Femoral Surface Reconstruction and Dysplasia Characterization using 3D Ultrasound and Deep Learning

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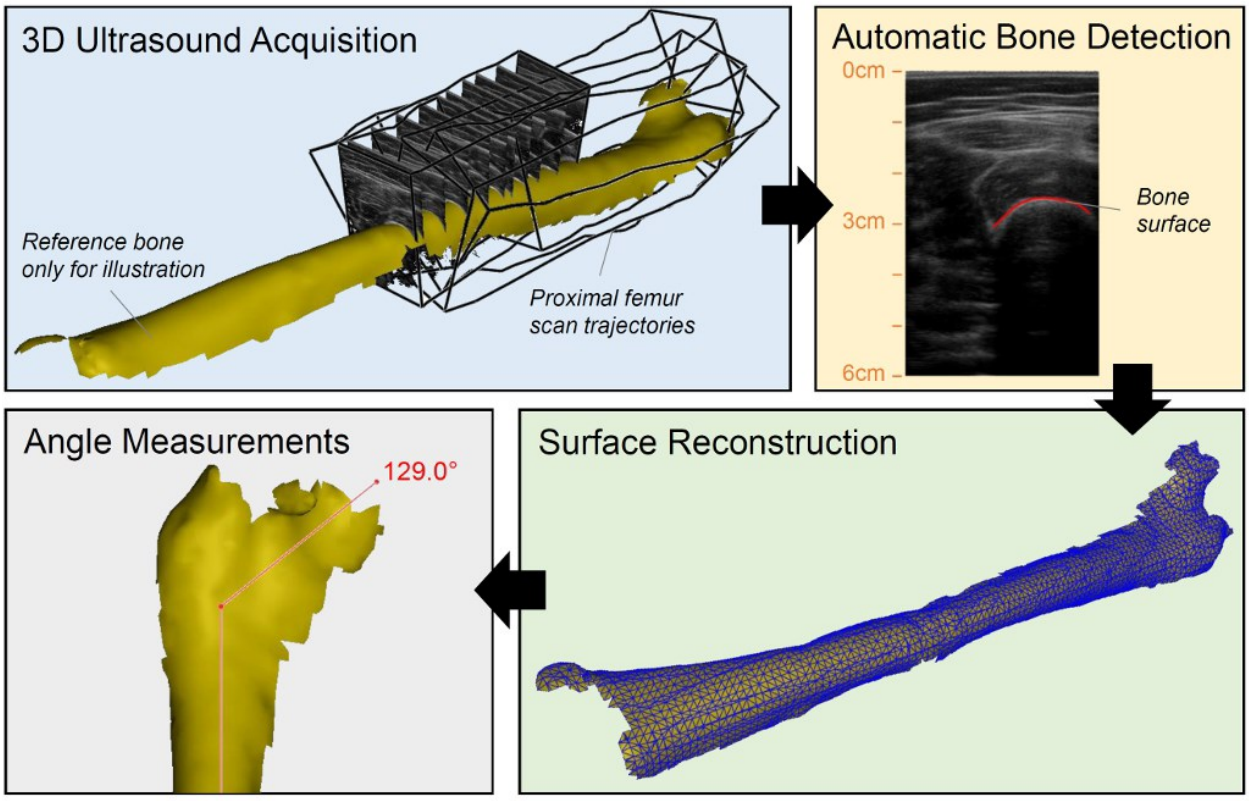
Objectives:

For the planning and execution of corrective osteotomies in patients with congenital hip dysplasia such as coxa valga et antetorta, precise measurements of the caput-collum-diaphyseal (CCD) angle and the femoral antetorsion (AT) are required. While these angles are routinely measured on Dunn-Rippstein radiographs, radiation dose reduction efforts call for alternative approaches. The aim of this study is to obtain angular measurements as well as a 3D surface reconstruction solely through 3D ultrasound (US). We present the experimental set-up and report preliminary findings on a synthetic bone model as well as a first patient case.

Methods:

We used a portable spryTrack 180 optical tracking system (Atracsys, CH) to determine where in space each 2D US image (Samsung HM70A scanner, linear transducer) was obtained. The sonographer was instructed to acquire cross-sectional images by slowly moving the transducer several times from knee to hip and from lateral to medial leg section. All image processing steps were performed in the ImFusion Suite (ImFusion, DE). A convolutional neural network previously trained on more than 1,000 manually labeled extremity bone scans was employed to automatically detect the femoral bone surface in all US frames. The acquisition was split into several segments at every direction change, and individually reconstructed in 3D. To overcome minor movements of the femur during the scan, the segments were then locally registered using intensity-based registration. Finally, a 3D point cloud and a single surface mesh were reconstructed using all segments combined, which allowed for direct CCD and AT angle measurements in 3D space. The surface reconstruction accuracy was validated on a synthetic model consisting of an additively manufactured polyamide femur (based on CT data of a 7-year-old child) surrounded by paraffin wax mimicking soft tissue. Furthermore, on a patient (8 years old) with enhanced femoral anteversion, angle measurements were performed by means of Dunn-Rippstein radiographs and 3D US, the latter in supine position with the knee fixated.



Workflow to obtain surface reconstruction and angular measurements through 3D ultrasound.

Results and Conclusion:

On a reconstructed mesh with 34,446 vertices, the surface errors of the bone model after registration were 0.54±0.45mm, median 0.39mm. A comparison of angle measurements from Dunn-Rippstein I/II radiographs and 3D US for the patient is reported in the table below.

	X-ray (projected)	X-ray (real)	3D US	Error
CCD angle	135.4°	129.5°	129.0°	0.5°
AT angle	29.1°	35.6°	37.6°	2.0°

Patient caput-collum-diaphyseal angle & antetorsion measurements in radiographs and 3D ultrasound.

This study showed the feasibility of the method with reliable surface reconstruction and angular errors of up to 2° to routine assessment. In the future, the error margins and validity of the method will be systematically determined on a larger patient cohort.