FORCE-TORQUE MEASUREMENT SYSTEM FOR FRACTURE SURGERY

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INTRODUCTION

Many surgical procedures are now performed using the techniques of minimally invasive surgery (MIS), in which the surgeon manipulates instruments inserted into the patients through small incisions. In MIS, the surgeon has no direct contact with internal body parts. Applying an optimal force and torque via the instruments is necessary to conduct an operation without causing any damage to the internal tissue. Most studies have so far been reported for general MIS where force-feedback is added to laparoscopic instruments using various sensing technologies (Menciassi 2001), (Song 2011). This paper reports our work on minimally invasive fracture surgery, where the issue of force feedback is as important and relates to the manual manipulation of externally fixated pins inserted in the fracture fragments to reduce the displacements. The related work in this field includes developments of surgical robots for fracture reduction of femur. Some of these robots e.g. (Douke 2008), (Gösling 2006) are equipped with the force measuring sensors to compensate for the inaccuracy of bone motion caused by surrounding ligaments and muscles. Forces and torques have been measured and reported in phantoms (Douke 2008) and in patients during femur fracture reduction (Gösling 2006). Our study is focusing on robot-assisted reduction of fractures that include joints (Raabe, 2012). The surgical procedure of this type of fractures involves moving individual fragments to the correct anatomical position. The forces required to execute these manoeuvres have to be established in order to design robot controllers and safety parameters for the system. The measurements will be recorded during manual displacement of the bone fragments using a periosteal elevator (orthopaedic instrument used to handle periosteum and bone fragments during a fracture surgery) on patients' legs subjected to these forces.

For this purpose we have created a modified instrument that can be used in real surgeries.

MATERIALS AND METHODS

A periosteal elevator has been instrumented with a 6-DOF load cell (FTSens, Istituto Italiano di Tecnologia, Italy) (Fig.1a), to measure forces and torques applied to bone fragments by the surgeon in-vivo. The periosteal elevator has been cut in two parts between the tip and the handle and the load cell has been fixed in between. The tip of the device has been kept intact in order to assure bio-compatibility, but it can be removed from the device to allow proper sterilisation according to the hospital procedures. The FTSens (Fig.1b) is capable of measuring simultaneously 3 components of force (Fx, Fy, Fz) and 3 of torque (Tx, Ty, Tz), and to transmit these data in digital form on a CAN-bus line. A 5mm acetal disk is separating the tip and the FTSens (Fig.1a). Six plastic PEEK socket head screws fasten the tip to the load cell to ensure non-conductivity for patient safety. A formal verification process has been conducted for checking the insulation parameters according to clause 4.10 of IEC60601-1 given that the device is classified as a Safety Extra-Low Voltage (SELV).
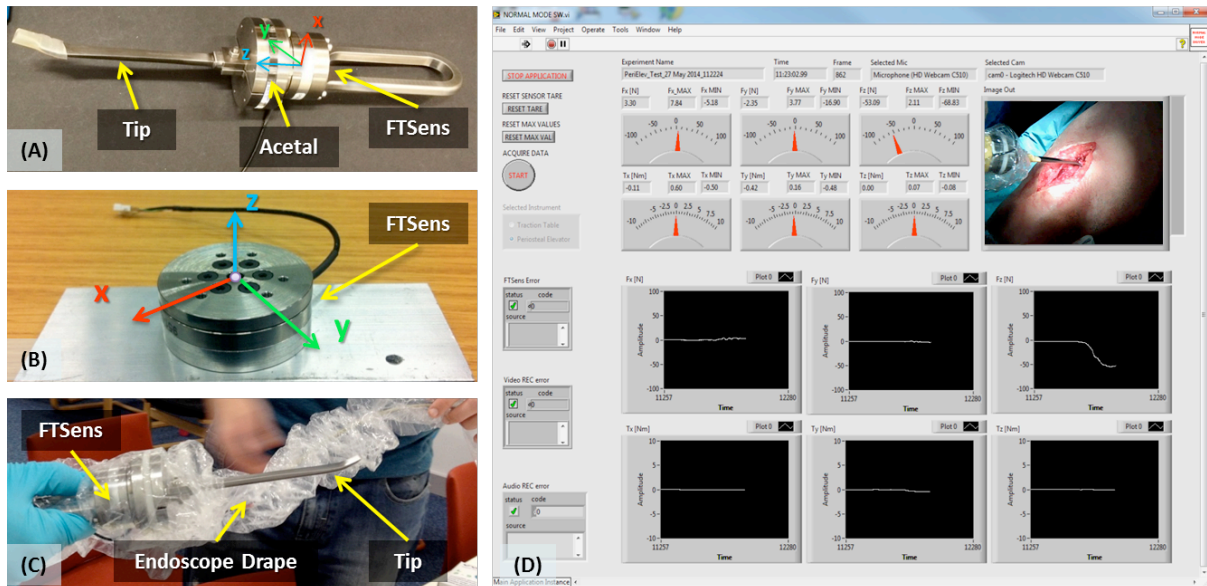
Figure 1: Measurement system setup: the assembled measuring device (A); the FTSens and its coordinate frame (B); the measuring device in the sterile endoscope drape; and the acquisition software GUI (D).

We aim to acquire force/torque measured by the FTSens together with visual information of the tip interacting with the bone fragments, while recording surgeon's voice describing the manoeuvres. All recordings have been integrated into a Force Measurement Software (FMS) developed in LabView and running on a laptop PC. A graphical user interface (GUI) (Fig.1d) allows the user to acquire and visualize the force/torque data in real-time together with video and audio information provided by a USB camera with a microphone. These three sources of information are time synchronized and simultaneously recorded for off-line analysis.

As a pilot study, the system was tested during a real orthopaedic surgery involving removal of a metal plate from the femur shaft. The following sterilisation protocol has been followed: the tip of the device was sterilised in autoclave and the other parts of the device (FTSens and device handle) were put inside a sterile endoscope drape, leaving only the sterile tip in contact with the tissues (Fig.1c). Data were acquired using the proposed system only during two sub-states of the surgical procedure, namely periosteum lifting and plate removal, and subsequently analysed off-line.

RESULTS

Dedicated software for off-line data analysis was developed in LabView to study the forces/torques applied during each state of the surgery (i.e. periosteum lifting and plate removal). Force/torque and video data encode the type of the tool-tissue interaction, while audio data encode the corresponding state of the surgery. Results are presented in Fig.2.

DISCUSSION

We proposed a new 6-DOF system for force/torque measurement during in-vivo fracture surgery. The developed technology and surgical protocol were tested in a pilot study during real orthopaedic surgery, resulting reliable and usable. Coupling force/torque data with video and audio information produced quantitative knowledge of forces/torques applied by the surgeon during a specific state of the surgery, as clearly shown by the results from off-line data analysis (Fig.2). This knowledge can be used to create a database for surgical skills evaluations allowing objective measurement of skill, improving movement efficiency, and reducing soft-tissue injuries (Rosen 1999). Also, this technology can be used to design force sensing systems for robot-assisted surgery (Gonenc 2013, Ortmaier 2007).
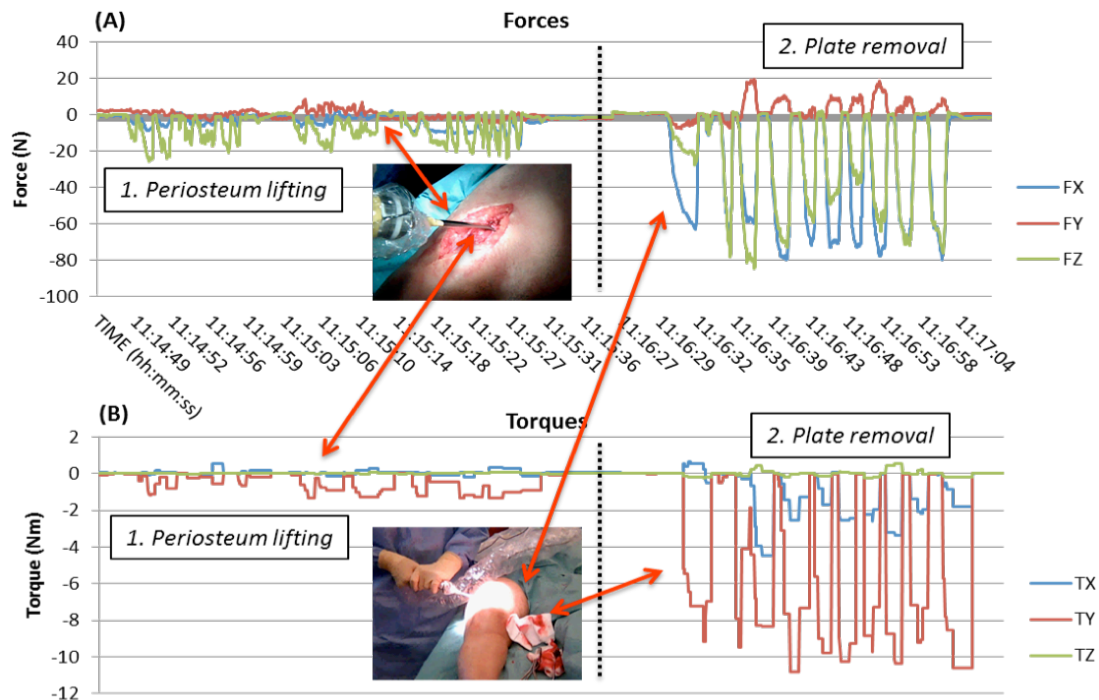
Figure 2: Results from the pilot study: forces (A) and torques (B) data are plotted together with their relative surgical states (from audio data) and samples of surgical images (from video data).

At the Bristol Robotics Laboratory, research toward improving joint fracture surgery is conducted to create a robotic system for minimally invasive robot-assisted fracture surgery (RAFS) (Raabe 2012). The approach outlined in this study will be used to perform intensive force measurements during orthopaedic surgeries. The generated quantitative knowledge will be used to design a force controller and optimized actuators for the RAFS system.

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