Contrasting disturbance levels within a cochlea.

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Abstract— **Hearing implants are an important aspect for combating deafness over the next 15 years. In this paper we focus on the means to determine the sensitivity of the hearing organ to disturbances produced by implants and disturbances, and those induced by implantation. The preservation of residual hearing is an important aspect to be considered, however the sensitivity of this to the process of implantation, device location and power levels is not well understood. Within this paper a new experimental set-up to contrast the merits of different implantation techniques, implant location and power transmission is discussed and the initial results on disturbance levels using different surgical techniques are described.**

Keywords-component;cochlea, surgery, transients)

I. INTRODUCTION

Hearing implants will be an important solution for combating deafness over the next 15 years. In this paper we focus on the means to determine the sensitivity of the hearing organ to disturbances produced by implants and disturbances induced by implantation [1]. The preservation of residual hearing is an important aspect to be considered, however the sensitivity of this to the process of implantation, device location and power levels is not well understood. Within this paper a new experimental set-up to contrast the merits of different implantation techniques, implant location and power transmission is discussed and the initial results on disturbance levels using different surgical techniques are discussed.

At this stage the work has concentrated on producing a suitable test rig that combines micro-actuation of hearing mechanisms and measurement of disturbances within the closed bone structure of the cochlea. The challenges are the small scale and precision of motion required for actuation, to observe disturbances within the closed fluid system of the cochlea and to eliminate normal ambient disturbances that the normal hearing mechanism is sensitive to.

The paper and presentation will map out the design of the laboratory system that has been a substantial challenge for mechatronics. This integrates confocal microscopes, novel micro-actuators and a micro-scanning laser vibrometer in the final solution. It also relies on other novel tools such as the smart micro-drill [2] to prepare appropriate access points without invasion of the inner space of the cochlea.

For the first time we have been able to observe real transients corresponding with actuation of the hearing chain and disturbances induced by the insertion of hearing implants without invading the cochlea space. This is as close to the real disturbances that can be expected in practice.

The paper describes the anatomy under consideration, the integrated mechatronic system and typical results that have been produced so far.

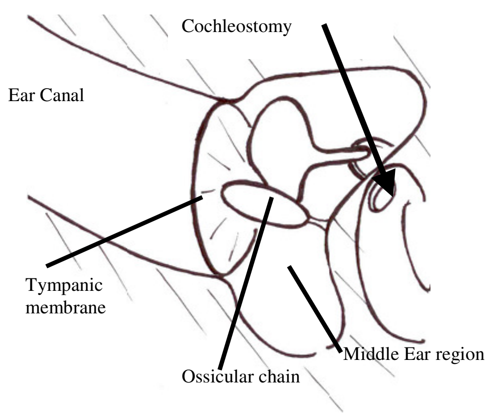

Figure 1. Schematic of the cochlea

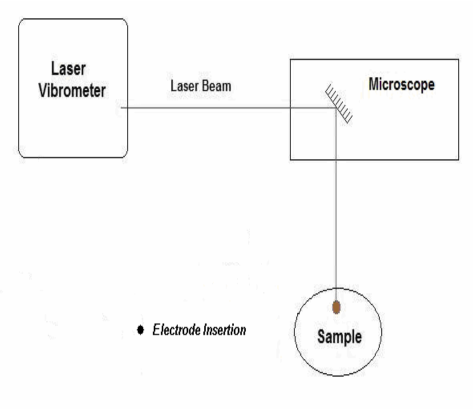

Figure 2. Schematic of experimental set-up.

Figure 3. A complete cochlea

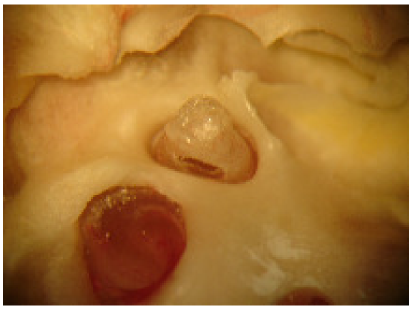

Figure 4. The promontory aspect showing the stapes

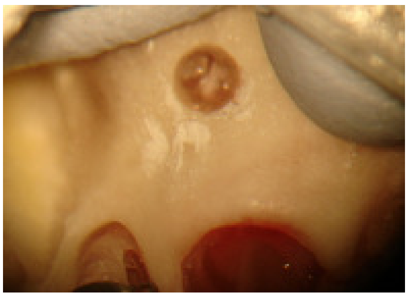

Figure 5. The intact endosteal membrane

II. THE COCHLEA

The cochlea is the core mechanismof the hearing organ. It converts sound pressure disturbances at the tympanic membrane via the ossicular chain within the middle ear into electrical stimulus of the brain. The cochlea is located in the inner ear region as illustrated in Figure1. The sensitivity of pressure disturbances within the fluid endosteal lumen of the cochlea to disturbances produced by surgical tools and the insertion of implants is considered to be an important factor in hearing preservation. Within the cochlea are delicate structures. These separate different fluids and also incorporate the delicate receptor mechanisms for the transduction of disturbances. The cochlea is a small (approx 10 mm diameter) coiled structure which, if uncoiled, would form a tube approximately 35 mm long. Both the oval window (activated by the stapes of the ossicles in the middle ear region) and round window are at the basal end of this tube. Figure 1 also shows the configuration of the middle ear and cochlea, and shows the relative orientation of a cochleostomy, one of the procedures leading to cochlear implantation. Preparation of the cochleostomy and electrode insertion are currently processes of concern to hearing preservation.

III. EXPERIMENTAL SET-UP

In the early studies, the aim has been to contrast disturbances induced by typical processes of implantation. This is to serve to identify how surgical techniques may have an impact on hearing preservation. The experimental set-up is to measure and contrast displacements of the endosteum through an aperture produced by the robotic surgical micro-drill. This drill has the significant and unique property that it is able to produce consistent apertures through the bone tissue of the cochlea, leaving a delicate membrane of the endosteum intact ([2]. Displacements induced at the endosteum are a measure of pressure amplitude. This method has advantage over invading the vestibular lumen and inserting pressure transducers, for example, where fluid lost in the process risks changing the dynamical behaviour of the lumen [3].

To monitor displacements of the endosteum a scanning laser doppler vibrometer is used working through a microscope to aim the laser onto the small target area, Figure2. Figure 3 shows a complete cochlea harvested from a porcine specimen and Figure 4 shows a magnified image where the cura of the stapes are visible. The stiffness and size of the porcine cochlea is similar to that of human cochlea [4].

The micro-drill is used to prepare a cochleostomy leaving the endosteal membrane intact, Figure 5. The test then can commence with the laser trained onto the target through the microscope with the cochlea held in position using a supporting plate Figure 6, and the disturbing process applied.

IV. RESULTS

In the initial studies, the results have shown significant outcome with respect to surgical technique. Drilling on the cochlea, is the normal processes associated with preparing a cochleostomy,, and in the experiment two methods were used.

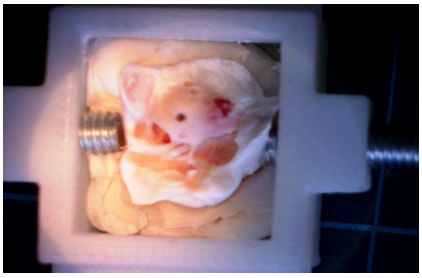

Figure 6. The support plate

A conventional hand-held surgical drill was applied and produced disturbance amplitudes in the range shown as peaks in velocity up to 1.2 m/s in Figure 7. This can be contrasted when using the robotic micro-drill which produced much smaller disturbances with velocity amplitudes up to 0.01 m/s in Figure 8. The significant reduction shows that there are substantial benefits leading to a reduction in disturbance amplitude down to 0.1% by using the new robotic micro-drill system. Further studies have shown that disturbance level increases with feed force. Cutting under controlled feed force was achieved using the robotic micro-drill and showed that peak amplitude is approximately proportional to the applied feed force. These results show that the robotic micro-drill offers considerable benefit towards reducing induced disturbance. However to optimize will probably require an understanding of the relationship between amplitude and persistence with respect to hearing preservation as low feed force implies a low rate of cutting and increased cutting time.

Electrode insertion rate is an additional concern that needs to be investigated using the experimental set-up. There is both the entry of the electrode into the endosteal lumen and the velocity profile during insertion that can be investigated by this technique to define the velocity rendering required to minimize disturbance.

V. CONCLUSION

The robotic surgical micro-drill is able to remove bone tissue of the cochlea to produce a small hole down to the underlying endosteal membrane, where it also prepares a diaphragm of consistent diameter.Using a laser Doppler vibrometer working through a microscope it has been possible to measure the motion of the diaphragm of the endosteal membrane within the cochlea to infer the amplitude of pressure transients occurring within the cochlear fluids. Other approaches where pressure transducers are inserted into the endosteal lumen perforate the closed fluid volume. Loss of fluid severely affects the resulting dynamics of this space. The method described here cannot return an absolute pressure value, however its merit is its use to contrast disturbances produced by different surgical techniques. This will enable optimisation of processes with respect to avoiding disturbances that could lead to hearing loss. As an example, manual drilling is contrasted with drilling using the robotic surgical micro-drill to prepare a cochleostomy. It is shown that the resulting velocity amplitudes are 0.1% of values produced when micro-drilling manually.

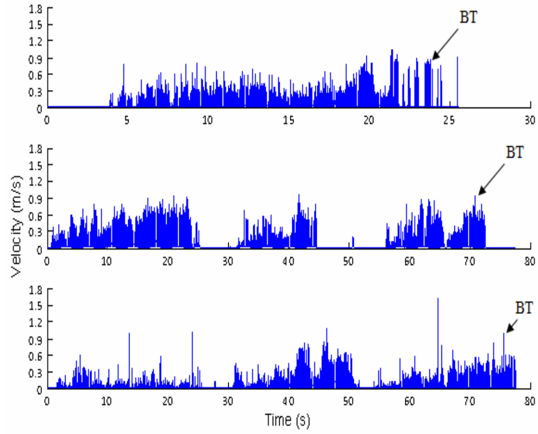

Figure 7. Pressure transients when drilling manually

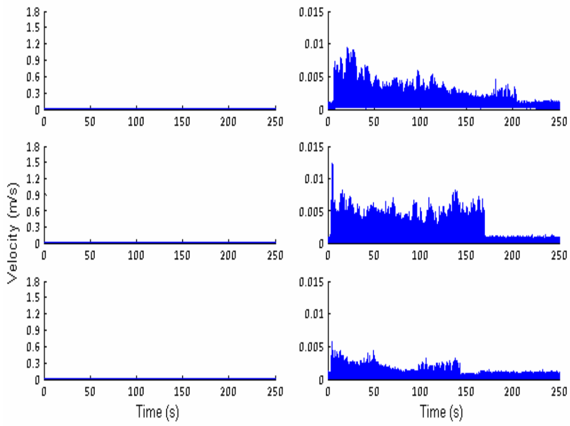

Figure 8. Pressure transients when using the robotic drill

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