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Original article

# Three dimensional scapular prints for evaluating glenoid morphology: An exploratory study☆

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ABSTRACT

*Background:* Computerised Tomography (CT) scans are conventionally employed to assess the glenoid morphology prior to total shoulder arthroplasty (TSA). This study explores the role of three-dimensional (3D) models for assessing glenoid morphology.
*Methods:* CT scans of 32 patients scheduled for TSA were reconstructed to scapular models using customised software and a desktop 3D printer. The size and aspect ratios were maintained. Glenoid version, glenoid maximum height and width, and the maximum acromion antero-posterior (AP) length were compared between the models and CT scans.
*Results:* The models were an accurate qualitative reflection of scapular anatomy. The average retroversion in 3D models was 8.19°±30.8° compared to 10.26°±42.5° in scan images. The mean difference was 2.07°±24.6° (p=0.408). However, the mean absolute error was 5.02°±12.3°. The mean difference of the glenoid maximum width and the acromion maximum AP length was 0.22±3.33mm (p=0.862) and 0.32±14.12mm (p=0.213) respectively. However, the mean difference was significant for the glenoid maximum height measuring 3.67±12.04mm with p=0.004. The correlation between the examiners was high for all parameters, with intraclass correlation ranging between 0.94 and 0.99.
*Conclusion:* 3D printing technology promises to be a useful tool for preoperative planning with accurate reproduction of transverse plane anatomy. 3D prints represent superior definition of reconstructed anatomical measures such as glenoid height as compared to conventional CT Scans.



## 1. Introduction

Accurate assessment of the glenoid dimensions and morphology should be performed prior to performing TSA.[1] Conventional plain shoulder radiographs are deficient in assessing the glenoid version and thus may misrepresent the accurate three-dimensional anatomy of the glenoid due to the scapula composition and its variations in positioning, the projection errors and the overlapping bones.[2,3]

2D CT scans measure glenoid dimensions and version more accurately. However, the accuracy of the measurements depends on the position of the scapula at the time of obtaining the scan, since any rotation of the scapula may change the glenoid version by up to 10°.[4] Hoenecke et al [5] demonstrated that the use of CT scan prior to TSA is vital in the planning of this surgery. They found out that 2D CT images are not as accurate as 3D CT reconstructions and recommended the use of the latter to fully assess the glenoid prior to TSA. Similarly, Kwon et al[3] noted the advantage of using 3D reconstruction as it reflects the true shape and dimensions of the glenoid

Several studies have shown that glenoid component loosening is the most common mid-term and long-term complication of Total Shoulder Arthroplasty (TSA), leading to loss of shoulder function, shoulder pain and in some cases the need for revising the surgery.[1,6] The glenoid version directly affects the humeral head displacement and the biomechanics of the glenoid component.[7] Moreover, glenoid retroversion leads to increased asymmetric posterior load on the glenoid surface, which in turn leads to increased stress and micro-motion, negatively affecting the biomechanics of TSA and increasing the risk of glenoid component loosening.[8] Therefore, glenoid retroversion correction is vital for the planning of TSA. This correction is usually achieved by eccentric reaming of the glenoid fossa during TSA surgery. This reaming is aimed to fulfil three main objectives: rectifying the glenoid version, creating complete contact between the prosthesis and the underlying bone, and maintaining adequate bone stock for secure

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glenoid embedding.[9] However, excessive reaming of the glenoid may lead to significant bone loss, hence perforation and failure of the glenoid component.[10,11] Retroversion can also be corrected by posterior cement adjustment or bone grafting which is recommended for retroversion greater than 15°.[11]

Three dimensional (3D) prototyping is a cutting edge technology through which specialised printers produce a three dimensional replica of a previously prepared 3D digital design. Rengier et al [12] summed up the stages of 3D printing in the context of medical imaging into three stages: The first is image acquisition that can be done by computed tomography, magnetic resonance imaging, ultrasonography and Positron Emission Tomography. The second step is image post-processing, where the acquired images are segmented using specialised 3D computer software, then changed into a format readable by the printer, such as Computer Aided design (CAD) software. The final step is 3D prototyping, where the scanned object is structured by ultra-thin layers of a material that is used to form the solid subject. This technology has been used in orthognathic surgery,[13] as well as in neurosurgical [14] and cardiovascular pre-operative planning.[15]

In this exploratory study, we used three dimensional printing technology to create scapular 3D models, using the CT scan images, of patients who underwent TSA. The aim was to explore how this technology can be incorporated into the pre-operative planning for TSA in assessing the glenoid morphology, and to compare results of printed scapular 3D models with the conventional CT scan.

## 2. Methods and materials

This research project was approved by the Research and Development (R&D) department at the Wrightington, Wigan and Leigh NHS Foundation Trust, UK. Thirty-five patients diagnosed with gleno-humeral arthritis, who had TSA performed in the Upper Limb Unit at Wrightington Hospital between January 2013 and December 2013, were retrospectively selected. Patients had CT scans done between May 2012 and September 2013 at Wrightington, Wigan and Leigh NHS trust. Patients who had previous glenoid fractures or had previous metal work were excluded since the former distorts normal glenoid anatomy while the latter distorts CT images. Thirty two out of the thirty five patients were eligible, seventeen males and fifteen females. Nineteen patients had CT scans done to their right shoulders, while the remaining thirteen had the scans done to their left shoulders. CT scan images were obtained with 1mm slice thickness.

### 2.1. CT scan measurements

The measuring tools in Centricity PACS systems (GE Healthcare) were used to measure the following glenoid parameters: the maximum glenoid antero-posterior length (AP length) corresponding to the distance between the most anterior to the most posterior glenoid surface point in the axial images; the maximum glenoid supero-inferior length (SI length) which was measured in the coronal oblique images and corresponds to the distance between the highest and lowest points of the glenoid fossa; the maximum acromion process antero-posterior length (AP acromion) measured in the axial images, covering the length between the most anterior to the most posterior point of the acromion; and the glenoid version which was measured in CT axial slides following the method described by Freidman et al [16] In this method the angle is measured in the axial views between a line drawn perpendicular to the scapular axis and a line representing the glenoid surface that is joining the anterior and posterior glenoid edges. These lines were drawn at the level of the mid glenoid which is determined at 10 slides below the level of the tip of the coracoid, since the CT slide thickness was 1mm.

### 2.2. CT images segmentation

CT scan images of the 32 patients were acquired in DICOM mode. The data acquired was then uploaded to Analyze 11.0 software, using the software's DICOM tool. The bone surfaces were then segmented by using a low threshold at 100 HU (Hounsfield units) and all low density pixels were filtered out. This allowed for the isolation of the bony structures (humerus, scapula, clavicle and scanned ribs) from the soft tissues. The scapulae were subsequently isolated from other bony structures by the "region grow" feature. These segmentations resulted in obtaining the 3D shape of the scapula as shown in Fig. 1.

### 2.3. 3D printing and models production

The obtained 3D digital models of scapula were changed into SteroLithography (STL) format through Analyze software. This file format is supported by most rapid prototyping printers. The desktop printer used was MakerBot Replicator 2®, it uses Fused Deposition Modeling (FDM) technology. The material was Polylactic Acid (PLA) filament. In this technology, the filament is loaded into the printer. The nozzle is heated to a required temperature and

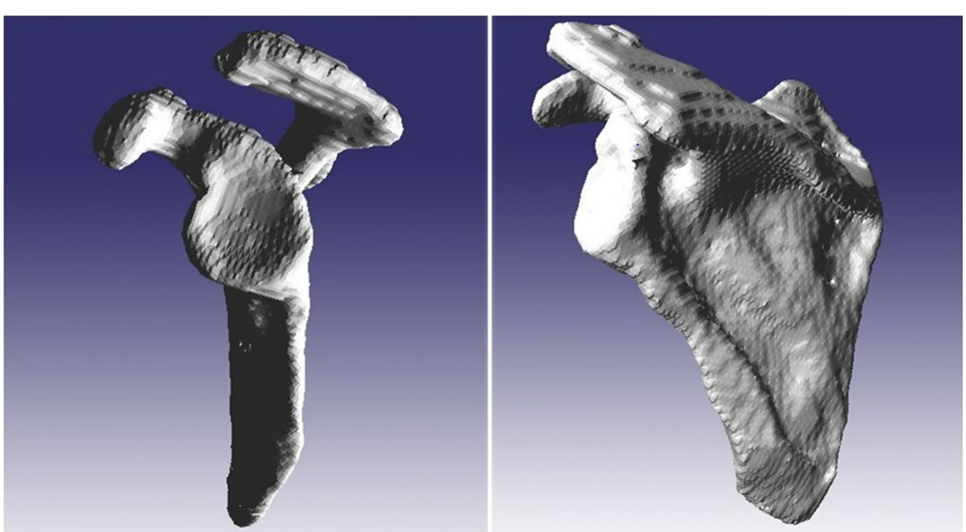

**Fig. 1.** 3D models in STL format after segmenting and rendering.