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Functional Safe Zone for Cup Orientation in THA

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Abstract

The usual safe zone for cup orientation in THA is not suitable for all patients, as the pelvic tilt varies with the movements of daily activities. A new Functional Safe Zone (FSZ) is proposed that considers the pelvic tilt in different positions. The aims of this study were to validate the proposed FSZ and to evaluate how the pelvic mobility impact it.

We measured the pelvic tilts of 30 patients when standing, sitting and supine, using our ultrasound-based device and computed their FSZs. The FSZs accuracy was assessed using a Computer-Aided-Design (CAD) software. The pelvic mobility influence onto the FSZ was assessed by jointly analysing the patients' FSZs and their pelvic tilt difference between positions.

The true FSZ provided by the CAD software and the estimated FSZ were similar by 92% and differed by less than 0.5° at borders and at the mean orientation. Patients with stiff pelvic mobility obtained small FSZs, and conversely, patients with large pelvic tilt variations between positions obtained large FSZs.

The proposed method allows the computation of a patient-specific FSZ without requiring additional X-ray or CT images. Patients having a low pelvic mobility with a higher risk of postoperative instability could be better managed using this FSZ.

1 Introduction

While the Lewinnek safe zone is broadly accepted for THA, how to make the cup orientation more patient-specific to reduce the risks of dislocation is still an ongoing question. Since the 00's several authors proposed different safe zones, based on the spine-hip mobility [1], the pelvic tilt [2], or the range of motion (ROM) of the hip [3]. Lately, some authors proposed more exhaustive approachs to compute a safe zone adapted to the patient morphology and the hip ROM in two positions while limiting edge loading [4, 5]. However, these methods require additional invasive imaging and do not take into account the pelvic mobility, *i.e.* the variations of pelvic tilt when sitting, standing and lying down.

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Thus we propose a non invasive approach to compute a functional safe zone (FSZ), based on the patient pelvic mobility, to limit the risks of prosthetic impingement. This study aims to validate the FSZ and to evaluate the pelvic mobility influence on the FSZ.

2 Materials & Methods

The proposed FSZ is based on the target zone proposed by Hsu *et al.* [6]. This target zone is defined regarding a target ROM, the patient-specific pelvic tilt and several prosthetic parameters (cup opening angle, femoral head and neck diameters, and femoral neck orientation). As proposed by Marchadour *et al.* [7], our FSZ corresponds to the merging of three target zones computed for the supine, sitting and standing positions.

2.1 Cohort

The pelvic tilts of 30 patients planned for THA (with mean BMI 25.5±3.1 kg/m^2 and mean age 66±14 years old) were obtained in a prospective, multicentre, non-randomized clinical study[1]. The pelvic tilts were measured in supine, sitting and standing positions by using an ultrasound based device [8] and further used for the validation and analysis of the FSZ.

2.2 Validation

The FSZ validation was performed on 10 patients randomly chosen from the described cohort. For each patient a ROM was randomly chosen. We modelled the movements of a 3D model prosthesis and performed a collision detection using SolidWorks (Dassault Systèmes, Vélizy-Villacoublay, France). The true FSZ, evaluated through collision detection, and the estimated FSZ, computed by the proposed method, were then compared in terms of average anteversion difference, average inclination difference, distance between borders and IoU coefficient (intersection over union). Results are reported as mean ± standard deviation.

2.3 Pelvic Mobility Impact

We selected 6 patients within the cohort, with either low, moderate or high pelvic tilt differences between the supine, standing and sitting positions. A FSZ has been computed for these patients, using the same prosthetic and ROM parameters. The influence of the pelvic mobility was evaluated by jointly analysing the patients differences of pelvic tilt and their obtained FSZ.

3 Results

3.1 Validation

The mean error between the true and the estimated functional safe zone was $-0.2 \pm 0.3°$ for average anteversion, $0.0 \pm 0.1°$ for average inclination, and $0.4 \pm 0.5°$ for average distance at borders. The mean IoU was 0.92 ± 0.03.

[1] Study registered under the identification number NCT03555812 in the clinical trials.gov database.

3.2 Pelvic Mobility Impact

The pelvic tilt differences between positions and the FSZs of patients with median and extreme pelvic tilt differences, is presented in Figure 1.

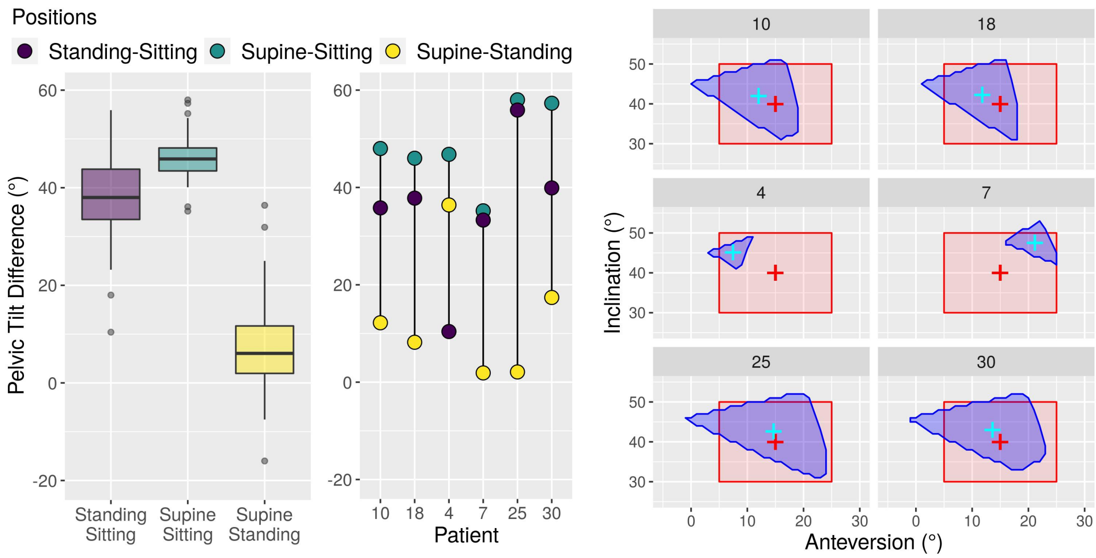

Figure 1: Pelvic tilt (PT) differences between positions and FSZ of selected patients:
• patients 10 and 18 have PT differences close to the medians values,
• patients 4 and 7 have the lowest PT differences between sitting and standing or supine,
• patients 25 and 30 have the highest PT differences between sitting and standing or supine.
The box plots show the distribution of PT differences between positions, over the 30 patients. The blue and red zones are respectively the functional and Lewinnek safe zones.

4 Discussion

To restore the patient mobility after THA, some authors recently proposed new safe zones, integrating several postures but requiring additional X-ray or CT images [4, 5]. The proposed method allows the imageless computation of a FSZ, considering the patient-specific pelvic tilts in standing, sitting and supine positions, acquired by our non-ionizing ultrasound-based device. We validated the proposed FSZ and evaluated the impact of the pelvic mobility on it.

Patients with a mobile pelvis, *i.e.* with large pelvic tilt variations between positions, obtained the largest FSZ whereas those with a stiff pelvis, *i.e.* small pelvic tilt variations, obtained the smallest FSZ. This is consistent with previous studies on the spinopelvic mobility [9, 10], as the low variation of pelvic tilt when sitting reduces the opening of the acetabulum thus increasing the risks of impingement [11]. The acquisition of the pelvic tilts in different daily positions using our ultrasound-based device, could eventually be sufficient to adapt the cup orientation to the patient's pelvic mobility and be a non-ionizing alternative to the X-ray images commonly used to evaluate the spinopelvic mobility

The FSZ adaptation to the patient's pelvic tilts demonstrates the need for a patient-specific cup orientation, in particular for patients with low pelvic mobility. Yet, further clinical study should be performed to confirm that the FSZ ensures the absence of prosthetic impingements.

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