ORIGINAL ARTICLE

Temperature rises in the round window caused by various light sources during insertion of rigid endoscopes: an experimental animal study

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Objectives: The instruments used in endoscopic surgery include rigid endoscopes of different diameters and angles, sources of light and monitors. In this study, we explored temperature rises in the round window caused by insertion of rigid endoscopes of different diameters into the middle ear; the endoscopes were fitted with different light sources.
Design: An experimental animal study.
Setting: We subjected seven guinea pigs to simulate otological surgery at room temperature. We monitored body temperatures, along with temperature rises caused by the use of 0° rigid endoscopes of diameters 3 or 4 mm, fitted with light sources including a halogen light, a light-emitting diode (LED) and a xenon light. Data were collected every second from a sensor placed in the round window.
Participants: An experimental study on 7 guinea pigs.
Main Outcome Measures: Rise of the temperature on round window.
Results: Rigid endoscopes caused the temperature of the tympanum to rise when xenon and halogen light sources were used, regardless of endoscope diameter. However, the temperature rise was less when a LED light source was employed.
Conclusion: The endoscopic instruments used in middle ear surgery caused the temperature of the round window to rise. The rise varied with endoscope diameter and the type of light source used.

Interest in endoscopic approaches is growing although otological surgery is generally performed under a microscope.[1] Endoscopes, originally used by Mer *et al.*[2] in otology, were originally diagnostic tools, not aids to surgery. However, this has changed over the past 25 years. Endoscopes have become preferred surgical tools, as they afford highly detailed visual views of the middle ear cavity, which is narrow.

The instruments of endoscopic surgery include rigid endoscopes with different diameters and angles, light sources and monitors. Rigid endoscopes generally have diameters of 2.7, 3 or 4 mm, and those angled at 0° and 30° are the most popular. The bigger the endoscope is, the more the light is generated and the better the view is. However, combining another instrument with an endoscope in patients with narrow external auditory canals is difficult. In terms of light sources, halogen, xenon lights and light-emitting diodes are currently available.[3] Rigid endoscopes with effective light sources enable the relatively narrow middle ear cavity to be viewed clearly, in detail, and completely, allowing surgeons to work effectively in the area. Another advantage of an endoscopic system is that it is minimally invasive. However, during otological surgery, the surgeon works with one hand and the endoscope tips are often soiled, which may occasionally limit the utility of the instrument.[4]

The use of endoscopes has certain technical disadvantages, the most serious of which is a rise in temperature caused by reflected light. The temperature may attain a level that damages important structures close to the middle ear cavity, which is narrow and relatively poorly vascularised. The prime concern is the cochlea, which directly contacts the tympanum through the round and oval windows. The neurosensorial cells of the cochlea are highly sensitive to environmental factors such as noise, trauma and changes in temperature.[5,6]

Only a few studies on this topic have been published, and none of them placed endoscopes in a surgical field of an animal model to evaluate temperature changes by direct measurement at the round window. We documented increases in temperature in the round window caused by rigid endoscopes of different diameter fitted with different light sources.

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Materials and methods

The work was performed at Harran University, Şanlıurfa/Turkey, and followed the principles of the Declaration of Helsinki.[7] The Dolvett Veterinary Center was responsible for animal adaptation and care, and all experimental work was performed at the centre.

Animals

Seven female guinea pigs (450–550 g) were used. The study was approved by the Committee for Ethical Issues of Harran University (10.12.2014; No. 65). All animal procedures were performed in accordance with approved protocols. All animal interventions were conducted under appropriate conditions.

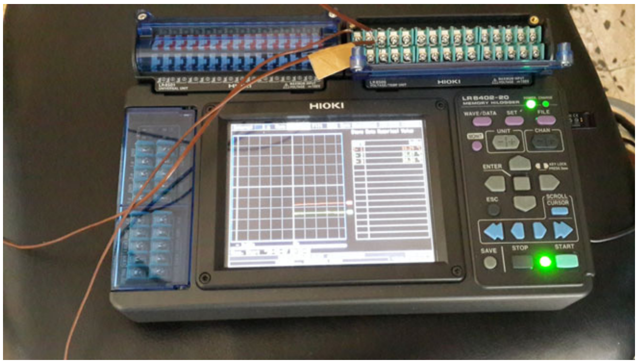

Fig. 1. The data logger.

Instruments

The endoscopic instruments used included 14-cm-long, 0° rigid endoscopes of diameters 3 mm and 4 mm, and halogen, light-emitting diode and xenon light sources (Karl Storz Endoskope, Tuttlingen, Germany).

Temperature measurement

Temperature was measured using T-type (Copper-Constantan) thermocouples, and the data were logged. The T-type thermocouple is very stable and has many applications in industry and the laboratory. Its measurement range is between −200°C to 200°C, its resolution is ±0.01°C, and its accuracy is ±0.6°C between 0°C and 100°C. Data were recorded on a standard 30-channel HiOKi LR 8401-20 data logger at 1-s increments (Fig. 1). Thermal conditions in the operation room were measured using a Kanomax IAQ monitor Japan (Model 2211). A Testo 885-2 thermal imager was employed; this is a high-resolution (to 640 × 480 pixels) camera that, at the standard resolution of 320 × 240 pixels, has a thermal sensitivity <30 mK (0.03°C).

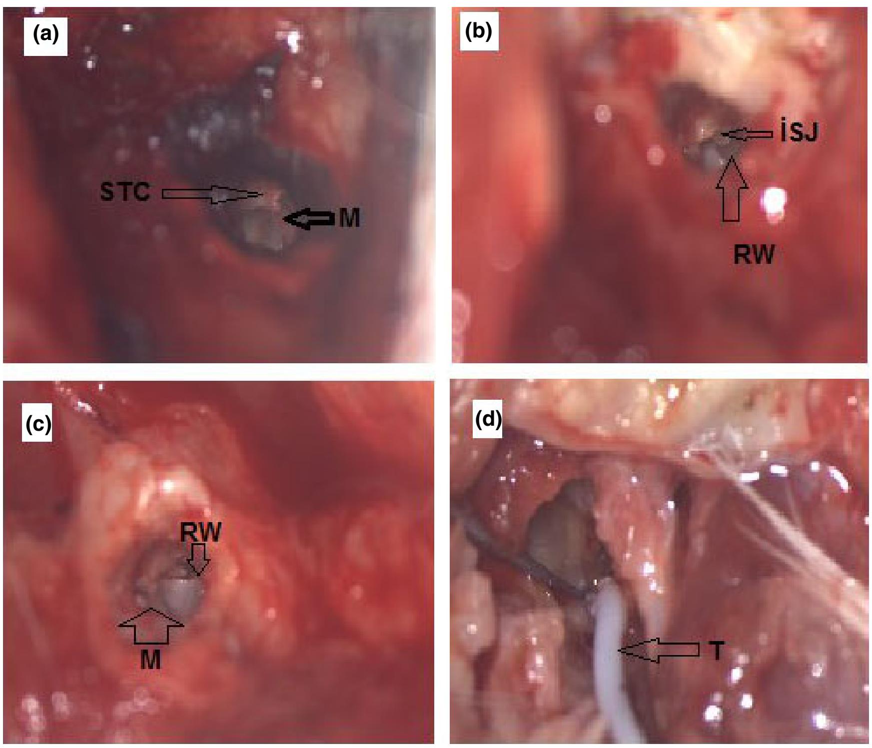

Fig. 2. (a) Elevated tympanic membrane (STC, supertympanic crest; M, malleus); (b) round window (RW) and the incudostapedial joint (ISJ); (c) RW and M; (d) a thermocouple (T) in the round window.

Methods

During all experiments, guinea pigs were sedated with 10 mg/kg xylazine and 30 mg/kg ketamine, delivered intraperitoneally. Next, the retroauricular area was infused with Jetocaine and incision was commenced. The auricle was tilted towards the front. The tympanic membrane was exposed, and the tympanic membrane was completely removed using a pick (Fig. 2a). The malleus and round window were exposed. Next, the posterior and superior tympanic bones were drilled out to enhance exposure. A thermocouple was placed in the round window through a slot created with the drill (Fig. 2b–d). Body temperatures were measured using the thermal camera (Fig. 3a), and thermocouples were placed in the external auditory canals prior to intervention, to record average data.

Next, a 0° rigid endoscope of diameter 3 or 4 mm was inserted via the external auditory canal towards the middle ear to the level of the tympanic membrane (Fig. 3b); three different light sources were individually used. The endoscope was held in place for 120 s and then withdrawn.

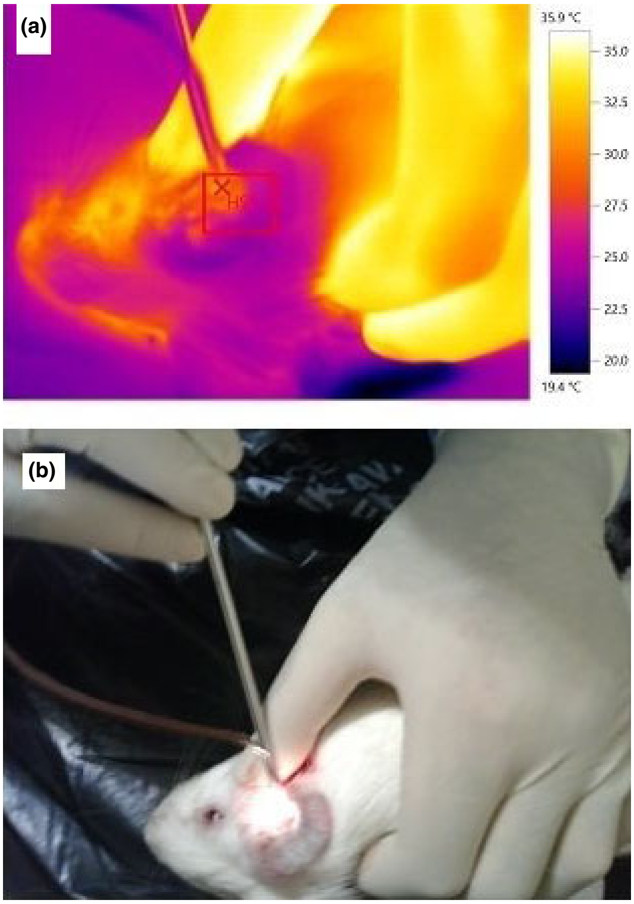

Fig. 3. (a) Thermal image (b) operative view.

The temperature in the round window membrane was recorded every second by the thermocouple. Following withdrawal of the endoscope, the time of cooling to the physiological temperature was recorded.

Data analysis

Temperature readings were stored on the USB memory device of the data logger in real time and were uploaded to a computer. Thermal images were analysed using TESTO IRSOFT Software (Testo Inc., Germany, version 3.1). Statistical analyses were conducted with the aid of Microsoft Excel.

Results

Figures 4–6 show the variation in mean temperature over time for different light sources. For all lights, the temperature increased with time and rapidly declined to the physiological level when the light was turned off. For the light-emitting diode, the temperature did not significantly vary over time (Fig. 6). Ear temperature rose significantly under microscopic light (Fig. 7). Figure 8 shows the minimum, maximum and average elevations of temperature, $\Delta T = T_{\text{initial}} - T_{\text{final}}$, when different light sources were used. The greatest values were observed using a combination of the xenon light at 100% power and the 4-mm-diameter endoscope; the lowest values were observed using a combination of the light-emitting diode light and the 3-mm-diameter endoscope. The greater the endoscope diameter is, the higher the temperature is attained, with all light sources. Microscopic light also raised the temperature significantly, to a level higher than those attained using the 3-mm instrument with the xenon or halogen lights. The maximum temperature was recorded when using the 4-mm instrument with the xenon light at 100% power. When the power level was reduced to 50%, the temperature fell 35% from that at the 100% power level.

Discussion

Optical systems began to find medical use at the turn of the 19th century, developed over time and found many applications. Endoscopic procedures are preferred both diagnostically and therapeutically, especially because they afford direct visualisation. In recent years, such procedures have found many applications in otolaryngology; they have both advantages and disadvantages. One technical consideration is important: the rise in tissue temperature caused by the light source.[8,9] Only a few studies have explored the functional outcomes of this temperature rise on the hearing system. Such rises trigger varying responses in neurosensorial cells, as revealed by hearing tests.[10,11]

Many otological surgeons perform middle ear surgery under an operating microscope. However, despite providing direct exposure, microscopy may be insufficient in the viewing of certain areas during surgery. Although there are no exposure problems in the posterior and inferior areas, there may be exposure problems caused by the anterior wall prominence. Hidden areas such as sinus tympani, facial recess or attic that cannot be seen under a microscope can be better observed via endoscopic approach with different angles rigid endoscopes. In the endoscopic middle ear surgery procedure, rigid endoscopes allow for functional reconstruction during surgery and the performance of minimally invasive procedures and conservative surgeries with protection of the anatomy.[12] Karhuketo *et al.*[13] emphasised that the use of endoscopic methods in ear surgery fulfils the requirements of minimally invasive surgery and the least trauma to the normal tissues can be achieved in this way.

The rigid endoscopes used in otology are fitted with fibre-optic cables that deliver light from high-density sources to the surgical site. In general, halogen, xenon or light-emitting diode light sources are used. Endoscopic surgeons are aware of the risks of thermal effects caused by endoscopes; however, no such risk has yet been clearly and precisely demonstrated in live tissue.[14]

We measured temperature rises in the round window membrane upon insertion of rigid endoscopes into the middle ear of a live animal. We used various combinations of light sources and rigid endoscopes with different diameters. We evaluated increases in temperature in the round window because this site is very close to the extremely sensitive neurosensorial cells of the cochlea.

Only a few prior studies on the subject have been published. Hensman *et al.*[15] reported that the temperature of the tip of a rigid endoscope of diameter 10 mm, and that at the end of a fibre-optic cable, attained very high levels. Bottrill *et al.*[8] found that the temperature rise caused by insertion of an endoscope into the lateral semi-circular canal was similar to that caused by a standard caloric stimulus, which may be delivered by a middle ear endoscope via transmission of heat to the perilymph. Endoscopes of wider diameter triggered higher temperature rises.

Kozin *et al.*[9] studied freshly frozen, human, temporal bone cadaveric materials. Temperature rises around the round window were measured at specific intervals after insertion of a 0° rigid endoscope of diameter 3 mm, fitted with either a xenon or an light-emitting diode light source.

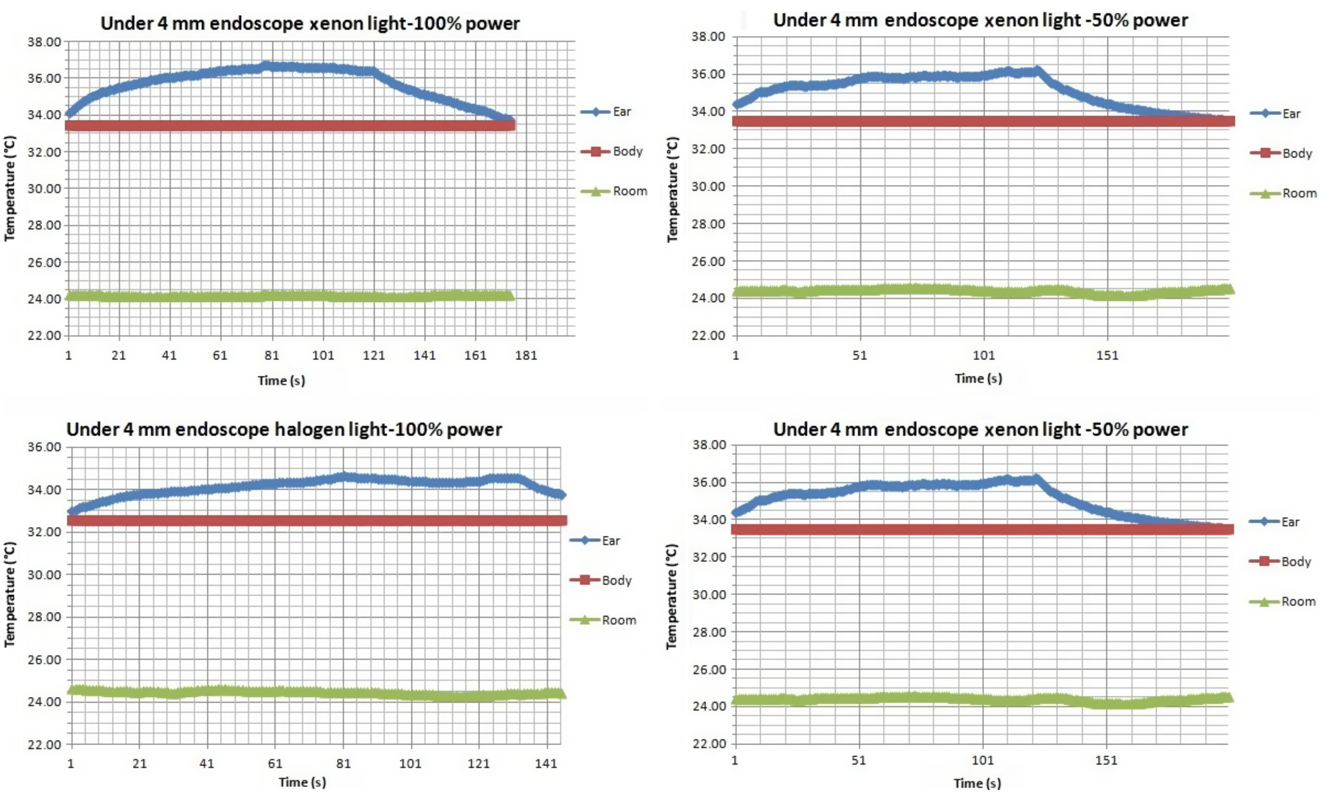

Fig. 4. Mean changes in temperature when using a 4-mm-diameter rigid endoscope with halogen and xenon light sources.

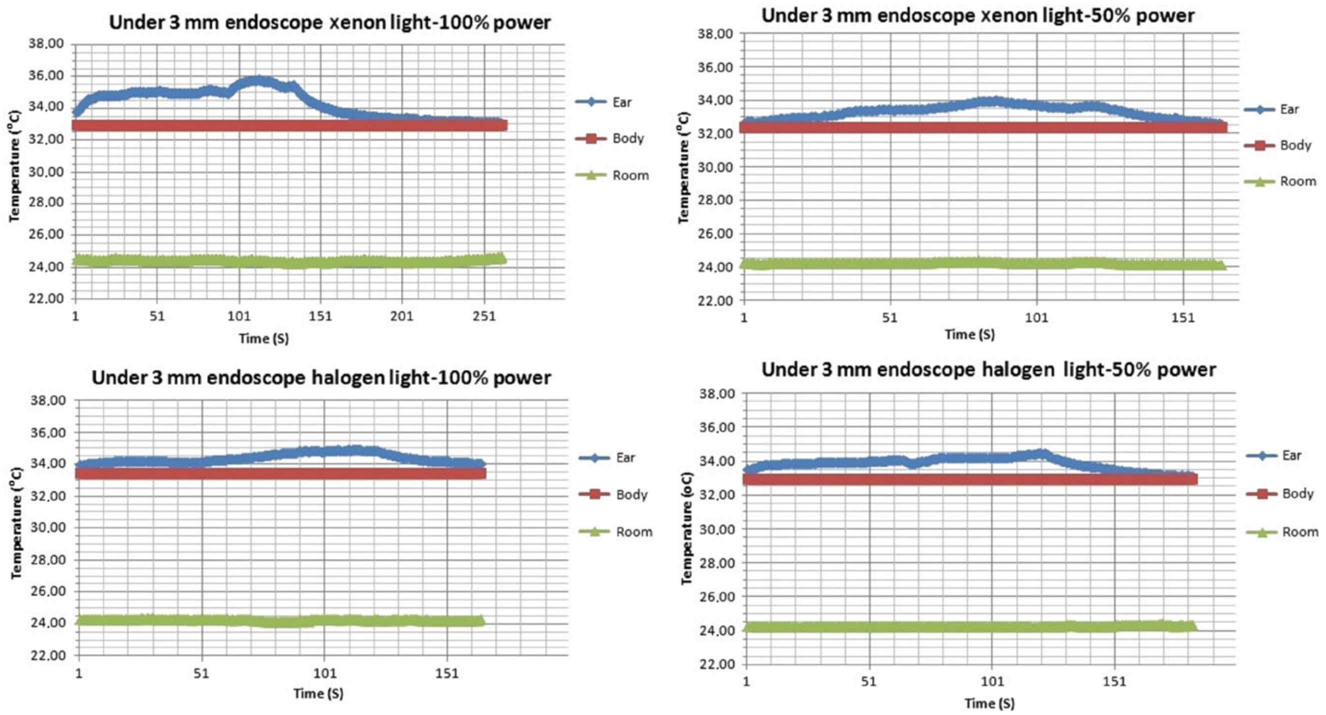

Fig. 5. Mean changes in temperature when using a 3-mm-diameter rigid endoscope with halogen and xenon light sources.

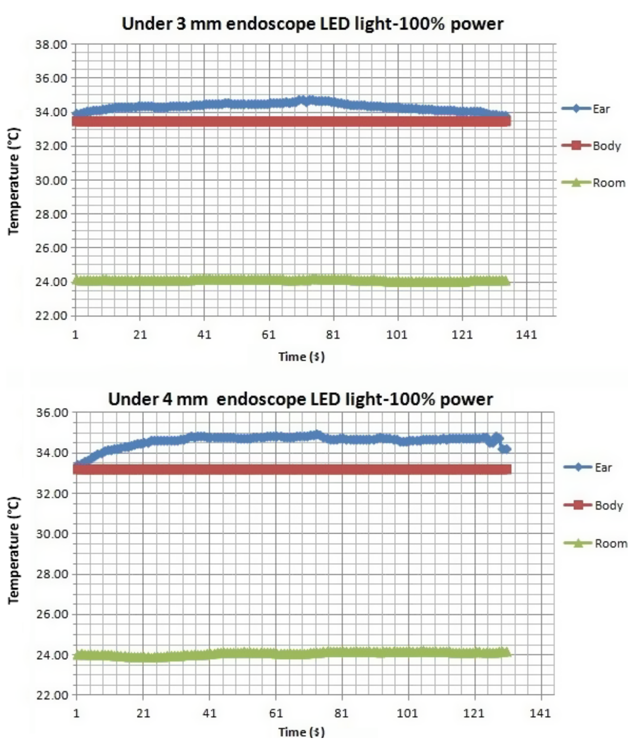

Fig. 6. Mean changes in temperature when using a 3- or 4-mm-diameter rigid endoscope with light-emitting diode light sources.

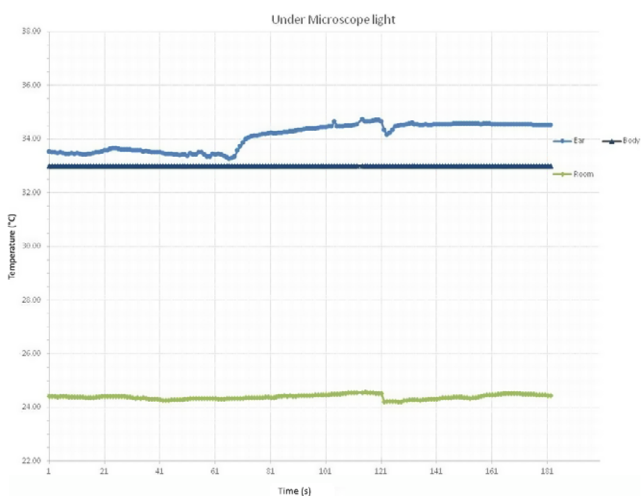

Fig. 7. Mean changes in temperature when using a microscope.

Significant rises in temperature were noted; however, the tissue cooled rapidly when the endoscope was withdrawn. MacKeith *et al.*[14] used different types of endoscopes and found that the temperature at the tip increased notably within the first 35 s. The endoscopes cooled rapidly when the light was turned off. The safest and most effective light source was an light-emitting

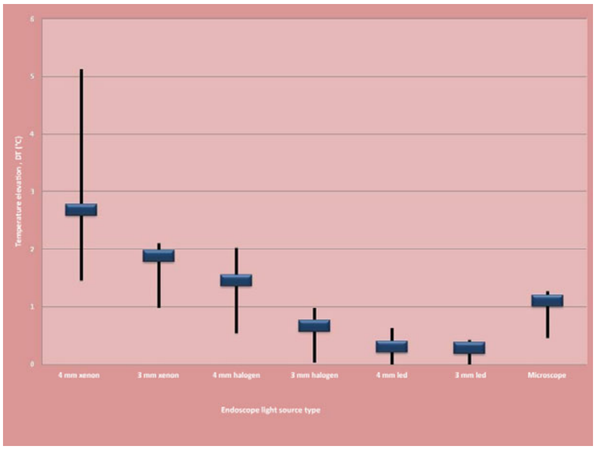

Fig. 8. Minimum, maximum and average increases in temperature when using different light sources.

diode, and the xenon light source caused the greatest rise in temperature.

We planned our work after reviewing earlier data and sought to measure temperature increases in the round window membrane of live tissue (of an animal) caused by insertion of rigid endoscopes of diameter 3 or 4 mm (which are often used in endoscopic ear surgery) fitted with halogen, xenon or light-emitting diode light sources. The guinea pig tympanum is similar to that of the humans. The xenon light source triggered the greatest temperature rise (using either endoscope), and the light-emitting diode triggered the least change. Furthermore, the temperature rose later and to a lower level, when the 3-mm-diameter endoscope was inserted. We emphasise that our data are objective because we worked with live tissue.

Periodic removal of the endoscope allowed the tissue to cool to the physiological level at a rate identical to that noted when the light source was switched off. Although the rise in temperature was less when the light-emitting diode light source was employed, rises were nonetheless apparent. Therefore, the choice of an light-emitting diode does not alone solve the problem.

Our study had two limitations. First, the distance between the endoscope and the target site was fixed. Had the distance been variable, the temperature rises may have differed. We attempted to use the shortest possible distance to measure the greatest temperature rise that could occur. Second, we did not objectively measure any potential heat-induced damage. We believe that overcoming these limitations will make future results clearer.

Conclusion

The rigid endoscopes and light sources used in endoscopic ear surgery may cause significant increases in temperature in the middle ear. When three light sources were compared, we found that the xenon light and the light-emitting diode were associated with the greatest and least temperature rises, respectively. Heat transmitted by endoscopes attained maximum levels within the first 120 s, and the elevated temperatures were maintained over time. The tissue rapidly cooled when the endoscope was withdrawn.

Keypoints

- All light sources cause a temperature rise in round window which is transmitted to the perilymph.
- The lowest temperature rise was observed with LED sources.

Conflict of interest

None to declare.

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