Glenoid morphology in obstetrical brachial plexus lesion
a three-dimensional computed tomography study

Frich, Lars Henrik; Schmidt, P.H.; Torfing, Trine

Published in:
Journal of Shoulder and Elbow Surgery

DOI:
10.1016/j.jse.2017.02.020

Publication date:
2017

Document version
Publisher's PDF; also known as Version of record

Document license
CC BY-NC-ND

Citation for published version (APA):

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

• Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
• You may not further distribute the material or use it for any profit-making activity or commercial gain
• You may freely distribute the URL identifying the publication in the public portal

Take down policy
If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Download date: 22. dec., 2018
Glenoid morphology in obstetrical brachial plexus lesion: a three-dimensional computed tomography study

Lars H. Frich, MD, PhD\textsuperscript{a,b,*}, Pernille H. Schmidt, MD\textsuperscript{a}, Trine Torfing, MD\textsuperscript{c}

\textsuperscript{a}Department of Orthopaedics, Odense University Hospital, Odense, Denmark
\textsuperscript{b}Orthopaedic Research Unit, Department of Clinical Research, University of Southern Denmark, Odense, Denmark
\textsuperscript{c}Department of Radiology, Odense University Hospital, Odense, Denmark

\textbf{Background:} Obstetric brachial plexus lesion (OBPL) frequently leads to glenohumeral dysplasia, and excessive retroversion of the glenoid is among the best known developmental disturbances. Most analyses of the glenoid are based on 2-dimensional (D) imaging and do not address glenoid inclination or provide information on the glenoid in the sagittal plane. We aim to describe the 3-D deformity of the glenoid in children with OBPL.

\textbf{Methods:} Preoperative computed tomography (CT) scans of the nonaffected and the affected scapula of 24 children (aged 5 to 12 years) with developmental disturbances after OBPL years were analyzed. The dimensions of the scapula and the deformation of the glenoid were visualized in 3-D.

\textbf{Results:} The retroversion of the glenoid fossa was greater in all affected shoulders, and 2-D measurements significantly overestimated retroversion compared with angles measured in 3-D. The inclination of the glenoid fossa was altered, and a distal bony edge loss was observed on 3-D reformations in the sagittal plane. The reliability of the measured angles was excellent, and the \( \kappa \) agreement for the description of the glenoid form was substantial. Furthermore, the dimensions of the scapula were significantly smaller on the affected shoulders.

\textbf{Conclusion:} OBPL is indeed a 3-D disorder. Our measurements revealed excessive retroversion of the glenoid fossa, and the reliability of the 3-D CT measurements was superior to their 2-D counterparts. 3-D CT reformations of the glenoid in the coronal and the sagittal plane added further to 3-D understanding of glenoid morphology in OBPL. These new findings legitimatize a 3-D CT-based description of the glenoid deformities connected with OBPL.

\textbf{Level of evidence:} Basic Science; Anatomy Study; Imaging

\( \text{© 2017 The Author(s). This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).} \)

\textbf{Keywords:} Glenoid deformity; brachial plexus palsy; glenoid version; glenoid inclination; glenoid form; shoulder

Obstetric brachial plexus lesion (OBPL) is a flaccid paresis of the upper extremity\textsuperscript{12} that occurs in 1 to 5 per 1000 births.\textsuperscript{1} The etiology is presumed to be traumatic traction of the brachial plexus nerve roots (C5-T1) during childbirth.\textsuperscript{25,28} Recent evidence suggests that the natural history of OBPL is favorable in 75\%.\textsuperscript{1,26}
3-D Glenoid Morphology in OBPL

When recovery is incomplete, developmental disturbances of the shoulder girdle are commonly seen. Decreased growth of the dorsal and ventral sides of the glenoid has been suggested, and the often associated excessive retroversion of the glenoid is among the best known developmental disturbances. Morphologic changes of the humeral head and of the glenoid fossa may appear early in life and are often seen in connection with posterior (dorsal) subluxations of the glenohumeral joint (GHJ). Deformities progress with age and correlate with internal rotation contracture.

Dysplasia is, however, not just an internal-external imbalance, it is a 3-dimensional (D), unbalanced joint, and pathology must therefore be assessed from 3-D data. Failure to incorporate 3-D measurements forces clinicians to base treatment decisions on less reliable 2-D osseous deformation parameters that do not provide a complete understanding of the pathology. Treating glenoid 3-D deformity requires 3-D information on the bony structure, and only a full 3-D correction may help improve functional outcomes.

The deformity is commonly studied using magnetic resonance imaging (MRI) or computed tomography (CT) techniques, and much of the current literature has focused on measurements of glenoid retroversion using axial plane images. The true form of a 3-D joint fossa is difficult to define from a single CT or MRI sequence obtained through the surface. Besides, 2-D transverse images of the glenoid do not address the inclination of the glenoid or provide information on the glenoid in the sagittal plane. Although MRI, to some extent, allows measurements in 3-D, there are several technical limitations, and reproducibility is still not proven. This aspect, CT is superior to MRI because it also allows true bilateral 3-D reformations of the bony structures that constitute the GHJ.

This study was therefore designed to provide a full 3-D description of the glenoid deformity in OBPL using CT as well as a description provided by CT of the developmental disturbances of the entire scapula. We also assessed differences in glenoid morphology between the affected ipsilateral and the nonaffected contralateral shoulders. Finally, the interrater and intrarater reliability of 2-D and 3-D measurements was assessed. We hypothesized that the dysplasia of the glenoid fossa in OBPL is 3-D and that 3-D CT is superior to 2-D CT in providing a more accurate description of the glenoid morphology in OBPL.

Materials and methods

Between October 2003 and May 2008, 31 children underwent CT evaluation for developmental disturbances after OBPL at our institution. Five were excluded because of inadequate quality of the CT scanning, and 2 were excluded because they were younger than 5 years old. The remaining 24 children (13 boys, 11 girls) were enrolled in the study. They were a mean age of 8 years, 4 months (interquartile range, 5 years, 4 months–12 years, 3 months). The right shoulder was affected in 17 children and the left shoulder was affected in the remaining 7. None of the children in the study had undergone surgery before inclusion.

A multidisciplinary team clinically examined all of the children. The severity of the lesion in each child was assessed using the Mallet score, which has been developed to assess the ability of the affected upper extremity to perform functional activities of daily living, denoting 1 to 3 points for each of the 5 activities tested. The Mallet score was only properly documented in 17 of 24 children.

CT imaging examinations

The imaging examination protocol for children with OBPL included bilateral CT scanning of the shoulders. Scans were performed in a GE 4 Slice LightSpeed CT scanner (GE Healthcare, Waukesha, WI, USA). The images were acquired at 140 kV, 200 mA, and a rotation speed of 0.5 seconds. The images were obtained in 2.5-mm contiguous slices from 1 cm above the acromion to 1 cm below the inferior angle of the scapula. The CT scanning was performed with the child placed supine and with the hands under the thighs, whenever possible. The effective radiation dose was estimated to be 2.4 mSv. Radiation of our current CT protocol (U = 120 kVp, I = 99 mA, t_rot = 0.5s, pitch = 0.53:1) is estimated to be less than 2 mSv.

All data were retrieved from the image archiving and communication system and transferred to local workstations. Multiplanar image reformations were created using a software algorithm (AW Volume Share 2, GE Healthcare, Brøndby, Denmark) when processing the images. The images were digitally manipulated, and all other bony structures were removed, except for the entire scapular body. Two-D axial (Fig. 1) and coronal slices and 3-D reformations were used in the evaluation process.

Morphologic measurements

Scapular length was measured at the midglenoid level as the horizontal distance between the medial side of the scapula and the glenoid fossa. The height of the scapula was measured as the distance between the tips of the superior and inferior angles. All measurements were done on the nonaffected and the affected scapula to enable comparison.

The dimensions of the glenoid were assessed from the Saller line (Fig. 2). The orientation of the glenoid fossa relative to the scapula

Figure 1 Two-dimensional axial presentation of glenoid retroversion. Two lines were drawn, one passing through the anterior and posterior margins of the glenoid and a second intersecting line from the medial margin of the scapula through the center of the glenoid. The posteromedial angle was measured, and 90° was subtracted to determine the 2-dimensional version. The arrow points to the inclination angle.
was assessed by measurements of the glenoid version,\(^{18}\) and inclination was measured as shown in Fig. 3.\(^{16}\)

The last parameter studied was the form of the glenoid fossa, which is normally ovoid or pear shaped.\(^{15}\) The affected glenoid may show other characteristics. Therefore, in the present study, a qualitative description of the glenoid fossa, based on the 3-D CT appearance in the sagittal plane, was proposed to correlate deformity and clinical severity.

**Statistical methods**

Descriptive statistics (mean, standard deviation [SD], and range) were calculated for the dependent variables; height (mm), width (mm), inclination angle (°), 2-D and 3-D version for each shoulder, and for differences in retroversion and inclination (only 3-D) between the affected and nonaffected shoulders in each child.

Comparison of the means between the nonaffected and affected shoulder was done using the paired Student \(t\) test. Correlation between the difference measurements and the Mallet score was determined using Spearman rank correlation. All statistical analyses were performed with PASW Statistics 22 software (IBM Corp., Armonk, NY, USA).

Two independent radiologist assessors were blinded to all clinical data except for the side of OBPL. To assess the reliability, all measurements were repeated twice. The intraclass correlation coefficient (ICC; 2.1, 2-way mixed model, agreement definition) with corresponding 95% confidence intervals (CIs) were calculated. An ICC value of \(\leq 0.40\) indicated poor reliability, 0.40 to 0.75 fair to good reliability, and \(\geq 0.75\) excellent reliability.\(^{23}\)

The inter-rater and intrarater reliability for the qualitative description of the glenoid form was analyzed using \(\kappa\) statistics. The following standards for strength of agreement for the \(\kappa\) coefficient was suggested by Landis and Koch\(^{19}\): \(<0\), poor; 0.01 to 0.20, slight; 0.21 to 0.40, fair, 0.41 to 0.60, moderate; 0.61 to 0.80, substantial; and 0.81 to 1.0, almost perfect. \(P\) values of \(<0.05\) were considered statistically significant.

**Results**

All shoulders in this study appeared to be subdislocated but to different degrees (please refer to Table I for demographic

---

**Figure 2** Measurements of the glenoid height and width. Glenoid height was defined as the distance between the most superior and inferior points of the glenoid fossa (Saller line). The width of the glenoid was measured on planes perpendicular to this line.

**Figure 3** Three-dimensional (3-D) assessments of glenoid version and inclination angle. (A) The glenoid retroversion was determined on the 3-D reformations of the glenoid fossa, and measurements were performed at the midglenoid level.\(^{33}\) Two lines were drawn, one (solid line) passing through the anterior and posterior margins of the glenoid, and a second (solid line) intersecting line from the medial margin of the scapula through the center of the glenoid. (B) To determine the angle, a line between the superior and inferior point of the glenoid fossa (solid line) and a line connecting the superior angle of the scapula and the superior point of the glenoid fossa (solid line) was drawn. The inclination angle was measured between these lines.
Table I  Patient demographics and measurements of version and inclination of the affected and normal glenoid

<table>
<thead>
<tr>
<th>Patient</th>
<th>Sex</th>
<th>Age, y.mo</th>
<th>Mallet score</th>
<th>Left/right</th>
<th>Height, mm</th>
<th>Total width, mm</th>
<th>Inclination,°</th>
<th>3-D version,°</th>
<th>2-D version,°</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Affected side</td>
<td>Normal side</td>
<td>Affected side</td>
<td>Normal side</td>
<td>Affected side</td>
</tr>
<tr>
<td>1</td>
<td>M</td>
<td>6.10</td>
<td>7</td>
<td>Right</td>
<td>32</td>
<td>22</td>
<td>17</td>
<td>17</td>
<td>60</td>
</tr>
<tr>
<td>2</td>
<td>M</td>
<td>7.9</td>
<td>10</td>
<td>Right</td>
<td>26</td>
<td>28</td>
<td>19</td>
<td>20</td>
<td>75</td>
</tr>
<tr>
<td>3</td>
<td>M</td>
<td>7.11</td>
<td>12</td>
<td>Right</td>
<td>27</td>
<td>26</td>
<td>17</td>
<td>19</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>F</td>
<td>10.9</td>
<td>. . .</td>
<td>Left</td>
<td>35</td>
<td>30</td>
<td>23</td>
<td>22</td>
<td>80</td>
</tr>
<tr>
<td>5</td>
<td>F</td>
<td>6.7</td>
<td>. . .</td>
<td>Right</td>
<td>27</td>
<td>21</td>
<td>17</td>
<td>14</td>
<td>67</td>
</tr>
<tr>
<td>6</td>
<td>M</td>
<td>7.9</td>
<td>8</td>
<td>Right</td>
<td>23</td>
<td>24</td>
<td>12</td>
<td>17</td>
<td>65</td>
</tr>
<tr>
<td>7</td>
<td>M</td>
<td>6.10</td>
<td>8</td>
<td>Right</td>
<td>28</td>
<td>26</td>
<td>12</td>
<td>16</td>
<td>59</td>
</tr>
<tr>
<td>8</td>
<td>M</td>
<td>5.4</td>
<td>. . .</td>
<td>Right</td>
<td>26</td>
<td>23</td>
<td>16</td>
<td>17</td>
<td>68</td>
</tr>
<tr>
<td>9</td>
<td>F</td>
<td>7.4</td>
<td>9</td>
<td>Right</td>
<td>29</td>
<td>26</td>
<td>20</td>
<td>18</td>
<td>70</td>
</tr>
<tr>
<td>10</td>
<td>M</td>
<td>6.7</td>
<td>. . .</td>
<td>Right</td>
<td>27</td>
<td>26</td>
<td>19</td>
<td>18</td>
<td>. . .</td>
</tr>
<tr>
<td>11</td>
<td>F</td>
<td>9</td>
<td>. . .</td>
<td>Right</td>
<td>22</td>
<td>23</td>
<td>17</td>
<td>18</td>
<td>70</td>
</tr>
<tr>
<td>12</td>
<td>F</td>
<td>6.1</td>
<td>9</td>
<td>Left</td>
<td>26</td>
<td>21</td>
<td>16</td>
<td>15</td>
<td>66</td>
</tr>
<tr>
<td>13</td>
<td>M</td>
<td>8.6</td>
<td>. . .</td>
<td>Right</td>
<td>26</td>
<td>29</td>
<td>17</td>
<td>17</td>
<td>71</td>
</tr>
<tr>
<td>14</td>
<td>M</td>
<td>8.7</td>
<td>12</td>
<td>Right</td>
<td>25</td>
<td>20</td>
<td>17</td>
<td>15</td>
<td>64</td>
</tr>
<tr>
<td>15</td>
<td>F</td>
<td>7.5</td>
<td>12</td>
<td>Left</td>
<td>28</td>
<td>25</td>
<td>19</td>
<td>16</td>
<td>60</td>
</tr>
<tr>
<td>16</td>
<td>F</td>
<td>10.7</td>
<td>15</td>
<td>Right</td>
<td>27</td>
<td>25</td>
<td>18</td>
<td>18</td>
<td>58</td>
</tr>
<tr>
<td>17</td>
<td>F</td>
<td>8.11</td>
<td>15</td>
<td>Right</td>
<td>25</td>
<td>25</td>
<td>17</td>
<td>20</td>
<td>62</td>
</tr>
<tr>
<td>18</td>
<td>M</td>
<td>5.5</td>
<td>10</td>
<td>Right</td>
<td>27</td>
<td>23</td>
<td>17</td>
<td>16</td>
<td>70</td>
</tr>
<tr>
<td>19</td>
<td>F</td>
<td>12.3</td>
<td>. . .</td>
<td>Left</td>
<td>28</td>
<td>31</td>
<td>23</td>
<td>22</td>
<td>64</td>
</tr>
<tr>
<td>20</td>
<td>F</td>
<td>12.1</td>
<td>9</td>
<td>Right</td>
<td>30</td>
<td>33</td>
<td>21</td>
<td>21</td>
<td>81</td>
</tr>
<tr>
<td>21</td>
<td>M</td>
<td>10.8</td>
<td>10</td>
<td>Left</td>
<td>25</td>
<td>24</td>
<td>20</td>
<td>19</td>
<td>69</td>
</tr>
<tr>
<td>22</td>
<td>M</td>
<td>7.11</td>
<td>. . .</td>
<td>Left</td>
<td>23</td>
<td>24</td>
<td>16</td>
<td>18</td>
<td>70</td>
</tr>
<tr>
<td>23</td>
<td>F</td>
<td>10.4</td>
<td>15</td>
<td>Left</td>
<td>33</td>
<td>35</td>
<td>20</td>
<td>22</td>
<td>73</td>
</tr>
<tr>
<td>24</td>
<td>M</td>
<td>9.7</td>
<td>10</td>
<td>Right</td>
<td>24</td>
<td>26</td>
<td>18</td>
<td>20</td>
<td>59</td>
</tr>
</tbody>
</table>

D, dimensional; F, female; M, male.

A negative value indicates retroversion of the glenoid, and a positive number indicates anteversion of the glenoid fossa.
data of each child). The mean Mallet score was 9 (range, 3-15; Table I), where the score 15 represents a well-functioning shoulder.

**Glenoid measurements**

Measurements of the affected and nonaffected shoulders revealed significant differences (Tables I and II) in the height, the inclination angle, and the retroversion angle between the 2 sides (P < .05; Table II). A significant association between the Mallet score and the version was found, in addition to a significant negative correlation between the Mallet score and the inclination angle (compare Table I with Table II). The total width of the glenoid was not affected by OBPL (Table II). In the affected shoulders, the height of the glenoid was larger and the inclination angle was greater, indicating a more inferiorly facing glenoid fossa (Table II). Measurements of glenoid retroversion obtained at approximately the same level of the glenoid revealed a 2-D retroversion that was significantly greater than the 3-D measured retroversion (P < .001; Table III). The 3-D reformations of the glenoid fossa showed that retroversion varied depending on the level of the glenoid fossa where the measurements were performed. In particular, increasing angles of retroversion were measured toward the inferior pole of the glenoid fossa in the most affected children (Fig. 4, B-D). The glenoid in 4 children was antverted (Table I).

The form of the glenoid cavity on the nonaffected side was ovoid in 13 children (54%), and pear shaped in 11 (46%). The form of the affected glenoid showed different characteristics, which were related to distal undergrowth of the anterior and posterior glenoid vault. A dorsal edge loss was regularly seen in 21 children (Fig. 4, B-D). In cases of a combined dorsal and ventral bone loss, the glenoid appeared diamond shaped (Fig. 4, C). A ventral edge loss also appeared in combination with an increasingly retroverted distal part of the glenoid fossa (Fig. 4, D). The glenoid fossa appeared normal and pear shaped in 3 clinically affected children (Fig. 4, A).

**Scapular measurements**

The heights and the dorsal and ventral width of the entire scapula were significantly smaller in the affected shoulder compared with the nonaffected shoulder (Table IV).

**Inter-rater and intrarater reliability**

The relative reliability between the 2 radiologists was excellent for measurements on the affected side (ICC, 0.92; 95% CI, 0.46-0.97) and on the non-affected side (ICC, 0.79; 95% CI, 0.74-0.96). The agreement for the qualitative description of the glenoid form was substantial, with a κ value of 0.90 (range, 0.74-0.96).

### Table II

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Shoulder</th>
<th>No.</th>
<th>Mean</th>
<th>SD</th>
<th>Minimum</th>
<th>Maximum</th>
<th>P value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height, mm</td>
<td>Normal</td>
<td>24</td>
<td>24.96</td>
<td>4.40</td>
<td>15</td>
<td>35</td>
<td>.045</td>
</tr>
<tr>
<td></td>
<td>Affected</td>
<td>24</td>
<td>26.31</td>
<td>4.02</td>
<td>15</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>Total width, mm</td>
<td>Normal</td>
<td>24</td>
<td>17.57</td>
<td>2.80</td>
<td>11</td>
<td>22</td>
<td>.502</td>
</tr>
<tr>
<td></td>
<td>Affected</td>
<td>24</td>
<td>17.32</td>
<td>3.20</td>
<td>9</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>Inclination angle,°</td>
<td>Normal</td>
<td>24</td>
<td>64.54</td>
<td>7.17</td>
<td>54</td>
<td>84</td>
<td>.030</td>
</tr>
<tr>
<td></td>
<td>Affected</td>
<td>24</td>
<td>67.55</td>
<td>6.33</td>
<td>58</td>
<td>81</td>
<td></td>
</tr>
<tr>
<td>3-D version,°</td>
<td>Normal</td>
<td>24</td>
<td>1.73</td>
<td>3.62</td>
<td>−5</td>
<td>9</td>
<td>&lt;.001</td>
</tr>
<tr>
<td></td>
<td>Affected</td>
<td>24</td>
<td>−7.23</td>
<td>9.38</td>
<td>−39</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>2-D version,°</td>
<td>Normal</td>
<td>24</td>
<td>−5.58</td>
<td>5.24</td>
<td>−15</td>
<td>2</td>
<td>&lt;.001</td>
</tr>
<tr>
<td></td>
<td>Affected</td>
<td>24</td>
<td>−19.77</td>
<td>11.02</td>
<td>−54</td>
<td>−5</td>
<td></td>
</tr>
</tbody>
</table>

D, dimensional; SD, standard deviation.
*P < .05 indicates statistical significance.

### Table III

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Normal glenoid</th>
<th>Affected glenoid</th>
<th>Difference between shoulders</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3-D version</td>
<td>2-D version</td>
<td>3-D version</td>
</tr>
<tr>
<td>Mean ± SD</td>
<td>−5.58 ±5.24</td>
<td>−19.77 ±11.02</td>
<td>9.10 ± 10.28</td>
</tr>
<tr>
<td>P value*</td>
<td>&lt;.001</td>
<td>&lt;.001</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

D, dimensional; SD, standard deviation.
*P < .05 indicates statistical significance.
Discussion

To our knowledge, this study is the first to provide full CT-based 3-D descriptions of glenoid morphology in OBPL. Specific anatomic landmarks were easily defined from 3-D reformations of the glenoid fossa, and we identified several until now undiscovered features and provided new insight into osseous glenoid dysplasia. We observed that glenoid version varied significantly from top to bottom in the most severe cases, just as an increased inclination in the coronal plane was found to correlate with increased retroversion of the glenoid fossa. Our study also demonstrated bone loss of the distal glenoid.

**Table IV** Values of scapular width on ventral and dorsal side of affected and normal shoulder

<table>
<thead>
<tr>
<th>Variable</th>
<th>Shoulder</th>
<th>No.</th>
<th>Mean</th>
<th>SD</th>
<th>Minimum</th>
<th>Maximum</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height, mm</td>
<td>Normal</td>
<td>21</td>
<td>108.9</td>
<td>18.7</td>
<td>61.1</td>
<td>137.5</td>
<td>&lt;.001</td>
</tr>
<tr>
<td></td>
<td>Affected</td>
<td>21</td>
<td>104.5</td>
<td>1.9</td>
<td>60.2</td>
<td>126.9</td>
<td></td>
</tr>
<tr>
<td>Ventral width, mm</td>
<td>Normal</td>
<td>24</td>
<td>73.1</td>
<td>11.3</td>
<td>42.0</td>
<td>92.7</td>
<td>&lt;.001</td>
</tr>
<tr>
<td></td>
<td>Affected</td>
<td>24</td>
<td>66.2</td>
<td>10.8</td>
<td>37.6</td>
<td>82.7</td>
<td></td>
</tr>
<tr>
<td>Dorsal width, mm</td>
<td>Normal</td>
<td>24</td>
<td>71.7</td>
<td>10.9</td>
<td>42.2</td>
<td>88.8</td>
<td>&lt;.001</td>
</tr>
<tr>
<td></td>
<td>Affected</td>
<td>24</td>
<td>62.6</td>
<td>10.4</td>
<td>36.2</td>
<td>80.8</td>
<td></td>
</tr>
</tbody>
</table>

*D*, dimensional; *SD*, standard deviation.

*P* <.05 indicates statistical significance.

**Figure 4** Three-dimensional reformations of the glenoid fossa. (A) A normal glenoid shape was found in 3 children (12.5%). (B) A posterior edge loss of the bony glenoid was found in 13 children (54%). (C) A posterior and anterior edge loss of the bony glenoid was found in 5 children (21%). The * in B and C points to the flattened dorsal edge of the glenoid and the # in C points to the ventral edge loss. (D) A posterior and anterior edge loss combined with excessive retroversion of the inferior part was found in 3 children (12.5%).
vault leading to dysplasia in the sagittal plane. Finally, we also showed good inter-rater and intrarater reliability, comparable to other recent studies.5,11

Glenoid version has traditionally been studied in a 2-D setup using CT or MRI. The version of the glenoid is conventionally measured at the midglenoid level,33 which was also the case in the present study. However, all of the reporting authors inconsistently define the center of the glenoid.2,17,22,30,31,35 Our study revealed significant differences between 2-D axial plane measurements compared with angles measured on 3-D CT reformations. Glenoid version, in an age-matched, normal pediatric population, is reported to be approximately −2°.21 For reference, we measured a mean version of −1.5° using 3-D in the normal nonaffected shoulder compared with −6° when measured 2-D. We therefore believe that 2-D measurements tend to overestimate the angle of retroversion. The cause of this discrepancy between 2-D and 3-D measurements may be found in the positioning of the scapula during the scanning procedure, because the axial CT plane will not always be perpendicular to the scapular plane. In cases where the mean angle between the axial scan plane and the scapular body exceeds 35°, the axial image will display an oblique cut of the glenoid.13 Bokor et al5 also found the angle of glenoid retroversion varied with the rotation of the scapula in the coronal plane. The result in both scenarios is increased variability and reduced accuracy in 2-D measurements of the glenoid version.

Asymmetry in reduction of the shoulder joint and asymmetry in the forces created in the GHJ, as seen in OBPL, affect joint development and lead to glenoid deformity.2,25,30,35 The result is undergrowth of the glenoid bone, which is evident already within the first 6 months of life and tends to worsen during unbalanced GH growth.32 Dysplasia may therefore warrant early treatment to try to balance the joint.24 A recent report14 addressed glenoid dysplasia in 3-D using an MRI protocol, reaching conclusions contradictory to current knowledge of glenoid growth.13 On the contrary, Eismann et al,11 suggested that glenoid retroversion mainly results from growth restrictions of the posterior part of the glenoid.

The results of our study do not support the suggested undergrowth of the posterior part of the glenoid and the unchanged growth of the anterior glenoid. We demonstrated deformities of the distal glenoid fossa, which is characterized by dorsal bony edge loss and in the more severe cases also anterior bony edge loss. We also classified the form of the glenoid fossa from sagittal 3-D CT reformations of the affected shoulders. In normal shoulders, a true circle defines the borders of the inferior part of the glenoid.9,27 The glenoid form in 3 shoulders in our study could be described as normal, whereas the glenoid fossa in 21 shoulders was abnormally shaped. In instances in which the glenoid fossa presented as diamond shaped probably corresponded to the biconcave glenoid or pseudoglenoid defined by Birch3 and confirmed by others studies.25,29

Mintzer et al13 found that glenoid version in the youngest children varies with age and that adult retroversion is reached at the end of the first decade. In adults, the version is also known to vary according to the level of the glenoid surface,8 and the inferior glenoid fossa is reported to have a consistent retroversion.13,14 We demonstrated from our CT study that retroversion in OBPL varies substantially from top to bottom in the glenoid fossa, reaching the highest values distally in the more dysplastic cases. We did not find any correlation between age and version on the affected side, but on the nonaffected side, retroversion tended to decrease with age. MRI reveals mainly chondral changes and fails to reveal such dysplasia.5,11 Besides, true remodeling of the joint surface is known to take place at the subchondral level underneath the growth plate,7 which could explain the discrepancy between MRI findings and our results.

Glenoid dysplasia is not limited to the axial plane. Waters et al35 observed a caudal position of the glenoid on MRI coronal slides but did not address this issue further. Nath et al22 found a downward rotation of the entire scapula in diseased shoulders. Eismann et al,11 in an MRI based 3-D study, reported that less declination of the glenoid in the coronal plane correlated with greater 3-D glenoid retroversion, demonstrating a negative correlation between the 2 parameters. In contrast, we in the present study found an increased inclination in the coronal plane of the glenoid in the affected shoulders. The recent study by Brochard et al3 supported this view and stressed that an increased inferior inclination of the glenoid could cause the inferior migration of the humerus, thereby contributing to subluxation in the GHJ.

Our study revealed that the dimensions of the affected scapulae were decreased in height and width. This is in agreement with the hypoplasia caused by the lesion, also found in previous studies.11,22,28

Associations between the radiologic findings and the shoulder function could be very useful in the evaluation of children with OBPL.21,33 Preoperative Mallet scores were available in 17 children. We found a significant negative correlation with the inclination angle but not with the glenoid version. A significant association between version and global abduction has been reported, but not with the other functional parameters incorporated in the Mallet score.20 The limited data and that this parameter has only been sparsely studied made it difficult to draw any final conclusions on this aspect.

Several authors recommend MRI as the primary imaging modality in the evaluation of children with OBPL.5,11,30,35 In contrast to CT, MRI can visualize the cartilaginous part of the nonossified glenoid and MRI is therefore more suitable to evaluate dysplasia in the youngest children. In this study of children aged between 5 and 12 years, it was evident that defining the glenoid borders was more difficult in younger children than in older children.

Several considerations must be taken into account in the discussion of the advantage of CT vs MRI scanning. One of the advantages of using CT is that the child’s normal shoulder can be used as a reference. This is essential, because the version of the affected shoulder can be normal or slightly anteverted21 but still retroverted compared with an anteverted
nonaffected shoulder. This was the case in 4 children in this study.

CT-based morphologic measurements seem to be very accurate. Kwon et al\(^6\) obtained morphologic measurements from CT scanning of excised cadaveric scapulae. They concluded that 3-D CT reflects the true anatomy of the glenoid. Bryce et al\(^6\) validated the accuracy and precision of 3-D CT scapular models created from in situ scapulae. Their results suggested that 3-D models had sufficient accuracy to differentiate morphometric features of the scapula.

Another strong point is that measurements on 3-D reformatted CT images eliminated difficulties obtaining accurate measurements of retroversion caused by problems positioning the child during the scan procedure. As stated earlier, 2-D measurements tend to overestimate retroversion, and we believe that the measurements based on 3-D give a more correct presentation of the retroverted glenoid surface.

Plain radiographs do not provide 3-D insight into dysplasia. The true concavity of a 3-D surface is difficult to define from a single CT or MRI sequence obtained in the axial plane.\(^5\) Besides, 2-D transverse images of the glenoid do not address the inclination of the glenoid or provide information on the glenoid in the sagittal plane. The different shapes of the glenoid fossa observed in the sagittal plane mean that simplifying the 3-D shape into concavity vs. convexity would be inadequate. We have added a further dimension to glenoid dysplasia by providing information on the glenoid fossa in the sagittal plane. The use of 2-D measures may therefore be questionable for treatment planning.

A point of concern is that CT scanning results in exposure to radiation. Modern CT has, however, reduced radiation to a minimum, making CT less problematic for future clinical investigations.

Reproducibility in our study was excellent. The mean \(\kappa\) values for measurements of version and inclination were substantial and almost ideal, demonstrating high levels of understanding and agreement on glenoid dysplasia between the 2 independent radiologists.

Our study’s strengths are the homogeneous set of children and the imaging technique suited for the study of anatomic structures and for contralateral comparison. A weakness in this study is the relatively limited number of children included. A further limitation of our study, as well as of most other imaging studies, was the lack of a reference standard using 3-D image rendering.

**Conclusion**

OBPL is indeed a 3-D disorder. Measurements in the transverse plane revealed excessive retroversion, and the reliability of the 3-D CT method demonstrated that these measures are superior to their 2-D counterparts. Inclination was increased, as observed on 3-D reformations in the coronal plane, and reformations in the sagittal plane demonstrated bone loss at the inferior glenoid pole.

We have added a further dimension to glenoid dysplasia by providing information of the glenoid fossa in coronal and in the sagittal plane. Only reliable 3-D information allows the surgeon to fully comprehend the osseous deformations of the glenoid. These new findings further legitimate a 3-D CT-based description of the specific deformities connected with OBPL.

**Disclaimer**

The authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

This study was part of an MD thesis for author Pernille H. Schmidt (former Madsen).

**References**

5. Hoenecke HR Jr, Hermida JC, Flores-Hernandez C, D’Lima DD. Accuracy of CT-based measurements of glenoid version for total shoulder...


