SHOULDER AND ELBOW

A new classification of glenoid bone loss to help plan the implantation of a glenoid component before revision arthroplasty of the shoulder

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Aims
Glenoid bone loss can be a challenging problem when revising a shoulder arthroplasty. Precise pre-operative planning based on plain radiographs or CT scans is essential. We have investigated a new radiological classification system to describe the degree of medialisation of the bony glenoid and that will indicate the amount of bone potentially available for supporting a glenoid component. It depends on the relationship between the most medial part of the articular surface of the glenoid with the base of the coracoid process and the spinoglenoid notch: it classifies the degree of bone loss into three types.

It also attempts to predict the type of glenoid reconstruction that may be possible (impaction bone grafting, structural grafting or simple non-augmented arthroplasty) and gives guidance about whether a pre-operative CT scan is indicated.

Patients and Methods
Inter-method reliability between plain radiographs and CT scans was assessed retrospectively by three independent observers using data from 39 randomly selected patients.

Inter-observer reliability and test-retest reliability was tested on the same cohort using Cohen's kappa statistics. Correlation of the type of glenoid with the Constant score and its pain component was analysed using the Kruskal-Wallis method on data from 128 patients.

Anatomical studies of the scapula were reviewed to explain the findings.

Results
Excellent inter-method reliability, inter-observer and test-retest reliability were seen. The system did not correlate with the Constant score, but correlated well with its pain component.

Take home message: Our system of classification is a helpful guide to the degree of glenoid bone loss when embarking on revision shoulder arthroplasty.

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Implanting a prosthetic glenoid component in total shoulder arthroplasty (TSA) can be difficult if the bony glenoid is deficient.1,2 It may be a problem in primary arthroplasty if a Walch Type B2 or C gelenoid is present, or in revision shoulder arthroplasty3 where there is loss of the gelenoid bone stock from erosion or osteolysis. We propose a classification system, based on the degree of bone loss, to predict the most suitable method of reconstruction in these circumstances.

According to data published by Walch, approximately 32% of shoulders with primary gelenohumeral osteoarthritis fall into type B and 9% into type C.4

The gelenoid component often fails. The Australian Orthopaedic Association National Joint Replacement Registry stated in their 2013 Supplementary Reports that in 2012 10.7% of all types of shoulder arthroplasty (including resurfacing and hemiarthroplasty) were revisions, and 48% of these involved the gelenoid component.5

Several classifications have been published to describe gelenoid bone loss, the most popular of which are those of Walch et al4 who described the morphology of the bony gelenoid in primary gelenohumeral osteoarthritis; Favard,6 Seebauer,7 Hamada et al,8 and Sirveaux et al9 who described cuff tear arthropathy; Samilson and Prieto10 who described dislocation arthropathy, and Levigne and Franchesch16 who described gelenoid wear in rheumatoid arthritis.

There are also several classifications which describe loosening of the gelenoid component in
A NEW CLASSIFICATION OF GLENOID BONE LOSS TO HELP PLAN THE IMPLANTATION OF A GLENOID COMPONENT

TSA. Many of these are based on the radiolucent lines or cavities seen around the glenoid implant. Such scores include those of Torchia, et al.11 Franklin, et al.12 Mole,6 Kepler et al.13 and Lazarus et al.14

The classification of Antuna et al.15 describes deficiencies in glenoid bone. It is based on the face-on appearance of the glenoid at operation and can therefore not be applied preoperatively.

Severe erosion of the bony glenoid can occur quite rapidly with loosening of the glenoid component (Figs 1 and 2).

In this paper we propose a new method of classifying bone loss of the glenoid: we also assess its validity.

Materials and Methods
The classification system. Anteroposterior (AP) and axial radiographs of the shoulder are needed to evaluate the bony glenoid. If it is not possible to carry out an axial view because the shoulder is stiff, a modified axial view can be taken.16 CT images can also be used of which horizontal and coronal plane images are the most useful.

The two anatomical reference points we use are the most medial point of the spino-glenoid notch and the most lateral edge of the base of the coracoid.

If the most medial (or ‘lowest’) point of the intact glenoid articular surface is at the level of, or lateral to the base of the coracoid (Zone 1), the bony glenoid is classified as Type 1 (Figs 3 and 4).

If the most medial (or lowest) point of the intact glenoid articular surface falls between the base of the coracoid and the most medial point of the spino-glenoid notch (Zone 2), the bony glenoid is classified as Type 2 (Figs 3 and 4).

If the most medial (or lowest) point of the glenoid articular surface reaches the level of the spino-glenoid notch or is medial to it (Zone 3), the bony glenoid is classified as Type 3 (Figs 3 and 4).

Internal validity. Inter- and intra-observer validity testing was undertaken by three assessors. One was a senior orthopaedic registrar (GK), one a consultant orthopaedic surgeon (DST), and the third a consultant radiologist trained in musculoskeletal radiology (KJF).

To test internal validity, 41 shoulders (39 patients) were randomly selected.

Our method for random selection throughout this study was as follows. From the Nottingham Shoulder Database we identify the eligible patients and then each patient is assigned a number. Then we use a random number generator to select the patient.
The selected group included 19 shoulders with a radiologically normal glenoid and 22 shoulders with either a TSA with a loose or stable glenoid component, a hemiarthroplasty or osteoarthritis/rheumatoid arthritis with glenoid erosion. Both a CT scan and a complete series of plain radiographs of the affected shoulder had to be available and obtained no further than six months apart. All imaging data was anonymised and the assessors were blinded to patient data.

Each assessor assigned a type (1 to 3) to the set of anonymised plain radiographs for all 41 shoulders. Two weeks later these were repeated on the anonymised set of CT scan images. A further two weeks later all anonymised plain radiographs were again assigned a type and yet another fortnight later these were repeated on the anonymised CT scans. All together this gave four sets of types per assessor, two carried out on plain radiographs four weeks apart, and two on CT scans.

To assess intra-observer reliability, correlation was established for each assessor between the first and second sets of radiographs and then between the first and second CTs. The type assessed from the radiographs was then compared with the type assessed from the CTs for each assessor, to evaluate the relative reliability of the radiographic and CT systems of typing.

For inter-observer reliability, the types determined from the radiographs and CTs were compared between assessors. As radiographs are known to be subject to projectional errors we also took a set of axial radiographs of a human scapula mounted on a radiolucent stand in different degrees of rotation. We started from the standard, well-positioned axial view and then rotated the scapula clockwise and anticlockwise by 10° and 20° along the sagittal axis, taking images in each position. We then repeated this with the scapula tilted forwards and backwards by 10° and 20°, acquiring axial images in each position. In all, we obtained 25 radiographs which we assessed for projectional errors and distortion.

External validity. A total of 130 patients were randomly selected from our TSA Database. The case mix predominately included patients with a Nottingham TSA (Biomet UK Ltd.), at various lengths of follow-up. Patients had to have adequate radiographs of their shoulder available and a matching Constant score\textsuperscript{17,18} (recorded within one month before or after the radiographs) with the pain score element of the Constant score separately recorded. One patient was excluded from the analysis due to a missing Constant score. All confidential data was removed before data analysis was carried out.

The 129 cases were assessed by GK using our new glenoid typing, with 14 identified as Type 1, 99 as Type 2, and 16 as Type 3.

All patients (24) who had undergone revision with impaction grafting between July 2000 and March 2012 were identified. Pre-revision radiographs were reviewed to assess if the severity of the erosion found during surgery had been reflected by the pre-operative glenoid type.

Statistical analysis. SPSS v21.0 software (IBM Corporation, Armonk, New York) was used for all analyses. The intra- and inter-observer reliability were assessed by calculating the weighted Kappa statistics. External validity was examined with Kruskal-Wallis analysis of variance was performed with post hoc tests.

Results

Internal validity. Intra- and inter-observer reliability of our classification indicated a high degree of reproducibility and reliability. The worst Kappa value for intra-observer reliability was 0.838 (standard error (SE) 0.076). The worst Kappa value for inter-observer reliability was 0.714 (SE 0.094). For further details please refer to Table I and Table II.

In terms of projectional distortion, the radiographic images of the scapula in different rotational positions showed that the relative position of the glenoid surface and the spino-glenoid notch was easily and reliably identifiable. The relative position of the lateral base of the coracoid and the glenoid surface was, however, difficult to assess at the extremes of rotation. With reasonably well-positioned radiographs with no more than 10° rotation in any direction, the identification of the lateral base of the coracoid and the glenoid surface was not difficult.

External validity. There was no significant relationship between Constant score and glenoid type (p = 0.213, p > 0.05). That is, the Constant scores of patients with a Type 3 glenoid were not significantly worse than those of patients with a Type 1 or Type 2 glenoid.

There was, however, a significant association between the pain element of the Constant score and glenoid type (Kruskal-Wallis with post hoc tests). Patients with a type 3 glenoid had a significantly higher mean pain score and those with a Type 2 glenoid (p = 0.014, p < 0.05). There was no significant difference between the pain scores of patients with a Type 1 and a Type 2 glenoid (p = 0.209, p > 0.05). The pain scores of patients with a Type 3 glenoid...
were significantly worse than those with a Type 1 glenoid (p = 0.012, p < 0.05).

We selected 24 patients in whom the degree of bone loss from the glenoid was such that implanting a glenoid component had not been possible, and impaction grafting was performed as a salvage procedure. In each case, the preoperative radiographs showed a Type 2 or Type 3 glenoid. Due to the small sample size, statistical analysis could not be carried out.

Discussion

The justification for the existence of any classification is to assist in management of the patient. Our classification can guide surgeons in their choice of the most appropriate surgical technique, and also indicate the need for further imaging.

A Type 1 glenoid should allow a relatively straightforward TSA: further imaging is rarely needed and any possible adjustments are usually correctable by preferential reaming. This group is usually classified as Walch A1: this recommendation is consistent with the currently accepted concepts.1

A Type 2 glenoid usually requires bone grafting. Structural bone grafting appears to be the most logical option as there is usually sufficient bony support to anchor the implant: preferential reaming would cause too much mediatisation and bone loss. An augmented glenoid component19 or the use of a non-standard glenoid component20 may also be options. Other means of structural support (for example a custom-made implant) should also be considered. Further imaging is advisable. These recommendations are also consistent with the currently accepted concepts.1

A Type 3 glenoid is too small for the safe and stable mounting of most currently available glenoid components, and impaction bone grafting should be considered as a salvage procedure.21,22 Further imaging should be part of the mandatory evaluation for these patients.

Figures 3 and 4 show a clinical example of a Type 1 glenoid, Figures 5 and 6 a Type 2 glenoid and Figures 7 to 9 a Type 3 glenoid.

The rationale behind our classification is summarised as follows:

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**Table I. Intra-observer reliability for the three raters**

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<tr>
<th>Assessor</th>
<th>Assessed</th>
<th>Kappa</th>
<th>Standard error</th>
<th>p-value</th>
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<td>JF</td>
<td>Radiograph1 vs Radiograph2</td>
<td>0.883</td>
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<tr>
<td>GK</td>
<td>Radiograph1 vs Radiograph2</td>
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<td>0.076</td>
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<tr>
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**Table II. Inter-observer reliability for the three raters**

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<th>p-value</th>
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<tr>
<td>DT vs GK</td>
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Reliable reference points are needed for the accurate assessment of the extent of bone damage and the dimensions of the remaining glenoid. The shape and the variability of the anatomy of the bony scapula is only part of the problem. A reference point has to be easily identifiable on pre-operative imaging and anatomically and surgically relevant. Although other classifications describe the most important morphological features of glenoid erosion, they do not describe how much of the glenoid remains available at revision. Our classification uses the spino-glenoid notch as the basic reference point, and we propose this for important anatomical reasons.

A precise analysis of the osseous anatomy of the scapula was carried out by von Schroeder et al. They found that the mean dimensions of the bony glenoid were 29 mm (standard deviation (SD) 3 mm) in the AP direction and 36 mm (SD 4 mm) in the infero-superior (IS) direction at the level of the face of the glenoid. The AP thickness of the neck of the scapula 1 cm from its surface was a mean of 22 mm (SD 4 mm). The AP thickness of the neck of the scapula 2 cm from the surface was a mean 12.9 mm (SD 3). The last value was 11.0 mm (SD 1.8) in women and 14.5 mm (3.5) in men. This indicates a rapid fall in the AP dimension of the neck of the scapula from the articular surface of the glenoid to the spino-glenoid notch (Fig. 10).

In practice, this means that if the remaining intact articular surface of the glenoid is at the level, or medial to the spino-glenoid notch, it may be impossible to implant a glenoid component or even a stable structural bone graft, because the glenoid is too narrow. As there is no evidence in the literature about how much bony support is needed for a glenoid component to be considered stable, we base this observation our own experience with 24 cases of revision shoulder arthroplasty in patients with a type 3 glenoid in
which re-implantation of a glenoid component proved to be impossible (unpublished data). Under these circumstances, impaction bone grafting may be the salvage procedure of choice. Figure 7 and 8 show a Type 3 glenoid in which the deepest point of the erosion has reached the spino-glenoid notch.

The other reference point chosen was the lateral aspect of the base of the coracoid. This point has been proposed before as reference point but on the basis of a different concept.26

If the articular surface of the glenoid is lateral to the lateral aspect of the base of the coracoid, the neck of the scapula is of good width, and implanting the glenoid component should not be too difficult. Figures 3 and 4 show a Type 1 glenoid.

CT images can also be used to classify the type of glenoid as the reference points can be clearly identified. For patients with a Type I glenoid a CT scan is unnecessary. Patients with a Type 2 or 3 glenoid the extent of the bone loss often makes it necessary to carry out a CT scan.

In cases of posterior erosion of the glenoid, the assessment follows the general rule that the medial point of the defect needs to be considered as the reference point for classification.

Distortion and magnification can be a problem with radiographs. Our classification avoids that pitfall as it is based on reference points instead of measurable distances. In this study we found that with reasonably accurate, well positioned, good quality radiographs, the classification is reliable, as is shown by the excellent correlation between radiographs and CT images. As CT images are free from projectional distortion, we believe that comparing the results of classification by radiographs to those acquired from CT images is a reliable method for validation. Our radiographic-based study on projectional error also suggests that this method is reliable.

We found good inter-observer reliability. The three assessors agreed that the classification was easy to use.

When uncertainty existed between the types we recommend that the glenoid is classified as the worse of the two types.

Our results show that significant bone loss and medialisation of the glenoid is accompanied by increased pain, although we could not confirm a significant change in the full Constant score for patients in each group. We believe this is the consequence of the complexity of the measures used by the Constant score. Other published scores have not, to our knowledge, been correlated with any clinical score.

We must stress that this method was primarily designed for pre-operative planning and recognise the limitations of our study. Several other factors, such as bone loss during removal of the old components may also have an impact on the amount of bone remaining for implantation of a glenoid component. We acknowledge we have not carried out a correlation analysis between the extent of glenoid erosion and an achievable revision glenoid arthroplasty, as this needs a prospective study design.

Our classification of glenoid bone loss was devised as an aid to primary and revision shoulder arthroplasty and to give guidance on the need for further imaging. It has good intra- and inter-observer reliability, as well as good correlation between the results of classification by plain radiographs and CT images. It also shows correlation with the patients’ perception of pain.

We offer this classification as a tool to aid the pre-operative planning of revision surgery of the glenoid.

Author contributions:
G. Kocsis: Basic concept of paper, design of study, radiology assessment, data evaluation, writing of paper.
D. S. Thyagarajan: Discussion of concept, radiology assessment, review of data analysis, writing of paper.
K. J. Fairbairn: Discussion of concept, radiology assessment, review of data analysis, writing of paper.
W. A. Wallace: Design of research programme for PhD, supervision of PhD, general guidance on research methodology, editing of paper.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

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References


