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ORIGINAL ARTICLE

Virtual reconstruction of glenoid bone defects using a statistical shape model

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Background: Description of the native shape of a glenoid helps surgeons to preoperatively plan the position of a shoulder implant. A statistical shape model (SSM) can be used to virtually reconstruct a glenoid bone defect and to predict the inclination, version, and center position of the native glenoid. An SSM-based reconstruction method has already been developed for acetabular bone reconstruction. The goal of this study was to evaluate the SSM-based method for the reconstruction of glenoid bone defects and the prediction of native anatomic parameters.
Methods: First, an SSM was created on the basis of 66 healthy scapulae. Then, artificial bone defects were created in all scapulae and reconstructed using the SSM-based reconstruction method. For each bone defect, the reconstructed surface was compared with the original surface. Furthermore, the inclination, version, and glenoid center point of the reconstructed surface were compared with the original parameters of each scapula.
Results: For small glenoid bone defects, the healthy surface of the glenoid was reconstructed with a root mean square error of 1.2 ± 0.4 mm. Inclination, version, and glenoid center point were predicted with an accuracy of 2.4° ± 2.1°, 2.9° ± 2.2°, and 1.8 ± 0.8 mm, respectively.
Discussion and conclusion: The SSM-based reconstruction method is able to accurately reconstruct the native glenoid surface and to predict the native anatomic parameters. Based on this outcome, statistical shape modeling can be considered a successful technique for use in the preoperative planning of shoulder arthroplasty.
Level of evidence: Basic Science Study; Computer Modeling

Keywords: Glenoid bone defects; shoulder arthroplasty; virtual reconstruction; preoperative planning; statistical shape modeling; reconstruction performance; anatomic parameters

Shoulder implants are commonly used to treat patients with an arthritic glenoid and to restore the function of the shoulder joint.[1,9,22] The inclination, version, and position of the glenoid implant are generally known to affect stability

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and range of motion of the shoulder joint.[2,12,15,23] Assessment of the original inclination, version, and glenoid center position is thus an important factor in the surgical planning of shoulder joint replacements.[18] A virtual glenoid bone reconstruction allows estimation of these parameters and supports surgeons in the preoperative planning of shoulder implants.

Currently, several techniques exist to assess the native shape of a glenoid. The most common method is to use the contralateral bone as a template.[5,6,10] Glenoid arthritis, however, is often reported on both sides, therefore making this method not usable. Moreover, in general, only a unilateral scan is taken to avoid the extra radiation dose. To overcome these limitations, Scalise et al[24] used a standard model of the healthy glenoid vault as a template to estimate glenoid version. Although this template does not take into account glenoid shape variability, it was able to predict glenoid version with a mean accuracy of 3.68° on a data set of 19 arthritic scapulae.[9] Besides template-based methods, the native glenoid parameters can also be assessed using correlations between scan measurements. Ganapathi et al[9] found that the anterior glenoid wall angle and the Resch angle of a pathologic glenoid could predict the native glenoid version using a linear regression model. On the same data set of 19 arthritic scapulae, the anterior glenoid wall angle and Resch angle models were able to assess the native glenoid version with a mean error of 3.23° and 4.70°, respectively. Hence, both template-based methods and measurement-based methods can be used to predict glenoid version of an arthritic scapula with similar accuracies. The disadvantage of these methods, however, is that their current use is limited to version estimation only.

A statistical shape model (SSM) can also be used for the reconstruction of a glenoid bone defect and the prediction of glenoid inclination, version, and center point position. An SSM is a mathematical model that represents the mean shape of a population and shape variations in that population. Vanden Berghe et al[25] proposed an SSM-based reconstruction method for the acetabulum and evaluated the prediction of anatomic hip joint parameters. The acetabular center point and plane direction were reconstructed with a mean accuracy of 3.5° ± 1.9° and 3.0 ± 1.3 mm, respectively. Although this SSM-based reconstruction approach should at least in theory be applicable to glenoid bone defects, its use has not yet been evaluated. Therefore, this paper aimed to assess the performance of an SSM-based reconstruction method on glenoid bone reconstruction and anatomic parameter prediction.

Materials and methods

Data set and SSM construction

A set of 66 healthy and unpaired scapulae was selected by an experienced surgeon and used to construct the SSM. Only scapulae without glenohumeral arthropathy signs were included. The scapula scans were segmented in the image processing software Mimics (Materialise, Leuven, Belgium) and converted to 3-dimensional models, with a mean triangular edge length of 1.5 mm. The SSM was created in 3 subsequent steps (Fig. 1), as described in Vanden Berghe et al,[25] using MATLAB (MathWorks, Natick, MA, USA). First, one model of the data set was registered to all other models to obtain corresponding surfaces.[3] Second, the models were aligned to exclude all translational and rotational variations.[11] No scaling was performed to maintain the size information of the models. Finally, the mean shape and the shape variations of the models were extracted by performing a principal component analysis.

SSM-based reconstruction method

Using statistical shape modeling, a deformed scapula can be reconstructed by the method proposed by Vanden Berghe et al (Fig. 2).[25] This method assumes that the native shape of a deformed scapula can be predicted by extrapolating the shape of its unaffected or healthy parts. The reconstruction method consists of 2 steps. First, the deformed parts of the scapula are manually removed using the modeling software 3-matic (Materialise). Then, the SSM is fitted to the remaining healthy structures of the scapula using MATLAB. The proposed fitting algorithm optimizes the shape coefficients of the SSM one by one to minimize the distance between the SSM and the healthy parts of the scapula.[25] As explained in Vanden Berghe et al,[25] only the most prominent shape variations are optimized while using one or more iterations. A sensitivity analysis was performed to select an optimal number of shape variations and iterations for the fitting.

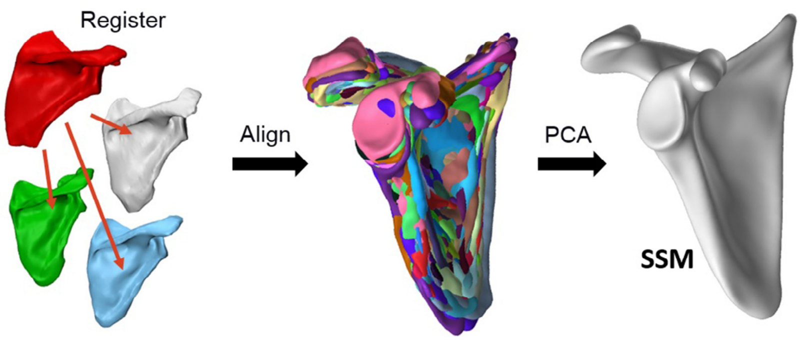

Figure 1 The subsequent steps in the creation of a statistical shape model (*SSM*). *PCA*, principal component analysis.