EPiC Series in Health Sciences
Volume 1, 2017, Pages 47–50
CAOS 2017. 17th Annual Meeting of the International Society for Computer Assisted Orthopaedic Surgery

Measuring pelvic tilt with the use of a navigated smart-device based ultrasound system

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Abstract

The key for a successful total hip replacement (THR) and the longevity of the implant is the correct alignment of the acetabular cup which is to be considered as the most critical component. The alignment of the cup is defined with respect to anterior pelvic plane (APP). The APP defines the reference for the anteversion and inclination angles which sets the basis for the correct alignment of the implant. The angle of the plane is created by three distinct anatomical landmarks which are represented by two anterior superior iliac spines (ASIS) and the symphysis pubis. The angle of the APP in respect to the coronal plane defines the pelvic tilt (PT) which can be anterior or posterior. The rotation of the pelvis highly depends on the individual anatomy of the subject. This means that a neutral pelvic tilt (PT) in supine position is rarely observed and also may be dissimilar in standing position. In this paper we present a non-invasiveness and cost-effective prototype for measuring the patient-specific PT under the use of a navigated smart-device based ultrasound system for supporting surgery planning. In view of the non-invasiveness method the system can be used to measure pre- and postoperative pelvic orientation. With the use of an artificial hip reference model different cases were measured. The computed results look very promising with a standard deviation of ±1°.

1 Introduction

The key for a successful total hip replacement (THR) is the correct alignment of the acetabular cup which is to be considered as the most critical component. The right positioning of the acetabular cup defines the functional performance and longevity of the entire endoprosthesis. A common cause of complications is the malposition of the acetabular component which can result in dislocations, impingement and limited range of motion (Biedermann 2005). For a three-dimensional orientation during THR and positioning of the acetabular cup the anterior pelvic plane (APP) is commonly used as a superficial anatomical reference to improve the accuracy of implantation. The APP defines the reference for the anteversion and inclination angles which sets the basis for the correct alignment of the implant. The angle of the plane is created by three distinct anatomical landmarks which are represented by two anterior superior iliac spines (ASIS) and the symphysis pubis. The angle of the APP in respect to the coronal plane defines the pelvic tilt (PT) which can be anterior or posterior. Generally in clinical practice, the most used implantation angles are 40°±10° of inclination and 15°±10° of anteversion which were proposed by Lewinnek et al., as a "safe zone" (Lewinnek 1978). Lewinnek's assumption is that the orientation of the APP in a relaxed lying position is horizontal and the PT is the angle between APP and horizontal plane (0° PT). Abdel et al. reported that 58% out of more than 200 dislocated implants had been placed in Lewinnek's safe zone (Abdel 2015). However, studies on pelvic tilt have reported that the rotation of the pelvis highly depends on the individual anatomy of the subject. This means that a neutral PT in supine position is rarely observed and also may be different in standing and lying position (Mayr 2005, Murphy 2013). Currently, the measurements of the pelvic tilt are based on preoperative image acquisition using computer tomography (CT) or magnetic resonance imaging (MRI) in a lying patient position. In this work a cost-effective measurement system using navigated ultrasound was developed for preoperative acquisition of patient-specific PT in a standing and supine position. For that purpose an ultrasound probe is tracked with an optical localizer which is implemented in a hand-held smart device. In comparison to CT/MRI this allows for a fast preoperative real-time screening. The system is tested by taking measurements with an artificial hip reference model (Fig.1).

2 Materials and Methods

The system consists of a central unit (MS Surface). On the central unit the ultrasound device is connected and a Unity app is running to obtain the ultrasound image.

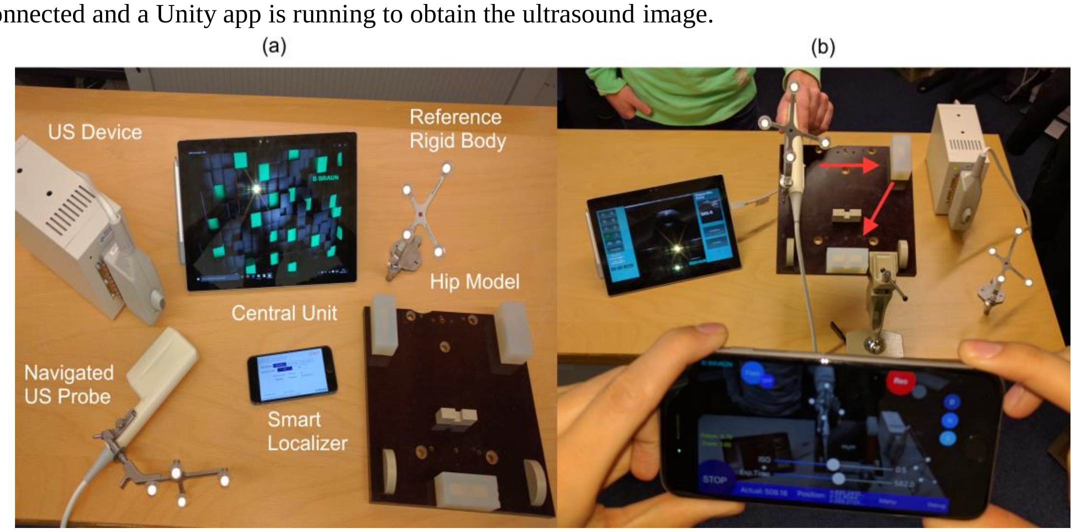

Figure 1: The system consists of the following components: ultrasound device (Telemed Echo Blaster 128), two rigid bodies (Aesculap AG), mobile localizer (iOS) and a central unit (Windows Surface) (a); Test environment for the measurements: One person have to control the mobile localizer to record the actual 3D position of the ultrasound probe. The three pelvic landmarks were recorded in the following order: ASIS right, ASIS left and symphysis pubis (b).

For recording the required landmarks a rigid body is attached to the ultrasound probe. A second rigid body is fixed around the subject and acts as a reference for the recorded landmarks. For the optical localisation each rigid body is equipped with four retroreflective spheres. A smartphone (Apple iPhone) app based on the principle of imageless navigation is used to real-time localization and 3D position calculation of both rigid bodies (Daniol 2015). The smartphone is connected over WiFi with the central unit and can be held and operated in the hand. Each measurement consists of an ultrasound image and navigation data recorded by smartphone localizer. After performing landmark measurements the desired structure needs to be marked on each ultrasound image. Ideally, the highest point on the contour of the left and right ASIS is selected. For the symphysis pubis, the ultrasound probe is placed longitudinal over the pubic prominence. The ASIS can be considered as bright hypoechoic curved structures. The pubic symphysis is seen as a darker hypoechoic line between the two bony structures. After performing those steps, the pelvic tilt is computed by the central unit app.

3 Results

For the evaluation and feasibility of the pelvic tilt measurement system a hip phantom was used. The phantom was fixed through a rotatable clamp and placed in five different angle positions (25° anterior, 10° anterior, 0°, 80° & 100° posterior). The PT was calculated in relation to the coronal plane. A calibrated inclinometer was used to verify the set position. The camera position of the localizer was about 1 meter away from the target (Fig.1 b). 100 recordings were made for each hip position. For every position the results were calculated and the average, standard deviation and variance were calculated. The results of the measurements are summarized in Table 1.

Position	Mean	Standard Deviation	Variance
25° anterior	24.65°	± 0.78°	± 0.61°
10° anterior	9.90°	± 0.77°	± 0.59°
0°	0.33°	± 1.02°	± 1.05°
80° posterior	80.58°	± 0.39°	± 0.15°
100° posterior	99.20°	± 0.63°	± 0.40°

Table 1: Calculated results for five different positions in degree. For measurements, the vertical plane was assumed as a reference (0° PT).

4 Discussion

An easy-to-use prototype application for navigated ultrasound has been developed. This system meets all minimally-invasive surgery needs, in use and calculation of the pelvic tilt. The maximum measurement error was about one degree and the results look promising with respect to the accuracy of the application. The whole measurement workflow operates with no radiation exposure which is of high importance for patients and surgeons which have to perform hundreds of surgeries a year. For further work the measured PT can be applied to readjust the implantation angles by previous studies from Babisch et al. (Babisch 2008) and Lembeck et al. (Lembeck 2005).

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