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Review Articles

Surgical skills training in middle-ear surgery

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Abstract
Until recently the practice of otological procedures on cadaver temporal bones was a common occurrence in otolaryngology departments. The difficulty in acquiring specimens has led to alternative techniques which involve artificial and computer-aided models. This article looks at the present situation in these rapidly developing areas and describes an artificial model developed by the senior author for training in middle-ear procedures.

Key words: Temporal Bone; Models, Anatomic; Tympanoplasty; Education, Medical

Introduction

Learning to be a competent middle-ear surgeon involves acquiring a knowledge of the detailed anatomy of the temporal bone. Ultimately the surgeon needs a three-dimensional mental map that takes account of possible variations in anatomy and the effects of disease processes. In addition a number of core skills must be acquired. This cannot be achieved by surgical practice alone, if the interests of the patient are to be safeguarded.

Temporal bone dissection is the most effective way of learning temporal bone anatomy and is an essential part of otological training. Preserved temporal bones are adequate for anatomical work and can be used for some surgical exercises. However, in the UK, the Anatomy Act has made it more difficult to use temporal bones in surgical training as its terms only permit dissections for anatomical purposes. In any case the availability of preserved temporal bones will diminish as medical schools phase out cadaver dissection. These specimens are less suitable for procedures involving dissection of soft tissues, as the effects of fixation alter their handling characteristics. Fresh temporal bones obtained during post-mortem examinations are more suitable for this type of exercise. They can be stored in a freezer without adverse effects on the soft tissues. The Anatomy act does not apply to these temporal bones but they are covered by the provisions of the Human Tissue Act. Unfortunately fewer post-mortems are now carried out with the result that fewer fresh temporal bones are now available than was previously the case.[1] There is also the theoretical risk of viral transmission.

Recent publicity concerning the use of organs removed at post-mortem without explicit consent has made it almost impossible to obtain an adequate number of temporal bone specimens. This represents a challenge to those of us involved in otological training. The way forward is to establish mechanisms by which temporal bones can be obtained with consent. This involves the production of relative information and consent forms specifically designed for the harvesting of temporal bones. In addition systems must be put in place to facilitate the process of obtaining of consent.[2]

Surgical training exercises not involving patients or human tissues have been developed within a number of surgical disciplines. Animal tissue models have been developed for training in nasal surgery,[3] bronchoscopy[4] and percutaneous tracheostomy[5] and have been used in other surgical disciplines as well.[6,7] Unfortunately species differences limit the usefulness of this approach in otology.

An alternative approach is the creation of artificial models of the ear, such as Pettigrew temporal bones.[8] These are plastic models of the temporal bone designed to allow the trainee to practice a number of surgical procedures and they are an integral part of the Glasgow Temporal Bone Course. The mastoid process has a 'facial nerve' running through it and the semicircular canals are also simulated. The addition of red dye to the irrigation fluid during drilling creates an illusion of bleeding. The ossicular chain is mobile and various middle-ear operations can be

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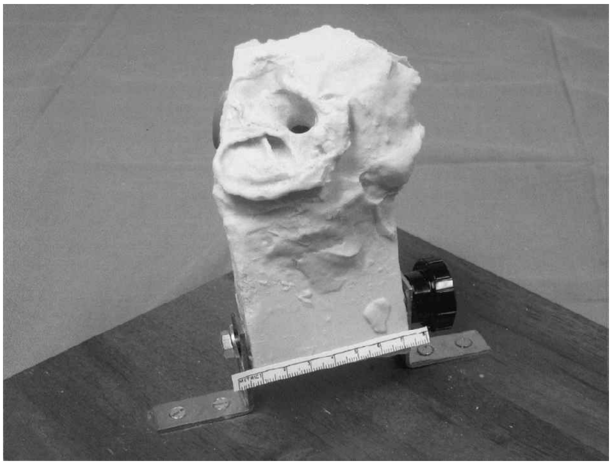

FIG. 1a
Temporal bone model.

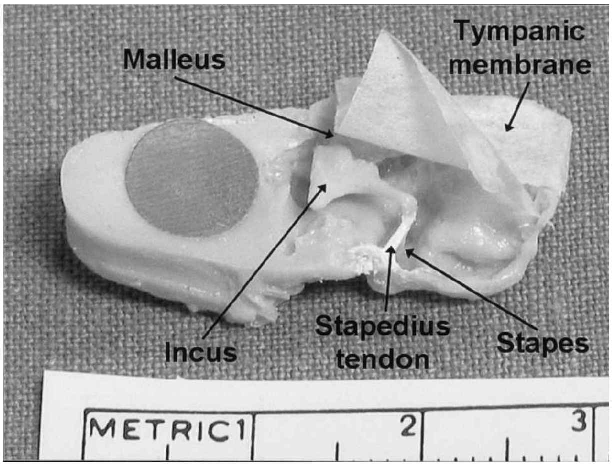

FIG. 2a
Intact ossicular chain with fixed Stapes.

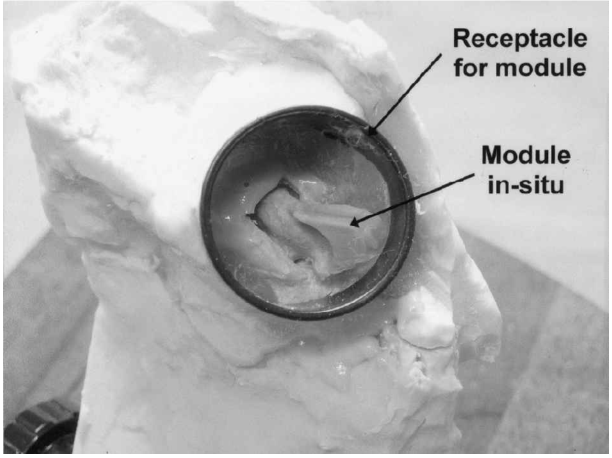

FIG. 1b
Receptacle for individual modules.

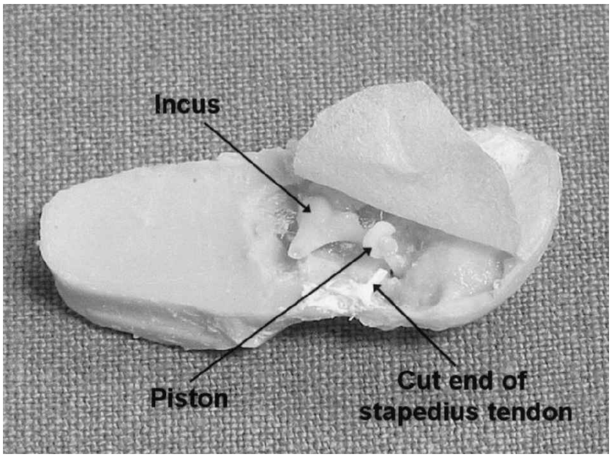

FIG. 2b
Piston in position following stapedectomy.

practised. In contrast to human and animal tissue models, the use of these training exercises is not restricted to a laboratory environment.

The Middle Ear Surgery Trainer developed by the authors has the more limited aim of facilitating training in procedures involving the external auditory meatus and middle ear. The system consists of a number of middle-ear modules, each presenting a different surgical problem. Each of these fits into the middle ear section of a temporal bone with its own tilting stand (Figure 1). A pinna is attached and an endaural incision is simulated. This trainer was developed by the senior author for the Foundation Course in Middle Ear Surgery held at the Royal College of Surgeons of Edinburgh annually. The current version is the culmination of eight years of development work. At present each component is hand-made, but it is hoped to develop a version suitable for mass production in due course.

The stapedotomy exercise involves division of the stapedius tendon and stapes arch (Figure 2(a)), opening of the incudostapedial joint, fracture of the anterior crus and extraction of the stapes arch, fenestration of the foot plate and insertion of a piston (Figure 2(b)). Piston placement can then be practised repeatedly and different pistons can be tried. Three different ossiculoplasty exercises are available. Figure 3 shows a module with a malleus handle and a stapes arch. This can be used for reconstructions using an incus (Figure 3(a), 3(b)), or a prosthesis. A module with a malleus handle but no stapes arch allows malleus-foot plate reconstructions to be practised (Figure 4(a), 4(b)). The fourth module has a stapes and an eroded incus long process and can be used to learn the incus-stapes 'sleeve' reconstruction (Figure 5(a), 5(b)). A module with a perforated drum and an attached cuff of 'meatal skin' can be used for practising myringoplasty and another with an intact drum can be used for myringotomy and grommet insertion and for procedures such as microsuction and wax removal.

The development of exercises such as these involves more than simply creating appropriately shaped replicas of anatomical structures. The authors chose polyurethane as the material to create the models because it drills to dust like bone. Other materials do not behave in this way. The colour and general appearance of plastic is not dissimilar to

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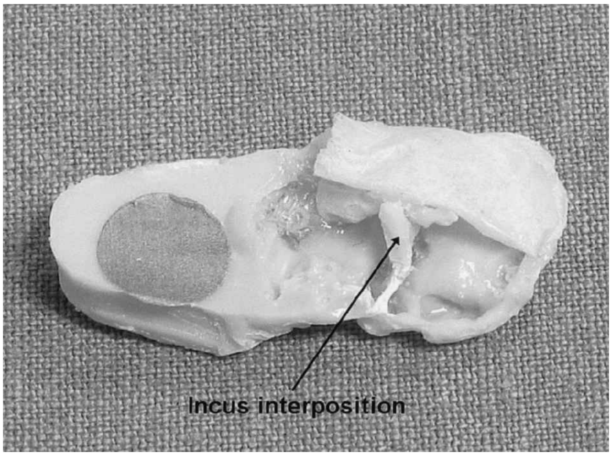

FIG. 3a
Incus interposition Pennington type.

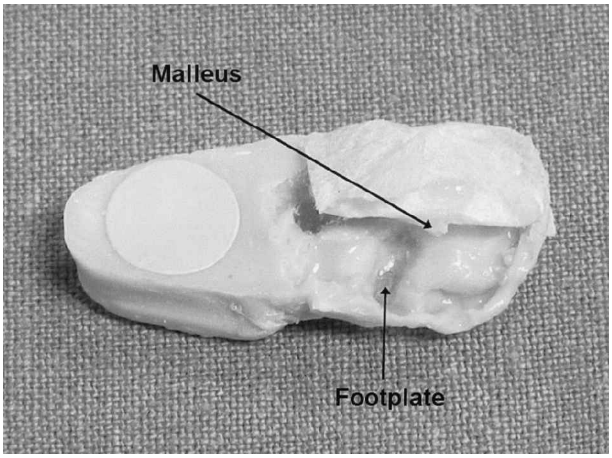

FIG. 4a
Module with no stapes arch.

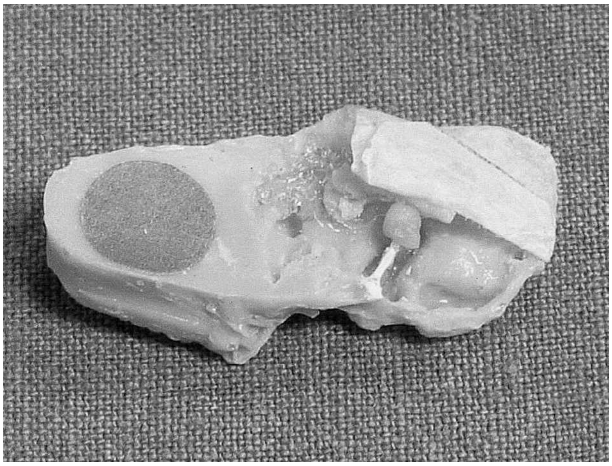

FIG. 3b
Incus interposition David Austin type.

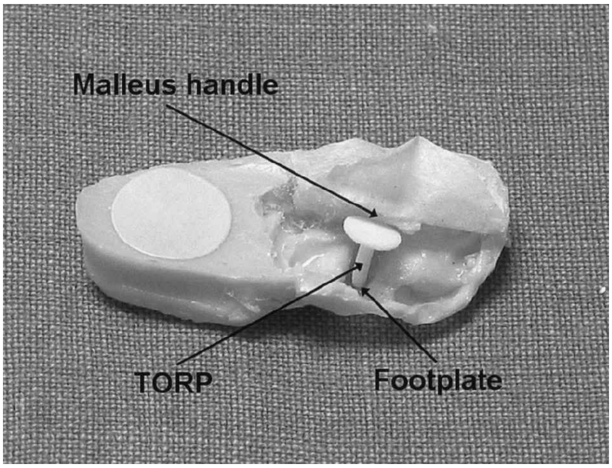

FIG. 4b
Malleus footplate reconstruction.

bone. Its main drawback is the need to use moulding techniques to produce the components of the model. Especially with very small structures, such as the ossicles, air bubbles are difficult to eliminate leading to a significant failure rate. This, together with the ability to create cavities easily within a structure, has led others to use stereolithography ('rapid prototyping') to generate temporal bone models from spiral computed tomography (CT) images.[9] This involves the curing of a suitable resin by laser light. While this method has much to recommend it, the model must be made from an appropriate epoxy-resin and these materials tend not to look like, or handle like, bone.

The simulation of the middle cavity and ossicles is only part of the process. The ossicular chain should be mobile and this can be achieved by suspending it using transparent silicone sealant. White silicone sealant can be used to create a stapedius muscle tendon that can be cut with microscissors or a sickle knife during the stapedectomy exercise (Figure 2). In the Middle Ear Surgery Trainer the tympanic membrane is simulated using translucent toilet paper ('Izal'), while in the Pettigrew temporal bone a flexible plastic is used. In the real middle ear procedures such as ossiculoplasty are facilitated by the fact that the environment is moist. Grafts and prostheses can be suspended from middle-ear structures using surface tension. The dry environment of the plastic middle does not allow this to happen and plastic incus grafts easily fall into the hypotympanum. The authors have overcome this problem by applying a transparent, tacky, hydrophilic coating to the medial wall of the middle ear and to the ossicular chain. The handling qualities of grafts and prostheses are surprisingly natural in this environment.

Physical models are the best option available at present and further developments continue to increase their realism. However, the future may lie in virtual reality modelling and human-computer interface developments. Current projects are divided into visual simulation[10] where procedures are only carried out on screen using the conventional mouse and keyboard computer interface, such as the 'temporal bone dissector' produced by C.V. Mosby, and more adventurous projects which allow a more realistic reproduction of a procedure with respect to tactile feedback. Visual, auditory and haptic input and feedback need to be considered to allow a realistic human-computer interface.[11] Such develop-

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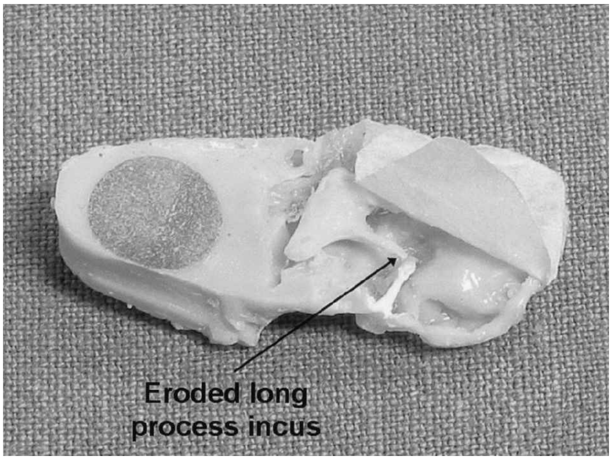

FIG. 5a
Incus erosion.

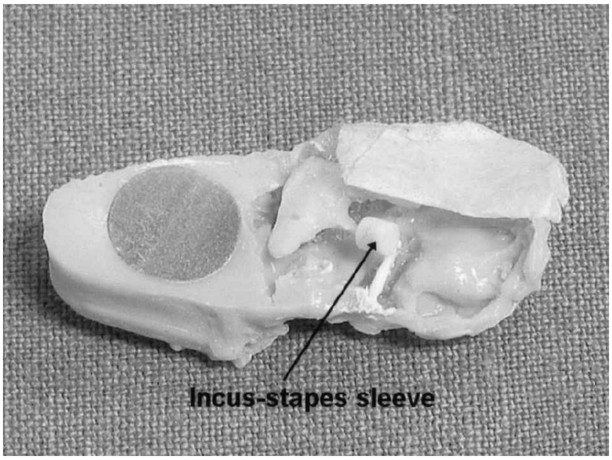

FIG. 5b
Incus-stapes sleeve reconstruction.

ments require huge computing resources and the human-computer interfaces are still in their infancy. With computing power still increasing according to Moore's Law and with human computer interface development not being restricted to medical applications, we may see a viable alternative to visible models within the next decade.

A possible scenario may involve a modified microscope set-up with separate images for each eyepiece from a cathode ray tube display to simulate stereo vision. The microscope will have sensors to determine the orientation and the distance from the object. Headphones will provide auditory feedback to simulate the speed of the drill and will indicate when the drill exposes the dura or sigmoid sinus. An instrument or a variety of instruments will provide tactile feedback regarding the texture and firmness of the surface being touched. Force feedback will also prevent a pair of forceps from passing through a virtual bone and will simulate the vibration associated with using a drill.

Virtual reality simulations are already available for training in other disciplines.[12–15] The development of ear surgery models is currently being undertaken by groups such as the team at Baylor College of Medicine.[16] They have used CT, magnetic resonance imaging (MRI) and digitized anatomical slices as the starting point for the development. Specific pathologies and anatomical variations can be built into the model and if the operator makes a mistake advice can be provided and the operation can be 'rewound' to a point before the error was made so that a further attempt can be made. In addition the trainee can compare his performance against that of an 'expert' technique built into the model.

In the future virtual reality simulations of surgical procedures may replace the physical models described above, but for the time being they represent the best way forward in surgical training. Most of the technical restrictions limiting the production of virtual reality surgical simulators have been surmounted, but the available technology must be applied to the simulation of otological procedures.[17] Some idea of how such simulations will look can be obtained by visiting the University of Hamburg website.[18]

Simulation methods also have the potential to offer the practising surgeon the opportunity to maintain his skill levels by regular practice. No golf professional would step onto the first tee in a competition without having spent time on the practice ground. By contrast a surgeon may commence an operation such as a stapedectomy having not carried out the operation for several months. In other situations an experienced surgeon could plan an operation by carrying out the procedure using data obtained from scans of the patient involved. This could also form part of the development process for new surgical techniques.

Surgeons are selected for intellectual ability by the examination system, but no formal attempt is made to test practical skills relevant to practice. This is partly because no validated tests of core surgical skills exist. Surgical simulations offer a set of standardized exercises which have the potential to be developed into such tests. However, it will be necessary to establish valid methods of assessment and minimal acceptable scores. Further research is required to define the core skills required for different types of surgical activity. It will also be necessary to extend this approach to other aspects of otolaryngological practice, so that potential ear, nose and throat trainees can be fully assessed.

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