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THREE DIMENSIONAL GLENO-HUMERAL DEFORMITIES IN OBSTETRIC BRACHIAL PLEXUS PALSY

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SUMMARY

The aims of this study were to quantify the three-dimensional (3D) glenoid version and humeral head migration in children with unilateral obstetric brachial plexus palsy (OBPP). To accomplish this aim, a methodology was created (and its reliability quantified) for the measurement of 3D glenoid-humeral morphology.

INTRODUCTION

OBPP is a complex peripheral nerve injury associated with severe functional limitations and a high probability of early onset osteoarthritis. This nerve injury leads to muscle strength imbalances and contractures, which commonly result in bone deformations such as glenoid retroversion and posterior humeral head migration (HHM) [1]. The functional sequelae of these neuromuscular-skeletal impairments are wide ranging, requiring extension rehabilitation, and may require invasive interventions or surgery.

Although the shoulder joint has a large range of 3D motion, current evaluation and treatment planning for OBPP relies on 2D axial plane measures [2]. Such measures not only ignore the three-dimensionality of the joint, but are difficult to acquire consistently across, as well as longitudinally within subjects. A more reliable, 3D quantification of the skeletal changes associated with OBPP will enable clinicians and surgeons to make more informed interventional decisions while performing rebalancing surgeries and glenoid osteotomies. Thus, the aims of this study were (1) to characterize the 3D glenoid version and HHM and (2) to compare the reliability of the typically used 2D measures and the newly developed 3D measures.

METHODS

Thirteen children with unilateral OBPP (9M/4F, age= 11.8 ± 4.5years, Mallet score=15.1±3.0, 5/8 L/R side involvement) participated in this Institutional Review Board approved study. Both shoulders were scanned generating the data for 26 shoulders. Subjects were placed supine in a 3T magnetic resonance (MR) scanner (Siemens GmBH, Verio, Germany) with the upper arm alongside the trunk and the palm of the hand facing down. One cardiac coil was positioned posterior to the shoulder, and an additional cardiac coil was wrapped around the lateral-anterior aspect of the shoulder. Each shoulder was scanned independently in order to position the shoulder at the scanner's isocenter. A T1-gradient recalled echo sequence was acquired, with all scanning parameters being held constant between subjects, except the field of view (416x312x192 pixels, slice thickness=1.2mm TR=16.6 msec, TE=5.1msec, imaging time=5min 40 sec). A slight variation of pixel resolution across subjects (0.55–0.63mm^2) was allowed to ensure proper resolution for smaller subjects, without excessive scan time for larger subjects. All scans acquired data in volume spanning the distal humerus to the acromion process and the mid-spine to the lateral elbow.

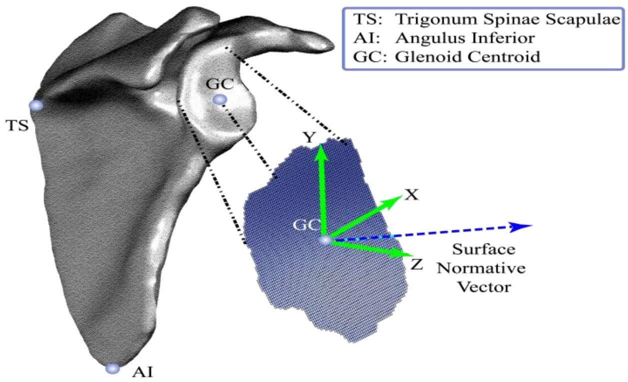

Figure 1: The thin-plate spline (TPS) surface fitted to the glenoid. The orientation of the surface normative vector was expressed in the local scapula coordinate system

Two-dimensional measures of the glenoid antero-posterior (AP) version and humeral head migration (HHM) were determined at the axial slice below the coracoid process [2] using MIPAV (NIH, Bethesda, MD). AP-version was defined as the acute angle between the glenoid line and scapular axes [2]. HHM was measured as the ratio, with a denominator equal to the maximal radius of the humeral head that was orthogonal to the scapular axis and whose numerator was the portion of this line that was anterior to the scapula axis [2].

For the 3D measures, the glenoid bone outlines were first manually segmented and imported in MATLAB (Mathworks Inc., Natick, MA) as a point cloud to which a custom thin-plate spline (TPS) surface was fitted in order to generate a 3D model of the glenoid bone surface [3]. The trigonum spinae scapulae, angulus inferior, and glenoid centroid (GC) were used to define the scapular coordinate system (Figure 1), based on the ISB recommendations

[4].The first two points were visually identified in MIPAV. The GC location was defined as the centroid of the TPS glenoid bone surface model and was set as the origin of the coordinate system. A surface normative vector of the entire glenoid surface was determined using the average direction of all the normals defined by TPS surface grid patch (Figure 1). This vector was used to calculate the antereior-posterior (AP) and superior-inferior (SI) glenoid version in the scapular coordinate system. Finally, a 3D model of the humerus was created by segmenting the outer cortical bone (MIPAV) and wrapping the resulting point cloud with a NURB surface (Geomagic, Research Triangle Park, NC). The humeral head was separated from the shaft at the medial inflection point between the head and shaft. The center of the best fit sphere to the humeral head was then defined as the humeral center (HC). The 3D HHM was defined as distance from GC to HC in the scapula coordinate system, with anterior, superior, and lateral being positive.

Measures were acquired for all shoulders by two independent observers, who were blinded to the side of impairment and to each other's results from image selection to the final measure. Inter-rater reliability was defined by intraclass correlation coefficients (ICCs), using a two-way mixed effects model. Differences between the impaired and non-impaired shoulder were tested using a paired-Wilcoxon signed rank test. P<0.05 was considered significant.

RESULTS-DISCUSSION

In agreement with past results, the impaired glenoid was retroverted (rotated posteriorly, Figure 2). Interestingly, this was accompanied by an inferior version that was nearly identical in magnitude (-7.0°, p=0.02). The inferior glenoid version is a clinically relevant result that has not been recognized in children with OBPP previously. Current surgical techniques often target glenoid retroversion, but do not address the inferior version [5]. Given the mulit-directional nature of glenoid version in OBPP, consideration should be given to adapting surgical techniques to simultaneously address both pathological posterior and inferior version. This combined approach would provide a full 3D correction of the glenoid deformation and may help achieve better functional outcomes.

The humeral head center was migrated posteriorly in the affected arm for both the 2D (difference between sides = 20.8%, p=0.002) and 3D measures (Figure 2), consistent with previous studies [2]. Direct comparison of 3D to the 2D measures is complicated by the fact that 2D measures are expressed in percent values. More importantly, the 3D analysis demonstrated that this migration was significantly inferior (3.6mm) and medial (3.2mm), as well. Work is ongoing to determine if scaling could help provide further consistency in the 3D HHM measures. The etiology of the inferior migration is likely to be multifactorial. For example, subscapularis contracture has been shown to be correlated to posterior glenoid migration [6] and may be a component of the inferior migration In addition, muscle weakness and imbalance in the deltoid, pectoralis major and rotator cuff muscles along with humeral head deformation may also be contributing factors. As with version, interventions targeting humeral head migration should be expanded to include the complete 3D migration.

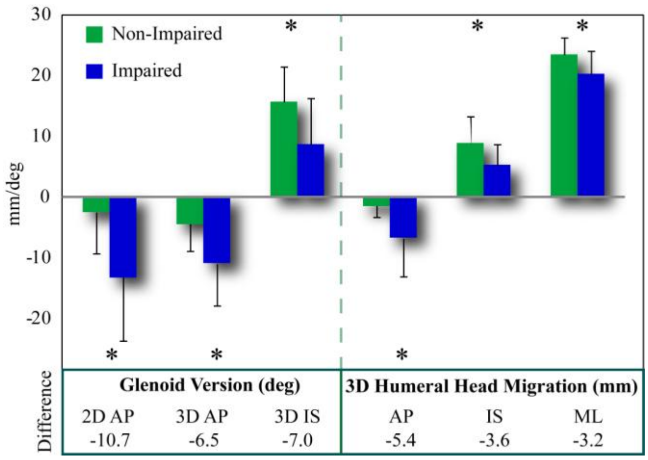

Figure 2: Glenoid Version (2D and 3D) and 3D Humeral Head Migration. AP: anterior-posterior, IS: inferior-superior, ML: medial-lateral. *p<0.05.

The inter-rater reliability was better for the 3D (ICC: 0.97-0.98), relative to the 2D (ICC: 0.66-0.73) measures. The standard error of measurement (SEM) for all 2D measures were greater than 3D measures (e.g, the SEM of 3D glenoid AP version in the impaired side was 1° where as it was 3.34°). These differences may be explained by the fact that the 2D analysis used a single slice and the measures relied heavily on specific anatomical landmarks, which may be difficult to identify in pathology; whereas the 3D measures used the entire glenoid (or glenoid-humeral) surfaces and were quantified using quantitative mathematical definitions.

Although the 3D measures, at first glance, may appear to be difficult to acquire, in reality the data is already available to clinicians, as most pre-surgical planning includes a CT of the impaired shoulder. Unlike the MRI used in the current study (chosen to eliminate the exposure to radiation), CT scans provide automatic segmentation of the bones. Thus, with computational codes that are readily available, the current 3D analysis can be quickly and easily carried out using these 3D pre-surgical CTs.

CONCLUSION

This study presents a novel 3D quantification of glenoid and gleno-humeral bone deformities in children with OBPP, with the results that have immediate implications for surgical planning. Previous studies and surgical planning have relied on purely 2D measures that could not capture the full joint deformity. Besides providing a more complete definition of the glenoid-humeral joint deformation, the vastly improved reliability of the 3D method demonstrates that these measures are superior for longitudinal follow-up and surgical planning than their 2D counter-parts.

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