

Conclusion

Robotic laser guidance is feasible for needle placement procedures and could be more accurate than standard methods. Although speculative, improved accuracy could lead to safer procedures, reduced procedure time and improved clinical outcomes.

Correlation of mastoid bone density and drilling force during direct cochlear access

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Keywords Robotic surgery · Bone density · Drilling force · Cochlear implantation

Purpose

The introduction of robotic manipulators into a surgical environment theoretically allows for the completion of surgical tasks with levels of accuracy impossible for even a skilled surgeon to achieve. Despite this, very few robotic systems have been implemented in a clinical setting. The simultaneous achievement of high accuracy, safety and clinical integrability can be restrictive. In order to achieve good clinical outcomes the system should be able to perform the defined surgical task under a variety of conditions, while also being able to adapt to changes in the surgical environment during a procedure. A key component of this is the collection and utilization of information from a variety of sensor sources. The larger the amount of information and the wider the range of sources the more confident one can be in their knowledge of the surgical situation, assuming that the information is of high quality and is utilized appropriately.

The accuracy required to successfully complete a Direct Cochlear Access (DCA) procedure (an alternative, minimally invasive approach for the implantation of cochlear hearing assist devices) is prohibitively high, a variation of not more than 0.5 mm at the target is the commonly cited threshold [1]. These accuracy requirements are due to the density of critical structures within the facial recess, through which a DCA trajectory typically passes. The current method of accessing the inner ear involves the removal of a large portion of bone tissue in the form of a mastoidectomy. This technique allows the visualization, and therefore avoidance, of these vital structures. When accessing the cochlea through minimally invasive methods, the surgeon can no longer directly visualize the location of the tool, but is instead reliant on the accuracy of the navigation or robotic system. These systems typically employ some form of visual feedback system exclusively; the current position of the tool as determined through the tracking of the instrument by a surgical navigation system is provided to the surgeon who proceeds based on this information. Robotic systems can utilize the same information to directly control the position of the tool without the surgeon's intervention. The purpose of this work was to demonstrate the possibility of utilizing additional sensor information, in the form of force-torque data, in order to provide further information about drill positioning while within the skull and subsequently improve the overall level of safety for the patient.

The human temporal bone is not a homogenous structure, but instead contains regions of higher and lower density bone as well as being honeycombed with air filled cavities (mastoid cells) [2]. Information about the location of these cavities and the approximate density of the bone is relatively simple to extract from 3D medical imaging modalities such as high accuracy cone beam CT (CBCT), while existing research has demonstrated the correlation between the density of bone and the force required when drilling [3] or cutting [4]. This work investigates the possibility of utilizing this information for tool localization; it was hypothesized that it would be possible to find

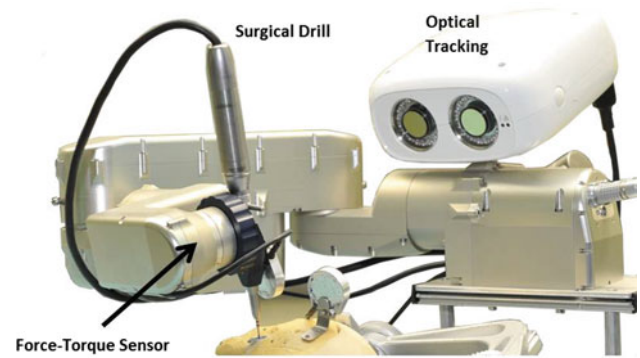


Fig. 1 The robotic system utilizes visual information to guide a surgical drill for minimally invasive drilling tasks. A Force-Torque sensor is integrated at the wrist

a correlation between the force observed during drilling and the relative density of bone at the related point along a trajectory and that this information would allow the surgeon to more accurately judge the position of the tool within the skull and prevent damage to the facial nerve or other structures.

Methods

A single anatomical whole-head specimen, preserved in Thiel solution, was utilized in this study. Pre-operative CBCT (ProMax, Planmeca Oy, Finland. 0.15 mm isometric voxel size) scans were taken and a trajectory planned from the outer surface of the temporal bone, through the facial recess, to the inner ear. This trajectory was then drilled using a robotic manipulator fitted with a 6 degree-of freedom force-torque sensor (Mini40, ATI Industrial Automation USA) at the wrist, as shown in Fig. 1 [6]. The force applied on the robot wrist was observed and recorded throughout the drilling process. The position of the manipulator was also recorded in the robot world coordinate system and subsequently transformed to the image coordinate system. Once the drilling process was completed, a wire was inserted into the drilled trajectory and post-operative CBCT scans taken.

The inserted wire, as well a number of implanted fiducial landmarks, was segmented in the post-operative image and the fiducial screws used to rigidly co-register the post- and pre-operative images. The density was calculated along the actual drilled path by integrating the voxel values at slices determined by the recorded position of the robot during drilling. The force and density values along the trajectory were then plotted and compared.

Results

Drilling was successfully completed, force values were extracted from the robot log data, image segmentation and registration completed and approximate density values calculated. The approach taken demonstrated that, as expected, a correlation appears to exist between the density of the material and the force applied on the drill. Figure 2 shows the calculated bone density and drilling force along the trajectory. The density of bone is highest at the external surface of the temporal bone, and decreases as the trajectory approaches the inner ear. The large cavity, visible as an extended portion of low density material, represents the middle ear space. The final peak in both the force and density curves was caused by contact of the drill with the outer surface of the cochlear at the promontory between the round and oval windows.

Conclusion

Previous research [5] has demonstrated the current impossibility of drawing quantitative conclusions from CBCT scan data with respect to accurate measurement of bone density due to the distortion of Hounsfield units throughout the imaging volume. Of more importance

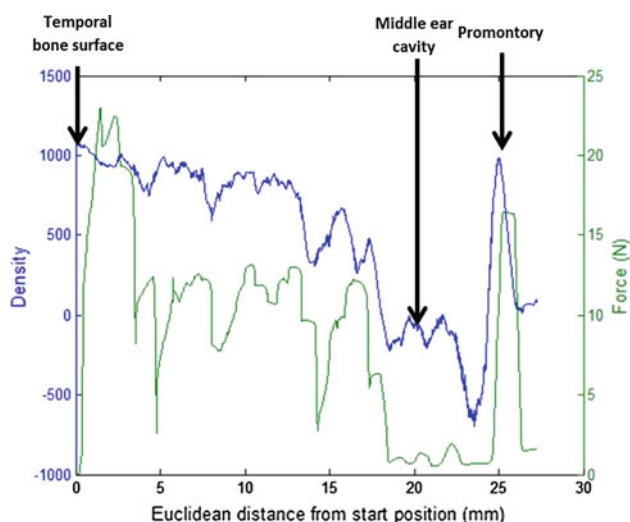


Fig. 2 Bone density and measured force along drilled trajectory

for this work is the relative change in density along the planned trajectory which allows information about errors due to incorrectly calibrated tools, registration and control to be observed indirectly and decisions regarding the relative safety of the patient, i.e. whether to continue the drilling process or revert to a traditional mastoidectomy, to be made. The results obtained demonstrate the possibility of utilizing force-torque data with a surgical robotic system in order to provide further information about the position of the surgical drill within the temporal bone during DCA drilling. It is expected that this will lead to increased levels of patient safety and system robustness as well as ensuring the integrity of vital structures within the facial recess. This data also allows for the possibility of further sensor fusion through the integration of alternative physiological data such as nerve response.

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Ex vivo walking performance of a bio-inspired intra-abdominal robot for laparoscopic surgery

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Surgical robots can presently perform a wide range of procedures across different types of surgery (e. g cardiac, abdominal, bone and brain surgery), manoeuvring different types of tools (e.g. knives, tweezers, scissors, drills). Laparoscopic surgery (surgery through several small incisions in the abdomen) offers the patient benefits of reduced trauma and reduced scarring [1, 2]. As a result, healthcare providers profit from shorter recovery times. Robotic laparoscopic surgical devices comprise of a set of robotic arms which operate inside the body but are mounted outside of it. These robots have successfully performed a wide range of surgical procedures. However, these devices are expensive and cumbersome, normally requiring substantial reconfiguration of the operating theatre. If the size and cost of surgical robots could be reduced, many more patients would benefit from the clear advantages of robotic surgery.

Researchers have recently begun development of the next generation of surgical robots that will have the ability to travel inside the body performing inspection, characterization and eventually surgical procedures.

Towards this goal, this paper presents a novel robotic system designed to provide new visual information within the body through moving a camera across the surface of the peritoneum to new vantage points. This is possible through biologically inspired adhesive pads that enable the robot to adhere to the peritoneum surface [3].

Purpose

The purpose of the set of experiments presented in this paper is to characterize the locomotion of the robot on a representative ex vivo surface. The adhesive force of biologically inspired micro-structured polymers has been measured on the rat peritoneum and this data used to design representative magnetic pads to attach to a steel plate. Progressing from that, the robot will then walk on porcine tissue using bio-inspired adhesion provided by the afore-mentioned micro-structured polymers. In this way, the locomotion performance of the robot is tested both working with adhesion-reliant technology on a visco-elastic surface (real application environment) and with magnetic pads on a rigid ceiling. Comparison of the results determines the extent of the robot’s functionality and shows the direction of future improvements.

Methods

The robot is a Cartesian walker composed of four interlinked feet (see Fig. 1). Each foot is actuated by three linear controlling its position on the surface of the peritoneum and the distance from it. Locomotion is performed through eight miniature piezo-electric motors in total, which allow attachment, repositioning, and detachment of the feet in sequence [4].

The design of the robot draws inspiration from nature in several respects: (1) the adhesive technology is inspired by the micro-structure surface found in tree frogs; (2) the horizontal motion of the robot resembles that of amoebas in so far as it is based on deformation of

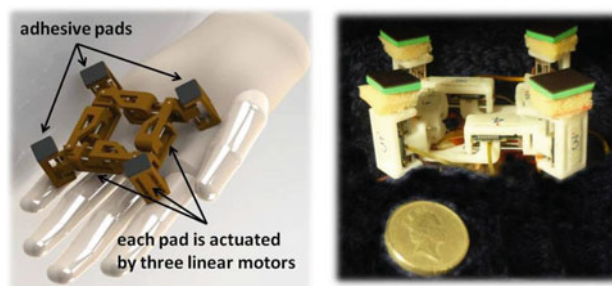


Fig. 1 Conceptual model and first prototype of the intra-abdominal robot