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3XPlan: A Novel Technology for 3D Prosthesis Planning using 2D X-ray Radiographs

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Abstract

The purpose of this paper is to present a clinical validation of a novel technology called '3XPlan' which allows for 3D prosthesis planning using 2D X-ray radiographs. After a local institution review board (IRB) approval, 3XPlan was evaluated on 25 patients TKA. Pre-operatively, all the patients underwent a CT scan according to a standard protocol. All the CT images were segmented to extract 3D surface models of both femur and tibia, which were regarded as the ground truth. Additionally, 2 X-ray images were acquired for each affected leg and were used in '3XPlan' to derive patient-specific models of the leg. For 3D models derived from both modalities (CT vs. X-ray), five most relevant anatomical parameters for planning TKA were measured and compared with each other. Except for tibial torsion, the average differences for all other anatomical parameters are smaller than or close to 3 degrees.

1 Introduction

Good clinical outcomes of Total Knee Arthroplasty (TKA) demand the ability to plan a surgery precisely and measure the outcome accurately. In comparison with plain radiograph, CT-based 3D planning offers several advantages. More specifically, CT has the benefits of avoiding errors resulting from magnification and inaccurate patient positioning. Additional benefits include the assessment in the axial plane and the replacement of 2D projections with 3D data. The concern on 3D CT-based planning, however, lies in the increase of radiation dosage to the patients [2]. An alternative is to reconstruct a patient-specific 3D model of the complete lower extremity from 2D X-ray radiographs [4]. This study presents a clinical validation of a novel technology called '3XPlan' which allows for 3D prosthesis planning using 2D X-ray radiographs.

2 Materials and Methods

There are three core components in 3XPlan technology (Fig. 1): (1) a knee joint immobilization apparatus; (2) an X-ray image calibration cage; and (3) a statistical shape model-based 2D-3D

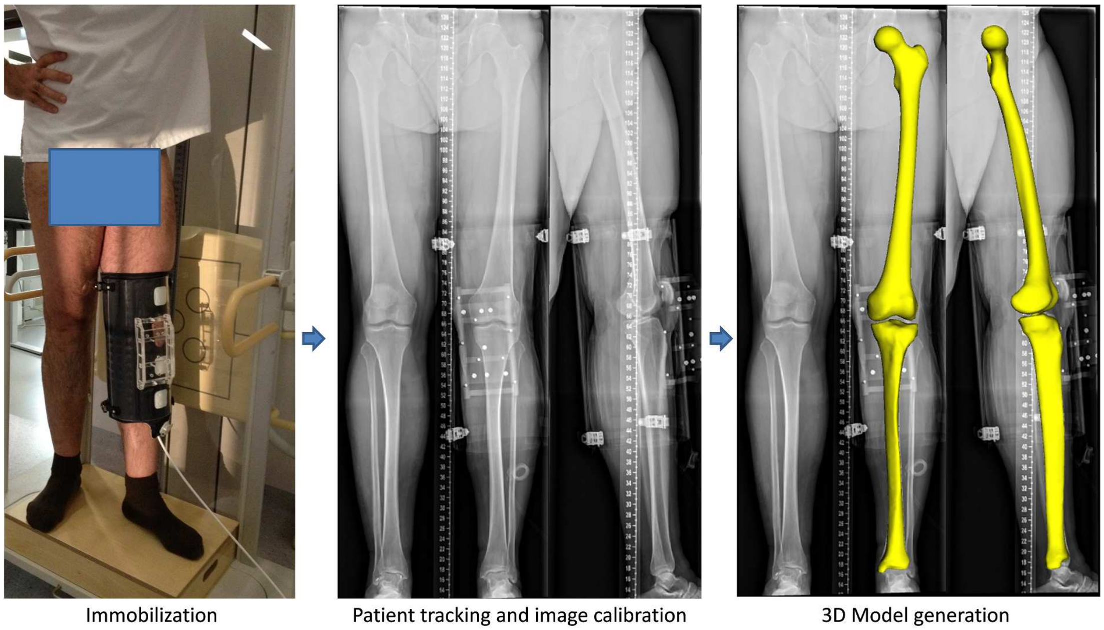

Figure 1: A schematic overview of 3XPlan technology. From left right: immobilization, patient tracking and image calibration, and 3D model reconstruction

reconstruction algorithm. These three components are integrated in a systematic way in 3XPlan technology to derive 3D models of the complete lower extremity from 2 2D X-ray radiographs in a weight-bearing position. More specifically, the knee joint immobilization apparatus is used to rigidly fix the X-ray calibration cage with respect to the underlying anatomy during the image acquisition. The calibration cage then serves for two purposes. For one side, the cage will allow one to calibrate the projection parameters of any acquired X-ray image. For the other side, the cage also allows one to track positions of 2 X-ray images, acquired from different positions, which is a pre-requisite condition for the third component to compute patient-specific 3D models from 2D X-ray images and the associated statistical shape models. Prosthesis planning is then done based on the reconstructed 3D models..

After a local institution review board (IRB) approval, 3XPlan was evaluated on 25 patients TKA. Pre-operatively, all the patients underwent a CT scan according to a standard protocol. Image acquisition consisted of three separate short spiral axial scans: 1) ipsilateral hip, 2) affected knee and 3) ipsilateral ankle. All the CT images were segmented to extract 3D surface models of both femur and tibia, which were regarded as the ground truth. Additionally, 2 X-ray images were acquired for each affected leg and were used in 3XPlan to derive patient-specific models of the leg. For 3D models derived from both modalities (CT vs. X-ray), specific anatomical parameters were measured and compared with each other.

3 Results

Two cases had to be drop out of the study due to problems in image acquisition. For the remaining 23 cases, Table 1 shows a summary of five most relevant parameters for the planning of TKA. Except for tibial torsion, the average differences for all other anatomical parameters are smaller than or close to 3 degrees.

Table 1: Differences between the anatomical parameters derived from the reconstructed model in comparison with those derived from ground truth models

Parameters	Mean ± STD (degrees)
Angle between femoral anatomical and mechanical axes	0.2 ± 0.2
Femoral antetorsion	3.5 ± 2.8
Femoral neck-shaft angle	2.0 ± 1.9
Posterior tibia slope	2.9 ± 2.1
Tibial torsion	4.4 ± 3.1

4 Discussions

In this study, we conduct a clinical study to investigate the accuracy of a new technology called '3XPlan', which allows for the reconstruction of patient-specific 3D models of a complete lower extremity from only 2D X-ray radiographs. Our experimental results demonstrate the accuracy of this novel technology.

It is worth to discuss the differences between 3XPlan and other technologies in the literature. For example, Chriet at al. [3] proposed to use a calibration jacket based solution for the 3D reconstruction of the human spine and rib cage from biplanar X-ray images. However, only using a calibration jacket is hard to prevent the relative movement between the calibration cage and the underlying anatomy during image acquisition. An alternative solution is to develop specialized X-ray imaging device, as exemplified by the development of EOS imaging system [1], where two images are simultaneously acquired, thus eliminating the requirement of patient tracking. However, due to the relative high acquisition and maintenance costs, the EOS imaging system at this moment is only available in a few big clinical centers and is not widely available. In contrast, 3XPlan can work with any conventional X-ray machine, which is not only cost-effective but also facilitate wide distribution.

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