Oval Window Temperature Changes in an Endoscopic Stapedectomy

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Objectives: Following the initial use of endoscopes in otology, the pros and cons of these instruments have been questioned increasingly. These instruments cause an increase in temperature that needs to be investigated. In this study, the authors aimed to investigate the temperature increase caused by endoscopes and light sources in the perilymph by performing a stapedotomy in an animal model under anesthesia.

Study design: The study was performed in a guinea pig model.

Methods: In the animal model, a simulated otologic stapes surgery was performed at room temperature. The body temperatures of the guinea pigs were monitored; the temperature increase caused by the 0-degree rigid endoscopes with diameters of 3 and 4 mm as well as the light sources, including halogen, light-emitting diode (LED), and xenon lamps, were monitored following the stapedotomy to measure and document the continuous temperature increase in the perilymph using sensors placed at the oval window.

Results: Rigid endoscopes cause a temperature increase in the tympanum regardless of their diameter when used with xenon and halogen light sources. The LED light caused a relatively small temperature increase.

Conclusions: The endoscopic instruments used in the stapes operation caused a temperature increase in the oval window. The authors concluded that this heat could easily be transmitted to the cochlea by the perilymph, which has obstructed contact with the outer environment following stapedomy, resulting in neurosensorial damage.

Key Words: Light-emitting diode, light source, rigid endoscope, stapedotomy

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Since the introduction of the classical stapes surgery by Shea, many surgical variations have been reported in the otology literature. However, these techniques use the surgical microscope. Endoscope-assisted stapedotomy was first described by Poe[1] in 2000. The use of endoscopes was introduced in middle ear surgeries >20 years ago, but the role of endoscopes has been rather limited in the treatment of chronic otitis media and otosclerosis.[2] Some authors[3–6] have also proposed the endoscopic technique, an alternative technique for stapes surgery; these authors argue that it allows a better view of the ossicle chain, and it does not require resection of the scutum or stretching of the chorda tympani nerve (CTN). Scutum resection can occasionally lead to complications such as ossicle chain luxation or long-term tympanic retraction in patients with tubal dysfunction. Additionally, the CTN may be touched and stretched. This procedure also allows a controlled downfracture of the stapedial crus by direct endoscopic guidance.[4]

Certain technological advances have contributed to its evolution, such as the design of instruments suited for endoscopic ear surgery and the development of small-diameter high-definition endoscopes (2.7–3 mm) with better fields of view than previous 4 mm endoscopes. This allows a proper visualization of all structures in the middle ear.[6] As for working distance, shorter endoscopes (6–10 cm) have the drawback of requiring both hands to be at the same height; hence, longer endoscopes (14–18 cm) are generally preferred.[3] Nevertheless, endoscopic surgery also has limitations, such as one-handed surgery, lack of stereoscopic vision, and the need to develop specific skills.[1,3,4,7]

The use of endoscopes may also entail certain technical disadvantages. One of the disadvantages requiring the utmost attention is the temperature increase that occurs in the tympanum during endoscope use. The temperature increase occurs because of the light that is reflected. This temperature increase may reach levels that might be harmful for the important adjacent structures near the tympanic cavity. Ranking first among such structures is the cochlea because of its direct contact with the tympanum via the round and oval windows. In fact, the neurosensorial cells in the cochlea are highly sensitive to changes in environmental factors such as noise, trauma, and heat increases or decreases.[8] Heat transfer to the cochlea via the perilymph may be possible, especially in cases where the oval window is opened and the perilymph is in direct contact with the outer environment such as during a stapes operation.

In this study, we aimed to measure the temperature change caused by the light reflected during an endoscopic stapedotomy in a living guinea pig, under anesthesia using sensors placed at the oval window, thereby making it possible to obtain measurements and improve the safety of the surgery.

MATERIALS AND METHODS

This study was conducted at Harran University and followed the principles of the Declaration of Helsinki.[9] Adaptation and care of the animals and the experimental study were performed at the Dolvett veterinary center.

Animal Subjects

Six female guinea pigs (weighing 450–550 g) were used in this study. Approval for the study was obtained from the Committee for Ethical Issues of Harran University and the local ethics committee

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(Date: 10.12.2014, No: 65). All animal procedures were performed in accordance with the approved protocol. All animal interventions were conducted under suitable conditions.

All the guinea pigs received an otomicroscopic examination before the operation. Guinea pigs that had abnormalities in their external auditory canal and tympanic membrane were excluded from the study. The right ears of guinea pigs were used for the study. The left ears were used for monitoring the body temperature.

Instruments

The endoscopic instruments used in the study included 14-cm-long, 0-degree rigid endoscopes with diameters of 3 and 4 mm; halogen, light-emitting diode (LED), and xenon light sources (Karl Storz Endoskope, Tuttlingen, Germany) and a surgical microscope (Leica, M320-F12/W12/C12, 240 W, 50–60 Hz, Heerbrugg, Switzerland).

Temperature Measurement

The temperature measurements were conducted with T type (copper-constantan) thermocouples and a data logger. The T Type is a very stable thermocouple and is often used in different industries and laboratory environments. The type T thermocouple is suited for measurements in the -200 to 200°C range. It has a $\pm$ 0.01°C resolution and $\pm$0.6°C accuracy between 0 and 100°C. The temperature measurements were recorded by a HiOKi (LR 8401-20, Japan) data logger with 30 standard channels at 1 second increments (Fig. 1). The thermal conditions of the operating room were measured with a Kanomax IAQ monitor (Model 2211, Japan). A thermal camera (Testo 885-2 thermal imager, Germany) was used to obtain thermal images (Fig. 2B). The thermal camera was a high-resolution (up to 640×480 pixels) camera with a standard resolution of 320×240 pixels and a thermal sensitivity of $<$30 mK (0.03°C).

Methods

During the experimental procedure, the guinea pigs were sedated using an intraperitoneal injection of 10 mg/kg xylazine and 30 mg/kg of ketamine. The body temperatures of all guinea pigs were measured in the external auditory canal using a thermal camera and thermocouples before the intervention to determine the average body temperatures (Fig. 2B). Then, the retroauricular site was infiltrated with jetocaine, and an incision was performed. The auricle was tilted towards the front. The tympanic membrane was visualized (v3a). The tympanic membrane was completely eliminated at the posterior site using a pick. Then, the postero-superior tympanic bone crest was drilled away to expose the ossicle system (Fig. 3B-C). The incudostapedial joint was dislocated. The stapes was removed, and the oval window was exposed. The oval window was opened with a pick from the posterior site, and a thermocouple tip was placed in this site (Fig. 4A-D)

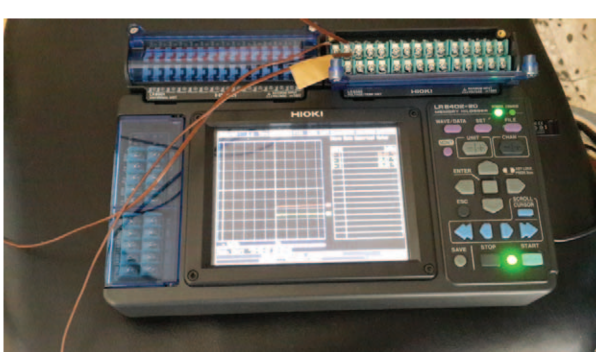

FIGURE 1. Data logger.

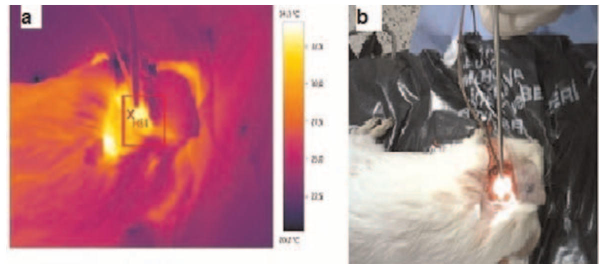

FIGURE 2. A, Thermal image; B, Operation view.

Following the surgical exposure, the 0-degree rigid endoscopes with diameters of 3 and 4 mm were oriented from the external auditory canal towards the oval window at the level of the tympanic membrane using 3 different light sources, individually (Fig. 2A). The endoscopes were maintained in place for 120 seconds; then, they were withdrawn from the site.

The temperature increase that occurred each second at the oval window was recorded using a thermocouple. The oval window was visualized under a surgical microscope, and the temperature increase in response to the microscopic light was also measured by the same method.

Data Analysis

The temperature measurements were recorded on a USB memory device on the data logger in real-time. The data were uploaded to a computer via the USB memory device. The thermal images were analyzed with Testo IRSoft Software (Testo Inc, Version 3.1). Statistical analyses were conducted with Microsoft Excel.

RESULTS

Figures 5 to 7 demonstrate the mean temperature variation over time for the different light sources during the operation. As observed in the figures, under xenon, halogen, and microscope light, the temperature increased with time; when the light was turned off, the ear temperature rapidly declined and returned its initial value. Under LED light, the temperature did not significantly vary with time (Fig. 7). As shown in Figure 7, the ear temperature

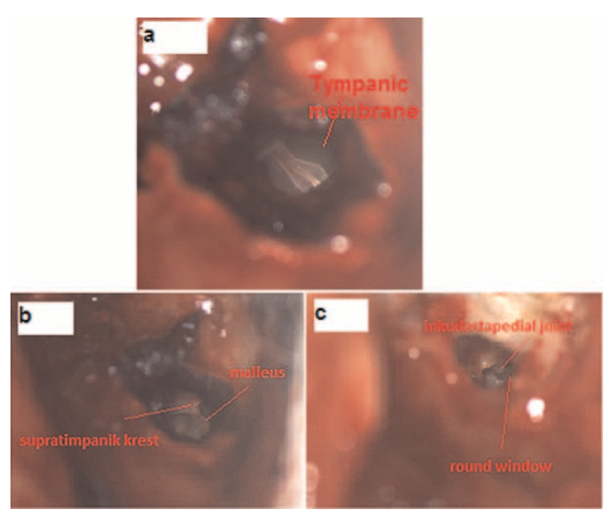

FIGURE 3. A, Image of tympanic membrane; B, Image of elevated tympanic membrane; C, Image of round window and incudostapedial joint.

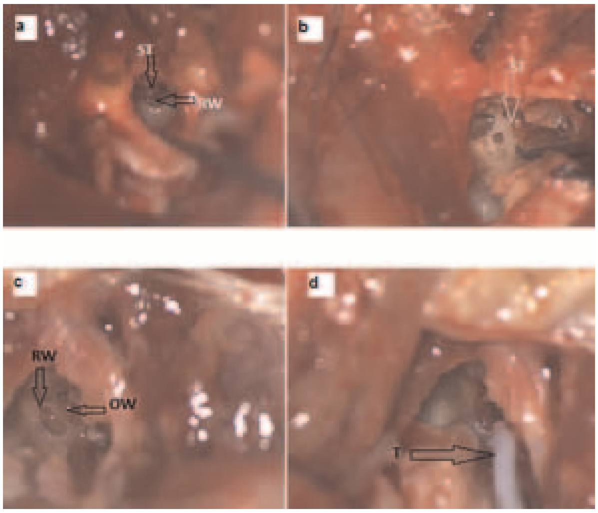

FIGURE 4. A, Caput stapes (ST), RW: round window; B, Image of the stapes after a stapedectomy; C, Exposure of the oval window (OW); D, Thermocouple (T) placement in the oval window.

significantly increased under microscope light. Figure 8 shows the minimum, maximum, and average temperature elevations, $\Delta T = T_{\text{i-initial}} - T_{\text{final}}$ (T: temperature), when using different light sources during a 120-second period. The values shown in the figure are the result of statistical analyses. As observed in Figure 8, the greatest temperature elevation occurs when the xenon light source is used (4 mm diameter, 100% power), whereas the minimum temperature increase occurs when the LED light is used (3 mm diameter). It has been observed that larger diameter endoscopes produce higher temperature elevations for all light sources. Figure 8 also shows that microscope light causes the temperature to increase significantly. The temperature elevation under microscope light was higher than that of the 3 mm xenon and 3 mm halogen lights. The maximum temperature was recorded with a 4 mm xenon light (100% power). When the power level was reduced to 50%, the temperature elevation decreased by 30% compared with the 100% power level.

DISCUSSION

Mer et al,[10] who originally used endoscopic instruments for diagnostic purposes in 1967, pioneered the use of these instruments in the medical field. Over time, endoscopes came to be used more frequently and in a wider range of sites. They were also adopted for use in the field of otolaryngology. Nomura[11] assessed the tympanum by inserting a rigid endoscope at the myringotomy site in 1982.

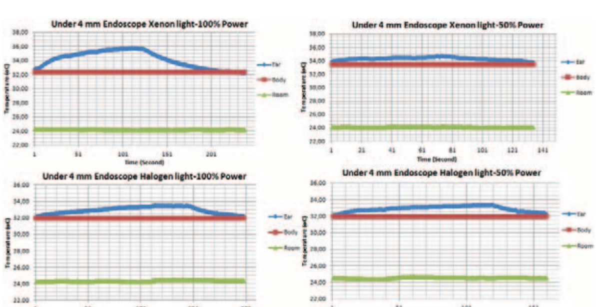

FIGURE 5. Mean temperature change caused by a 4 mm diameter rigid endoscope with halogen and xenon light sources.

FIGURE 6. Mean temperature change caused by a 3 mm diameter rigid endoscope with halogen and xenon light sources.

Fabinyi and Klug[12] conducted a study on the use of endoscopes for middle ear surgery in 1997, and they concluded that this method allowed minimally invasive surgery. Endoscopic instruments came to be used frequently in chronic otitis surgery as they not only enable minimally invasive surgery but also provide a significant visual advantage. As a result, their use has become common in stapes surgery, a major surgery in otology. Poe[1] was the first surgeon to describe an endoscope-assisted stapedotomy. Since then, several fully endoscopic stapedotomy series have been published[3–5,7] including Sarkar's[5] report, which was the most extensive study with 32 patients.

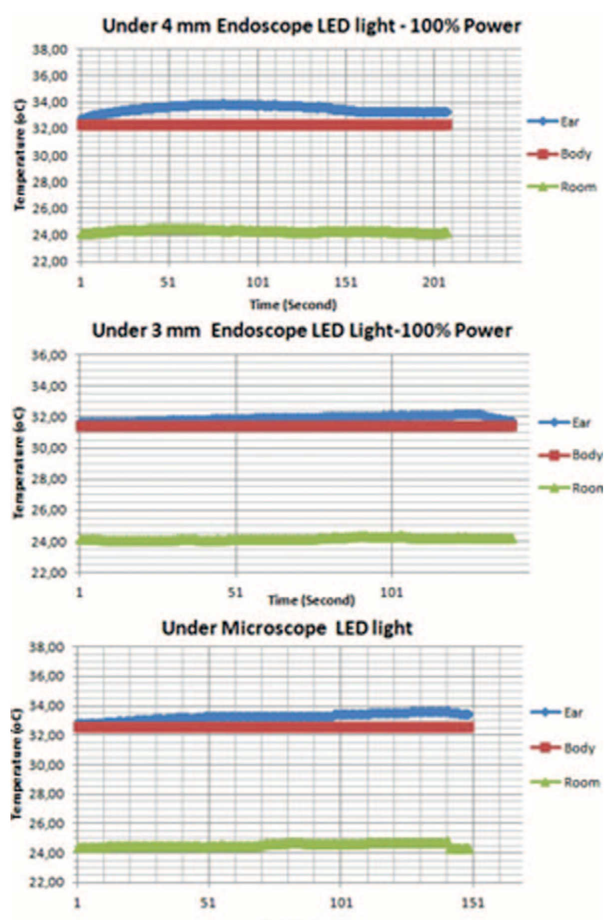

FIGURE 7. Mean temperature change caused by 3 and 4 mm diameter rigid endoscopes with an LED light source and under a microscope.

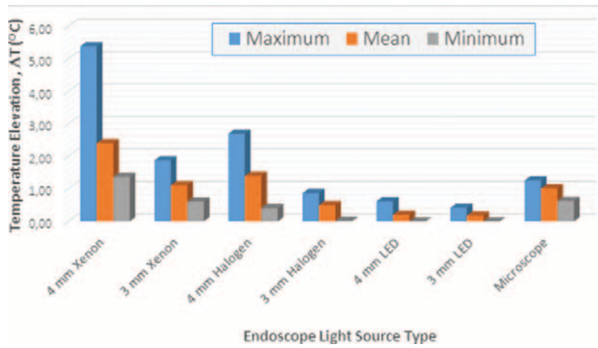

FIGURE 8. The minimum, maximum, and average temperature elevations using light sources.

In addition to its advantages, there are also several disadvantages of the endoscopic procedure. One important disadvantage, of which the importance has not been clearly demonstrated, is the temperature increase because of the light that was used.

There have been few studies conducted on the functional outcomes of temperature increase in the hearing system in the field of otology. It has been reported that temperature increases cause different responses in neurosensorial cells, and this situation has been demonstrated in hearing tests.[13,14,15]

Rigid endoscopes used in otology practice include fiber-optic cables, which reflect the light received from high-density light sources via fiber-optic cables to the surgical site. In general, halogen, xenon or LED light sources are used during such procedures. Otology surgeons who perform endoscopic surgery are cautious regarding the risk of thermal effect caused by endoscopes; however, this risk has not yet been substantially demonstrated in a precise numerical manner on live tissue.[16] Bottrill et al[17] conducted a study in which they reported that the temperature increase caused by endoscope use on the lateral semicircular canal resulted in an effect that was similar to a standard caloric stimulus, which may occur as a result of middle ear endoscopic use because of the transmission of heat to the perilymph. Endoscopes with wider diameters cause a higher temperature elevation.[17]

Another study on this subject was conducted by Kozin et al on freshly frozen human temporal bones from cadavers. In this study, the temperature increases around the round window was measured with regard to specific periods using xenon and LED light sources and a 0-degree rigid endoscope with a diameter of 3 mm. As a result, it was demonstrated that endoscopes caused significant temperature increase at this site; however, the tissue rapidly cooled when the endoscope was withdrawn.[18] MacKeith et al[16] used different types of endoscopes in their study and stated that the temperature at the tip of the endoscope increased at a tangible rate within the first 35 seconds. In the same study, it was reported that endoscopes could cool rapidly; the safest and most effective light source was the LED, and the xenon light source caused the highest temperature increase.[16]

Our study was based on previous studies, and it was targeted at identifying the temperature increase caused by rigid endoscopes with diameters of 3 and 4 mm, which are often used in endoscopic ear surgery with the aid of halogen, xenon, and LED light sources in the oval window after a stapedotomy in live tissue (animal model). In our study, guinea pigs, the experimental animals with the highest similarity to the human tympanum, were used. The light source that caused the highest temperature increase in our study was the xenon light source with the use of endoscopes of both diameters. The smallest temperature increase occurred when the LED light source was used. Furthermore, it was determined that the temperature increased later and stayed at lower levels when the 3-mm-diameter endoscope was used than when the 4-mm-diameter endoscope was used. We are convinced that this study has produced more objective results because it was conducted on live tissue.

According to our findings, we determined that periodic removal of the endoscope from the surgical site allowed the tissue to cool in a manner that was identical to that in which the tissue rapidly returned to its physiological basal temperature following the removal of the light source. Although lower temperature increases were obtained with the use of LED light sources than with the use of xenon and halogen light sources, we identified a temperature increase with the use of LED light sources as well. Therefore, the use of only LED light sources does solve the problem of temperature increases.

Our study has two limitations. First, the distance between the endoscope and target site was fixed. If this distance were variable, it may enable variable temperature increases. We attempted to identify the shortest distance, hence the highest temperature that could occur at the target site. Second, we were not able to demonstrate the damage that could potentially be caused by temperature increases using an objective test. We believe that clearer results could be achieved in future in vitro and in vivo studies if these limitations are overcome.

CONCLUSION

We conclude that the safest light source in terms of the amount of heat transmitted to the perilymph during an endoscopic stapes operation is the LED light source, whereas the xenon and halogen light sources may be risky in that respect; we also believe that this risk may be reduced with lower endoscope diameters and less light.

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