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Research report

Assessment of Middle Ear Anatomy Teaching Methodologies using Microscopy versus Endoscopy: A Randomized Comparative Study

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ABSTRACT

Teaching methodologies for the anatomy of the middle ear have not been investigated greatly due to the middle ear's highly complex structure and hidden location inside of the temporal bone. The aim of this randomized study was to quantitatively compare the suitability of using microscope- and endoscope-based methods for teaching the anatomy of the middle ear. We hypothesize that the endoscopic approach will be more efficient compared to the microscopic approach. To answer the study questions, 33 sixth-year medical students, residents and otorhinolaryngology specialists were randomized either into the endoscopy or the microscopy group. Their anatomical knowledge was assessed using a structured anatomical knowledge test before and after each session. Each participant received tutoring on a human cadaveric specimen using one of the two methods. They then performed a hands-on dissection. After 2-4 weeks, the same educational curriculum was repeated using the other technique. The mean gains in anatomical knowledge for the specialists, residents, and medical students were +19.0%, +34.6% and +23.4%, respectively. Multivariate analyses identified a statistically significant increase in performance for the endoscopic method compared to the microscopic technique ($P < 0.001$). For the recall of anatomical structures during dissection, the endoscopic method outperformed the microscopic technique independently of the randomization or the prior training level of the attendees ($P < 0.001$). In conclusion, the endoscopic approach to middle ear anatomy education is associated to an improved gain in knowledge as compared to the microscopic approach. The participants subjectively preferred the endoscope for educational purposes.

Key words: Middle ear anatomy; gross anatomy education; medical education, teaching; endoscopic ear surgery; microscope; endoscope; retrotympanum; facial nerve

INTRODUCTION

The anatomy of the middle ear is particularly complex and challenging (Marchioni et al., 2011). The hidden recesses of the retrotympanum are difficult to explore and therefore are poorly understood (Marchioni et al., 2010; Bonali et al., 2017; Alicandri-Ciufelli et al., 2018). Conditions affecting the middle ear, such as acute otitis media, transmissive hearing loss, chronic inflammation with or without cholesteatoma or ear drum perforations, are frequent among all age groups. Thus, the knowledge of the anatomy of the middle ear is relevant to all medical doctors, irrespective of their prior education or specialty.

Because the middle ear is hidden inside the temporal bone and has limited accessibility, several strategies have been developed to visualize its anatomy (Tschabitscher and Klug, 1999). Due to these difficulties, to date, simulations have gained increasing popularity in otolaryngology, especially for teaching the surgical anatomy of the middle ear and procedures used to treat it (Javia and Deutsch, 2012; Javia and Sardesai, 2017), including computer-based simulations (Abou-Elhamd et al., 2009, Clifton et al., 2011. Francis et al., 2012), problem-based learning (Abou-Elhamd et al., 2010), simulations using three-dimensional synthetic models (Mills and Lee, 2003; Bakhos et al., 2010; Rose et al., 2015; Barber et al., 2016; Luu et al., 2017, VanKoevering and Malloy 2017b) and even animal models (Anschuetz et al., 2017). Similar results have been described between virtual and cadaveric temporal bone dissections regarding the acquisition of surgical skills in the middle ear region (Wiet et al., 2012; Andersen et al., 2016a).

Despite the advancements and obvious advantages related to physical and virtual simulation models, the method through which medical providers are educated about the delicate anatomy of the middle ear is generally not addressed in the literature. Studies of anatomical professionals (Patel and Moxham, 2008) and medical students (Kerby et al., 2011) clearly favored peer-tutored cadaveric dissection as the most suitable method with regard to anatomical learning outcomes. A similar conclusion was published by George and De (2009), who considered the use of cadaveric specimens to be the gold standard in teaching otolaryngology trainees. However, middle ear anatomy dissections are difficult due to its size and limited accessibility. Therefore, a suitable setup for cadaveric dissection is challenging, as the relevant structures may not be perceptible by the unassisted eye. In this context, the use of magnification and illumination of the middle ear cleft is necessary for adequate education about its anatomy.

Until recently, the standard clinical tool used for visualization and treatment of the tympanic membrane and the middle ear was the microscope. However, because microscopes have a straight viewing field, the visibility of the curved middle ear is limited. Technical refinements over the last decade now allow for endoscopic explorations of the middle ear. To this end, a rod lens endoscope is introduced into the external auditory canal and the middle ear anatomy is studied in its natural state (Anschuetz et al., 2018). The differences in the visibility of the middle ear anatomy comparing the microscope and the endoscope methods have been previously studied, and the endoscopic technique was reported to have a clearer view (Bowdler and Walsh 1995; Bennett et al., 2016).

To date, no comparative studies have been done between the two techniques regarding teaching methodologies and education of the complex anatomy of the middle ear. However, knowledge about the optimal middle ear anatomy education methodology has important consequences because it could improve the anatomical knowledge of medical students, residents and otorhinolaryngology specialists.

The aim of this study was to quantitatively compare the suitability of using microscope- and endoscope-based methodologies for teaching the anatomy of the middle ear in a randomized crossover study using participants from different educational levels. We hypothesized that the endoscopic approach would be more efficient in teaching middle ear anatomy than the microscopic approach in terms of the learning outcomes.

MATERIAL AND METHODS

This study was reviewed and approved by the local ethical committee (KEK-BE ID REQ-2018-00310) and granted exemption from formal ethical approval for this type of study.

To compare the endoscopic and the microscopic approaches to middle ear anatomy education, we recruited medical students in their final sixth-year of training (medical curriculum in Switzerland is six years, with macroscopic anatomy courses in the first two years containing 2 lessons on middle ear and temporal bone anatomy; clinical anatomy is taught via lectures, in problem-based learning sessions and during internships), otorhinolaryngology residents from all levels (five-year postgraduate education in Switzerland before the specialist title is conferred) and specialists from the Department of Otorhinolaryngology, Head and Neck surgery (ORL-HNS) at the Inselspital, University Hospital of Bern, Switzerland.

Study participants were randomized into two groups, each containing the same proportion of medical students, residents and specialists. During the first session, group 1 received middle ear anatomy education using the endoscopic technique, and group 2 received the same education using the microscopic technique. After 2-4 weeks, the groups were crossed-over with group 1 receiving the microscopic method and group 2 receiving the endoscopic method. The study design is graphically illustrated in Figure 1.

Anatomy knowledge test

Participants' anatomical knowledge was assessed using a structured anatomical knowledge test containing 41 questions that were newly created for this purpose (see appendix for full anatomy knowledge test). This test was used to assess participants' anatomical knowledge at 4 different times: (1) baseline, (2) after the first educational session and dissection, (3) before the second session and (4) at the end of the second educational session. The validity and reliability of the test were statistically assessed using Kendall's tau B and Pearson correlations, respectively (see results).

Cadaveric Specimen Teaching

Each participant's baseline anatomical knowledge was assessed. Afterwards, they were tutored on a human cadaveric specimen. No theoretical preparation was required from the participants.

Identical standardized teaching sessions were performed independently of the educational level (student, resident, specialist) or the technique (endoscope, microscope). To minimize any bias related to anatomical variability, the same anatomical specimen was used for all sessions. The session sequence and the instructions given by the tutor were standardized and identical for every session and did not differ between the endoscopic (Karl Storz, Tuttlingen Germany) and the microscopic (Leica Microsystems, Wetzlar, Germany) techniques. The same tutor (LA) conducted all dissection sessions to minimize differences between the instructions given at each session. The duration of each session was between 90 and 120 minutes. First, general and technical instructions (manipulation of the endoscope or the microscope) were given to the participants in small groups of three to four. Thereafter, a standardized systematic description was given of the middle ear anatomy, starting with the ossicular chain, followed by the anatomical structures of the epitympanum, the retrotympanum, the mesotympanum and the protympanum. Basic ventilation patterns illustrating the physiology of the middle ear were also taught (Eustachian tube, tympanic isthmus, tensor fold). The description reviewed all of the structures assessed by the anatomy knowledge test (see appendix for full test).

Cadaveric Specimen Dissection

Thereafter, the attendees individually performed an exploration and dissection of the middle ear cleft under the supervision of the tutor (L.A.) in a one-to-one session. During the dissection, the attendees named all of the anatomical structures they were able to recall. The tutor recorded all correct items. At the end of dissection, the correctly named structures were summarized, and a score was assigned (maximum 39 points).

Learners' perception

At the end of session 2, every participant provided subjective feedback using a five-point Likert scale assessment form. The questions on the questionnaire are shown in Figure 2.

Statistical analyses

All data were exported to the Statistical Package for Social Sciences (SPSS), version 24 (IBM Corp., Armonk, NY) and to BrightStat.com, version 1.3.1 (Stricker, 2008). Descriptive and inferential statistical analyses were done, depending on the variables being tested. Significance tests were completed to examine the relationships between variables. To assess the validity of the anatomical knowledge test as well as the validity of the recall score of the anatomical structures during the dissection sessions, Kendall's Tau B was computed between the attendees' educational level and the two measurements. Moderate to high negative correlations were expected in the validity of the measurements because staff members (coded as 1) were expected to receive the highest results and students (coded as 3) were expected to have the lowest performance on the anatomical knowledge test and receive the lowest recall scores during the dissection sessions. Pearson correlation coefficients were used to assess test-retest reliability of the anatomical knowledge test as well as the recall of anatomical structures during the dissection sessions. High positive correlation coefficients were expected to account for the instruments' reliability.

Repeated measures analyses of variance were conducted to examine the influence of the technique (endoscopic vs. microscopic), dissection session (first vs. second), education level (staff member, resident or student) and randomization order (endoscope first vs. microscope first) on participants' anatomical knowledge and recall of the middle ear anatomy during the dissection sessions. Improvements in performance in anatomical knowledge were calculated separately for both dissection sessions as the difference in performance on the anatomical knowledge test before and after the session. A repeated measurement analysis of variance was used to check for an interaction between the dissection session and the randomization order for improvements in performance in anatomical knowledge. P-values less than 0.05 were considered to be statistically significant; however, due to the clinical relevance, only effects with observed effect sizes (partial eta-squared, η_p^2) greater than 0.2 are reported. Performance measures as well as measurements of performance improvements are reported in percentages.

RESULTS

Participants

A total of 33 participants were assessed: 9 sixth-year medical students, 14 residents and 10 ORL-HNS specialists (staff members). The demographic distribution as well as the professional experience of the participants is summarized in Table 1.

Anatomical knowledge

To assess the validity of the anatomical knowledge test, Kendall's Tau B's were computed between attendees' educational level and the performance scores for the four assessments. Coefficients ranged from -0.649 to -0.738, with all having $p < 0.001$. Given the relatively small sample size, these coefficients support the validity of the instrument. Test-retest reliability of the anatomical knowledge scores was assessed using Pearson correlation coefficients between the four assessments. The obtained correlation coefficients ranged from 0.751 to 0.955, with all having $p<0.001$. The results of the validity and test-retest reliability assessments are presented in detail in Table 2.

Performance on the baseline anatomical knowledge test (maximum 41 points) for the staff, residents, and medical students had mean values of 65.6% (SD ± 28.9%), 28.9% (SD ± 9.6%) and 7.3% (SD ± 5.3%), respectively. The last knowledge test after the two rounds of anatomical education (endoscopy and microscopy) after a median of 37 days revealed mean performance values of 84.6% (SD ± 17.4%) for staff members (+19.0%), 63.6% (SD ± 18.7%) for residents (+34.7%) and 30.6% (SD ± 11.1%) for medical students (+23.3%). The main effect of measurement time was significant ($F_{1, 27} = 89.215$, $p < 0.001$, $\eta_p^2 = 0.768$), indicating a large improvement in performance on the anatomical knowledge test between the first and the last measurement for all three education groups. Detailed results of the anatomical knowledge tests for each education group and all four assessments are presented in Table 3.

Figure 3A depicts the group mean performances and the 95% confidence intervals of the means of the anatomical knowledge tests for the four assessments in chronological order (horizontal axis) as well as the two randomization groups (gray and blue columns). Gray bars denote the randomization group that began with the endoscopic technique in session one, and blue bars denote the group that began with the microscopic technique. Improvements in performance between the pre and post assessment of anatomical knowledge was the highest for the endoscopic technique in both sessions, regardless of the randomization group. There was a highly significant interaction between *assessment and randomization* ($F_{3, 81}$ = 10.778, $p < 0.001$, $\eta_p^2 = 0.285$) in a repeated measures analysis of variance with the four *assessments* as a within subjects factor and *educational level* and *randomization* as between subjects factors. This result further supports the superiority of the endoscopic method over the microscopic technique.

To provide further insight into this effect, the improvement in performance between the pre and post assessment of the anatomical knowledge for each session was calculated. The calculated performance gains served as the dependent variable in a 2x2x3 repeated measures analysis of variance that included *session* (first vs. second) as a within subject factor as well as *randomization* and *educational level* as between subjects factors. The main effect of *educational level* ($F_{2, 27}$ = 4.012, p = 0.030, $\eta_p^2 = 0.229$) as well as the interaction between *session and randomization* ($F_{2, 27}$ = 23.555, $p < 0.001$, $\eta_p^2 = 0.466$) were significant. No other effects were significant. The interaction *session and randomization* is outlined in Figure 3B. It becomes obvious that performance improvements in the endoscopic technique were at least double the performance improvements in the microscopic technique no matter if the endoscopic technique was done in the first or in the second dissection session.

Concerning the main effect *educational level* a Tukey HSD post hoc comparison revealed that the mean gain in anatomical knowledge was significantly higher (p = 0.033) for residents compared to the staff members for the main effect of educational level. The mean improvement in anatomical knowledge of the students did not significantly differ from the mean improvement of the residents (p = 0.148) or the staff members (p = 1). Figure 4 depicts the separate improvements in anatomical knowledge for the endoscopic and microscopic techniques (horizontal axis) and the three education levels (gray, blue and green columns).

Recall of anatomical structures during dissection sessions.

First, the validity and reliability of the score for recalled anatomical structures, which was measured during the dissection sessions, was assessed using Kendall's Tau B and test-retest Pearson correlation coefficients. The Kendall's Tau B coefficients for education level and performance in the first and second sessions were -0.496 (p<0.001) and -0.596 (p<0.001), respectively. The test-retest correlation between the recall scores achieved during the first and second sessions was 0.597 (p<0.001). The highly negative Kendall Tau B coefficients indicate that staff members (coded as 1) demonstrated the highest recall scores and students (coded as 3) had the lowest. This finding supports the validity of the measurement.

The highly positive Pearson correlation coefficient between the performance in the two sessions show that the measurements were also reliable. Detailed results are provided in Table 4.

A repeated measures analysis of variance with recall performance as the dependent variable, *session* (first vs. second) as a within subjects factor and *educational level* and *randomization* as between subjects factors revealed a highly significant interaction between *session and randomization* ($F_{1, 27}$ = 45.987, p < 0.001, η_p^2 = 0.630).The main effects of *session* ($F_{1, 27}$ = 15.915, p < 0.001, η_p^2 = 0.371) and *educational level* ($F_{2, 27}$ = 23.571, p < 0.001, η_p^2 = 0.636) were also significant. Figure 5 shows the performance on the recall of anatomical structures task during the two dissection sessions (x-axis) for the two randomization groups. The bars for the endoscopic dissection sessions are marked separately. In both the first and second sessions, the performance after the endoscope session was superior to that of the microscope session. The performance on the recall of anatomical structures task was strongly dependent on the participants' educational level. A Tukey HSD post hoc comparison of the group means revealed that staff members performed significantly better than residents (p < 0.001), who performed significantly better than students (p = 0.013)

To examine participants' recognition and description of anatomical parts such as the facial nerve (FN), the tensor fold area (TFA), the retrotympanum (RT) and the internal carotid area (ICA), a repeated measures analysis of variance was conducted. The dependent variable was recognition (yes vs. no). The *anatomical parts* (FN, TFA, RT and ICA) and *technique* (endoscope vs. microscope) were included as within subject factors and *education level* and *randomization* were included as between subject factors.

The ANOVA revealed two significant main effects: *technique* ($F_{1, 27}$ = 32.853, p < 0.001, η_p^2 = 0.549) and *education level* ($F_{2, 27}$ = 11.211, p < 0.001, η_p^2 = 0.454). Regardless of the anatomical structure and the randomization group, staff members performed the best and students performed the worst on the recognition of anatomical structures task. The level of recognition was better for the endoscopic technique compared to the microscopic, regardless of randomization group, education level and the anatomical structure.

Subjective feedback

Figure 2 shows the means and standard deviations of the answers to the seven questions in the feedback survey for each education level on the five-point Likert scale. In questions 1, 2 and 7, it was especially clear that there were no responses disagreeing with the questions. Thus, the subjective feedback from the participants supported the superiority of the endoscopic method as well as its suitability for learning the anatomy of the middle ear.

DISCUSSION

This randomized crossover study compared endoscope-based and microscope-based dissection techniques for teaching the anatomy of the middle ear in a cohort of participants with different training levels.

Overall, we observed a statistically significant superiority of the endoscope method over the microscope method in terms of improvements in anatomical knowledge across all training levels.

Previous literature has reported that anatomical knowledge among young medical doctors is lower than expected and may be considered too low to guarantee a safe practice (Fasel et al., 2005). Our results support this idea, regarding participants' knowledge of the anatomy of the middle ear. Baseline scores for the 6^{th}-year medical students in this study were low, with a mean of 3 correct answers out of 41 questions. This finding raises the question about suitable teaching methods. Brenner et al. (2003) classified methods for teaching anatomy as follows: "hands-on" dissection, learning from prosected specimens, didactic teaching, models, computer-assisted learning, slides and teaching using living and radiological anatomy. A variety of simulators are used in otolaryngology education for teaching surgical skills across all subspecialties. (Nogueira Júnior and Cruz, 2010). A recent systematic review (Musbahi et al., 2017) identified 32 simulators for ear and temporal bone surgeries. Despite limited evidence and low levels of recommendation, simulations are well accepted in the ORL-HNS community. Most simulators are designed to enhance surgical skills, improving the performance of trainees in the operating room.

To date, there are only a few models that are focused on middle ear anatomy education. A previous randomized trial showed good efficacy of a computer-generated model of the middle ear (Nicholson et al., 2006). Recently, Ng et al. (2015) evaluated a computer-based three-dimensional model that showed good efficiency in teaching the complex anatomy of the epitympanum. However, compared to surgical models, simulations for anatomical education are less well-studied. This may be due to the complexity and small size of the middle ear and the anatomical structures it contains, which make it challenging to create a realistic simulation. Recent advances in 3-dimensional printing in the operating room and in surgical simulations (VanKoevering et al., 2017a) may help resolve the issues associated with cadaveric dissection (availability, hygiene, ethical considerations). Thus far, no suitable models have been proposed regarding the suitability of using 3-dimensional printing to teach middle ear anatomy. Therefore, cadaveric models are still considered the gold standard for education (Patel and Moxham, 2008; George and De, 2009; Kerby et al., 2011). However, the combination of novel technologies and computer-assisted models in combination with traditional dissection may be the future of anatomical education (Ghosh, 2017).

Cadaveric dissection of the middle ear is challenging. This is mainly due to the size of middle ear structures and their hidden location inside the temporal bone. As most structures are too small to be studied with the naked eye, appropriate visualizations of the middle ear cleft or alternative teaching methods are required. Therefore, this study compared the suitability of using the endoscope and the microscope to teach the anatomy of the middle ear. Both techniques are used in surgical practices to visualize the middle ear cleft and treat related pathologies. Our results show a statistically significant difference between these two techniques, favoring the endoscope for teaching the anatomy of the middle ear. The effect was observed across all training levels. This effect is mainly due to the inherent differences in the two approaches. The microscope has a rigid, straight view; thus, only a small excerpt of the middle ear may be seen at a time. Therefore, visualization of the different anatomical regions requires frequent repositioning of the microscope, which is technically demanding. Moreover, the recognition of topographical relationships between the different structures is cognitively challenging. In contrast, the introduction of a rod lens through the external auditory canal, as done with endoscopy, provides highly detailed panoramic views of the anatomy. This allows for the identification and understanding of the topographic relationships between the different structures. Moreover, the direct introduction of the endoscope adequately illuminates the middle ear cleft. Therefore, the anatomical structures may be viewed as closely as necessary to magnify the structures to a sufficient degree. The differences between the two techniques are illustrated in Figure 6. This consideration may also explain our observation that during endoscopic dissection, more participants identified crucial anatomical structures such as the FN, compared to the microscopic dissection. In line with our quantitative findings, the subjective feedback suggested high acceptance of the endoscopic approach, especially for teaching middle ear anatomy, across all educational levels. The preference for and superiority of the endoscopic technique were not correlated with the education level of the participants. By analyzing the learner's feedback, we observed fewer than 50% of the participants felt that endoscopes were more comfortable to use. For a novice in the endoscopic technique it is difficult to stabilize the endoscope and therefore the picture. The manipulation of the endoscope needs a learning curve, whereas the microscope immediately provides stable images. This could be a potential disadvantage in the adoption of endoscopes in teaching and surgery. A further drawback regarding the endoscopic technique are the two-dimensional (2D) images provided as compared to the three-dimensional (3D) images offered by the binocular microscopic view. It is well known, that 2D images do not provide the same information as 3D images regarding depth perception. Thus, form a cognitive point of view, the surgeon has to adopt and develop strategies to adequately estimate distances between structures (Falk et al., 2001). Moreover, Slobounov et al. (2014) reported in a study using virtual reality (VR) and electro-encephalography an increased use of brain resources using 3D VR compared to 2D VR during navigation tasks. Moreover, the 3D immersion improved error recognition and future learning. Recent investigations comparing 3D and 2D endoscopy revealed faster performance of surgical tasks under 3D views (Rampinelli et al., 2017). In the present study the 2D endoscopic technique outperformed the 3D microscopic technique regarding middle ear anatomy. In our opinion other reasons than differences between 2D and 3D views are responsible for this observation as specified above.

Andersen et al. (2016b) reported that using a virtual mastoidectomy training program was less cognitively demanding compared to performing cadaveric dissection. According to the cognitive load theory (Sweller, 1988), human working memory has a limited capacity. If overloaded, the quality of learning may suffer. Therefore, staged learning is important, especially when introducing a novel technique in a highly complex anatomical area such as the middle ear, where psychomotor and theoretical contents are demanding. Dedmon et al. (2018) described the importance of using simulators to train medical students to perform endoscopic ear surgeries to allow for improvements in endoscopic skills prior to teaching difficult theoretical contents. This idea agrees with a recently published pedagogical framework for procedural skills training in otolaryngology (Sawyer et al., 2015). The authors emphasize the importance of establishing a solid theoretical foundation prior to the development of complex psychomotor skills. Thorough anatomical knowledge is without a doubt the requisite foundation for any ear surgeon. Interestingly, we observed that the endoscopic technique not only benefited medical students and residents but also benefited ORL-HNS specialists. From this observation, we may conclude that the advantages of using endoscopy-based education may provide additional learning opportunities even for well-trained ear surgeons.

It is well known that students generally appreciate peer tutoring (Agius et al., 2018). Studies on medical students revealed active learning, i.e. peer-tutored cadaveric dissection, as the most suitable method regarding learning outcomes (Kerby et al., 2011). Also, for otolaryngology residents and fellows the gold standard in anatomical and surgical teaching is cadaveric dissection (George and De, 2009). In this context, we identify further advantages of the endoscopic approach: (1) since the endoscopic equipment is lightweight and compact, a commercially available dissection station could be brought to any dissection site for demonstration purposes; (2) while performing middle ear endoscopy, the dissector and the audience have the same view of the anatomy; (3) questions and teaching points can be immediately addressed.

In our opinion, the postgraduate education of residents, especially otology fellows, should include endoscopic middle ear anatomy sessions, since we observed a statistically significant improvement in the anatomical knowledge of these groups. We would thus advocate that an endoscopic anatomy session be included in microscopic surgical dissection courses. Therefore, even if an ear surgeon is mainly performing microscopic ear surgeries, it may still be wise to utilize the advantages of the endoscope regarding middle ear anatomy.

Limitation of the study

The limitations of this study include the limited availability of endoscopic and microscopic dissection suites and cadaveric specimens. Additionally, the training program focused exclusively on cadaveric dissection. Since cadaveric dissection is highly time consuming, it is not realistic to provide this type of training to all medical students. Using a combination of computer-based models and simulators along with the cadaveric dissection may have additional benefits (Ghosh, 2017) not assessed in this study. One tutor conducted all dissection sessions, the results may have a personal bias.

CONCLUSION

The endoscopic technique is associated with statistically higher benefits regarding the gain of anatomical knowledge, compared to the microscopic approach for teaching the anatomy of the middle ear. This result was observed independently of the participants' educational level. Moreover, the participants of this training program subjectively preferred the endoscope for educational purposes.

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FIGURE LEGENDS

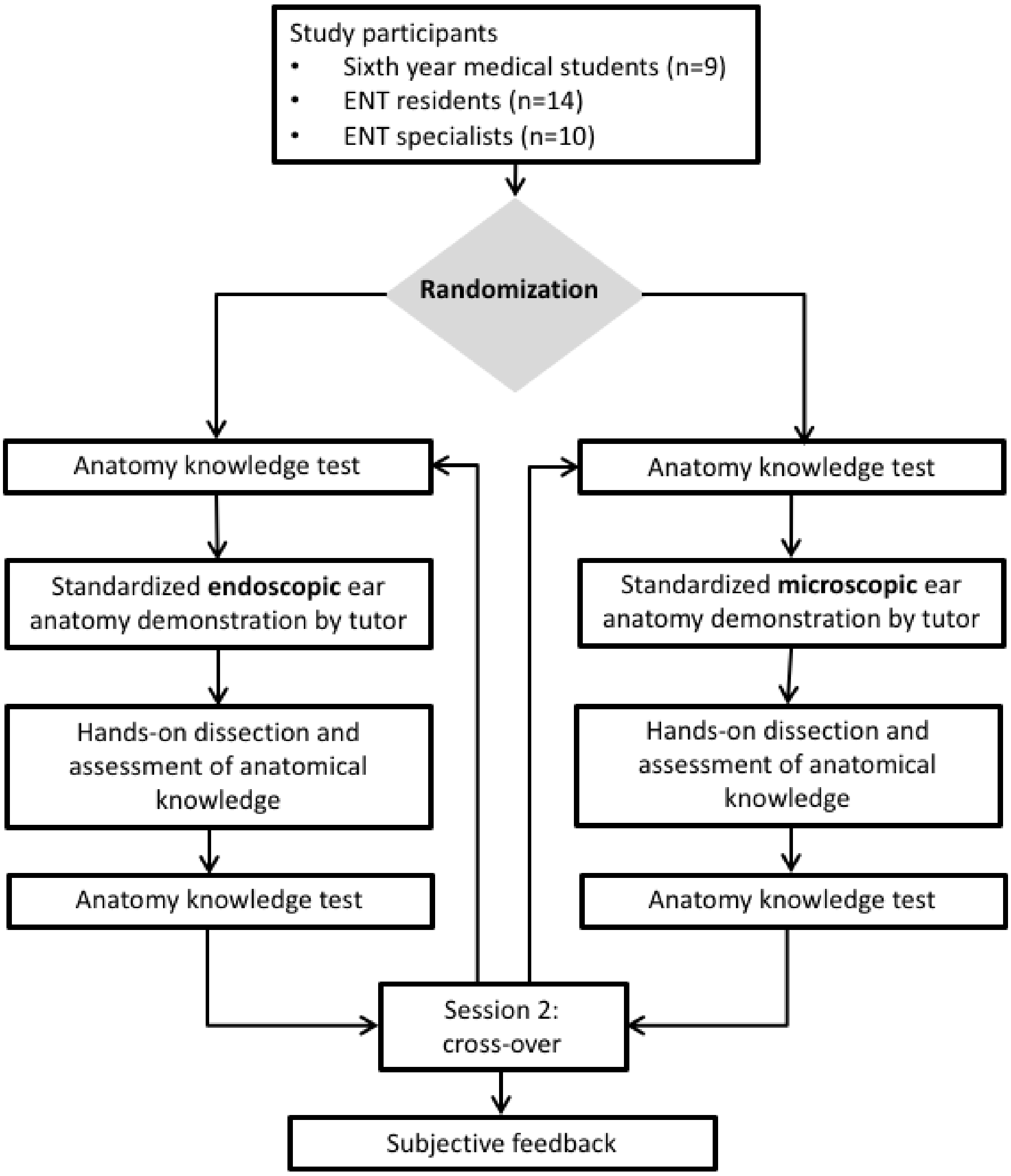

Figure 1: Graphical illustration of the experimental setup. After randomization one group received an endoscopic and the other group a microscopic education. Afterwards the groups were crossed over accordingly.

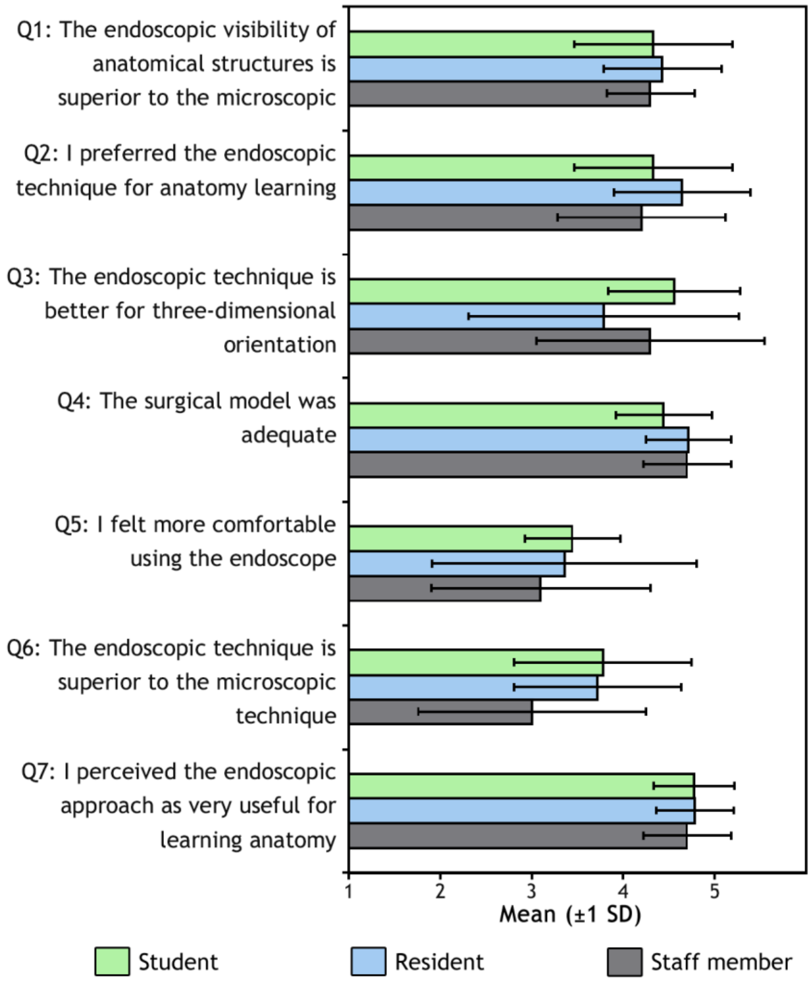

Figure 2: Learner's perception on a 5-point Likert-scale is displayed for all questions, by educational level. Means and standard deviations are displayed, bars denote education level.

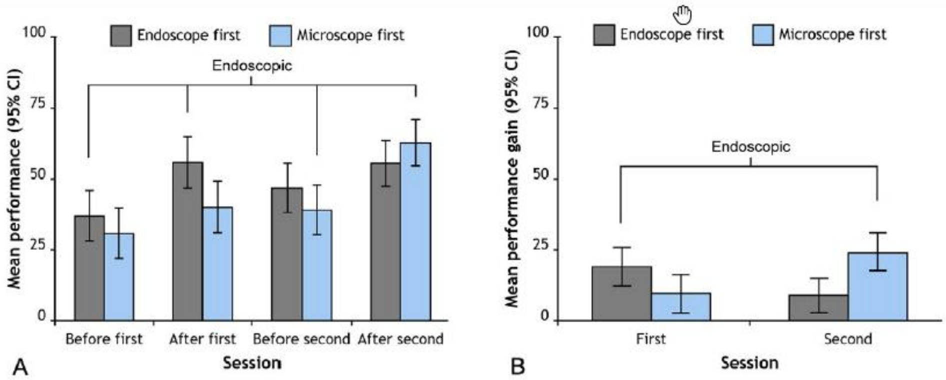

Figure 3: Performance (A) and improvements in performance (B) in anatomical knowledge in percentage units. A: The means for each assessment are displayed separately in chronological order (x-axis) for the randomization groups. B: Mean

performance gains between post and baseline assessments for each session (x-axis). Gray columns denote the group that began with the endoscopic technique in session one, blue columns denote the group that started with the microscopic technique. Error bars denote the 95% confidence intervals of the means.

Within subject comparisons revealed statistically significant differences in performance improvements between the two techniques with higher gain in anatomical knowledge during endoscopic session (p<0.01), compare Table 3 for detailed gain values.

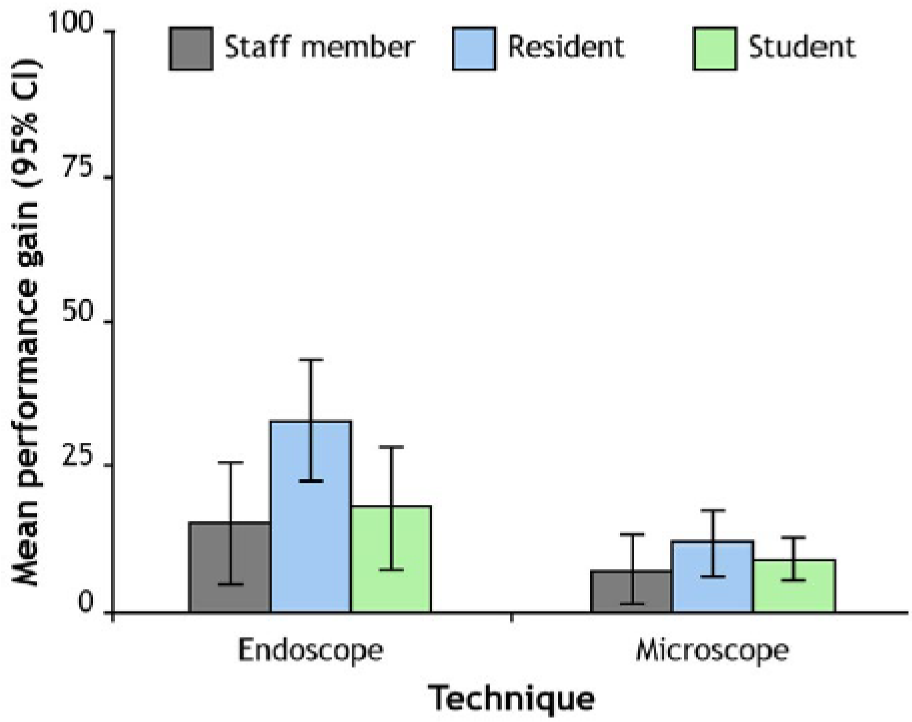

Figure 4: Improvements in anatomical knowledge in percentage units. Means and the 95% confidence interval of the means are displayed separately for each technique (x-axis) and education level (gray, blue and green columns).

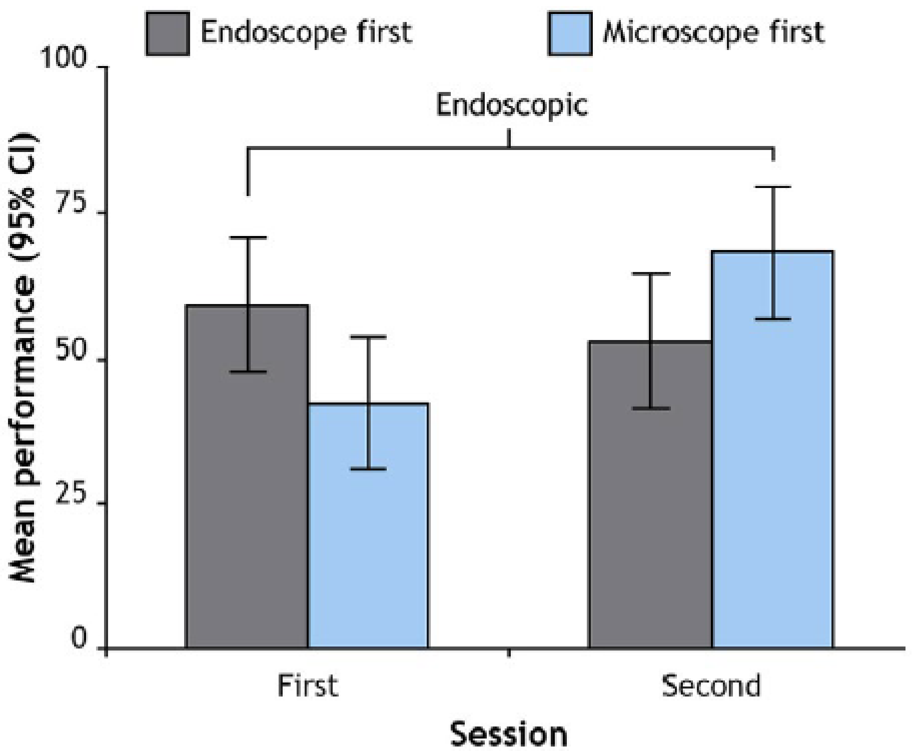

Figure 5: Mean performance in recalling anatomical structures during dissection sessions. Means are displayed in percentage units and error bars denote the 95% confidence intervals of the means. Gray columns denote the group performing the endoscopic technique in session one, blue columns denote the group performing the microscopic technique in session one.

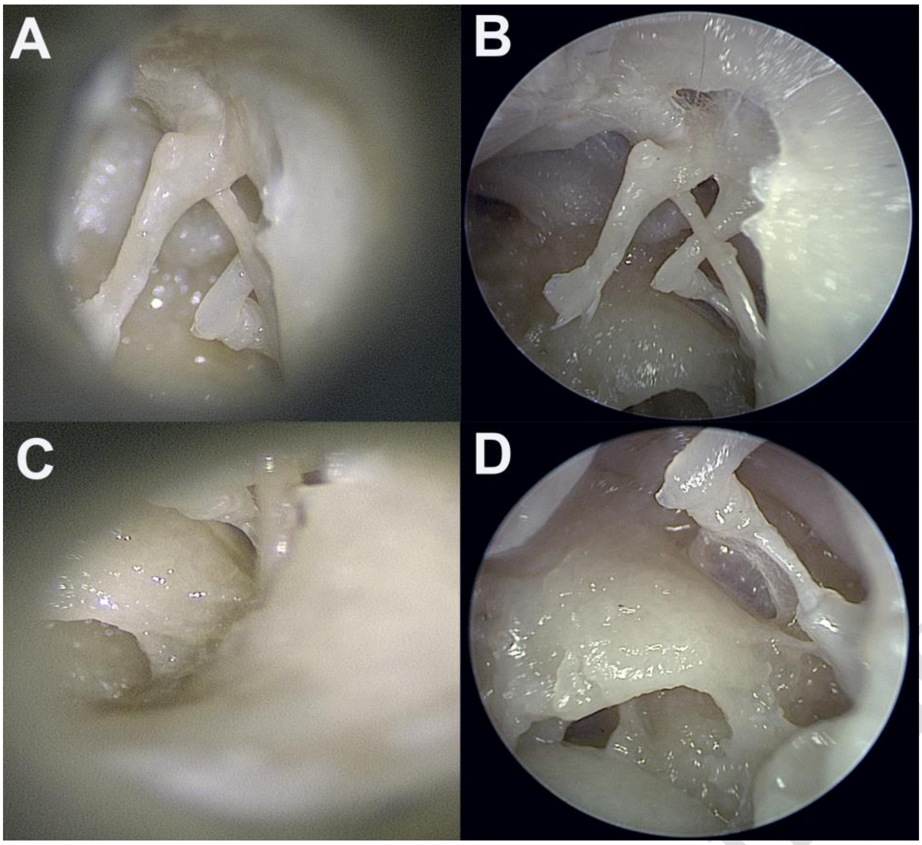

Figure 6: Direct comparison of the visibility of the transcanal microscopic and endoscopic views in a left ear. Panel A: microscopic technique, ossicular chain; B: endoscopic technique, ossicular chain; C: microscopic technique, round window niche and retrotympanum, D: endoscopic technique, round window niche and retrotympanum.

Table 1: Demographics of study participants. Represented as median values (min, max).

	N male / female	Mean age (SD), years	Median experience, years (min, max)	Median middle ear surgery procedures, microscopic or endoscopic (min, max)
Medical students	4 / 5	26.3 (2.2)	0 (0, 1)	0 (0, 0)
Residents	7 / 7	32.2 (3.6)	4 (1, 5)	0 (0, 15)
Staff members	8 / 2	38.5 (7.7)	8 (5, 32)	65 (4, >400)

Table 2: Correlations between educational level and the performances in the anatomy quiz taken before and after the first and second session (a: Kendall's Tau-b, b: Pearson Correlation, *** p < .001).

	Educational level[a]	Before 1st session[b]	After 1st session[b]	Before 2nd session[b]
Before 1st session	-.738 ***			
After 1st session	-.649 ***	.803 ***		
Before 2nd session	-.660 ***	.907 ***	.751 ***	
After 2nd session	-.662 ***	.869 ***	.801 ***	.955 ***

Table 3: Performance in anatomical knowledge in mean percentage (Standard deviation) for each group and measurement according to randomization. Endoscopic sessions are marked by blue background. The comparison within each group between gain in anatomical knowledge is statistically significant ($p<0.01$) favoring the endoscopic technique for teaching middle ear anatomy.

		Session 1		Session 2	
		Before	After	Before	After
Endoscope first	Staff (n=5)	75.1 (29.5)	82.9 (24.0)	79.5 (26.9)	81.5 (23.7)
	Resident (n=6)	27.2 (12.1)	54.1 (16.4)	38.6 (10.2)	52.0 (15.5)
	Student (n=5)	8.3 (4.8)	30.2 (18.3)	22.0 (10.9)	32.7 (11.0)
	Total (n=16)	36.3 (32.9)	55.6 (28.2)	46.2 (29.1)	55.2 (25.8)
	Gain (n=16)	19.3 (17.8)		9.0 (8.7)	
Microscope first	Staff (n=5)	56.1 (27.9)	67.8 (22.6)	65.9 (25.6)	87.8 (9.6)
	Resident (n=8)	30.2 (7.9)	40.2 (12.4)	35.4 (11.2)	72.3 (16.6)
	Student (n=4)	6.1 (6.5)	12.2 (8.2)	15.9 (9.0)	28.0 (12.4)
	Total (n=17)	32.1 (24.1)	41.8 (25.3)	39.7 (24.5)	66.4 (26.5)

	Gain (n=17)	9.7 (7.7)	26.7 (17.1)

Table 4: Performance in recall of anatomical structures during dissection sessions in mean percentage (Standard deviation) for each group and measurement. Endoscopic sessions are marked by blue background. The performance during the endoscope session was superior to that of the microscope session (p<0.001) and strongly dependent on the participants' educational level (p<0.001).

		Session 1	Session 2
Endoscope first	Staff (n=5)	81.0 (22.1)	76.4 (22.3)
	Resident (n=6)	52.6 (6.2)	44.9 (10.1)
	Student (n=5)	45.1 (16.1)	39.0 (9.3)
	Total (n=16)	59.1 (21.3)	52.9 (21.6)
Microscope first	Staff (n=5)	63.6 (24.3)	85.1 (11.8)
	Resident (n=8)	40.4 (11.9)	73.4 (8.4)
	Student (n=4)	19.9 (5.3)	36.5 (17.8)
	Total (n=17)	42.4 (22.0)	68.2 (21.9)