SUBSPECIALTY PROCEDURES

THREE-DIMENSIONAL TEMPLATING AND USE OF STANDARD INSTRUMENTATION IN PRIMARY ANATOMIC TOTAL SHOULDER ARTHROPLASTY

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Introduction

Three-dimensional (3D) templating of the glenoid in anatomic shoulder arthroplasty allows for more accurate planning and more optimal positioning of the glenoid component than 2-dimensional computed tomography (2D CT) scans through an improved understanding of both the pathologic and the premorbid glenoid joint line, version, and inclination in reference to an idealized calculated glenoid position.

The frequency of shoulder arthroplasty in the United States is rising rapidly, having increased 2.5-fold between 1998 and 2008¹. Loosening of the glenoid component remains the most common mode of late failure after anatomic total shoulder arthroplasty (TSA)². Causes of glenoid component loosening include malposition, incomplete correction of pathologic retroversion, persistent humeral head subluxation, and rotator cuff deficiency³⁻¹¹. Reasons for malposition of the glenoid component are inaccurate assessment of the pathologic anatomy of the glenoid⁷, incorrect choice of implant and/or position of the implant to correct the pathologic condition, and inaccurate surgical execution of the preoperative plan^{12,13}.

Because of the limitations of standard radiographs, many surgeons use 2D CT scans to evaluate glenoid morphology and version according to the method described by Friedman et al.^{14,15}. However, multiple studies from our research group and others have demonstrated that 3D CT scans are more accurate and reliable than 2D scans^{16,17}, particularly in the face of advanced disease and bone loss¹⁸. Although correction of retroversion to reorient the joint line and minimize stress at the bone-cement-prosthesis interfaces is common practice in TSA, we believe native glenoid anatomy should serve as a guide and reference for selection of the implant that will best correct the pathologic version, inclination, and location of the joint line to the premorbid state. The ideal implant would minimize removal of the subchondral bone plate, avoid excessive medialization of the joint line and the resultant laxity of

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the soft tissues, and not place excessive stress at the material interfaces¹⁹. Literature supports the correction of glenoid retroversion generally to $<15^{\circ}$ ¹¹, although the amount of correction may be limited in some patients to avoid excessive reaming, preserve the subchondral bone plate, and prevent excessive medialization of the glenohumeral joint line²⁰. With use of 3D CT templating, the surgeon can select the implant to be used and define the optimal placement of that implant to correct the pathologic condition and achieve full backside support, while maintaining the integrity of the glenoid vault.

We describe the principles of planning and the surgical steps used for advanced 3D CT templating with standard surgical instruments to execute the preoperative plan in several patient scenarios.

Indications & Contraindications

Indications

- Glenohumeral arthritis with any degree of acquired bone loss as seen on high-quality true anteroposterior and axillary lateral radiographs or a 2D CT scan.

Contraindications

- None.

Step 1: Obtain a CT Scan with 3D Reconstruction and Define Glenoid Version and Inclination

Obtain a CT scan of the entire scapula and proximal part of the humerus with slices of ≤ 1 mm and a 3D reconstruction with subtraction of the humeral head, and identify the scapular and glenoid planes to define the pathologic version and inclination, which can be done in any commercially available software program while following these basic principles (Video 1).

- Import the original 2D DICOM (Digital Imaging and Communications in Medicine) images into a 3D imaging software program containing solid models of the implants that can be used for surgical reconstruction. We use 0.6-mm slice thickness in OrthoVis (Custom Orthopaedic Solutions). Perform a 3D reconstruction of the scapula with subtraction of the humerus.
- In the software program, define the pathologic glenoid anatomy on the basis of the plane of the scapula and the plane of the glenoid face. The plane of the scapula is defined by 3 points: the center of the glenoid, the junction of the scapular spine and body at the medial border (trigonum scapulae), and the inferior angle. The plane of the glenoid is defined by 3 points placed on the peripheral surface of the glenoid fossa, avoiding any rim osteophytes. Glenoid version is the angle between the plane of the glenoid face and the scapular plane, while glenoid inclination is the angle between the plane of the glenoid face and the scapular center line defined by the center of the glenoid face to the trigonum scapulae. The pathologic glenoid is not a uniform surface in many cases, however, and the plane defined by the 3 glenoid fossa points represents an averaged version and inclination relative to the plane of the scapula. In a biconcave or Walch type-B2 glenoid, this method does not individually measure the anterior premorbid or paleoglenoid, representing the patient's native version, inclination, and joint line, or the posterior pathologic or neoglenoid, which has a different version, inclination, and joint line as a result of bone loss. Subluxation of the humeral head is measured in 2 ways, glenohumeral (relative to a perpendicular from the face of the glenoid fossa and called the humeral glenoid alignment) and scapulohumeral (relative to the plane of the scapula and called the humeral scapular alignment)²¹.

Video 1 Defining anatomic landmarks on the 3D CT.

Step 2: Define Premorbid Glenoid Morphology

Carefully evaluate for the presence of the native glenoid, noting its version and inclination, and be careful to distinguish the true native glenoid from osteophytes (Video 2).

- Use the premorbid glenoid morphology as a patient-specific guide for the selection of the implant and its placement, to reconstruct normal glenoid version and inclination, and to restore the normal premorbid joint line position. Most patients have native glenoid version between 6° and 8° of retroversion²². Correcting version to neutral for all patients would lead to overcorrection of pathologic version and unnecessary removal of bone, particularly of the anterior subchondral bone. Several clinical and biomechanical studies have shown the importance of maintaining subchondral bone in supporting the glenoid component and minimizing the risk of loosening and subsidence^{19,20,23,24}. Further, complete correction of retroversion by reaming the anterior high side to neutral leads to greater medialization of the joint line than correction to the premorbid version. Greater medialization may lead to laxity in the soft tissues, which may lead to recurrent posterior subluxation of the humeral head and resultant glenoid loosening because of eccentric loading. Augmented polyethylene components can improve the ability to restore the premorbid joint line in patients with asymmetric bone loss because there is less reaming of the anterior high side of the glenoid for the same amount of correction of pathologic version or inclination.
- In classic type-B2 glenoids, in which the inflection point of the biconcave glenoid divides the glenoid roughly in half, identify the anterior premorbid paleoglenoid and its orientation, which can be readily accomplished preoperatively on the CT scan (Figs. 1-A and 1-B). However, restoration of anatomy in the face of more severe glenoid wear is challenging. For example, anterior osteophytes may obscure what remains of the premorbid glenoid, and further glenoid erosion causes the inflection line to move more anteriorly, sometimes to the point that no paleoglenoid remains (Walch type-B3 glenoid morphology). This may cause severe cases of acquired bone loss to resemble a type-C, dysplastic glenoid; however, the bone loss is distinctly acquired in this scenario rather than developmental.

Fig. 1-A

Fig. 1-B

Video 2 Defining the premorbid glenoid.

Figs. 1-A and 1-B Identification of premorbid glenoid anatomy in a patient with bone loss from wear. **Fig. 1-A** Axial CT scan at the mid-glenoid reveals 35° of retroversion and no obvious premorbid glenoid surface. **Fig. 1-B** Three-dimensional reconstruction of the glenoid reveals a biconcave Walch type-B3 glenoid with an intact premorbid glenoid anterosuperiorly. When identifying landmarks in the software and at the time of surgery, it is critical to distinguish the true premorbid glenoid from osteophytes.

Step 3: Place the Virtual Implant

Place the virtual glenoid component to restore the premorbid glenoid anatomy (Video 3).

- After defining premorbid and pathologic glenoid anatomy, carry out 3D templating using prepopulated 3D renderings of commercially available implants. Premorbid glenoid anatomy should serve as the reference for ideal implant placement. Restoration of the premorbid anatomy is a long-held concept in hip arthroplasty and is an emerging trend in knee arthroplasty in the form of kinematic alignment. Although soft-tissue contractures are commonly present in osteoarthritic shoulders, removal of humeral and glenoid osteophytes, and release and/or excision of the pathologic capsule, allows the surgeon to place the implants to restore the premorbid glenohumeral anatomy and joint line position. This reestablishes adequate tension on the posterior rotator cuff, which we believe is critical in minimizing recurrent posterior humeral head subluxation. We routinely perform a circumferential release of the capsule by excising the entire anterior and inferior capsule, releasing the superior capsule, and excising the posterior part of the labrum and a portion of the posterior capsule. This extensive release of the posterior capsule when associated with posterior humeral head subluxation is only performed when the preoperative planning demonstrates that an augmented glenoid component can correct the pathologic glenoid version, inclination, and joint line within the premorbid anatomy.
- In the presence of acquired bone loss, such as a biconcave type-B2 glenoid, use the nonworn, intact anterior glenoid surface (paleoglenoid), which typically represents the premorbid glenoid morphology²⁵, as a guide for the selection of the optimal glenoid implant and its position. As noted previously, the surgeon should carefully identify the presence and location of the biconcavity and any osteophytes that may obscure appreciation of premorbid anatomy.
- In TSA, the ideal implant position should restore premorbid glenoid version and inclination, in addition to the medial-lateral position of the joint line. Retroversion should typically be corrected to $<15^\circ$, and ideally $<10^\circ$ in most patients. We correct inclination in the type-B2 glenoid as we build up the posteroinferior wear seen in this morphology with an augmented glenoid component. The glenoid component should ideally have 100% backside support, particularly posteriorly in shoulders with retroversion and/or posterior humeral head subluxation. Occasional perforation by the posterior-inferior peg may occur because of the depth of the glenoid vault in posteriorly eroded cases. This is acceptable; however, containment of the central peg is critical for implant stability in most glenoid component configurations. In addition, pay attention to the size of the implant in the anteroposterior and superoinferior directions to contain the pegs or keel of the implant, and to avoid overhang of the implant. Figures 2-A, 2-B, and 2-C demonstrate a substantial glenoid deformity that, if treated with corrective reaming of the anterior part of the glenoid, would result in unacceptable joint line medialization and removal of the subchondral bone plate.

Fig. 2-A

Fig. 2-B

Fig. 2-C

Video 3 Placing the virtual implant.

Figs. 2-A, 2-B, and 2-C Templating the glenoid component in a severely retroverted type-B2 glenoid to restore premorbid version, inclination, and joint line position. **Fig. 2-A** Placing the glenoid component (red outline) in neutral version requires removal of a substantial amount of bone and further medialization of the joint line by 6.3 mm. **Fig. 2-B** Placing the glenoid component to match the patient's premorbid version defined by the intact anterior paleoglenoid results in less bone removal and less medialization. **Fig. 2-C** Placing a posteriorly augmented glenoid component to match the version of the paleoglenoid results in the least bone removal and restores the lateral position of the glenohumeral joint line. Alternatively, a posterior glenoid graft with a standard glenoid component would result in the same effect.

Step 4: Evaluate the Need for an Augmented Glenoid Component, Bone Graft, or Eccentric Reaming

In the presence of bone loss from posterior glenoid wear, assess the need for an augmented glenoid component, bone graft, or eccentric reaming to achieve adequate backside seating (Video 4).

- In the setting of acquired bone loss, restore premorbid glenoid morphology, which may be achieved by eccentrically reaming to correct glenoid version. However, attempting to correct more than 15° to 20° of retroversion may lead to excessive medialization of the joint line with loss of glenohumeral offset and loss of the subchondral bone to support the implant. In addition, this will make the remaining vault shallower and narrower, requiring placement of a smaller glenoid component, and may lead to peg perforation^{7,26-28}. Alternatively, use an augmented glenoid component or bone graft from the resected humeral head (Fig. 2-C) to address posterior glenoid bone loss and correct version to restore the medial-lateral position of the joint line, and subsequently, lateral glenohumeral offset.

Step 5: Note the Center Pin Position and Trajectory

Once the glenoid component has been templated, note the starting location and trajectory of the center pin used for cannulated glenoid reaming and bone preparation (Video 5).

- After choosing the desired position of the selected glenoid component, the implant and the location of the reamed surfaces can be alternately shown within the software, demonstrating the amount of bone to be removed to place the selected implant in the desired location. In addition, the images can demonstrate the location and orientation of the central guide pin in relation to the osseous landmarks (Figs. 3-A and 3-B).
- Carefully assess the trajectory of the center pin relative to the patient's glenoid version and inclination as well as the position of the center pin on the glenoid face in an anteroposterior and superoinferior direction. The surgeon should recognize that when acquired bone loss has altered the glenoid morphology, the center pin is often not placed in the center of the surface of the arthritic glenoid fossa. In the deformed glenoid fossa, osteophytes may skew the shape of the glenoid surface and lead to inaccurate assessment of the ideal pin starting point (Figs. 3-A and 3-B). Place the center pin, and subsequently the central peg of the glenoid

Fig. 3-A

Fig. 3-B

Video 4 Evaluating the need for an augmented glenoid, bone graft, or eccentric reaming.

Video 5 Noting the position of the virtual center pin for the plan.

Figs. 3-A and 3-B Proper placement of the central guide pin. **Fig. 3-A** Note that the center pin (gray cylinder) does not follow the same path as the central glenoid axis (white line), and also note that the starting point for the center pin is slightly posterior to the center point of the glenoid fossa defined by the central glenoid axis. In this case, the surgeon should note the planned position of the center pin relative to the inflection line of the biconcavity (black line) and any other osseous landmarks, such as any identifiable peripheral osteophytes. Noting the relationship of the pin to these landmarks, and even intraoperative referencing of this image, will facilitate intraoperative pin placement as planned. **Fig. 3-B** If the pin guide to place the center pin is the same size and shape as the definitive implant, the pin guide can be placed in the same position on the glenoid face as seen in the *en face* view in the templated plan.

component, in the axis of the glenoid vault in the proper angular orientation, rather than in the center of the surface of the arthritic glenoid fossa.

- Pay careful attention to the position of the center pin relative to the exact anatomy of the glenoid surface with all soft tissue removed, as seen on the 3D CT scan, to facilitate intraoperative execution of the plan. Note the presence and size of osteophytes, small prominences or indentations on the surface or periphery, and the position and angle of an inflection line in biconcave glenoids. In the classic type-B2 glenoid, where the paleoglenoid is approximately 40% to 50% of the native glenoid surface area, the center pin typically enters on or near the line of glenoid biconcavity (Figs. 3-A and 3-B). All of these landmarks assist when using standard instrumentation to place the glenoid component according to the 3D template preoperative plan. These steps are equally important when using patient-specific instrumentation.

Step 6: Remove Remaining Cartilage and Soft Tissue from the Glenoid Surface

Intraoperatively, remove remaining labrum and any remaining cartilage or soft tissue, and expose the glenoid periphery to clearly define the osseous anatomy, including the base of the coracoid, such that it mirrors what the 3D CT scan and preoperative plan display (Video 6).

- In shoulder arthritis, wear can often be asymmetric, such as a biconcave type-B2 glenoid or in rotator cuff tear arthropathy with superior wear. In these cases, the eccentrically loaded side of the glenoid has worn down to sclerotic bone, while the unloaded side has remaining degenerative cartilage and labrum. Although the transition between the worn and unworn areas of the glenoid may easily be seen on the CT scan, this transition is not as obvious intraoperatively as a result of the remaining soft tissues on the intact portion of the glenoid (Fig. 4-A). In addition to removal of the remaining soft tissues, circumferential release of the capsule from the glenoid rim enables visualization of both large osteophytes and small prominences or indentations along the periphery that allow the surgeon to intraoperatively identify the same landmarks seen on the 3D CT scan during virtual templating (Fig. 4-B).

Fig. 4-A

Fig. 4-B

Video 6 Removing cartilage, labrum, or other soft tissue from the glenoid to expose the true osseous anatomy.

Figs. 4-A through 4-F Using the premorbid glenoid as a patient-specific guide for placing the glenoid center pin. In biconcave glenoids, the anterior surface, or paleoglenoid, represents the patient's premorbid anatomy. When the premorbid glenoid is of sufficient size, it can serve as a patient-specific guide for placing the glenoid center pin. The first step intraoperatively involves removing remaining cartilage and/or other soft tissue from the glenoid fossa. **Fig. 4-A** In this intraoperative photograph, the posteroinferior two-thirds of the glenoid has eroded to sclerotic bone while the anterior one-third has remaining soft tissue (white outline). **Fig. 4-B** After curettage, the paleoglenoid (black outline) is visible, although large anterior osteophytes (white outline) partially cover it.

Step 7: Place the Center Pin According to the Preoperative Plan

Place the center pin for glenoid preparation in the previously templated location and trajectory to emulate the surgical plan defined in the software (Video 7).

- After careful preparation to remove any remaining soft tissues from the surface and periphery of the glenoid, reference digital or printed images of the virtual plan with the center pin placed and again note the precise location of the pin relative to osteophytes, small prominences and indentations, and/or an inflection line when biconcavity is present.
- Identify these same osseous landmarks in vivo and use them to place the center pin in the same position as the virtual plan. This requires careful attention to the microanatomy of the glenoid noted in the previous bullet point and intraoperative referencing of images from the 3D-templated plan.
- When managing asymmetric bone loss associated with the type-B2 glenoid, use a pin guide, or drill guide, with a curved backside placed onto the surface of the paleoglenoid cleared of all soft tissue. Be sure to avoid or remove any osteophyte to be contiguous with the native concave surface. Place axial pressure on the pin guide so that the guide is on the paleoglenoid and the posterior side of the pin guide is not touching the worn posterior portion of the glenoid. Assuming that there is sufficient remaining surface of the unaffected paleoglenoid, the pin guide will be placed in the patient's native version and inclination (Figs. 4-C through 4-F). If the pin guide represents the same dimensions of the desired final implant, then the guide can be positioned in the anteroposterior and superoinferior dimensions to reproduce the position of the center pin on the surface of the glenoid as shown in the 3D imaging template. The center pin is then placed perpendicular to the pin guide using the center hole within the pin guide.

Fig. 4-C

Fig. 4-D

Fig. 4-E

Fig. 4-F

Video 7 Placing the center pin to recreate the virtually planned center pin and implant placement.

Fig. 4-C In this model, the paleoglenoid (solid outline) is visible, although it is substantially altered by anterior osteophytes (dashed outline). **Fig. 4-D** Because anterior osteophytes would prevent using the paleoglenoid as a resting surface for a glenoid pin guide, they are removed. **Fig. 4-E** The pin guide is then placed firmly against the paleoglenoid, and the guide is placed according to the patient's premorbid anatomy. **Fig. 4-F** The glenoid is then prepared for the definitive implant.

- For patients with minimal paleoglenoid for accurate placement of the pin guide, add a linear measurement (A) from the intact anterior surface of the bone to the back side of the templated component and the linear dimension (B) of the largest glenoid bone defect that will be filled with bone graft or by an augmented component (Fig. 5). Measurement A represents the amount of reaming necessary on the anterior aspect of the glenoid, while measurement B represents the size of the augment or graft. If the pin guide has a posterior post equal to the sum of these measurements ($A + B$) that can be placed on the posterior aspect of the glenoid, and the anterior portion of the guide is placed in the same anterior location as shown in the preoperative plan, then a pin placed perpendicular to the surface of the pin guide will replicate the preoperative plan. This can be accomplished using the asymmetric pin guides designed for the STEPTECH glenoid components (GLOBAL STEPTECH Anchor Peg Glenoid; DePuy Synthes). For the case shown, A is 2.9 mm, and B (the size of the augment) is 7 mm, resulting in a total of 9.9 mm. The available 9-mm asymmetric guide is placed on the anterior part of the glenoid, while being held roughly 1 mm off the posterior part of the glenoid. This technique places the center pin in the templated version, and after reaming the anterior edge 2.9 mm (so that the anterior half of the glenoid is reamed flat), the posterior defect is filled by the 7-mm augment to recreate the planned joint line.
- If the guide is the same size as the final implant, then it can be placed in the correct location on the face of the glenoid using the preoperative planning images (Fig. 3-B).
- Once the pin placement is ideal, proceed with preparation of the glenoid according to manufacturer-specific recommendations for the implant chosen during virtual templating.

Fig. 5

Fig. 5 Placement of the glenoid center pin when there is insufficient premorbid glenoid to serve as a guide for ideal version. In severe cases of posterior wear, the biconcave line moves more anteriorly, sometimes to the point that the premorbid glenoid is insufficient in size to use as a guide for version. In such cases, once templating is complete, the surgeon should measure the amount of bone to be removed at the most anterior aspect of the component (line A) and add this measurement to the size of the posterior augment or bone graft (line B). In this case, the templated plan requires removal of 2.9 mm of bone anteriorly, and the size of the augment posteriorly measures 7 mm, which yields a sum of 9.9 mm. For this particular implant, the GLOBAL STEPTECH Glenoid (DePuy Synthes), the largest augmented pin guide measures 9 mm, so the surgeon would rest the anterior edge of the 9-mm STEPTECH pin guide on the anterior part of the glenoid, not the rim osteophyte, and keep the posterior edge of the pin guide 0.9 mm, or roughly 1 mm, off the bone to reach the sum of 9.9 mm from the preoperative plan. After reaming 2.9 mm anteriorly (so that the anterior aspect of the glenoid is reamed flat), the 7-mm augment will fill the posterior defect to recreate the planned joint line position and version.

Results

We performed a prospective, randomized controlled trial of positioning of the glenoid component in anatomic TSA using preoperative planning with 3D CT scans and standard instrumentation compared with using 3D CT preoperative planning with patient-specific instrumentation²⁹. These results were also compared with a historical control group of patients using the same standard surgical instrumentation with traditional 2D imaging without templating. There were no differences in the preoperative severity of glenoid pathology, including the Walch classification. There was less deviation in implant position from the preoperative plan in the 3D groups than in the 2D group and no difference between 3D planning with standard instrumentation when used in a patient-specific way, as discussed above, compared with an adjustable and reusable patient-specific instrument. The mean deviation in actual implant position from the plan was 6.9° of version (95% confidence interval [CI], 4.8° to 9.0°) and 11.1° of inclination (95% CI, 8.2° to 14.1°) in the 2D group and 4.3° of version (95% CI, 3.1° to 5.5°) and 4.1° of inclination (95% CI, 2.7° to 5.5°) in the 3D group with standard instruments. There was a significantly greater likelihood of placing the glenoid in >10° of version or inclination in the 2D group than in the 3D groups. The treating surgeons did not plan for or use an augmented glenoid component in any shoulder in the 2D CT control group. Retrospectively, 5 of 17 shoulders in the 2D group were determined to require an augmented component, which was not different from the rate in the 3D groups.

Previous work from our research group²⁵ demonstrated that use of 3D planning allows for accurate measurement of pathologic anatomy and glenoid bone loss. We have also shown better interobserver agreement on pathology when using 3D CT scans compared with 2D CT scans¹⁸. Surgeons agreed more on glenoid version, location and amount of bone loss, glenoid prosthetic fit, including perforation of the inner vault, and surgical decision making.

Pitfalls & Challenges

- Careful evaluation of high-quality radiographs minimizes the risk of missing the presence of abnormal glenoid morphology. When radiographs are equivocal, a CT scan is a more reliable way to define glenoid anatomy^{16,17}.
- Obtain thin slices on CT, preferably <1 mm, and include the entire scapula to allow accurate measures of glenoid pathology and virtual implant position.
- Carefully prepare the glenoid intraoperatively. This requires initially maintaining both small and large osteophytes while removing any remaining cartilage, labrum, and capsule. The process requires time and attention to detail, but it facilitates identification of all small and large osseous landmarks identified on the 3D CT scan during planning. Osteophytes can be removed after placing the trial glenoid component.
- Place the center pin on the glenoid surface according to the plan, rather than choosing the central point on the glenoid surface when viewed en face. Osteophytes and bone loss alter glenoid anatomy such that the central point on the surface will lead to improper placement of the implant, including increased risk of peg perforation¹⁸. Use of these landmarks along with the 3D templated images and proper use of the pin guides are necessary for accurate center pin placement.
- Proper use of asymmetric pin guides as defined by the preoperative planning software improves center pin placement for both location and trajectory.

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References

- Kim SH, Wise BL, Zhang Y, Szabo RM. Increasing incidence of shoulder arthroplasty in the United States. *J Bone Joint Surg Am*. 2011 Dec 21;93(24):2249-54.
- Papadonikolakis A, Neradilek MB, Matsen FA 3rd. Failure of the glenoid component in anatomic total shoulder arthroplasty: a systematic review of the English-language literature between 2006 and 2012. *J Bone Joint Surg Am*. 2013 Dec 18;95(24):2205-12.
- Antuna SA, Sperling JW, Cofield RH, Rowland CM. Glenoid revision surgery after total shoulder arthroplasty. *J Shoulder Elbow Surg*. 2001 May-Jun;10(3):217-24.
- Hasan SS, Leith JM, Campbell B, Kapil R, Smith KL, Matsen FA 3rd. Characteristics of unsatisfactory shoulder arthroplasties. *J Shoulder Elbow Surg*. 2002 Sep-Oct;11(5):431-41.
- Iannotti JP, Spencer EE, Winter U, Deffenbaugh D, Williams G. Prosthetic positioning in total shoulder arthroplasty. *J Shoulder Elbow Surg*. 2005 Jan-Feb;14(1)(Suppl S):111S-21S.
- Nyffeler RW, Sheikh R, Atkinson TS, Jacob HA, Favre P, Gerber C. Effects of glenoid component version on humeral head displacement and joint reaction forces: an experimental study. *J Shoulder Elbow Surg*. 2006 Sep-Oct;15(5):625-9.
- Iannotti JP, Greeson C, Downing D, Sabesan V, Bryan JA. Effect of glenoid deformity on glenoid component placement in primary shoulder arthroplasty. *J Shoulder Elbow Surg*. 2012 Jan;21(1):48-55. Epub 2011 May 20.
- Verborgt O, De Smedt T, Vanhees M, Clockaerts S, Parizel PM, Van Glabbeek F. Accuracy of placement of the glenoid component in reversed shoulder arthroplasty with and without navigation. *J Shoulder Elbow Surg*. 2011 Jan;20(1):21-6.
- Farron A, Terrier A, Büchler P. Risks of loosening of a prosthetic glenoid implanted in retroversion. *J Shoulder Elbow Surg*. 2006 Jul-Aug;15(4):521-6.
- Franta AK, Lenters TR, Mounce D, Neradilek B, Matsen FA 3rd. The complex characteristics of 282 unsatisfactory shoulder arthroplasties. *J Shoulder Elbow Surg*. 2007 Sep-Oct;16(5):555-62. Epub 2007 May 16.
- Ho JC, Sabesan VJ, Iannotti JP. Glenoid component retroversion is associated with osteolysis. *J Bone Joint Surg Am*. 2013 Jun 19;95(12):e82.
- Hendel MD, Bryan JA, Barsoum WK, Rodriguez EJ, Brems JJ, Evans PJ, Iannotti JP. Comparison of patient-specific instruments with standard surgical instruments in determining glenoid component position: a randomized prospective clinical trial. *J Bone Joint Surg Am*. 2012 Dec 5;94(23):2167-75.
- Iannotti J, Baker J, Rodriguez E, Brems J, Ricchetti E, Mesiha M, Bryan J. Three-dimensional preoperative planning software and a novel information transfer technology improve glenoid component positioning. *J Bone Joint Surg Am*. 2014 May 7;96(9):e71.
- Friedman RJ, Hawthorne KB, Genez BM. The use of computerized tomography in the measurement of glenoid version. *J Bone Joint Surg Am*. 1992 Aug;74(7):1032-7.
- Nyffeler RW, Jost B, Pfirrmann CWA, Gerber C. Measurement of glenoid version: conventional radiographs versus computed tomography scans. *J Shoulder Elbow Surg*. 2003 Sep-Oct;12(5):493-6.
- Budge MD, Lewis GS, Schaefer E, Coquia S, Flemming DJ, Armstrong AD. Comparison of standard two-dimensional and three-dimensional corrected glenoid version measurements. *J Shoulder Elbow Surg*. 2011 Jun;20(4):577-83. Epub 2011 Feb 16.
- Kwon YW, Powell KA, Yum JK, Brems JJ, Iannotti JP. Use of three-dimensional computed tomography for the analysis of the glenoid anatomy. *J Shoulder Elbow Surg*. 2005 Jan-Feb;14(1):85-90.
- Scalise JJ, Codsi 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 Nov;90(11):2438-45.
- Yongpravat C, Kim HM, Gardner TR, Bigliani LU, Levine WN, Ahmad CS. Glenoid implant orientation and cement failure in total shoulder arthroplasty: a finite element analysis. *J Shoulder Elbow Surg*. 2013 Jul;22(7):940-7. Epub 2013 Jan 10.
- Szabo I, Buscayret F, Edwards TB, Nemoz C, Boileau P, Walch G. Radiographic comparison of flat-back and convex-back glenoid components in total shoulder arthroplasty. *J Shoulder Elbow Surg*. 2005 Nov-Dec;14(6):636-42.
- Bercik MJ, Kruse K 2nd, Yalozis M, Gauci MO, Chaoui J, Walch G. A modification to the Walch classification of the glenoid in primary glenohumeral osteoarthritis using three-dimensional imaging. *J Shoulder Elbow Surg*. 2016 Oct;25(10):1601-6. Epub 2016 Jun 6.
- Ricchetti ET, Hendel MD, Collins DN, Iannotti JP. Is pre-morbid glenoid anatomy altered in patients with glenohumeral osteoarthritis? *Clin Orthop Relat Res*. 2013 Sep;471(9):2932-9. Epub 2013 May 18.
- Walch G, Young AA, Boileau P, Loew M, Gazielly D, Molé D. Patterns of loosening of polyethylene keeled glenoid components after shoulder arthroplasty for primary osteoarthritis: results of a multicenter study with more than five years of follow-up. *J Bone Joint Surg Am*. 2012 Jan 18;94(2):145-50.
- Walch G, Young AA, Melis B, Gazielly D, Loew M, Boileau P. Results of a convex-back cemented keeled glenoid component in primary osteoarthritis: multicenter study with a follow-up greater than 5 years. *J Shoulder Elbow Surg*. 2011 Apr;20(3):385-94. Epub 2010 Nov 5.
- Scalise JJ, Bryan J, Polster J, Brems JJ, Iannotti JP. Quantitative analysis of glenoid bone loss in osteoarthritis using three-dimensional computed tomography scans. *J Shoulder Elbow Surg*. 2008 Mar-Apr;17(2):328-35. Epub 2008 Jan 22.
- Clavert P, Millett PJ, Warner JJ. Glenoid resurfacing: what are the limits to asymmetric reaming for posterior erosion? *J Shoulder Elbow Surg*. 2007 Nov-Dec;16(6):843-8.
- Gillespie R, Lyons R, Lazarus M. Eccentric reaming in total shoulder arthroplasty: a cadaveric study. *Orthopedics*. 2009 Jan;32(1):21.
- Nowak DD, Bahu MJ, Gardner TR, Dyrszka MD, Levine WN, Bigliani LU, Ahmad CS. Simulation of surgical glenoid resurfacing using three-dimensional computed tomography of the arthritic glenohumeral joint: the amount of glenoid retroversion that can be corrected. *J Shoulder Elbow Surg*. 2009 Sep-Oct;18(5):680-8. Epub 2009 May 31.
- Iannotti JP, Weiner S, Rodriguez E, Subhas N, Patterson TE, Jun BJ, Ricchetti ET. Three-dimensional imaging and templating improve glenoid implant positioning. *J Bone Joint Surg Am*. 2015 Apr 15;97(8):651-8.