Normative Humeral Development Through the Arc of Childhood – a 3D MRI Study

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INTRODUCTION: A quantitative understanding of humeral head morphology throughout the arc of pediatric development is crucial in optimizing treatment of shoulder-related orthopedic disorders and athletic overuse injuries in the pediatric population. For example, it generally accepted that the humeral head anteverts throughout childhood, but quantitative data describing humeral size and shape development are not yet available. Thus, the purpose of this study was to define the humeral growth and morphological changes from early infancy to adulthood.

METHODS:

3D gradient recall echo axial MR images of the dominant arm were acquired from typically developing children (9/12 females/males, age 7.3-18.7 years) and from the uninvolved arm in children with unilateral birth related brachial plexus palsy (BRBPP, 20/13 females/males, age 0.6-18.8 years). The humerus was manually segmented from these images to create 3D models. We quantified humeral length, epicondylar width, and head size (the 3 mutually perpendicular radii of the best fit ellipse to the humeral head – R1, R2, R3), along with inclination (the coronal plane angle between R1 (primary radii) and the epicondylar axis) and two measures of version (Fig 1,2). The latter were measured as the angle between the epicondylar axis and the primary head radius (Version R1) and the angle between the epicondylar axis and the vector from the center of the bicipital groove to the head center (Version BG_HC). To ensure the measures from the uninvolved limb were not affected by the involved limb in the children with BRBPP, we compared all measures in 11 children with BRBPP to typically developing children, matched by sex, age, and height. A quadratic regression analysis (SPSS ver 20.0.2.0) was used to determine the relationship between each parameter and age.

RESULTS: No differences were found in the matched comparison between the BRBPP and healthy cohorts, demonstrating that size and shape parameters of the uninvolved limb were not affected by the pathological side and could be assumed to follow normative development. Size and anteversion measures all followed a second-order polynomial trend with increasing age, with the linear term being much larger than the quadratic (Table 1). Size measurements had the strongest regressions with age (R1: $R^2=0.909$, $p<0.01$; humeral length: $R^2=0.959$, $p<0.001$; epicondylar width: $R^2=0.894$, $p<0.001$, Fig 3&4). The 3 radii of the best fit ellipse to the humeral head (Fig 3) all followed nearly identical patterns, increasing ~15mm from 6 months to 18 years of age. Version (Fig 4) was more variable and less strongly correlated with age ($R^2=0.316$ to 0.395, $p<0.001$), whereas inclination demonstrated a weak regression with age ($R^2=0.120$, $p=0.05$).

DISCUSSION AND CONCLUSION:

This study is the first to present quantitative 3D data regarding normative humeral shape and size development. Such data provide a foundation for enhanced clinical understanding of and future interventional planning for the upper limb. For example, these data form a basis for implant design and offer a roadmap for developing predictive pediatric upper limb musculoskeletal models. Further, when pathology or overuse is unilateral (e.g. BRPP, single overhand sports), the current growth models will potentially help to identify maladaptive compensations in the unaffected side in the effort to optimize function.

Although it is generally accepted that the humerus anteverts with age, only a moderate and variable relationship was found. This variability should be taken into account when evaluating pathology/injuries leading to alterations in humeral development. The shallow curve fits indicate that there was not a single age where either shape or size reached adult values. Future work is needed to more fully understand what parameters (e.g., sex, activity) contribute to the variability in humeral shape development.

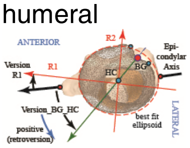
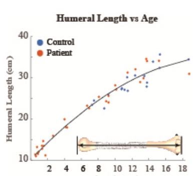


Fig 2: R1, R2, R3: radii of best-fit ellipsoid to the humeral head. VerBG_HC: angle subended by vector between bicipital groove and humeral head centers and epidcondylar axis, VerR1: angle subtended by vector R1 and the epicondylar axis.



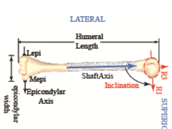
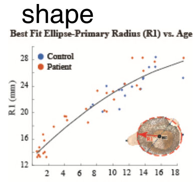


Figure 1: Humeral length: most superior to interior point distance. Shaft axis: central axis of the best-fit cylinder to the humeral shaft. Lepi (Mepi): the most lateral (medial) elbow points.



	Size Parameters				
	R1	R2	R3	Humeral Length	Epicondylar Width
R^2	0.909	0.936	0.918	0.959	0.894
p	<0.001	<0.001	<0.001	<0.001	<0.001

	Shape Parameters		
	Version R1	Version BG-HC	Inclincation
R^2	0.316	0.395	0.12
p	<0.001	<0.001	≤0.05

Table 1: Quadratic Curve Fitting of Humeral Shape and Size with Age
Regression coefficient (R^2) and p-values listed.