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Three-dimensional humeral morphologic alterations and atrophy associated with obstetrical brachial plexus palsy

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Background: Obstetrical brachial plexus palsy (OBPP) is a common birth injury, resulting in severe functional losses. Yet, little is known about how OBPP affects the 3-dimensional (3D) humeral morphology. Thus, the purpose of this study was to measure the 3D humeral architecture in children with unilateral OBPP.
Methods: Thirteen individuals (4 female and 9 male patients; mean age, 11.8 $\pm$ 3.3 years; mean Mallet score, 15.1 $\pm$ 3.0) participated in this institutional review board approved study. A 3D T1-weighted gradient-recalled echo magnetic resonance image set was acquired for both upper limbs (involved and noninvolved). Humeral size, version, and inclination were quantified from 3D humeral models derived from these images.
Results: The involved humeral head was significantly less retroverted and in declination (medial humeral head pointed anteriorly and inferiorly) relative to the noninvolved side. Osseous atrophy was present in all 3 dimensions and affected the entire humerus. The inter-rater reliability was excellent (intraclass correlation coefficient, 0.96-1.00).
Discussion: This study showed that both humeral atrophy and bone shape deformities associated with OBPP are not limited to the axial plane but are 3D phenomena. Incorporating information related to these multi-planar, 3D humeral deformities into surgical planning could potentially improve functional outcomes after surgery. The documented reduction in retroversion is an osseous adaptation, which may help maintain glenohumeral congruency by partially compensating for the internal rotation of the arm. The humeral head declination is a novel finding and may be an important factor to consider when one is developing OBPP management strategies because it has been shown to lead to significant supraspinatus inefficiencies and increased required elevation forces.
Level of evidence: Anatomic Study, Imaging.

Keywords: Reliability; magnetic resonance imaging; shape; retroversion; version; inclination

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Obstetrical brachial plexus palsy (OBPP) is a common birth injury, occurring in approximately 3 of every 1,000 births.[3,26,29,37] Children who do not recover completely are left with shoulder muscle imbalance, contracture, disuse, and significant glenohumeral deformities.[20,23,40,41,50] The persisting sequelae are wide-ranging, severely restrict the arm function, limit activities of daily living independence,[43] and reduce the quality of life for patients and their caregivers.[31,43] Because of the severity of these persistent sequelae, many children and adolescents with OBPP require extensive rehabilitation and are often referred for invasive interventions and/or surgery.[1,12,32,47] Enhanced knowledge of how the sequelae associated with OBPP affect the 3-dimensional (3D) humeral architecture will likely support improved efficacy of OBPP management strategies.

Two-dimensional (2D) glenoid retroversion and glenohumeral subluxation have been well studied in OBPP,[10,21,24,27,34,37] but few studies have quantified humeral deformity in isolation. The studies that have focused on humeral pathology showed atrophy[28,37,38] and "retroversion" on the involved side.[46] These studies were limited to 2D axial- or sagittal-plane analyses. As such, even though humeral deformity is complex and likely 3-dimensional, surgical procedures, such as humeral derotation osteotomy[2,36,48,51] and humeral head relocation,[36] are being recommended based on limited 2D knowledge. Thus, it is imperative to fill the knowledge gap with regard to how the neurologic deficits arising from this birth injury ultimately result in pathologic humeral shape. For example, humeral head inclination (equivalent to the femoral neck-shaft angle) has not been measured in children with OBPP. This is a potentially large oversight because changes in humeral head inclination have been shown to limit shoulder function[49] and restoring correct 3D humeral morphology is considered crucial for successful shoulder arthroplasty.[17,18,25,39]

Of all the humeral architectural properties, version has been the most well studied, primarily in adults, with a focus on shoulder arthroplasty[6,17,22,25,39] and overuse-induced injuries.[9,52-55] Cadaveric studies have the advantage of direct investigation of the 3D bone surfaces, which cannot be performed in living subjects.[14,15,17,22,25,39] The 2D measures acquired using radiographs, computed tomography (CT), or magnetic resonance (MR) imaging[6,8,13,16,19,46] can be severely affected by the location and orientation of the imaging plane relative to the anatomy studied.[7,16,17,42] Lastly, ultrasound[52-55] is non-ionizing, portable, and less expensive than MR or CT. However, it is a 2D analysis, is highly user-dependent, and relies solely on 2 closely spaced points of the bicipital groove. Thus, it primarily quantifies bicipital groove axial-plane orientation and not humeral head version. Humeral head inclination has been less well studied,[6,56] and measures in typically developing children and children with OBPP are currently unavailable.

The purpose of this study was to develop a noninvasive methodology for measuring the in vivo 3D humeral morphology in individuals with unilateral OBPP and to test the following hypotheses: (1) The involved humeral head shows significantly decreased retroversion. (2) The articular surface of the involved humeral head is rotated inferiorly. (3) The involved humerus is atrophic in all 3 dimensions. For all hypotheses, the patient's noninvolved arm served as the control. As a test of the clinical utility of the humeral architectural measures, the inter-rater reliability was tested. Lastly, the relationship among the morphologic parameters, age, functional/impairment levels, and limits to passive external glenohumeral rotation was investigated to evaluate the feasibility of predicting functional/impairment levels using a multivariate regression analysis.

Methods

Sixteen young patients with unilateral OBPP were recruited for this study. Each child or adolescent provided written assent with a legal guardian providing written consent. One patient was aged 18 years and provided written consent. After consent, a pediatric physiatrist obtained a complete history and performed a physical examination, which included the Mallet score[4,45] and Narakas classification score,[30] along with the passive range of shoulder motion. Three patients declined MR imaging scanning because of fear, complaints of noise, or dizziness and withdrew. The remaining cohort of 13 patients had an age range of 6.7 to 18.7 years (age, 11.8 $\pm$ 3.3 years; height, 154.8 $\pm$ 21.4 cm; weight, 51.8 $\pm$ 16.0 kg; Mallet score, 15.1 $\pm$ 3.0; Narakas score, 2.5 $\pm$ 0.8), with 4 female patients and 5 patients with left-side involvement. The mean differences (impaired – unimpaired) in shoulder passive range of flexion/extension, abduction, and internal/external rotation were $-5° \pm 10°/-45° \pm 17°$, $-11° \pm 21°$, $-17° \pm 22°/-33° \pm -20°$, respectively. For external rotation and extension, all patients showed limited ranges of motion (involved side). For flexion, abduction, and internal rotation, there were no side-to-side differences in 6, 9, and 4 patients, respectively. All other patients showed reduced ranges of motion (involved side).

Before scanning, each participant was given time to acclimate to the scanner. The patient was then placed supine on the plinth of a 3-T MR scanner (Verio: Siemens, Erlangen, Germany) with the arm as close to anatomic position as possible but with the forearm pronated and the palm facing the bed for comfort. A standard cardiac coil was placed on the bed (posterior to the shoulder) while its pair was wrapped around the patient's shoulder and chest. When required, in taller patients, a flexible coil was wrapped around the elbow, maintaining coverage through the distal humerus. No sedatives or anesthesia were used. To prevent patient or coil movement during scanning, sandbags were placed alongside the arm and a large supportive strap was gently secured around the coils and chest. Both the impaired and unimpaired arms were scanned, but the scans were acquired independently, enabling the shoulder to be positioned at the MR isocenter. A T1-weighted gradient-recalled echo sequence was acquired for each shoulder. With the exception of the in-plane field of view, all scanning parameters were held constant across patients (416 $\times$ 312 $\times$ 192 pixels; slice thickness, 1.2 mm; repetition time, 16.6 milliseconds; echo time, 5.1 milliseconds; imaging time, 4 minutes 22 seconds). This resulted in a slight variation in the in-plane resolution across patients (range, 0.55-0.63 mm^2), enabling higher resolution for smaller patients. When needed, a