Title:
Application and evaluation of a principled approach to designing realistic haptic drilling interaction in surgical simulators

Aims:
The aim of this work is to apply and evaluate a principled approach to the development of haptic interaction in virtual reality surgical drilling simulators. This approach is based on ex vivo measurements of real forces. Force measurements provide an objective way to calibrate the haptic feedback of a surgical simulator and can be used to validate its tactile fidelity. We have applied this approach to the analysis of drilling interaction for a dentoalveolar drilling simulator, with the objective of training dentistry students to distinguish tooth and bone.

Background:
Force feedback in virtual reality surgical simulators is typically developed through repeated cycles of expert feedback. This approach is subjective and time-consuming. Some researchers have begun to calibrate and validate simulators using measures of real forces. Agus et al [1,2] applied this approach to temporal bone surgery simulation and the Beihang University group [3,4,5,6] applied it to dental drilling simulation. Research in this area to date has been largely limited to drilling a single material, often using simplified drilling tasks. No investigations have been carried out using expert and novice surgeons to facilitate a comparison of the forces applied by individuals of different skill levels. This study aims to address some of these issues, while also providing data on the forces applied during alveolar drilling, which is currently absent from the literature.

Methods:
The studied drilling task was that of removing jaw bone to expose the root of a tooth without damaging the tooth itself. Current dentistry students, recent dentistry graduates and expert dentists performed this task on ovine jaws attached to a custom-built tri-axial force sensor. In addition to three dimensional force measurements, audio-visual records of each session were kept. Further recordings of tooth drilling forces were carried out in order to examine the resulting forces when tooth is unintentionally damaged by participants.

Results:
Statistical analyses were effective in establishing the force ranges and average forces involved in drilling tooth and bone, as well as providing an understanding of the force characteristics of each participant group. Experts were found to apply the largest forces, followed by current dentistry students. A comparison of forces over time showed that forces applied by students and recent dentistry graduates varied rapidly over time compared to experts, who had the smoothest force curves. Video data showed that students and recent graduates used rapid jabbing strokes while experts used long sweeping strokes.

Conclusions:
Teaching trainees to recognise the tooth-bone boundary during dentoalveolar procedures critically depends on a realistic simulated representation of this boundary. This study has developed a method of measuring the forces exerted while drilling at the interface of tooth and bone. This data has been used to show how differences in forces applied by participants can be used to determine their skill levels. The data is now being used to calibrate the haptic feedback of a dentoalveolar surgical training simulator, and in the future will be used to provide automated force-based feedback to trainees.

References: