**Name of Journal:** *World Journal of Orthopedics*

**Manuscript NO:** 41636

**Manuscript Type:** ORIGINAL ARTICLE

***Observational Study***

**Humeral retroversion and shoulder muscle changes in infants with internal rotation contractures following brachial plexus birth palsy**

van de Bunt F *et al.* Humeral retroversion alterations in infants with BPBI

Fabian van de Bunt, Michael L Pearl, Tom van Essen, Johannes A van der Sluijs

**Fabian van de Bunt**, **Tom van Essen, Johannes A van der Sluijs**, Department of Orthopedics, Amsterdam UMC, VU University Medical Center, Amsterdam 1081 HV, Netherlands

**Michael L Pearl**, Department of Shoulder and Elbow Surgery, Kaiser Permanente Medical Center, Los Angeles, Ca 90027, United States

**ORCID number:** Fabian van de Bunt (0000-0002-4169-0322); Michael L Pearl (0000-0003-3407-481X); Tom van Essen (0000-0001-9256-9269); Johannes A van der Sluijs (0000-0002-9879-8908).

**Authorship:** All authors made significant contributions to the manuscript, conform the standard proposed by the ICMJE.

**Author contributions:** van de Bunt F made the study design, data collection, analysis and interpretation of data, writing of (the firstdraft) of the manuscript, critical evaluation of the intelligent content of thefinal version;Pearl ML made the study design, interpretation of data, writing of themanuscript, critical evaluation of the intelligent content of the final version; van Essen T made the data collection, analysis and interpretation of data, writing of (the firstdraft) manuscript; van der Sluijs JA made the study design, interpretation of data, writing of the manuscript, critical evaluation of the intelligent content of the final version.

**Institutional review board statement:** We are pleased to confirm that the Medical Research Involving Human Subjects Act (WMO) does not apply to the above-mentioned study and that an official approval of this study by our committee is not required.

**Informed consent statement:** We received an IRB waiver from the Institutional review board since this was a retrospective observational study, utilizing MRI scans made strictly for clinical purposes. MRI’s were all anonymized by the Radiology department before conducting our study. See the attached IRB statement.

**Conflict-of-interest statement:** The authors whose names are listed immediately below certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers’ bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

**STROBE Statement:** The authors have read the STROBE Statement-checklist of items, and the manuscript was prepared and revised according to the STROBE Statement-checklist of items.

**Open-Access:** This article is an open-access article which was selected by an in-house editor and fully peer-reviewed by external reviewers. It is distributed in accordance with the Creative Commons Attribution Non Commercial (CC BY-NC 4.0) license, which permits others to distribute, remix, adapt, build upon this work non-commercially, and license their derivative works on different terms, provided the original work is properly cited and the use is non-commercial. See: http://creativecommons.org/licenses/by-nc/4.0/

**Manuscript source:** Unsolicited manuscript

**Correspondence to: Fabian van de Bunt, MD, MSc, Doctor, MD,** Department of Orthopedics, Amsterdam UMC, VU University Medical Center, De Boelelaan 1117, Amsterdam 1081HV, Netherlands. [fabianvdbunt@gmail.com](mailto:fabianvdbunt@gmail.com)

**Telephone:** +31-64-8482593

**Received:** August 22, 2018

**Peer-review started:** August 22, 2018

**First decision:** October 4, 2018

**Revised:** October 16, 2018

**Accepted:** November 15, 2018

**Article in press:**

**Published online:**

**Abstract**

***AIM***

To examine humeral retroversion in infants who sustained brachial plexus birth palsy (BPBI) and suffer from an internal rotation contracture. Additionally, the role of the infraspinatus (IS) and subscapularis (SSc) muscles in the genesis of this bony deformation is explored.

***METHODS***

Bilateral magnetic resonance imaging (MRI) scans of 35 infants (age range: 2-7 mo old) with BPBI were retrospectively analyzed. Retroversion was measured according to two proximal axes and one distal axis (transepicondylar axis). The proximal axes were: (1) the perpendicular line to the borders of the articular surface (humeral centerline); and (2) the longest diameter through the humeral head. Muscle cross-sectional areas of the IS and SSc muscles were measured on the MRI-slides representing the largest muscle belly. The difference in retroversion was correlated with the ratio of muscle-sizes and passive external rotation measurements.

***RESULTS***

Retroversion on the involved side was significantly decreased, 1.0° *vs* 27.6° (1) and 8.5° *vs* 27.2° (2), (*P* < 0.01), as compared to the uninvolved side. The muscle size of the SSc and IS muscles on the involved side was significantly decreased, 2.26 cm² *vs* 2.79 cm² and 1.53 cm² *vs* 2.19 cm², respectively (*P* < 0.05). Furthermore, muscle ratio (SSc/IS) at the involved side was significantly smaller compared to the uninvolved side (*P* = 0.007).

***CONCLUSION***

Even in our youngest patient population, humeral retroversion has a high likelihood of being decreased. Altered humeral retroversion warrants attention as a structural change in any child under evaluation for the treatment of an internal rotation contracture.

**Key words:** Humeral retroversion; Infants; Brachial plexus; Brachial plexus neuropathies; Shoulder; Humerus

**© The Author(s) 2018.** Published by Baishideng Publishing Group Inc. All rights reserved.

**Core tip:** This study examines humeral retroversion in infants who sustained neonatal brachial plexus palsy and suffer from an internal rotation contracture. The existing common treatment options all strive for better function of the upper extremity through an improved position of the hand in space. Therefore, a thorough understanding of the development of the pathogenesis of this injury is of importance. We found a significant reduction of humeral retroversion in our study group (mean difference 26.8). When treatment becomes warranted and contralateral humeral version measurements differ greatly, a humeral derotational osteotomy probably offers the best improvement regarding the position of the hand.

van de Bunt F, Pearl ML, van Essen T, van der Sluijs JA. Humeral retroversion and shoulder muscle changes in infants with internal rotation contractures following brachial plexus birth palsy. *World J Orthop* 2018; In press

**INTRODUCTION**

The most common musculoskeletal sequela of the neurologic injury of brachial plexus birth palsy (BPBI) is an internal rotation contracture of the shoulder. This contracture is frequently associated with deformity of the glenohumeral joint[1–5]. These bony deformities have been thought to be a consequence of abnormal muscular development[6-8].

The internal rotation contracture secondary to BPBI has been associated with alterations of humeral retroversion[9–12]. Previous studies presented opposite findings as both older studies reported an increased humeral version angle[10,11], and more recent studies reported a decrease in humeral retroversion[9,12]. Normal humeral retroversion is greatest at birth and gradually decreases through adolescence[13–15] to adult values averaging between 25-30 with well documented individual variation[16]. One well-studied exception is the throwing athlete, for whom retroversion has been shown to be greater on the dominant throwing side, due to repetitive throwing that usually begins in early childhood[17–21].

The existing common treatment options consist of soft tissue procedures (releases and tendon transfers) and bone realignment procedures (rotational osteotomy) all striving for better function of the upper extremity through an improved position of the hand in space[22–26]. This position is directly related to the humeral version angle. We studied humeral retroversion in 35 consecutive infants, who were under evaluation for treatment of their internal rotation contractures secondary to unilateral BPBI in this retrospective observational study. Our main goal was to further elucidate the timing that these anatomic changes may occur; therefore we included our youngest patient population. We hypothesized that the retroversion angle (RV-angle) on the involved side would be significantly decreased relative to the uninvolved side and that the difference would increase with age. Since the subscapularis (SSc) and infraspinatus (IS) muscles, are an agonist-antagonist muscle pair, regarding humeral rotation, we hypothesized that an imbalance between these muscles would correlate with altered humeral version.

**MATERIALS AND METHODS**

In this retrospective observational study we included 37 Magnetic resonance imaging (MRI) -scans from a consecutive series of infants (< 1 year old), with a unilateral BPBI**.** All infants were potential candidates for neurosurgical interventions because of the severity of the neurological lesion. This study was IRB approved.

MRI studies were performed on a 1.5-T MRI-unit (Magnetom 1.5 T Vision; Siemens, Erlangen, Germany). A FISP three-dimensional pulse acquisition sequence (repetition time, 25 msec; time to echo, 10 msec; flip angle 40°) with ranges from 0.8 to 1.5 mm partitions was used to obtain images from both shoulders and upper arms, representing the full humerus and glenohumeral joint, in the axial plane. All children were given pethidine, droperidol and chlorpromazine intramuscularly. During sedation, they were monitored by electrocardiograph, measurement of oxygen saturation, and by video. Children were not moved during the imaging protocol.

From these 37 studies, 2 were insufficient for completing our detailed measurement protocol, one study did not capture the entire humerus and motion artifacts compromised the other study.

Our Radiology department anonymized the MRI studies before performing our measurement protocol; Digital Imaging and Communications in Medicine files were imported as a numerical database into Osirix (Pixmeo, Geneva, Switzerland). For humeral version measurements, axial plane slides from the involved and uninvolved side that to our best efforts represented the midpoint of the humeral head were selected. For the measurement of muscle dimensions axial plane slides representing the largest cross-sectional area of the SSc muscle and infraspinatus muscle were selected and exported as TIFF files. The TIFF files were imported into Geometer’s Sketchpad version 5.03 (KCP Technologies, Emeryville, CA) for further retroversion analyses. The region of interest (ROI) tool available in Osirix for was used for muscle cross-sectional area measurements. The Narakas classifications were assigned as described by Narakas[27]. Passive external rotation was measured with the arm in adducted position and the elbow by the side.

***Measure of retroversion***

Retroversion was measured with respect to two different methods for the proximal humeral axis and the transepicondylar axis distally, conformed by Pearl *et al*[12].

The first proximal reference axis was chosen to provide continuity with earlier retroversion analysis performed in this specific patient group[10,11]. This axis is conforming to the longest diameter through the humeral head. A line segment was created which spanned the greatest distance from the periphery of the greater tuberosity to the medial articular surface and is labeled as the skew axis (SA) (Figure 1)[2].

Retroversion was analyzed using the humeral center-line (HCL) as proximal axis (Figure 1). This is a commonly used axis in various retroversion studies[19,28–32]. The HCL represents the perpendicular projection from the margins of the articular surface.

Based on the literature, retroversion of the humeral head is shown as a positive value and anteversion is shown as a negative value. Two investigators performed the humeral version measurements.

***Measure of surface area***

Cross-sectional areas of the IS and SSc muscles were measured using the closed (ROI) polygon tool in Osirix (Pixmeo). The MRI slides depicting the largest muscle bellies were identified for measurement of this cross-sectional area. Muscle size is determined by the muscle cross-sectional area in cm2 and muscle percentage relative to the corresponding muscle at the uninvolved side. Furthermore, the ratio of the SSc and IS muscle (SSc/IS) was calculated to compare muscle balance between both sides and correlate these with the ΔRV-angle.

***Analysis***

Statistical analysis was performed using SPSS software (version 22.0; SPSS Inc., Chicago, IL, USA). The distribution analysis showed an approximately normal distribution.

Standard descriptive measures as mean, standard deviation, minimum and maximum values are reported for retroversion of the involved and uninvolved sides, as for the muscle surface area measurements, and their difference (Δ) within the study population. Pearson product-moment or Spearman rank correlation coefficients are estimated between each of these and passive external rotation and Narakas classification, as appropriate, based on the underlying distribution and type of the data. Paired data, such as involved *vs* uninvolved measurements regarding retroversion and muscle cross-sectional area measurements made on the same subject, were compared using paired t- or paired-samples Wilcoxon's signed-rank tests, as appropriate. Inter-rater reliability assessment by Intraclass correlations coefficient (ICC) was performed. A Bland-Altman plot was created to visualize potential differences in retroversion measuring methods[33].

**RESULTS**

The 35 children included in our study had a mean age of 4.3 mo (range of 2.1-6.5 mo), they were classified according to the Narakas classification: Narakas I: 18 cases; Narakas II: 4 cases; Narakas III: 15 cases. Internal rotation contractures varied from -45° to 12°, with a mean of -18°, measured as passive external rotation with the elbow by the side (Table 1).

***Humeral retroversion by HCL***

Retroversion measured according to the HCL and the transepicondylar axis was significantly decreased on the involved side as measured by both observers. Mean RV-angles were 0.8° *vs* 27.7° (*P* < 0.001). Paired differences averaged 26.8°, with a range from -18.4° to 77.8°. Figure 2 shows the distribution of the measurements. In 2 patient’s retroversion was increased on the involved side (Table 1). Age was not correlated with a decrease in humeral retroversion (*r* = -0.108, *P* = 0.538).

***Humeral retroversion by SA***

Retroversion measured according to the SA and the transepicondylar axis was also significantly decreased on the involved side, as measured by both observers. Mean RV-angles were 8.5° *vs* 25.4° (*P* < 0.001). Paired differences averaged 17.5°, with a range from -22.2° to 53.3°. Figure 3 shows the distribution of measurements. In 5 patient’s retroversion was increased on the involved side (Table 1). ﻿Age was again not correlated with decrease in humeral retroversion (*r* = -0.120, *P* = 0.492).

***Muscle surface area***

Both muscles were significantly smaller at the involved side. The IS muscle measured a mean surface area of 2.35 cm2 *vs* 2.84 cm2 (83%) (*P* < 0.001), the SSc muscle 1.56 cm2 *vs* 2.20 cm2 (70%)(*P* < 0.001).

Furthermore, muscle ratio (SSc/IS) at the involved side was significantly smaller compared to the uninvolved side (*P* = 0.007). In Table 2the results of the muscle cross-sectional area measurements are summarized.

***Correlations***

Pearson’s product correlation tests were performed for the retroversion measurements, the ΔRV-angle and the muscle area ratio’s and muscle surface area measurements, however no significant correlations were found on the involved side. As were none, when correlating age with decrease of retroversion, the Spearman Rho test was performed for retroversion measurement and Narakas’ score and passive external rotation, no significant correlations were found (*P* > 0.05).

***HCL method vs SA***

For retroversion measured by the HCL, the ICC for interrater reliability on the involved side was 0.934 (95%CI: 0.863-0.967; *P* < 0.001). The ICC for interrater reliability on the uninvolved side was 0.889 (95%CI: 0.747-0.948; *P* < 0.001). For retroversion measured using the SA, the ICC for interrater reliability on the involved side was 0.934 (95%CI: 0.897-0.970; *P* < 0.001). The ICC for interrater reliability on the uninvolved side was 0.923 (95%CI: 0.853-0.960; *P* < 0.001).

The distribution of measurements was larger on the involved side (Figure 4). Both measurement methods yield comparable results in the uninvolved shoulder, however in the deformed humeral head the SA yields systematically higher values compared to the HCL.

**DISCUSSION**

We found a significant reduction of humeral retroversion on the involved side, as compared to the uninvolved side, in a consecutive series of patients with internal rotation contractures secondary to BPBI. Additionally, the muscle size of the SSc and IS muscles on the involved side was significantly decreased, as was the muscle ratio (SSc/IS) at the involved side significantly smaller compared to the uninvolved side.

Our results, considering the RV-angles measured, are similar to those reported by Pearl *et al*, which were: 1.8° and 5.8° compared to 20.2° and 18.9°, respectively, depending on method of measurement. However, the mean age of the study groups differed considerably, 3.2 years old *vs* 4.3 mo old, respectively. Our results suggest that declined humeral version is not something these children slowly grow into. The altered humeral version angle may already develop within the first weeks after birth, when the humerus is probably most prone to altered development caused by altered (muscle) forces gripping on the humeral head. This is supported by the lack of (significant) correlation found between age and decreased retroversion on the involved side in both studies.

Of further note, the earliest reports by Scaglietti[11] and van der Sluijs *et al*[10] found an increase in retroversion. Scaglietti’s study was in a very different era of imaging technology presenting his observations but with little quantitative data. van der Sluijs *et al*[10] utilized MRI but nearly two decades ago, in a somewhat older age group, when current software tools were not available for image analysis, and the lesser image quality might have influenced measurements. Perhaps these methodological differences explain these opposite findings.

Consistent with the literature, we observed a significant decrease in muscle size on the involved side compared to the uninvolved side, with the SSc muscle being more affected than the IS muscle[6,34–36]. However, no significant correlation between the muscle ratio (SSc/IS) and the humeral RV-angle were observed. Nonetheless, the reduction in this muscle ratio does not support the theory that the internal rotators overpower the injured (paralyzed) external rotators, but suggests that failure of the SSc to grow or develop may result in a contracted SSc, which restrict external rotation.

Another theory could be that the changes in humeral retroversion are (partly) related to injure muscles outside of the rotator cuff, perhaps those with at least some innervation outside of the original zone of injury. Further study of other muscles is warranted looking for evidence as to whether they were perhaps also injured resulting in impaired growth[7,37], or that they recovered so strongly that they overwhelmed their antagonists or are used differently in children with varying levels of recovery.

Also, animal studies have shown that impaired longitudinal muscle growth and strength imbalance mechanisms are capable of producing shoulder deformities, impaired growth to a somewhat greater extent than muscle imbalance[8,38–41]. However, this has not yet been related to altered humeral version. Impaired growth and increased stiffness of, for example, the muscle fibers of the SSc muscle may have a significant effect on humeral version development. Possibly combined with other internal rotator muscles such as the pectoralis muscle, mechanical stiffness of these muscle fibers may not be directly related to cross sectional muscle area measurements.

Further research is needed to clarify a causal relationship between those mechanisms and shoulder deformities, concerning both the humerus and glenoid, which will help guide clinical treatment decisions for BPBI.

This study has several limitations. The measurements made in this study were based on axial slices of the humerus, measurements made from a 3D-reconstruction as performed by Sheehan and others would have the potential for minimizing errors related to patient positioning and inconsistent image acquisition. The humeral head and epicondylar axis, in our studied age group, are mostly cartilaginous making 3D-reconstruction of the humeral anatomy much more challenging than in a skeletally mature subject. While the software tools do exist presently, they are labor intensive and extremely difficult to implement in clinical practice. Therefore, we chose to utilize methods often used in our clinic setting and shown in a prior publication[12].

Muscle analyses of the IS and SSc muscles are based on cross-sectional area measurements from the MRI-slice depicting the largest muscle belly as used in multiple previous studies[6,35,36]. Capturing the full volume of both muscles would likely have been more informative; however, such software tools were not available for us. Furthermore, muscle thickness was only assessed for the IS and SSc muscles, measurement of other external and internal rotator muscles may offer additional insight in muscle behavior and its effect on humeral retroversion in this population.

The most common sequel and focus of surgical intervention in children with BPBI is an internal rotation contracture at the shoulder. These surgical interventions all aim for better function through an improved position of the hand in space. Humeral version undeniably affects the functionality of the hand, because with all other factors being equal decreased humeral version results in an increase of the severity of the clinical presentation of an internal rotation contracture. A large reduction in humeral retroversion when compared to the uninvolved side, at a very young age, could be a predictor (or an argument when apparent at an older age) for the necessity of a humeral derotational osteotomy, to provide adequate improvement of function of the hand, and possibly the elbow. Furthermore, this study shows that secondary osseous changes can occur within several months in this patient population. A prospective study analyzing possible changes in humeral version in this patient population over time would be of interest. Since, it seems through these results and results from the most recent previous studies, that changes in humeral version occur early, but they may not change much after that.

In conclusion,humeral retroversion has a high likelihood of being significantly decreased in this patient population. These findings are of relevance for any child under consideration for surgical intervention aiming to improve external rotation, since all other factors being equal decreased humeral retroversion results in an increased severity of the clinical presentation of an internal rotation contracture. We measured these changes in infants of 2-7 mo old, showing that altered humeral development can occur very early in life in a population where internal rotation contractures are apparent.

**Article Highlights**

***Research background***

The existing common treatment options for children suffering from brachial plexus birth palsy all strive for better function of the upper extremity through an improved position of the hand in space. This position is directly related to the humeral version angle.

***Research motivation***

Since earlier studies did not reveal a correlation between age and decreased retroversion on the involved side, the question remained at what age this anatomic change may occur.

***Research objectives***

Our objective was to elucidate the timing that these anatomic changes (decreased retroversion) may occur; therefore we included our youngest patient population (2-7 mo old).

***Research methods***

We measured humeral version relative to two proximal axes and one distal axis (transepicondylar axis). The proximal axes were: (1) the perpendicular line to the borders of the articular surface (humeral centerline); and (2) the longest diameter through the humeral head. Additionally, muscle cross-sectional areas of the infraspinatus (IS) and subscapularis (SSc) muscles were measured. Difference in retroversion was correlated with the ratio of muscle-sizes.

***Research results***

Retroversion on the involved side was significantly decreased, 1.0° *vs* 27.6° (1) and 8.5° *vs* 27.2° (2), (*P* < 0.01), as compared to the uninvolved side. SSc and IS muscle size on the involved side was significantly decreased, 2.26 cm² *vs* 2.79 cm² and 1.53 cm² *vs* 2.19 cm², respectively (*P* < 0.05). Additionally, muscle ratio (SSc/IS) at the involved side was significantly smaller compared to the uninvolved side (*P* = 0.007), but not related to alterations in humeral version.

***Research conclusions***

Our results show that altered humeral development can occur very early in life in a population where internal rotation contractures are apparent.

***Research perspectives***

A large reduction in humeral retroversion at a very young age, could be a predictor (or an argument when apparent at an older age) for the necessity of a humeral derotational osteotomy, to provide adequate improvement of function of the hand, and possibly the elbow. A prospective study analyzing changes in humeral version over time would be of interest, to assess the predictive value of decreased retroversion at such a young age, concerning various treatment options (soft-tissue and bony).

**REFERENCES**

1 **Pearl ML**, Edgerton BW. Glenoid deformity secondary to brachial plexus birth palsy. *J Bone Joint Surg Am* 1998; **80**: 659-667 [PMID: 9611026 DOI: 10.2106/00004623-199805000-00006]

2 **Pearl ML**, Woolwine S, van de Bunt F, Merton G, Burchette R. Geometry of the proximal humeral articular surface in young children: a study to define normal and analyze the dysplasia due to brachial plexus birth palsy. *J Shoulder Elbow Surg* 2013; **22**: 1274-1284 [PMID: 23478467 DOI: 10.1016/j.jse.2012.12.031]

3 **Kozin SH**. Correlation between external rotation of the glenohumeral joint and deformity after brachial plexus birth palsy. *J Pediatr Orthop* 2004; **24**: 189-193 [PMID: 15076606 DOI: 10.1097/01241398-200403000-00011]

4 **Waters PM**, Smith GR, Jaramillo D. Glenohumeral deformity secondary to brachial plexus birth palsy. *J Bone Joint Surg Am* 1998; **80**: 668-677 [PMID: 9611027 DOI: 10.2106/00004623-199805000-00007]

5 **van der Sluijs JA**, van Ouwerkerk WJ, de Gast A, Wuisman PI, Nollet F, Manoliu RA. Deformities of the shoulder in infants younger than 12 months with an obstetric lesion of the brachial plexus. *J Bone Joint Surg Br* 2001; **83**: 551-555 [PMID: 11380130 DOI: 10.1302/0301-620x.83b4.11205]

6 **Waters PM**, Monica JT, Earp BE, Zurakowski D, Bae DS. Correlation of radiographic muscle cross-sectional area with glenohumeral deformity in children with brachial plexus birth palsy. *J Bone Joint Surg Am* 2009; **91**: 2367-2375 [PMID: 19797571 DOI: 10.2106/JBJS.H.00417]

7 **Nikolaou S**, Peterson E, Kim A, Wylie C, Cornwall R. Impaired growth of denervated muscle contributes to contracture formation following neonatal brachial plexus injury. *J Bone Joint Surg Am* 2011; **93**: 461-470 [PMID: 21368078 DOI: 10.2106/JBJS.J.00943]

8 **Soldado F**, Fontecha CG, Marotta M, Benito D, Casaccia M, Mascarenhas VV, Zlotolow D, Kozin SH. The role of muscle imbalance in the pathogenesis of shoulder contracture after neonatal brachial plexus palsy: a study in a rat model. *J Shoulder Elbow Surg* 2014; **23**: 1003-1009 [PMID: 24388715 DOI: 10.1016/j.jse.2013.09.031]

9 **Sheehan FT**, Brochard S, Behnam AJ, Alter KE. Three-dimensional humeral morphologic alterations and atrophy associated with obstetrical brachial plexus palsy. *J Shoulder Elbow Surg* 2014; **23**: 708-719 [PMID: 24291045 DOI: 10.1016/j.jse.2013.08.014]

10 **van der Sluijs JA**, van Ouwerkerk WJ, de Gast A, Wuisman P, Nollet F, Manoliu RA. Retroversion of the humeral head in children with an obstetric brachial plexus lesion. *J Bone Joint Surg Br* 2002; **84**: 583-587 [PMID: 12043783 DOI: 10.1302/0301-620x.84b4.12243]

11 **Scaglietti O.** The obstetrical shoulder trauma. *Surg Gynecol Obstet* 1938. pp. 868–877

12 **Pearl ML**, Batech M, van de Bunt F. Humeral Retroversion in Children with Shoulder Internal Rotation Contractures Secondary to Upper-Trunk Neonatal Brachial Plexus Palsy. *J Bone Joint Surg Am* 2016; **98**: 1988-1995 [PMID: 27926680 DOI: 10.2106/JBJS.15.01132]

13 **KRAHL VE**. The torsion of the humerus; its localization, cause and duration in man. *Am J Anat* 1947; **80**: 275-319 [PMID: 20296010 DOI: 10.1002/aja.1000800302]

14 **Edelson G**. The development of humeral head retroversion. *J Shoulder Elbow Surg* 2000; **9**: 316-318 [PMID: 10979528 DOI: 10.1067/mse.2000.106085]

15 **Cowgill LW**. Humeral torsion revisited: a functional and ontogenetic model for populational variation. *Am J Phys Anthropol* 2007; **134**: 472-480 [PMID: 17657784 DOI: 10.1002/ajpa.20689]

16 **Edelson G**. Variations in the retroversion of the humeral head. *J Shoulder Elbow Surg* 1999; **8**: 142-145 [PMID: 10226966 DOI: 10.1016/s1058-2746(99)90007-1]

17 **Yamamoto N**, Itoi E, Minagawa H, Urayama M, Saito H, Seki N, Iwase T, Kashiwaguchi S, Matsuura T. Why is the humeral retroversion of throwing athletes greater in dominant shoulders than in nondominant shoulders? *J Shoulder Elbow Surg* 2006; **15**: 571-575 [PMID: 16979051 DOI: 10.1016/j.jse.2005.06.009]

18 **Whiteley R**, Adams R, Ginn K, Nicholson L. Playing level achieved, throwing history, and humeral torsion in Masters baseball players. *J Sports Sci* 2010; **28**: 1223-1232 [PMID: 20694888 DOI: 10.1080/02640414.2010.498484]

19 **Chant CB**, Litchfield R, Griffin S, Thain LM. Humeral head retroversion in competitive baseball players and its relationship to glenohumeral rotation range of motion. *J Orthop Sports Phys Ther* 2007; **37**: 514-520 [PMID: 17939610 DOI: 10.2519/jospt.2007.2449]

20 **Myers JB**, Oyama S, Rucinski TJ, Creighton RA. Humeral retrotorsion in collegiate baseball pitchers with throwing-related upper extremity injury history. *Sports Health* 2011; **3**: 383-389 [PMID: 23016031 DOI: 10.1177/1941738111410636]

21 **Osbahr DC**, Cannon DL, Speer KP. Retroversion of the humerus in the throwing shoulder of college baseball pitchers. *Am J Sports Med* 2002; **30**: 347-353 [PMID: 12016074 DOI: 10.1177/03635465020300030801]

22 **Pearl ML**, Edgerton BW, Kazimiroff PA, Burchette RJ, Wong K. Arthroscopic release and latissimus dorsi transfer for shoulder internal rotation contractures and glenohumeral deformity secondary to brachial plexus birth palsy. *J Bone Joint Surg Am* 2006; **88**: 564-574 [PMID: 16510824 DOI: 10.2106/JBJS.D.02872]

23 **Kozin SH**, Boardman MJ, Chafetz RS, Williams GR, Hanlon A. Arthroscopic treatment of internal rotation contracture and glenohumeral dysplasia in children with brachial plexus birth palsy. *J Shoulder Elbow Surg* 2010; **19**: 102-110 [PMID: 19664938 DOI: 10.1016/j.jse.2009.05.011]

24 **Waters PM**, Bae DS. The effect of derotational humeral osteotomy on global shoulder function in brachial plexus birth palsy. *J Bone Joint Surg Am* 2006; **88**: 1035-1042 [PMID: 16651578 DOI: 10.2106/JBJS.E.00680]

25 **Gilbert A**, Brockman R, Carlioz H. Surgical treatment of brachial plexus birth palsy. *Clin Orthop Relat Res* 1991; : 39-47 [PMID: 1847671 DOI: 10.1097/00003086-199103000-00005]

26 **Kirkos JM**, Kyrkos MJ, Kapetanos GA, Haritidis JH. Brachial plexus palsy secondary to birth injuries. *J Bone Joint Surg Br* 2005; **87**: 231-235 [PMID: 15736749 DOI: 10.1302/0301-620X.88B4.17641]

27 **Birch R**. Obstetric brachial plexus palsy. *J Hand Surg Br* 2002; **27**: 3-8 [PMID: 11895337 DOI: 10.1054/jhsb.2001.0722]

28 **Boileau P**, Bicknell RT, Mazzoleni N, Walch G, Urien JP. CT scan method accurately assesses humeral head retroversion. *Clin Orthop Relat Res* 2008; **466**: 661-669 [PMID: 18264854 DOI: 10.1007/s11999-007-0089-z]

29 **DeLude JA**, Bicknell RT, MacKenzie GA, Ferreira LM, Dunning CE, King GJ, Johnson JA, Drosdowech DS. An anthropometric study of the bilateral anatomy of the humerus. *J Shoulder Elbow Surg* 2007; **16**: 477-483 [PMID: 17363290 DOI: 10.1016/j.jse.2006.09.016]

30 **Harrold F**, Wigderowitz C. A three-dimensional analysis of humeral head retroversion. *J Shoulder Elbow Surg* 2012; **21**: 612-617 [PMID: 21783384 DOI: 10.1016/j.jse.2011.04.005]

31 **Hernigou P**, Duparc F, Hernigou A. Determining humeral retroversion with computed tomography. *J Bone Joint Surg Am* 2002; **84-A**: 1753-1762 [PMID: 12377904 DOI: 10.2106/00004623-200306000-00035]

32 **Matsumura N**, Ogawa K, Kobayashi S, Oki S, Watanabe A, Ikegami H, Toyama Y. Morphologic features of humeral head and glenoid version in the normal glenohumeral joint. *J Shoulder Elbow Surg* 2014; **23**: 1724-1730 [PMID: 24862249 DOI: 10.1016/j.jse.2014.02.020]

33 **Bland JM**, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* 1986; **1**: 307-310 [PMID: 2868172 DOI: 10.1016/S0140-6736(86)90837-8]

34 **Hogendoorn S**, van Overvest KL, Watt I, Duijsens AH, Nelissen RG. Structural changes in muscle and glenohumeral joint deformity in neonatal brachial plexus palsy. *J Bone Joint Surg Am* 2010; **92**: 935-942 [PMID: 20360518 DOI: 10.2106/JBJS.I.00193]

35 **Van Gelein Vitringa VM**, Jaspers R, Mullender M, Ouwerkerk WJ, Van Der Sluijs JA. Early effects of muscle atrophy on shoulder joint development in infants with unilateral birth brachial plexus injury. *Dev Med Child Neurol* 2011; **53**: 173-178 [PMID: 20846159 DOI: 10.1111/j.1469-8749.2010.03783.x]

36 **Pöyhiä TH**, Nietosvaara YA, Remes VM, Kirjavainen MO, Peltonen JI, Lamminen AE. MRI of rotator cuff muscle atrophy in relation to glenohumeral joint incongruence in brachial plexus birth injury. *Pediatr Radiol* 2005; **35**: 402-409 [PMID: 15635469 DOI: 10.1007/s00247-004-1377-3]

37 **Einarsson F**, Hultgren T, Ljung BO, Runesson E, Fridén J. Subscapularis muscle mechanics in children with obstetric brachial plexus palsy. *J Hand Surg Eur Vol* 2008; **33**: 507-512 [PMID: 18687840 DOI: 10.1177/1753193408090764]

38 **Crouch DL**, Hutchinson ID, Plate JF, Antoniono J, Gong H, Cao G, Li Z, Saul KR. Biomechanical Basis of Shoulder Osseous Deformity and Contracture in a Rat Model of Brachial Plexus Birth Palsy. *J Bone Joint Surg Am* 2015; **97**: 1264-1271 [PMID: 26246261 DOI: 10.2106/JBJS.N.01247]

39 **Li Z**, Barnwell J, Tan J, Koman LA, Smith BP. Microcomputed tomography characterization of shoulder osseous deformity after brachial plexus birth palsy: a rat model study. *J Bone Joint Surg Am* 2010; **92**: 2583-2588 [PMID: 21048177 DOI: 10.2106/JBJS.I.01660]

40 **Li Z**, Ma J, Apel P, Carlson CS, Smith TL, Koman LA. Brachial plexus birth palsy-associated shoulder deformity: a rat model study. *J Hand Surg Am* 2008; **33**: 308-312 [PMID: 18343282 DOI: 10.1016/j.jhsa.2007.11.017]

41 **Soldado F**, Benito-Castillo D, Fontecha CG, Barber I, Marotta M, Haddad S, Menendez ME, Mascarenhas VV, Kozin SH. Muscular and glenohumeral changes in the shoulder after brachial plexus birth palsy: an MRI study in a rat model. *J Brachial Plex Peripher Nerve Inj* 2012; **7**: 9 [PMID: 23217052 DOI: 10.1186/1749-7221-7-9]

**P-Reviewer:** Emara KM, Wyatt MC **S-Editor:** Dou Y **L-Editor: E-Editor:**

**Specialty type:** Orthopedics

**Country of origin:** Netherlands

**Peer-review report classification**

Grade A (Excellent): 0

Grade B (Very good): 0

Grade C (Good): C, C

Grade D (Fair): 0

Grade E (Poor): 0



**Figure 1 ﻿Schematic illustration of measurement parameters applied to an magnetic resonance imaging slice from the proximal part of the normal, uninvolved, humerus.** (Reproduced, with modification, from: Pearl ML, *et al*. Geometry of the proximal humeral articular surface in young children: a study to define normal and analyze the dysplasia due to brachial plexus birth palsy. *J Shoulder Elbow Surg* 2013; **22**: 1274-84. Reproduced with permission from Elsevier.)



**Figure 2 The distribution among measurements using the humeral center line as a proximal axis.** HCL: Humeral center line; RV-angle: Retroversion angle.



**Figure 3 The distribution among measurements using the skew axis as a proximal axis.** In the deformed humeral head, the skew axis yields systematically higher values compared to the humeral center line. RV-angle: Retroversion angle.



**Figure 4 The distribution of measurement in the involved shoulder is larger than on the involved side, indicating measurement differences between the skew axis and humeral center line are larger on the involved side.** The blue and orange dotted lines represent the 95% limits of agreement.

**Table 1 Demographics**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Subject** | **Narakas** | **Age** | **External Rotation (passive)** | **Retroversion Involved (HCL)** | **Retroversion Involved (SA)** | **Retroversion Uninvolved (HCL)** | **Retroversion Uninvolved (SA)** |
|  |  | (mo) | (°) | (°) | (°) | (°) | (°) |
| 1 | 3 | 2.6 | -15 | 7.665 | 11.25 | 26.4 | 26.315 |
| 2 | 1 | 3.1 | -5 | -9.16 | 11.045 | 23.18 | 13.485 |
| 3 | 1 | 3.2 | -40 | -17.125 | 4.04 | 18.65 | 17.05 |
| 4 | 3 | 3.2 | -30 | 14.175 | 23.395 | 30.56 | 31.865 |
| 5 | 3 | 3.3 | 0 | -7.05 | 6.67 | 31.23 | 32.85 |
| 6 | 3 | 3.4 | -10 | -24.74 | -19.26 | 41.72 | 31.705 |
| 7 | 3 | 3.4 | 0 | 7.67 | 7.905 | 30.145 | 29.165 |
| 8 | 3 | 3.5 | -20 | 35.595 | 35.015 | 27.295 | 31.23 |
| 9 | 2 | 3.5 | -5 | -10.885 | 1.615 | 24.17 | 23.905 |
| 10 | 1 | 3.5 | -20 | 4.54 | 2.05 | 32.21 | 26.49 |
| 11 | 3 | 3.6 | -20 | 1,99 | 5.695 | 43.55 | 36.11 |
| 12 | 1 | 3.6 | -20 | 3.6 | 22.565 | 54.905 | 47.955 |
| 13 | 3 | 3.8 | -25 | 1.595 | 9.425 | 29.355 | 36.42 |
| 14 | 1 | 4 | -5 | -6.715 | 3.44 | 29.115 | 28.165 |
| 15 | 2 | 4.1 | -15 | -13.53 | -1.035 | 21.59 | 25.605 |
| 16 | 1 | 4.1 | -15 | 14.975 | 9.85 | 25.575 | 21.24 |
| 17 | 3 | 4.5 | -25 | 0.065 | -2.075 | 19.47 | 19.995 |
| 18 | 3 | 4.5 | -45 | 24.195 | 20.195 | 34.19 | 34.55 |
| 19 | 1 | 4.5 | -10 | -4.115 | 6.1 | 24.305 | 20.175 |
| 20 | 2 | 4.6 | -30 | -7.205 | 11.675 | 13.465 | 14.06 |
| 21 | 3 | 4.6 | -10 | -3.14 | 7.29 | 15.445 | 12.14 |
| 22 | 1 | 4.7 | -20 | 4.125 | 18.195 | 23.045 | 30.385 |
| 23 | 1 | 4.7 | -20 | -20.83 | 1.9 | 21.85 | 30.085 |
| 24 | 1 | 4.8 | -40 | 4.875 | 9.95 | 15.655 | 20.11 |
| 25 | 3 | 4.9 | -40 | 8.935 | 9.525 | 18.805 | 11.765 |
| 26 | 1 | 5 | -15 | 38.24 | 33.53 | 20.055 | 15.945 |
| 27 | 1 | 5 | 0 | -8.86 | 4.405 | 24.85 | 21.6 |
| 28 | 1 | 5 | -15 | -30.23 | -20.135 | 38.975 | 23.31 |
| 29 | 1 | 5 | -10 | 24.725 | 25.535 | 32.98 | 39.03 |
| 30 | 1 | 5.1 | -5 | 8.79 | 10.05 | 20.115 | -2.295 |
| 31 | 1 | 5.4 | -20 | -28.55 | -11.965 | 47.445 | 39.185 |
| 32 | 3 | 5.6 | -35 | 3.385 | 6.45 | 30.395 | 27.485 |
| 33 | 3 | 5.9 | -15 | -16.805 | 11.66 | 18.085 | 14.5 |
| 34 | 2 | 5.9 | -30 | 11.89 | 7.225 | 28.56 | 35.075 |
| 35 | 1 | 6.5 | -10 | 17.315 | 14.43 | 31.08 | 22.5 |
| Mean |  | 4.3 | -18,3 | 0.8 | 8.5 | 27.7 | 25.4 |
| Standard Deviation |  | 0.9 | 12,0 | 16.1 | 11.7 | 9.2 | 9.8 |
| Minimum |  | 2.6 | -45 | -30.23 | -20.135 | 13.465 | -2.295 |
| Maximum |  | 6.5 | 0 | 38.24 | 35.015 | 54.905 | 47.955 |

HCL: Humeral center-line; SA: Skew axis.

**Table 2 Main results of the muscle cross-sectional area measurements**

|  |  |  |  |
| --- | --- | --- | --- |
| Muscle area (cm2) | Mean - Involved | Mean - Uninvolved | *P* - value |
| Subscapularis muscle | 1.56 ± 0.315 | 2.20 ± 0.372 | < 0.001 |
| Infraspinatus muscle | 2.35 ± 0.520 | 2.84 ± 0.495 | < 0.001 |
| Ratio | 68.51 ± 16.90 | 78.88 ± 15.45 | 0.007 |