonstrated, using finite element analysis, that progressive correction of superior glenoid inclination with superiorly augmented glenoid components resulted in humeral head centralization, increased compressive loading at the implant–bone interface, and reduced eccentric loading, thereby potentially decreasing the mechanical factors associated with glenoid component lift-off and loosening. Further, Griffin et al.[12] demonstrated that correction of glenoid inclination and lower residual postoperative inclination were associated with improved functional outcomes after anatomic total shoulder arthroplasty.

However, despite the recognized biomechanical importance of glenoid inclination, it remains unknown whether commercially available implants are designed with neutral, superior, or inferior inclination, whether inclination differs between manufacturers, and whether consistency exists across implant sizes within the same system. Therefore, the purpose of the present study was to systematically quantify the intrinsic inclination of all available glenoid components (defined as the coronal inclination incorporated into the geometry of the glenoid component itself, independent of surgical positioning or native glenoid anatomy) for aTSA within a manufacturer-independent three-dimensional (3D) planning platform.

We hypothesized that the majority of contemporary anatomic glenoid components are designed with neutral coronal inclination, that intrinsic inclination varies between implant systems, and that inclination demonstrates minimal variation across available sizes within a given implant system.

Methods

Study Design

This cross-sectional geometric implant analysis was performed using mediCAD® 3D Shoulder (Hectec GmbH, Germany), a virtual, three-dimensional preoperative planning platform incorporating a manufacturer-specific virtual implant database developed and maintained in collaboration with implant manufacturers. The objective was to quantify the intrinsic inclination of commercially available glenoid components used in aTSA.

Implant Selection

All anatomic glenoid components available within the mediCAD® 3D Shoulder implant library at the time of analysis were evaluated (**Table 1**). Components from all manufacturers and all available implant sizes (i.e., implant height) were evaluated.

Table 1. Total shoulder arthroplasty glenoid systems available in mediCAD 3D Shoulder Software.

Nr.	Manufacturer	TSA System
1	3S Ortho	ARAMIS
2	Arthrex	Univers VaultLock® Glenoid System
3	Depuy Synthes	Global
4	Enovis	AltiVate Anatomic
		Turon Shoulder System
5	Evolutis	UNIC
6	Exactech	Equinox Anatomic Posterior Augmented Glenoid 8°
		Equinox Anatomic Posterior Augmented Glenoid 16°
7	FH Ortho	Arrow Prime
8	Implantcast	Agilon
9	Lima	SMR cemented
		SMR cemented with 3 pegs
		SMR glenoid insert with metal back
		SMR TT Hybrid glenoid
10	Link	LINK Embrace
11	Mathys	Affinis Glenoid PE cemented
		Affinis vitamys cemented
		Affinis vitamys cementless
12	Medacta	PE Glenoid Medacta Shoulder System
13	Stryker	ReUnion TSA
		Tornier Aequalis Perform
14	Zimmer Biomet	Anatomic Shoulder System
		Bigliani/Flatow Shoulder System
		Comprehensive Total Shoulder System
		T.E.S.S Shoulder System
		Zimmer Trabecular Metal Shoulder System

Three-Dimensional Implant Orientation

Each glenoid component was imported individually into the MediCAD 3D Shoulder environment and analyzed using a standardized orientation protocol.

First, the implant was positioned on a virtual flat reference surface with the articular surface oriented according to the sagittal plane. The component was then aligned such that its geometric center corresponded to the central sagittal

reference plane of the software environment (**Figure 1A**). This standardized positioning ensured reproducible orientation independent of implant manufacturer or size.

Following sagittal alignment, the corresponding orthogonal coronal plane passing through the geometric midpoint of the implant was selected for analysis (**Figure 1B**). This plane represented the central coronal section of the glenoid component and was used for all inclination measurements.

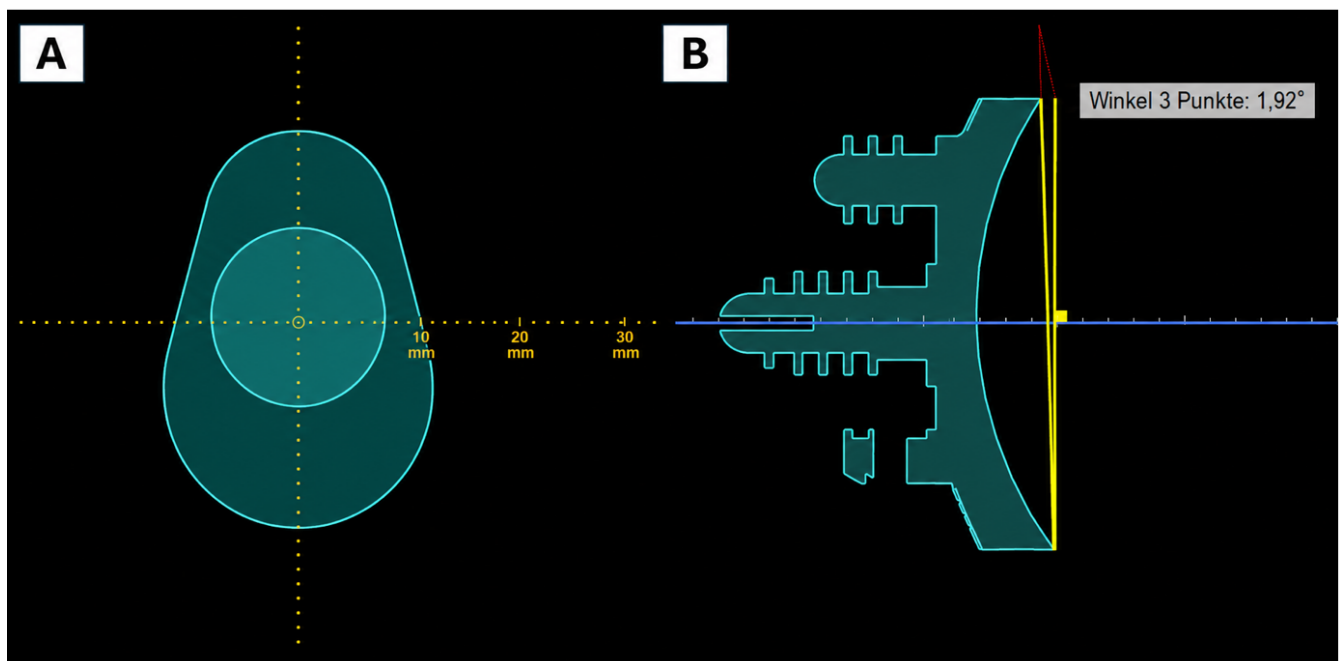


Figure 1. Standardized methodology used for three-dimensional glenoid component analysis. (A) Each glenoid component was positioned on a virtual flat reference surface and aligned such that its geometric center corresponded to the central sagittal reference plane of the software environment. The orthogonal coronal plane passing through the implant midpoint was then selected for analysis. (B) Inclination was measured in the central coronal plane as the angle between the glenoid articular surface and a line perpendicular to the central post axis. Positive values represented superior inclination and negative values represented inferior inclination.

Measurement of Glenoid Component Inclination

Coronal inclination was defined as the angle formed between the glenoid articular surface and the vertical reference plane of the virtual three-dimensional environment after establishment of the central coronal plane. For each implant, inclination was measured within the central coronal plane using the native angular measurement tools provided by the software. Positive values represented superior inclination, whereas negative values represented inferior inclination. Components demonstrating no deviation from the reference axis were recorded as having 0° inclination.

Measurements were obtained for every available implant size of each glenoid design to determine whether inclination varied within implant systems or remained constant across size ranges.

Data Collection

For each implant, the following variables were recorded: manufacturer, implant systems, implant size indicated by component height (mm), measured inclination (°). Data are summarized in **Table 2**.

Statistical Analysis

Analysis was performed in Python (v3.10.12) using the Pingouin package (v0.5.3). Descriptive statistics were calculated for all implant systems and manufacturers. Continuous variables are presented as mean $\pm$ standard deviation (SD) or median with interquartile range (IQR), as appropriate. Minimum and maximum values were also recorded. The distribution of glenoid component inclination across implant systems and implant sizes was evaluated descriptively.

Reliability Assessment

All inclination measurements were independently performed by two observers (A.S., A.A.) blinded to each other's results. To assess interobserver reliability, both observers independently measured all glenoid components using the standardized measurement protocol described above. Agreement between observers was evaluated using the intraclass correlation coefficient (ICC) using a two-way random-effects model with absolute agreement [ICC(2,1)]. To assess intraobserver reliability, each observer repeated all measurements 2 weeks after the initial assessment while remaining blinded to the previous measurements.

Table 2. Glenoid component inclination and height across different glenoid component sizes of various anatomical total shoulder arthroplasty systems.

Anatomic total shoulder arthroplasty system	Glenoid component size	Glenoid component inclination (°)	Glenoid component height (mm)
Univers VaultLock (Arthrex)	Small	1.9	32.8
	Medium	1.7	35.6
	Large	1.7	38.7
	Extra large	1.7	41.9
ARAMIS (3S ORTHO)	30	0	29.5
	33	0.1	32.4
	36	0.1	35.2
Global (Depuy Synthes)	40	0	29.5
	44	0	32.3
	48	0	35.1
	52	0	37.8
	56	0	40.8
	56XL	0	43.8
Altivate Anatomic (Enovis)	38	0	29.4
	42	0	30.1
	46	0	34.6
	50	0	37
	54	0	39.5
Turon Shoulder System (Enovis)	38	0	29.5
	42	0	31.9
	46	0	34.5
	50	0	37.4
	54	0	39.8
UNIC (Evolutis)	30	1.1	29.5
	33	0	32.5
	36	0	35.4
Equinoxe Anatomic Posterior Augmented Glenoid 8° (Exactech)	Small	0	28.3
	Medium	0	32.8
	Large	0	37
	Extra large	0	41.6

Anatomic total shoulder arthroplasty system	Glenoid component size	Glenoid component inclination (°)	Glenoid component height (mm)
Equinox Anatomic Posterior Augmented Glenoid 16° (Exactech)	Small	0	28.3
	Medium	0	32.8
	Large	0	37.2
	Extra large	0	41.5
Arrow Prime (FH Ortho)	50	0	43.7
Agilon (Implantcast)	Size 2	1.1	28.8
	Size 3	1.1	31.9
	Size 4	0.8	34.6
SMR Cemented (Lima)	Small-R	0	25.4
	Small	0	25.9
	Standard	0	29.9
SMR Cemented with 3 Pegs (Lima)	Extra-Small	0	24.7
	Small	0	26.6
	Standard	0	30.5
	Large	0	34.9
SMR glenoid insert with metal back (Lima)	Small-R	0	25.3
	Small	0	28.4
	Standard	0	25.8
	Large	0	33.4
SMR TT Hybrid glenoid (Lima)	Small	0	26.4
	Standard	0	30.7
	Large	0	34.6
LINK Embrace (Link)	Small	2.7	24.6
	Medium	2.8	29.3
	Large	2.8	33.5
	X-Large	2.7	37.5
Affinis Glenoid PE cemented (Mathys)	1	0	27.3
	2	0	31.6
	3	0	35.5
	4	0	39.6
Affinis vitamys cemented (Mathys)	1	0	25.1
	2	0	29.5
	3	0	33.6
	4	0	37.5

Anatomic total shoulder arthroplasty system	Glenoid component size	Glenoid component inclination (°)	Glenoid component height (mm)
Affinis vitamys cementless (Mathys)	1	0	25.1
	2	0	29.4
	3	0	33.6
	4	0	36.9
Medacta Shoulder System PE Glenoid (Medacta)	40	0	22.2
	42	0	23.3
	44	0	24.8
	46	0	25.7
	48	0	27
	50	0	28
	52	0	29.1
	54	0	30.5
	56	0	31.7
	58	0	32.8
ReUnion TSA (Stryker)	40	0	31.8
	44	0	34.1
	48	0	36.5
	52	0	38.9
	56	0	41.9
Tornier Aequalis Perform (Stryker)	S30	0	30.2
	S35	0	30.2
	S40	0	30.2
	M30	0	33.7
	M35	0	33.7
	M40	0	33.7
	L40	0	37.4
	L50	0	37.4
	L60	0	37.4
	XL 40	0	40.7
	XL 50	0	40.7
	XL 60	0	40.7
Anatomic Shoulder System (Zimmer Biomet)	Small	0	33.7
	Medium	0	36.6
	Large	0	39.8

Anatomic total shoulder arthroplasty system	Glenoid component size	Glenoid component inclination (°)	Glenoid component height (mm)
Bigliani/Flatow Shoulder System (Zimmer Biomet)	40	0	27.5
	46	0	32
	52	0	33.6
Comprehensive Total Shoulder System (Zimmer Biomet)	Small	4.4	28
	Medium	3.7	31.7
	Large	3.6	34.1
T.E.S.S Shoulder System (Zimmer Biomet)	S0	0	27.9
	S1	0	28
	S2	0	29.6
	S3	0	30.7
Zimmer Trabecular Metal Shoulder System (Zimmer Biomet)	40	0	27.8
	46	0	32.3
	52	0	34

Ethics

As this study involved geometric analysis of commercially available implant designs without patient data, human participants, cadaveric specimens, or identifiable information, institutional review board approval and informed consent were not required.

Results

A total of 111 glenoid components representing 26 anatomic total shoulder arthroplasty systems from 14 manufacturers were evaluated. All available implant sizes for each system contained within the MediCAD 3D Shoulder library were included in the analysis.

Glenoid Component Inclination

Most implant systems demonstrated no measurable intrinsic coronal-plane inclination. Twenty of the 26 evaluated systems (76.9%) had an intrinsic inclination of 0° across all available component sizes (**Table 2**). Six systems (23.1%) demonstrated non-neutral intrinsic inclination. The greatest mean inferior inclination was observed in the Comprehensive

Total Shoulder System (Zimmer Biomet) (−3.9°), followed by the LINK Embrace (Link) (−2.8°). Systems with superior inclination included Univers VaultLock (Arthrex) (+1.8°), Agilon (Implantcast) (+1°), UNIC (Evolutis) (+0.4°), and ARAMIS (3S ORTHO) (+0.1°). Across all 111 evaluated components, the overall mean inclination was $-0.1^{\circ} \pm 0.9^{\circ}$. The median inclination was 0° (IQR, 0°–0°), with values ranging from −4.4° to +1.9°.

Variation Across Implant Sizes

For the majority of implant systems, inclination remained constant across the available size range, whereas systems exhibiting size-dependent differences demonstrated only minor variation in inclination between sizes.

Glenoid Component Height

Glenoid component height varied substantially among implant systems and available sizes. Component height ranged from approximately 22.8 mm to 43.8 mm across the evaluated implants. The relationship between glenoid component height and inclination is illustrated in **Figure 2**.

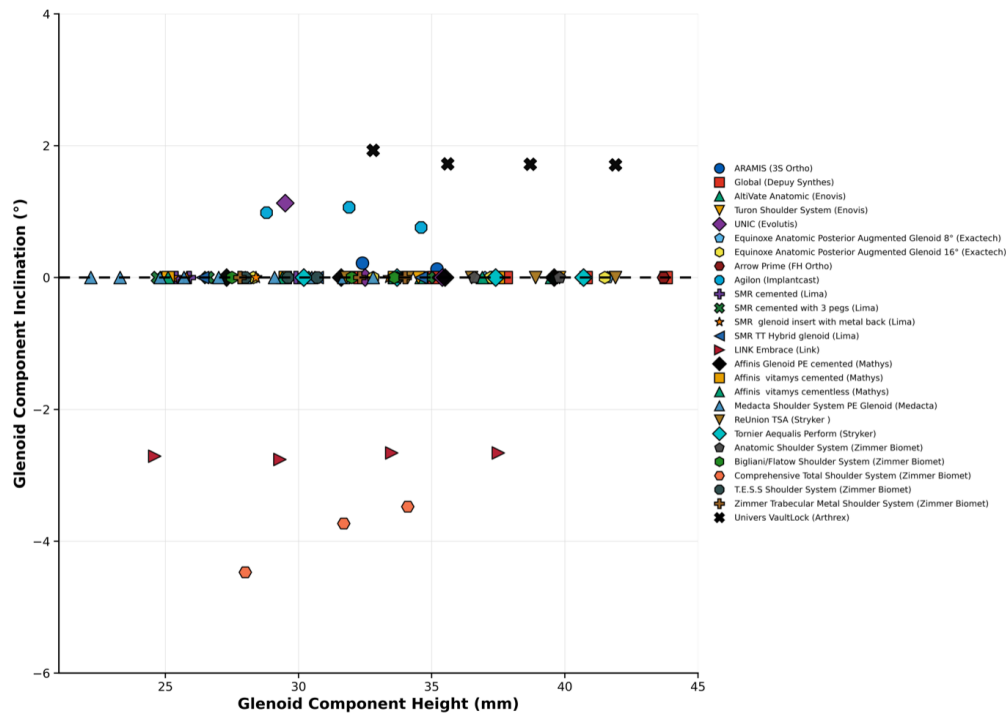


Figure 2. Relationship between glenoid component height and glenoid component inclination across 26 anatomic total shoulder arthroplasty systems. The dashed line indicates neutral inclination (0°).

Interobserver Reliability

Interobserver agreement for inclination measurements was excellent (ICC [2,1] = 0.999), with a mean difference between observers of 0.003°, indicating minimal systematic measurement bias. Intraobserver reliability was also excellent, with ICC values of 0.89 and 0.93 for observers 1 and 2, respectively.

Discussion

Our hypothesis was partially confirmed. As expected, the majority of contemporary anatomic glenoid components, 20 of 26 systems and 94 of 111 components, are designed with neutral coronal inclination, and intrinsic inclination differed between manufacturers, ranging from +1.9° of superior to -4.4° of inferior inclination. The hypothesis that intrinsic inclination is constant across sizes within a system was, however, only partly supported: it held in 20 of 26 systems and in four of the six non-neutral systems, whereas the Comprehensive and UNIC systems varied by 0.8° and 1.1° respectively across the available size range. Thus, knowledge of the intrinsic inclination specific to the selected glenoid component represents an important consideration in preoperative planning and intraoperative component positioning.

Although glenoid component design has traditionally focused on fixation characteristics, backside geometry, and radial mismatch, the inclination incorporated into the implant itself

has received comparatively little attention.^{[25][26][27]} To our knowledge, this is the first study to systematically quantify intrinsic glenoid component inclination across multiple implant systems and manufacturers.

The clinical importance of glenoid inclination in aTSA has been well established by previous biomechanical investigations. Superior glenoid inclination has consistently been associated with superior humeral head migration and altered force transmission across the glenohumeral joint.^{[24][28][29]} Flieg et al.^[28] demonstrated that increasing superior inclination decreased the force required for superior humeral head subluxation, whereas Knighton et al.^[11] reported lower glenohumeral joint forces in inferiorly inclined constructs compared with superiorly inclined configurations.

These investigations collectively indicate that even relatively small differences in implant inclination may alter joint biomechanics by influencing humeral head position and force transmission across the glenohumeral articulation. This is supported by clinical findings reported by Griffin et al.^[12]

Glenoid component loosening remains one of the leading causes of failure following aTSA, and superior inclination has repeatedly been associated with eccentric loading and the development of the rocking-horse phenomenon.^{[10][11]} Cyclic eccentric loading produces alternating compressive and tensile stresses at the implant–bone interface, potentially resulting in micromotion, radiolucent line formation, and eventual loosening.^{[10][11][24][30]} Previous

biomechanical studies support this concept. Karelse et al.[10] demonstrated that inferior tilting of the glenoid resection reduced eccentric loading, while Oosterom et al.[31] showed that decreasing superior inclination reduced rim deformation and improved resistance to superior humeral head subluxation under simulated loading conditions.

That said, glenoid component inclination is likely determined by at least two independent factors: the inclination incorporated into the implant design and the inclination created by the surgeon during glenoid preparation and component implantation. Consequently, two glenoid components implanted using identical surgical technique may ultimately result in different postoperative inclinations because of differences in implant geometry alone (**Figure 2**).

This is particularly relevant in patients with glenohumeral osteoarthritis, who frequently demonstrate increased native superior glenoid inclination. Chalmers et al.[4] reported greater superior glenoid inclination in osteoarthritic shoulders compared with non-pathologic shoulders, while Bockmann et al.[18] observed increasing glenoid inclination with advancing age. In these patients, the intrinsic inclination of the selected implant may either accentuate or partially compensate for the patient's pre-existing anatomy. Therefore, implant-specific inclination should be recognized as an additional variable when planning the desired postoperative glenoid inclination.

Although the inclination differences observed among implant systems appear modest, previous biomechanical investigations indicate that relatively small angular changes

may substantially influence glenohumeral mechanics. Loewen et al.[24] demonstrated that each 5° increment of inclination correction using superiorly augmented glenoid components progressively centralized the humeral head while increasing compressive loading across the implant–bone interface. Because compressive loading enhances implant stability whereas tensile loading promotes component liftoff, even differences of only a few degrees may influence implant loading patterns.[24] The present study identified intrinsic superior inclination differences approaching 2° among commercially available glenoid systems for aTSA.

A superiorly augmented glenoid component (**Figure 3**) lateralizes the joint line and may improve humeral head centering by introducing inferior inclination and limiting superior translation, as demonstrated by Loewen et al.[24] However, excessive augmentation could overconstrain the articulation and shift contact forces toward the inferior glenoid, and the optimal degree of superior augmentation remains unknown. In contrast, less constrained, superiorly inclined designs allow greater superior translation, promoting superior eccentric loading and rocking horse motion while theoretically preserving more anatomic rotator cuff tension. Overall, whether greater superior constraint or a less constrained articulation provides a more favorable biomechanical environment for long-term glenoid fixation and clinical outcome in aTSA has yet to be determined.

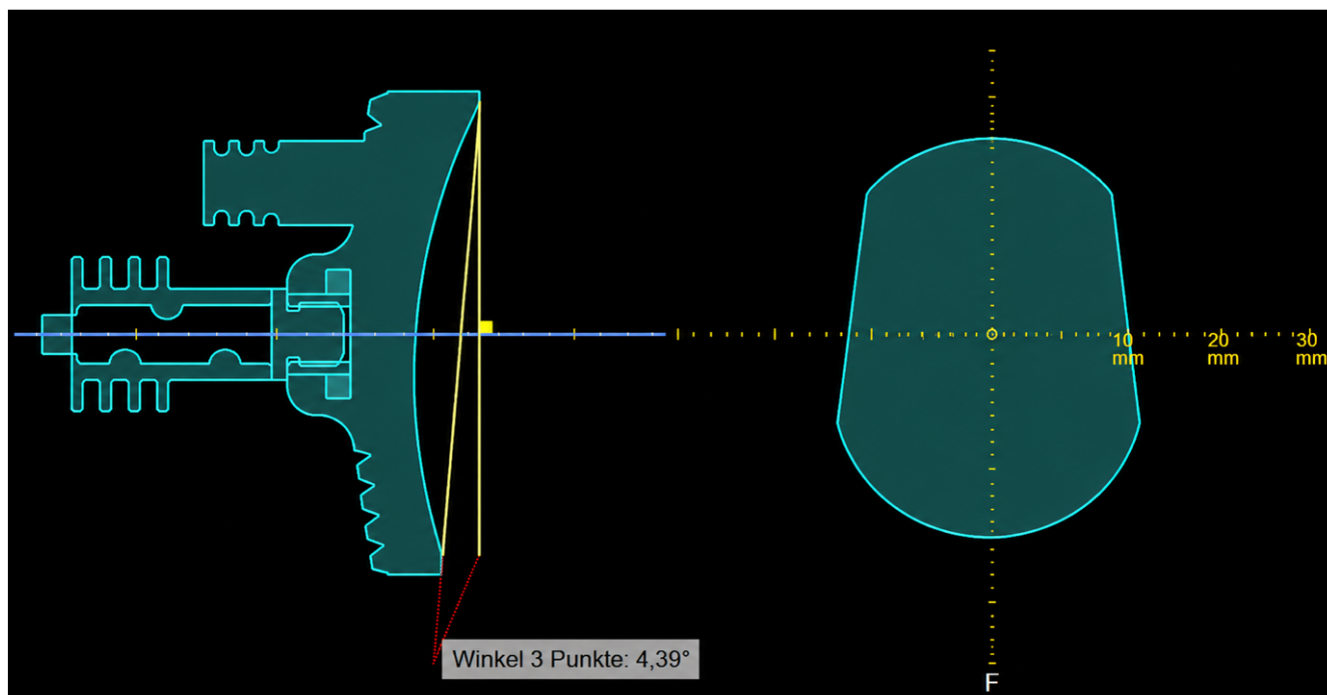


Figure 3. Representative example of a glenoid component with intrinsic inferior inclination.

In a recent study, Modelhart et al.[32] used magnetic resonance imaging of shoulders without glenohumeral pathology to demonstrate that the native labrum reduces effective glenoid surface inclination by a mean of 5.5°, thereby partially compensating for excessive superior bony inclination. Conceptually, this mirrors the theoretical rationale underlying superiorly augmented glenoid components, which restore a more neutral or inferiorly inclined articular surface.

Another factor that may influence implant biomechanics is the resting scapular rotation, as it determines the final orientation of the glenoid component relative to the gravitational vector. Recent work by Shekhihi et al.[33] demonstrated substantial interpatient variation in resting scapular rotation and showed that it significantly influences the global inclination of glenoid components in rTSA. It is therefore plausible that resting scapular rotation similarly contributes to the global inclination of glenoid components in aTSA and might influence glenohumeral ball-and-socket kinematics.

The findings of the present investigation should not be interpreted as evidence supporting one implant system over another. Rather, they identify a source of variability among contemporary glenoid component designs. Although the ideal glenoid inclination remains a matter of ongoing investigation, current biomechanical evidence consistently favors avoidance of superior inclination, with two of the three most rigorous studies further supporting slight inferior inclination.[10][11]

This study has several limitations. First, the analysis was limited to geometric assessment of implant designs and did not evaluate the postoperative orientation of implanted components, biomechanical loading, or clinical outcomes. Second, as this study evaluated virtual implant models rather than physical components, potential manufacturing tolerances and their resulting deviations from the measured virtual intrinsic inclination could not be assessed. Moreover, intrinsic inclination was quantified under standardized measurement conditions and does not account for patient-specific surgical positioning, scapular orientation, or soft-tissue balancing, all of which may further modify the functional orientation of the glenoid component. Nevertheless, the present findings indicate that optimization of glenoid component inclination in aTSA should be viewed not only as a matter of surgical technique but also as an implant design consideration. Standardized reporting of implant-specific intrinsic inclination in manufacturers' technical documentation may facilitate informed implant selection and preoperative planning.

Conclusion

Contemporary glenoid component designs differ only slightly in intrinsic inclination, as most systems exhibit a neutral (0°) inclination. Given the usual superior native glenoid inclination in osteoarthritic shoulders, neutral implant geometry alone may not always achieve the desired postoperative orientation without corrective reaming.

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Conflicts of Interest

Philipp Moroder serves as a consultant, receives royalties and fellowship support from Arthrex, is a shareholder and receives royalties from Alyve Medical, is a shareholder of Kairos Medical and Zurimed, is a patent co-applicant with Johnson & Johnson, and receives royalties from Medacta and Medi. Stefan Bauer is a consultant for Stryker and Enovis without any personal payments. The other authors, their immediate family, and any research foundation with which they are affiliated did not receive any financial payments or other benefits from any commercial entity related to the subject of this article.

Ethical Approval

Ethical approval was not required, as the study did not involve human participants, identifiable personal data, or animal subjects.

References

1. Raiss P, Schmitt M, Bruckner T, Kasten P, Pape G, Loew M, Zeifang F. Results of Cemented Total Shoulder Replacement with a Minimum Follow-up of Ten Years. *Journal of Bone and Joint Surgery*. 2012 Dec 5;94(23):e171. doi:10.2106/JBJS.K.00580
2. Rasmussen JV, Hole R, Metlie T, Brorson S, Äärimaa V, Demir Y, Salomonsson B, Jensen SL. Anatomical total shoulder arthroplasty used for glenohumeral osteoarthritis has higher survival rates than hemiarthroplasty: a Nordic registry-based study. *Osteoarthritis Cartilage*. 2018 May;26(5):659–65. doi:10.1016/j.joca.2018.02.896

3. Deshmukh A V., Koris M, Zurakowski D, Thornhill TS. Total shoulder arthroplasty: Long-term survivorship, functional outcome, and quality of life. *J Shoulder Elbow Surg.* 2005 Sep;14(5):471–9. doi:10.1016/j.jse.2005.02.009
4. Chalmers PN, Miller M, Wheelwright JC, Kawakami J, Henninger HB, Tashjian RZ. Acromial and glenoid morphology in glenohumeral osteoarthritis: a three-dimensional analysis. *JSES Int.* 2021 May;5(3):398–405. doi:10.1016/j.jseint.2021.01.006
5. Vera Valencia G, Collin P, Levy G, Guevara-Álvarez A, Lädermann A. Humeral Head Autograft Compaction for Glenoid Preparation in Anatomic Total Shoulder Arthroplasty. A Technical Note from the LaTour Study Group. *The Hive - Musculoskeletal Journal.* 2025. doi:10.70885/hmsj.2025.07.001
6. Taunton MJ, McIntosh AL, Sperling JW, Cofield RH. Total Shoulder Arthroplasty with a Metal-Backed, Bone-Ingrowth Glenoid Component. *The Journal of Bone and Joint Surgery-American Volume.* 2008 Oct;90(10):2180–8. doi:10.2106/JBJS.G.00966
7. Franta AK, Lenters TR, Mounce D, Neradilek B, Matsen FA. The complex characteristics of 282 unsatisfactory shoulder arthroplasties. *J Shoulder Elbow Surg.* 2007 Sep;16(5):555–62. doi:10.1016/j.jse.2006.11.004
8. Franklin JL, Barrett WP, Jackins SE, Matsen FA. Glenoid loosening in total shoulder arthroplasty. *J Arthroplasty.* 1988;3(1):39–46. doi:10.1016/S0883-5403(88)80051-2
9. Strauss EJ, Roche C, Flurin PH, Wright T, Zuckerman JD. The glenoid in shoulder arthroplasty. *J Shoulder and Elbow Surg.* 2009;18:819-33.v. doi:10.1016/j.jse.2009.05.008
10. Karelse A, Van Tongel A, Verstraeten T, Poncet D, De Wilde LF. Rocking-horse phenomenon of the glenoid component: the importance of inclination. *J Shoulder Elbow Surg.* 2015 Jul;24(7):1142–8. doi:10.1016/j.jse.2014.12.017
11. Knighton TW, Chalmers PN, Sulkar HJ, Aliaj K, Tashjian RZ, Henninger HB. Anatomic total shoulder glenoid component inclination affects glenohumeral kinetics during abduction: a cadaveric study. *J Shoulder Elbow Surg.* 2022 Oct;31(10):2023–33. doi:10.1016/j.jse.2022.03.028
12. Griffin JW, Denard P, Romeo A, Gobeze R, Lederman E, Werner B. Inclination correction is associated with improved clinical outcomes in anatomic total shoulder arthroplasty. *Seminars in Arthroplasty: JSES.* 2021 Sep;31(3):557–62. doi:10.1053/j.sart.2021.03.005
13. Hermida JC, Flores-Hernandez C, Hoenecke HR, D'Lima DD. Augmented wedge-shaped glenoid component for the correction of glenoid retroversion: a finite element analysis. *J Shoulder Elbow Surg.* 2014 Mar;23(3):347–54. doi:10.1016/j.jse.2013.06.008
14. Marchetti A, Schwäblein T, Baumert P, D'Ambrosi R, Braun S. Do partial rotator cuff tears limit the indication for anatomic shoulder replacement? A systematic review. *The Hive - Musculoskeletal Journal.* 2026. doi:10.70885/hmsj.2026.06.002
15. Al-Asadi M, Rajapaksege N, Abdel Khalik H, Abesteh J, Athwal GS, Khan M. Outcomes and complications of failed anatomic shoulder arthroplasty revised with reverse arthroplasty: a systematic review. *J Shoulder Elbow Surg.* 2024 Dec. doi:10.1016/j.jse.2024.10.012
16. Young AA, Walch G, Pape G, Gohlke F, Favard L. Secondary Rotator Cuff Dysfunction Following Total Shoulder Arthroplasty for Primary Glenohumeral Osteoarthritis: Results of a Multicenter Study with More Than Five Years of Follow-up. *Journal of Bone and Joint Surgery.* 2012 Apr 18;94(8):685–93. doi:10.2106/JBJS.J.00727
17. Levy D, Abrams G, Harris J, Bach B, Nicholson G, Romeo A. Rotator cuff tears after total shoulder arthroplasty in primary osteoarthritis: A systematic review. *Int J Shoulder Surg.* 2016;10(2):78. doi:10.4103/0973-6042.180720
18. Bockmann B, Soschynski S, Lechler P, Ruchholtz S, Debus F, Schwarting T, Frink M. Age-dependent variation of glenohumeral anatomy: a radiological study. *Int Orthop.* 2016 Jan 7;40(1):87–93. doi:10.1007/s00264-015-2863-y
19. Amini MH, Ricchetti ET, Iannotti JP. Three-Dimensional Templating and Use of Standard Instrumentation in Primary Anatomic Total Shoulder Arthroplasty. *JBJS Essent Surg Tech.* 2017 Sep 27;7(3):e28. doi:10.2106/JBJS.ST.17.00009
20. Nyffeler RW, Sheikh R, Atkinson TS, Jacob HAC, Favre P, Gerber C. Effects of glenoid component version on humeral head displacement and joint reaction forces: an experimental study. *J Shoulder and Elbow Surg.* 2006;15(5):625–629. doi:10.1016/j.jse.2005.09.016
21. Ricchetti ET, Jun BJ, Jin Y, Ho JC, Patterson TE, Dalton JE, Derwin KA, Iannotti JP. Relationship Between Glenoid Component Shift and Osteolysis After Anatomic Total Shoulder Arthroplasty. *Journal of Bone and Joint Surgery.* 2021 Aug 4;103(15):1417–30. doi:10.2106/JBJS.20.00833
22. Denard PJ, Romeo AA. Considerations for Shoulder Arthroplasty Implant Selection in Primary Glenohumeral Arthritis With Posterior Glenoid Deformity. *Journal of the American Academy of Orthopaedic Surgeons.* 2022 Oct 1;30(19):e1240–8. doi:10.5435/JAAOS-D-21-01219
23. Shields DW, A'Court J, Rashid MS, Monga P. Clinical outcome of wedged glenoid reconstruction in anatomic total shoulder arthroplasty for osteoarthritic retroverted glenoid: a minimum 2-year follow-up. *JSES Int.* 2024 Mar;8(2):343–8. doi:10.1016/j.jseint.2023.11.019
24. Loewen NM, Johnson JA, Athwal GS, Langohr GDG. Superior glenoid inclination in shoulder arthroplasty: a comparison of standard to superiorly augmented glenoid implants. *JSES Int.* 2026 Mar;10(2):101606. doi:10.1016/j.jseint.2025.101606
25. Raiss P, Godenèche A, Wittmann T, Schnetzke M, Bruckner T, Neyton L, Walch G. Short-term radiographic results of a cemented polyethylene keeled glenoid component with varying backside radiuses of curvature. *J Shoulder Elbow Surg.* 2018 May;27(5):839–45. doi:10.1016/j.jse.2017.10.026
26. Terrier A, Büchler P, Farron A. Influence of glenohumeral conformity on glenoid stresses after total shoulder arthroplasty. *J Shoulder Elbow Surg.* 2006 Jul;15(4):515–20. doi:10.1016/j.jse.2005.09.021
27. Terrier A, Obrist R, Malfroy Camine V, Becce F, Farron A. Biomechanical comparison of glenoid implants with adaptable and fixed backside curvatures in anatomic total shoulder arthroplasty. *J Shoulder Elbow Surg.* 2018 Sep;27(9):1656–63. doi:10.1016/j.jse.2018.02.050
28. Flieg NG, Gatti CJ, Doro LC, Langenderfer JE, Carpenter JE, Hughes RE. A stochastic analysis of glenoid inclination angle and superior migration of the humeral head. *Clinical Biomechanics.* 2008 Jun;23(5):554–61. doi:10.1016/j.clinbiomech.2008.01.001

29. Wong AS, Gallo L, Kuhn JE, Carpenter JE, Hughes RE. The effect of glenoid inclination on superior humeral head migration. *J Shoulder Elbow Surg.* 2003 Jul;12(4):360–4. doi:10.1016/S1058-2746(03)00026-0
30. Favard L, Berhouet J, Walch G, Chaoui J, Lévine C. Superior glenoid inclination and glenoid bone loss: Definition, assessment, biomechanical consequences, and surgical options. *Orthopade.* 2017;46(12):1015-1021. doi:10.1007/s00132-017-3496-1.
31. Oosterom R, Rozing PM, Bersee HEN. Effect of glenoid component inclination on its fixation and humeral head subluxation in total shoulder arthroplasty. *Clinical Biomechanics.* 2004 Dec;19(10):1000–8. doi:10.1016/j.clinbiomech.2004.07.001
32. Modelhart M, Herbst EC, Kunde AMH, Shekhbihi A, Hoffelner T, Scheibel M, Moroder P. While the bony glenoid is superiorly inclined, the glenoid surface is not. *JSES Int.* 2026 Jan;10(1):101377. doi:10.1016/j.jseint.2025.08.014
33. Shekhbihi A, Raiss P, Modelhart M, Randlkofer LM, Herbst EC, Moroder P. “The Global Glenoid Component Inclination: why scapulothoracic orientation should be considered when defining glenoid component inclination in reverse total shoulder arthroplasty.” *J Shoulder Elbow Surg.* 2026 Jun. doi:10.1016/j.jse.2026.06.011