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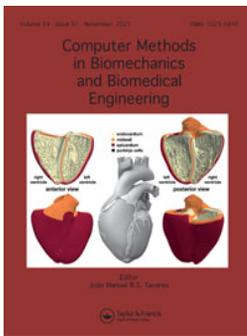
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Geometric reconstruction of a dual mobility cup liner using ultrasound imaging

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1. Introduction

The concept of the Dual Mobility Cup (DMC) was developed, in 1974, by G. Bousquet based on the 'Low Friction' principle defined by Charnley and McKee-Farrar's principle of using a larger femoral head to decrease implant instability (Neri et al. 2020). This hip prosthesis is composed of two joints: a large one, between the metal shell and the polyethylene liner, and a small one between the femoral head and the polyethylene liner. It helps to restore the hip joint range of motion, decrease wear, and increase implant stability (Neri et al. 2020). Despite numerous clinical studies showing benefits of the dual mobility cups to prevent instability, the biomechanical behavior of this prosthesis is still too little known (Terrier et al. 2017). In addition, to the best of our knowledge, no *in vivo* study has been carried out to understand the polyethylene liner movement.

Ultrasound (US) imaging is a non-invasive imaging method used in clinical routine to highlight conflicts between the hip prosthesis and psoas, diagnose tendinomyopathies, etc (Fantino et al. 2011). Therefore, this technology could also be useful in a clinical context to evaluate DMC *in vivo* behavior. To date, only Desmarchelier et al. 2016 used ultrasound imaging on a submerged DMC and proposed a methodology to visualize the liner position compared to the cup. However, manual processing which is time-consuming and operator dependant was the main limitation.

In this context, the aim of this study is to propose improved processing methods to reconstruct and visualize the liner and cup relative positions, on US images of a submerged DMC.

2. Methods

A dual mobility cup Novae Sunfit TH 47/28 (Serf®) was used and positioned in specific positions. A 3D

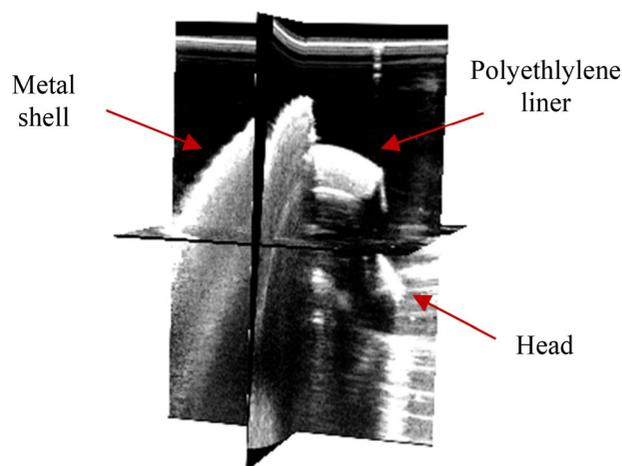


Figure 1. 3D Ultrasound image of the DMC.

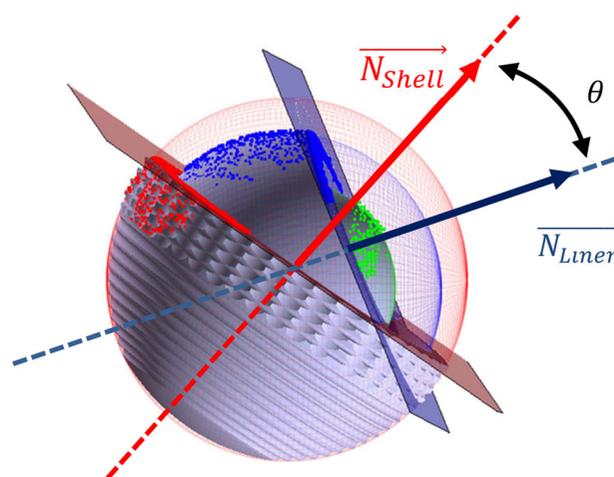


Figure 2. 3D Ultrasound process of the DMC (red dots, sphere, plane and normal = shell; blue dot, sphere, plane and normal = liner; green dots and sphere = head; grey = implant CAD models).

scan of the DMC was performed using a 3D laser scan (Metris 5128, Nikon®) and Focus software. Thereafter, DMC was submerged in water and ultrasound acquisitions of DMC proximal part were performed (Figure 1), using a 3D probe (Super Linear Volumetric 16-5) and an ultrasound system (Aixplorer® Supersonic Imagine®). This method was used for 22 different DMC positions corresponding to various orientations of the liner compared to the cup position. Data processing was carried out with Matlab (MathWorks®) and 3D Slicer software. Each DMC component was segmented on ultrasound imaging data using a threshold on the gray scale level of the B-mode image.

Three methods were developed to compare 3D scan and ultrasound data. Firstly, a 'Fit' method was used to fit spheres to the head, polyethylene liner, and metal shell data. Spheres diameters were

Table 1. Spheres diameters errors expressed in percentage, between constructor data and ultrasound or 3D scan, depending on imaging method; and spheres offset.

		Fit method		ICP method		Shell reference method		Desmarchelier et al. 2016	
		US	3D Scan	US	3D Scan	US	3D Scan	US	3D Scan
Error (%)	Shell	2,3	1,1	N/A	N/A	N/A	N/A	6,8	1,9
	Liner	-2,3	-1,9	N/A	N/A	-4,9	-0,9	4,3	1,1
	Head	-13,4	-1,3	N/A	N/A	-1,3	-0,2	5,7	1,3
Offset (mm)	Shell – Liner	1.9	1.3	1.7	1.3	N/A	N/A	N/A	N/A
	Shell – Head	5.1	2.3	1.8	0.9	N/A	N/A	N/A	N/A
	Liner – Head	3.8	2.2	1.7	1.3	N/A	N/A	N/A	N/A

Comparison with Desmarchelier et al. (2016).

calculated to minimize errors with ultrasound data. Secondly, an Iterative Closest Point (ICP) method was used to fit spheres, with known diameters from CAD models, to each component. For the third method called Shell reference method, metal shell diameter was fixed by constructor diameter (\emptyset 47 mm), and spheres were fit, with calculated diameters, to polyethylene liner and head data from the metal shell sphere center. For each method, a least mean square method was used to define liner and metal shell planes. Thanks to these data, angle between shell and liner planes was calculated using the normals of each plane. Moreover, offset between components centers and error with manufacturer specifications were measured for different methods.

3. Results and discussion

According to the experiments, mean angle difference (all methods), between ultrasound imaging and 3D scan, was 1.2° (SD: 0.8°). Moreover, the Fit method results showed a significative difference between experiments and manufacturer specification (error = -13.4%), for the head (Table 1). The Shell reference method errors between manufacturer specification and ultrasound and 3D scan imaging, were lower than 5% and better than the Fit method (except for polyethylene liner US data). The ICP method showed lower offset values (around 2mm or less) and seems to be the best of the three methods developed to reconstruct DMC (Figure 2).

The current study presents some limitations. Firstly, current experiments were carried out on sub-merged DMC. Soft tissues, bones, etc. around the dual mobility cup will undoubtedly modify the aspects of the images. In particular, ultrasound wave propagation in different soft tissues (muscles, fat, etc.), decrease the ultrasound images quality. Moreover metal shell, embedded in pelvis, will be probably invisible in the US images. Therefore, liner position may be alternatively defined, in pelvis reference frame, by abduction and anteversion angles. Secondly, the methods developed were not fully automatic, with

a non negligible time consuming (still lower than the full manual processing of Desmarchelier et al. 2016), and cannot be used in dynamics studies for now. Sphere results were generally similar to Desmarchelier et al. 2016. Only the angle between shell and liner planes was found more accurate (1.2° , SD: 0.8° vs. 2.2° , SD : 2.0°) but this is independent from the sphere reconstruction methods. Finally, ICP method was preferred to Fit and Shell reference method due to better accuracy. Results accuracy could be potentially increased with machine learning algorithms.

4. Conclusion

This current study demonstrates the feasibility to reconstruct the DMC using US imaging (except for the head diameters with Fit method). ICP method will be used for future *ex vivo* and *in vivo* studies where the polyethylene liner position will be quantified and visualized in a sequence of static hip poses.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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KEYWORDS Dual mobility cup; experiment; ultrasound; biomechanics

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