INTRODUCTION
The measure of glenoid bone morphology is critical for the optimal treatment of primary glenohumeral osteoarthritis [1]. Walch et al. [1] proposed a prognostic classification that is widely accepted. This classification is mainly based on the measure of the glenoid version and subluxation of the humeral head. Although this method uses a reproducible criterion to choose the level of the axial plane, the measurement is purely 2D and depends on the scapula and humerus position within the CT. This can induce measurement error and do not account for bone wear out of this plane. The other proposed methods to overcome this issue require a complete reconstruction of the entire scapulae, and do not fully account for the complex 3D surface of the glenoid.

In this study, we propose a 3D generalization of Walch 2D method, which can be used with regular clinical CT containing only the lateral part of the scapula.

METHODS
Several landmarks were manually identified on CT images of the lateral side of the scapula. We placed 6 points in the supraspinatus fossa and 6 points in the axillary border, evenly distributed. These 2 sets of points defined the scapular plane by a (mean-square) fit. Then, an axis was fit on the 1st set of points and projected on the scapular plane, to define the medio-lateral X-axis. The antero-posterior Y-axis was perpendicular to the X-axis and the scapular plane. The inferior-superior Z-axis was perpendicular to these two axes. The projection of the scapular notch on the X-axis defined the origin of this coordinate system (Fig. 1.a). The glenoid bone surface was reconstructed by a segmentation of the CT images. The glenoid surface boundary corresponded roughly to its curvature inversion. We identified manually 20 points evenly distributed on the humeral head articular surface. The manual measurements were done with a visualizing software (www.amira.com). Glenoid version and humerus subluxation index were calculated with 3D vector geometry, to generalize Walch 2D method. The centroid of the glenoid surface projected on the glenoid surface defined the glenoid center. A sphere was fitted on the glenoid surface. This sphere centered and the glenoid center defined the glenoid centerline. The plane containing the glenoid centerline and parallel to the X-axis defined the version measurement plane (Fig. 1.b). The angle between this plane and the Y-axis defined the version orientation (Vo). The angle between the glenoid centerline and the X-axis defined the glenoid version angle (Va). Another sphere was fitted on the humeral head points. The plane containing the glenoid centerline and the center of this sphere defined the subluxation measurement plane (Fig. 1.c). The angle between this plane and the Y-axis defined the subluxation orientation (So). The subluxation index (Si) was defined as the ratio between the fraction of the humeral head beyond the centerline and the humeral head diameter. In addition, the following morphological quantities were evaluated: glenoid-humerus radii ratio (R), and medio-lateral position of the glenoid center (W). This algorithm was implement in Matlab.

The method was applied on 16 osteoarthritis (OA) and 5 normal (nOA) glenohumeral joints. We compared this 3D measure to Walch 2D measure, and we compared OA to nOA joints.

RESULTS
Va, Vo, Si, So, R and W were measured for 2 the groups (Table 1). The comparison with Walch 2D method resulted in correlation coefficients of 0.56 and 0.26 for Va and Si. They were 0.79 and 0.70 when using the same axial plane as Walch. Va was higher, and Va, R, and W were lower in OA than in nOA. Vo and So were mainly in the postero-superior quadrant (0-90°) of the glenoid, with a high variability, especially in the OA group. For most samples, Vo and So were similar (<20°). The radii regular (R) indicates a higher radius for the glenoid than for the humerus, and a higher congruency for the AO group. The medio-lateral distance of the glenoid center to the coordinate system origin (W) was rather constant for the nOA group. It was significantly smaller and more variable in the AO group. Only R (p = 0.004) and W (p = 0.001) were statistically different in the 2 groups.

**Table 1.** Average and standard deviation of version angle (Va), version orientation (Vo), subluxation index (Si), subluxation orientation (So), glenoid-humerus radii ratio (R), medio-lateral glenoid position (W).

<table>
<thead>
<tr>
<th>Group</th>
<th>Va [°]</th>
<th>Vo [°]</th>
<th>Si [%]</th>
<th>So [°]</th>
<th>R</th>
<th>W [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>OA</td>
<td>14.7±9.1</td>
<td>27.3±60.6</td>
<td>55±3</td>
<td>24.1±79.0</td>
<td>1.12±0.1</td>
<td>18.1±4.2</td>
</tr>
<tr>
<td>nOA</td>
<td>11.5±3.3</td>
<td>31.1±49.7</td>
<td>56±2</td>
<td>28.3±46.0</td>
<td>1.33±0.1</td>
<td>22.6±0.6</td>
</tr>
</tbody>
</table>

DISCUSSION
We have proposed a new method to measure the glenoid morphology, with the future aim of improving the treatment of primary glenohumeral osteoarthritis. We have verified that this 3D method successfully generalized the accepted Walch 2D method. With a limited number of samples, we have identified two parameters that can distinguish osteoarthritic from healthy glenohumeral joints. The 3D measure of the glenoid version angle (Va) and humerus subluxation index (Si) was consistent with the literature. The low correlation with Walch method was rather related to choice of the measurement plane than the 3D vector geometry method itself. In our method, the measurement planes are assumed better, since there are not dependent on arbitrary CT axial planes, but constructed to match morphological landmarks. For example, the subluxation plane crosses the center of the humeral head, which is estimated by a spherical fit. In overall, the observed differences between the two groups can be related to bone wear and associated with osteoarthritis.

The strength of this study is to extend in 3D a well-accepted 2D measurement method. We would indeed get the same results as Walch in specific conditions. In addition, the present method can be used with a regular clinical CT, which usually does not include the entire scapula. For that purpose, we have defined a new coordinate system, which is based on bone landmarks that are away from wear zones. We have also added the ratio of the glenoid-humerus radii and the glenoid distance, which revealed to correlate with osteoarthritis. The main limitation of this study is the small number of samples. We have however verified that the AO joints followed the same distribution in the classification of Walch. To conclude, this method developed further to propose a more precise, reliable and complete measure of the morphology of osteoarthritic glenohumeral joint, with the potential advantage to improve its surgical treatment.

SIGNIFICANCE
This work addresses the problem of measuring bone wear in primary osteoarthritic glenohumeral joint, to eventually improve the positioning of the glenoid component in total shoulder arthroplasty.

REFERENCES

ACKNOWLEDGEMENTS
This project was supported by the Inter-Institutional Center for Translational Biomechanics (EPFL-CHUV-DAL), and Tornier (Tornier, Inc., Edina, MN).