A glenoid reaming study: how accurate are current reaming techniques?

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Background: Correct reaming of a degenerative glenoid can be a difficult procedure. We investigated how the quality of the reamed surface is influenced by different reamers, by the surgeon’s experience, and by glenoid erosion patterns.

Material and methods: Three shoulder surgeons performed reaming procedures with different types of reamers (flat, convex, K-wire guided, and nipple guided) on a series of similarly sized uniconcave and biconcave glenoids. The reproducibility of reaming and the effect of different reamers on different-shaped glenoids were measured and evaluated.

Results: The center and direction of reaming were constant for all surgeons in the case of type A glenoids. For type B2 glenoids, the center and direction of reaming differed significantly between surgeons. The congruity of the reamed surface was better after flat reaming than after convex reaming. Whether the reamers were guided by a central K-wire or by a nipple had no significant effect on the reamed surface. The experience of the surgeon had no effect on the congruity of reaming.

Conclusions: Reaming of a uniconcave glenoid is reproducible, but reaming of a biconcave glenoid seems much more difficult. Erosion and deformity of the glenoid influence the accuracy of reaming the most. Surgical experience plays a less important role. We conclude that there is a need for guidance in reaming of biconcave glenoids.

Level of evidence: Basic Science Study, Investigation of Surgical Technique.

Keywords: Glenoid; reaming; version; erosion; shoulder; prosthesis

Total shoulder replacement has proved to be superior to hemiarthroplasty in treatment of glenohumeral arthritis. Unfortunately, the glenoid component remains the weak link, and glenoid loosening is still the main complication and reason for revision. Correct placement of a glenoid component seems essential for longevity of the prosthesis and positively affects the functional outcome.1,4,16,18,21,33,35,44 Correct positioning and fixation are difficult and depend on numerous factors. These are surgeon dependent, implant and accompanying instrumentation related, and patient related, depending on the anatomic variations of the glenoid.
Surgeon-dependent variables are acquired experience and skills helping in determining the surgical bone landmarks but also a natural sense of 3-dimensional (3D) orientation, enabling the surgeon to determine the amount of correction of the eroded glenoid.

Implants and instrumentation aim at an optimally seated glenoid component. The type of reamer and the technique of reaming play an important role in obtaining this. The anatomy of the glenoid varies largely, and often posteroinferior erosion of the native glenoid, weakening of the subchondral bone, cysts, and osteoporosis are observed in arthritic shoulders. During surgery, it is important to find a balance between reaming to correct the orientation of the eroded glenoid and maintaining an optimal glenoid bone stock for adequate fixation of a glenoid component. This appears to be a difficult exercise even in experienced hands, and it explains the increasing interest in patient-specific instruments and navigation systems for guidance during this procedure.15,23,28,34,38

The goal of this study was to evaluate the accuracy of current glenoid reaming techniques and how the surgeon’s experience, the type of reamer, and the orientation of the glenoid influence this.

Materials and methods

This is a basic science study investigating different reaming techniques performed on uniconcave and biconcave glenoid models.

Bone models

Ninety glenoid bone models were created from Sawbones solid rigid polyurethane foam (Sawbones, Malmö, Sweden) with material properties similar to glenoid subchondral bone.7 The models were divided into 2 groups, 45 with a uniconcave shape and 45 with a biconcave shape, thereby mimicking type A and type B2 glenoids according to the Walch classification.43

The dimensions of an original female biconcave glenoid were used to create the B2 glenoid models with Mimics (Materialise, Haasrode, Belgium). The radius of the inferior circle of the native glenoid is 15 mm.14 The retroversion measured according to Friedman19 is 12°. The dimensions of the A model glenoids were chosen to be comparable in size to the B models, measuring 30 mm in width, 39 mm in length, and 5 mm in depth. The version was neutral, 0°. These A model glenoids were ovoid.10,31 The Standard Tessellation Language (STL) surface was used to prepare computer-aided design drawings (Fig. 1) and to generate computer-aided manufacturing commands for the milling process in NX 7.5 (Siemens PLM, Plano, TX, USA). Both type A and type B2 glenoids were milled from the polyurethane blocks by use of a 3-axis milling machine (Haas, Oxnard, CA, USA) (Fig. 2).

Methodology

A setup was prepared with the bone blocks positioned vertically at surgical working height. Three surgeons (L.D.W., A.K., A.V.T.) performed the reaming, representing an experienced, intermediate, and inexperienced surgeon with, respectively, more than 50, more than 20, and less than 20 total shoulder arthroplasties performed per year.22 The 3 surgeons each individually defined their preferred center on the glenoid for the reaming procedure. A flat semicircular guide (Zimmer, Warsaw, IN, USA) (Fig. 3) was used to orient and assist in finding this center. In doing this, the surgeons were guided by their personal preference: the center of the inferior circle guided by the anteroinferior glenoid rim,40,41 the gravity center of the glenoid,30 or the intersection point of superoinferior and widest anteroposterior line on the glenoid surface.13

The surgeons individually determined the direction of reaming to obtain the intended correction of version and inclination. For the A glenoids, the aim was to keep the version neutral; for the B2 glenoids, the aim was to correct the version as close to neutral as possible (retroversion between 10° and 0°).10 Correction of the version can be obtained in 2 ways. The surgeon can be guided by the anteroinferior glenoid rim, which indicates the native glenoid plane and helps in reconstructing the native glenoid orientation.14,40 Alternatively, one can focus entirely on the retroversion in the 2-dimensional (2D) orientation and correct to neutral.10 The flat guide used by all surgeons assisted in aiming for the correct plane.

For the A glenoids, reaming was performed until the reamer was over its entire surface in contact with glenoid bone, creating...
a smooth bone bed. For the B2 glenoids, reaming was performed similarly, taking into account a correction to a neutral version and inclination.

Four different reamers with a similar radius were used (Fig. 4):

- convex reamer guided by a K-wire (Global AP, diameter 33 mm; DePuy, Warsaw, IN, USA);
- convex reamer guided by a nipple (Global Advantage, diameter 33 mm, nipple 6 mm; DePuy, Warsaw, IN, USA);
- flat reamer guided by a K-wire (custom made, diameter 30 mm); and
- flat reamer guided by a nipple (diameter 30 mm, nipple 6 mm; Zimmer, Warsaw, IN, USA).

All reamers were used with the companies’ instruments with a set arm length of 18 cm. Each surgeon reamed a series of 3 A and 3 B2 glenoids with the 4 different reamers. An additional 9 B2 glenoids were reamed with a convex reamer guided by a K-wire with a short arm length (9 cm). This resulted in 27 reaming procedures per surgeon. Of 90 samples, 9 were defectively overreamed, and these were not used for the study. Eighty-one samples were reamed with success and included in the study.

Parameters and statistics

The reamed bone models were scanned with a 3D coordinate measuring machine (MC16; Coord3, Turin, Italy). The resulting point clouds were processed by GOM Inspect (Braunschweig, Germany), from which STLs were built in 3-Matic (Materialise, Haasrode, Belgium) for further analysis. All bone models were aligned in the software to the same identical coordinate system (“world coordinate system”), ensuring comparability between the parameters of different blocks. The following parameters were extracted from the A and B2 bone blocks: the center of reaming; the direction of reaming; the reaming depth; and the sphericity or flatness of the reamed surface for, respectively, convex and flat reamers used.

Sphericity describes the congruity of a convex surface, and flatness describes the congruity of a flat surface. Flatness (mm) and sphericity (mm) of the scanned reamed surfaces were determined in accordance with the methods used in geometrical dimensioning and tolerancing.32

The reaming center was expressed by its x, y, and z coordinates in the world coordinate system. The z-coordinate of the reaming center was used as a proxy for the reaming depth. The direction of reaming was determined as the normal to the surface for the flat reamer and as the direction of the line connecting the reaming center and the sphere center for bone blocks prepared with a convex reamer. These 3 direction angles were expressed with respect to the local anatomic x, y, and z axes (“anatomic coordinate system”) of the A and B2 glenoids defined according to Verstraeten41 (Fig. 5). Defining the angles with respect to this local anatomic coordinate system allowed a uniform and clinically relevant interpretation of the angles between A and B2 blocks. Repeatability of the parameter extraction procedure was verified for all parameters with 10 repetitions per parameter, resulting in a mean standard deviation of 0.23% on the parameter values.

Statistical analyses were performed with IBM SPSS Statistics, version 21 (SPSS Inc, Chicago, IL, USA).
testing between the 2 groups was performed by a $t$ test if both groups to be compared were normally distributed according to a Kolmogorov-Smirnov/Shapiro-Wilk normality test (depending on the subject size). Alternatively, a Mann-Whitney $U$ test was used if one of the groups failed to pass the normality test. When more than 2 levels per factor were compared, an analysis of variance was carried out if the normality assumption was satisfied or a Kruskal-Wallis test if this assumption was not fulfilled. Significance was assessed at the 5% level.

**Results**

**Center of reaming**

The 3 surgeons chose a similar center of reaming for the A glenoids. For the $x$-axis (anteroposterior axis of the glenoid), we noted a significant difference ($P = .015$) between surgeon 1 and surgeon 3 (Table I). For the $y$-axis (cranio-caudal axis of the glenoid) and the $z$-axis (depth), there was no difference.

There was a significant difference between surgeons for the chosen center of reaming for the B2 glenoids. There was a significant difference between 2 surgeons for the $x$-axis ($P = .020$) and between the 3 surgeons for the $y$-axis ($P = .043, .024$, and $.001$). There was no difference for the $z$-axis (Table I).

![Figure 4](image4.png) Different reamers used. (A) Convex reamer, K-wire guided. (B) Convex reamer, nipple guided. (C) Flat reamer, K-wire guided. (D) Flat reamer, nipple guided.

![Figure 5](image5.png) Anatomic coordinate system with the $x$-axis and $y$-axis in the plane of the glenoid and the $z$-axis perpendicular to this plane.

Concerning the reamers (convex and flat), there was no difference in center of reaming between K-wire–guided and nipple-guided reamers for all axes.
Reaming depth was similar for K-wire–guided and nipple-guided reamers, and there was no significant difference between surgeons, both for A ($P = .815$) and B2 ($P = .499$) glenoids.

**Direction of reaming**

The direction of reaming was constant for all 3 surgeons for the A glenoids, except for a slight difference between surgeon 1 and surgeon 2 for the $z$-axis ($P = .005$) (Table II).

The direction of reaming differed between all 3 surgeons on all axes in B2 glenoids ($x$-axis, $P = .002$; $y$-axis, $P = .007$; $z$-axis, $P = .003$) (Table III).

We did not find a difference in direction of reaming between K-wire–guided and nipple-guided reamers for all axes in both types of glenoids.

There was a significant difference in direction of reaming between long and short reamers ($x$-axis, $P = .001$; $y$-axis, $P = .002$; $z$-axis, $P = .001$). Reaming with short reamers was more variable (Table IV).

**Congruity of the surface**

The sphericity of the surface after convex reaming was similar for K-wire–guided and nipple-guided reamers. The flatness of the surface after use of the flat reamers was similar for K-wire–guided and nipple-guided reamers. This applied for both A ($P = .542$) and B2 ($P = .134$) glenoids.

There was a difference in congruity between the sphericity and flatness after reaming. Flat reaming resulted in better flatness than convex reaming resulted in sphericity. The difference was significant ($P = .004$). A short reamer created better sphericity than a long reamer ($P = .029$).

**Discussion**

Loosening of the glenoid component remains a matter of concern in total shoulder arthroplasty. The occurrence of both tilting and subsidence of the prosthesis is associated with reaming of the glenoid. Excessive reaming can result in weakening of the subchondral bone and loss of bone volume and surface area of the glenoid vault. The lack of solid strong bone to support the prosthesis enhances the chances of loosening. On the other hand, inaccurate reaming with failure to restore glenoid version also puts the prosthesis at risk for premature loosening. To minimize failure, the surgeon should aim for a solid and durable fixation of a correctly oriented glenoid component. Reaming is performed to create a congruent surface and to correct the orientation of the native glenoid. Multiple factors play a role in acquiring this.

To our knowledge, this is the first study to evaluate the surgical-, instrument-, and anatomy-related parameters affecting the reaming procedure of the glenoid. We were able to perform this study because 3D computed tomography (CT) scan reconstruction allowed us to create bone models of similarly sized A and B glenoids.

This study showed that reaming of a uniconcave, type A glenoid is reproducible. The 3 surgeons chose similar centers of reaming and reaming direction for type A glenoids. The center and the direction of reaming were independent of the type of reamer used.

A biconcave, B2 glenoid causes more difficulties, as is evident from the significant difference between both parameters. The center of reaming differed between all 3 surgeons (Table I). The angle of reaming differed largely between surgeons and individually (Table III).
The surgeon intends to reconstruct. It seems essential to

correct the native glenoid plane, but this plane is not well
defined. The inferior circular glenoid plane has the lowest
variability to the coronal scapular plane and is therefore the
most reliable plane in which to restore normal anatomy
according to Verstraeten. Preoperative measurement of
glenoid version on 2D CT images is common practice but
varies significantly with scapular rotation and is influenced
by the amount of deformity and osteophytes. The use of
3D reconstruction images to determine the native glenoid
plane has been shown to be more precise and is independent
of the position of the scapula. A 3D CT reconstruction
study by Beuckelaers showed that the orientation of the
erosion in a B1 glenoid is more inferior than in a B2 glenoid,
a finding that would be underestimated on a 2D CT scan. With
the knowledge of preoperative measurements, the surgeon
can estimate the desired amount of reaming. It is desirable to
approach normal version, which averages between 1° and 2°
of retroversion for the majority of the population. If retro-
version exceeds 10°, correction is advised to avoid eccentric
loading. The possibilities are limited, though; if retroversion exceeds 15°, corrective reaming already risks
violation of the glenoid vault, compromising placement of a
glenoid prosthesis. The 3D CT approach is difficult to
translate into exact surgical acts. The surgeon’s experience
and ability to work with 3D configurations are advantages
in accomplishing this. Patient-specific preoperative
planning and preoperative templating can be of help to decide
on correction and component sizing. This study shows
the variability in center and direction of reaming for the B2
glenoids. Of the 3 surgeons performing the reaming, 2 junior
surgeons were trained by the senior surgeon. Even 3 surgeons
with the same working methods and reaming strategy did not
manage to consistently ream a biconcave glenoid. This calls
for guidance during reaming in the case of eroded glenoids.

Different implants come with different reamers, and we
believed that the type of reamer might have an effect. The
glenoid implant must match the size, shape, and congruity
of the glenoid surface. Curved back components have a
biomechanical advantage over flat glenoids with a larger
contact area and a better spreading of pressure. A perfect
fit between the congruity of implant and glenoid im-
proves load transfer and reduces deformation and
displacement of the implant. Motorized reaming creates
the best conformity of the glenoid surface with the under-
surface of the implant and outperforms shaping with a curet
or hand reaming. This is to our knowledge the first study
to investigate the quality of the resulting surface after
reaming with various types of reamers. It shows that there
is no difference in sphericity or flatness of the surface
whether the reamers are guided by a central K-wire or by a
nipple. There is a significant difference in congruity after
convex and flat reaming. The flatness after reaming with
a flat reamer is better than the sphericity after reaming with
a convex reamer. The length of the reamer plays a signifi-
cant role: with the short reamer, the congruence of the
surface is better; and with the long reamer, there is less

Table III  Difference in reaming angle between surgeons for B2 glenoids

<table>
<thead>
<tr>
<th>Surgeon</th>
<th>N</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surgeon 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>z-axis</td>
<td>12</td>
<td>4</td>
<td>15</td>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td>y-axis</td>
<td>12</td>
<td>93</td>
<td>103</td>
<td>98</td>
<td>3</td>
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<tr>
<td>x-axis</td>
<td>12</td>
<td>78</td>
<td>87</td>
<td>85</td>
<td>3</td>
</tr>
<tr>
<td>Surgeon 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>z-axis</td>
<td>12</td>
<td>2</td>
<td>11</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>y-axis</td>
<td>12</td>
<td>89</td>
<td>99</td>
<td>94</td>
<td>3</td>
</tr>
<tr>
<td>x-axis</td>
<td>12</td>
<td>83</td>
<td>92</td>
<td>87</td>
<td>3</td>
</tr>
<tr>
<td>Surgeon 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>z-axis</td>
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<td>0</td>
<td>9</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>y-axis</td>
<td>12</td>
<td>90</td>
<td>99</td>
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<td>2</td>
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<tr>
<td>x-axis</td>
<td>12</td>
<td>86</td>
<td>92</td>
<td>89</td>
<td>2</td>
</tr>
</tbody>
</table>

Degrees relative to the local anatomic coordinate system.

Table IV  The direction of reaming differed significantly between long and short reamers

<table>
<thead>
<tr>
<th>Standard deviation</th>
<th>x-axis</th>
<th>y-axis</th>
<th>z-axis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short reamer</td>
<td>2.9</td>
<td>2.4</td>
<td>2.4</td>
</tr>
<tr>
<td>Long reamer</td>
<td>1.8</td>
<td>2.0</td>
<td>2.0</td>
</tr>
</tbody>
</table>

Reaming with short reamers showed more variation.
variation in direction of reaming. The longer reamer seems to create a more stable position to control the direction.

The experience of the surgeon seems to have no effect on the congruity of reaming.

We used reamers with small diameters (30 and 33 mm) because they fit into the cortical edge of the A and B2 glenoids with the dimensions of a female patient with a small glenoid. These reamers met the criteria (flat, convex, K-wire guided, and nipple guided) and were readily available for the study. The difference in diameter of the reamers had no effect on parameters of this study. It is obvious that severely eroded type B2 glenoids present difficulties for the surgeon. There is a lack of preoperative anatomic reference points available to the surgeon, and there is a lack of preoperative instrumentation and guidance. Computer-assisted surgical navigation might be the solution according to different surgeons.15,28,32 Disadvantages of these techniques include the intraoperative tracking system, which is vulnerable to technical mistakes; failure of the tracking devices; and high costs. Patient-specific instrumentation can avoid the use of these tracking devices. Suero38 used a custom-made jig for optimal implant positioning. With this instrument, accurate placement of a glenoid implant seems possible. Hendel23 compared patient-specific instrumentation with the standard surgical technique and found significant improvement in accuracy of glenoid component placement in version, inclination, and medial offset, in particular in patients with more severe retroversion. Although this patient-specific instrumentation eliminates some of the technical difficulties faced with surgical navigation, manufacturing costs of these devices are expensive as well.

Conclusions

The current study demonstrates that there is a need for guidance in reaming of biconcave glenoids. Erosion and deformity of the glenoid seem to influence accuracy of reaming the most. The congruity of the reamed surface is better after flat reaming than after convex reaming. Surgical experience plays a less important role.

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