INTRA-OPERATIVE SHAPE ACQUISITION OF TIBIO-FEMORAL JOINTS USING 3D LASER SCANNING FOR COMPUTER ASSISTED ORTHOPAEDIC SURGERY: A PROOF OF CONCEPT

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INTRODUCTION

Image registration is an important aspect in all computer assisted orthopaedic surgery (CAOS). It is a process of developing a spatial relationship between pre-operative data, such as Computed Tomography (CT) scans or Magnetic Resonance Imaging (MRI) scans and the physical patient in the operation theatre. Current image registration techniques for CAOS in minimally invasive Unicompartmental Knee Arthroplasty surgery (UKA) are invasive, time consuming and often take 15-20 minutes and are therefore costly (Mozes et al., 2009; Hagag et al., 2011; Banger et al., 2013). The rationale for this study was to develop a new operation theatre compliant, quick, cost effective, contactless, automated shape acquisition technique during CAOS based on an accurate rigid body model of the ends of the exposed knee joint produced using 3D laser scans taken intra-operatively by a Laser Displacement Sensor.

MATERIALS AND METHODS

Bespoke automated 3D laser scanning techniques based on the DAVID Laserscanner method were developed and were used to scan surface geometry of the knee joints in cadaveric legs. Pre-operatively 11 cadaveric knee joint compartments were MRI scanned using 3D FLASH technique. These scans were segmented in Mimics, 12.0 to generate the 3D surface models of the articular cartilage (figure 1(a)). Intra-operatively acquired 3D laser scanned knee joint models (figure 1(b)) were registered with the pre-operative models (figure 1(c)) and the average absolute errors (AAE) were evaluated in the robust digital image software package, Geomagic Qualify® 12. Furthermore, trends in the AAE with respect to two variables (type of exposure: UKA and TKA, type of setup: Bespoke extrusion based and MAKO RIO based) were studied.

RESULTS

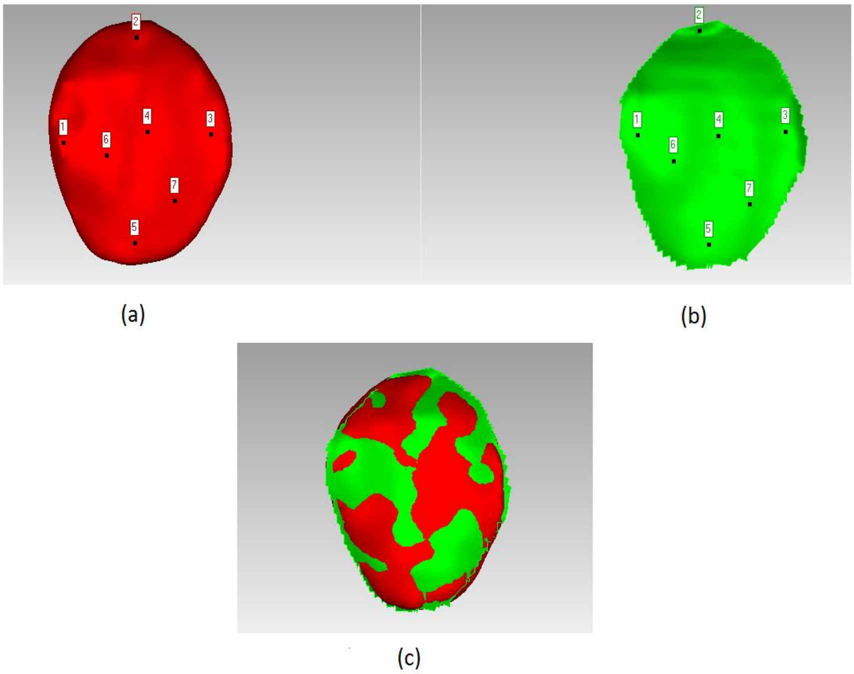

Figure 1: Manual registration by selecting random points over the lateral tibial surface (a): 3D model of the lateral tibial cartilage generated using pre-operative MRI scans. (b): Corresponding intra-operatively acquired 3D laser scan of the lateral tibial cartilage. (c): Registered models.

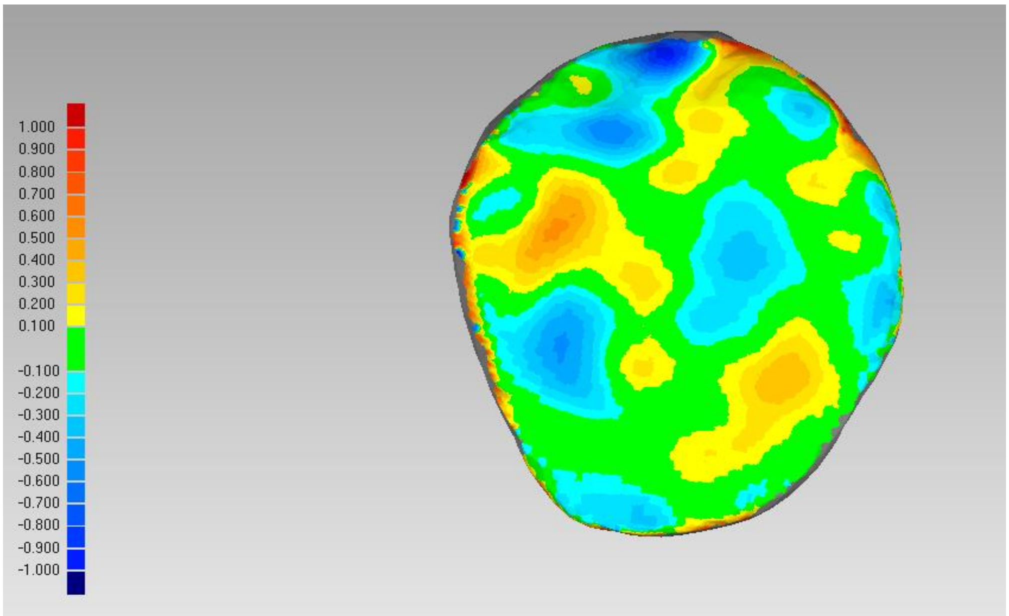

Figure 2: Top view of the colour deviation map for the spatial distribution of the deviations between the reference (MRI) and the test (laser) model of a left tibial lateral cartilage

DISCUSSION

This study has addressed an important issue by providing a 'proof of concept' to replace the current invasive, time consuming and costly manual intra-operative image registration process of CAOS using 3D laser scanning. After an extensive literature review and a set of pilot studies, a clinically safe laser sensor with suitable parameters (650 nm, 1 mW) was chosen to acquire the 3D digitized data of the articular cartilage and bones in the human tibio-femoral joints (Marmulla et al., 2004; Bowers et al., 2008). Using this laser sensor a quick, inexpensive, contactless and automated 3D laser scanner was developed. The total cost of the scanning hardware was less than £200. The overall time for scanning, post-processing and the registration required less than 4 minutes for every model. On the other hand, registering each surface using MAKO Surgical registration approach required more than 8-10 minutes.

A series of experiments showed that the AAE between the pre-operative MRI models and the intra-operative 3D laser scans were in general less than half a millimetre. This suggests that the system can repeatedly acquire accurate 3D scans of the tibio-femoral joints and most importantly in the operation theatre environment. Results also indicated that the type of setup had no significant effect on the deviations, $P>0.05$, thus bulky extrusion based scanner can be replaced with a compact MAKO RIO based scanner. The scans were acquired with two types of exposures, UKA (80-100 mm) and TKA (150-220 mm). Results indicated that due to the 'edge effect', deviations with TKA exposures were significantly larger than the UKA exposures, $P>0.05$. It can also be seen from figure 2 that due to the edge effect the deviations with higher magnitudes appeared on the peripheries of the model (Herbert and Kortkov, 1992; Huising and Pereira, 1998; Bao and Yao, 2001; Boehler et al., 2003).

In this study the feasibility of using a novel laser scanning technique was demonstrated where by acquiring scans of the tibio-femoral joint in theatre, complete 3D models of the geometry and surface texture can be developed which can be registered with the pre-operative scan. The developed system proved to be suitable for scanning knee joint surface geometry in theatre and to an accuracy suitable for CAOS knee surgery.

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