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Quantitative measurement of airborne particles during endoscopic and microscopic ear surgery in the operating room

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Main Article

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Abstract

Objective. This study aimed to quantitatively investigate airborne particle load in the operating room during endoscopic or microscopic epitympanectomy or mastoidectomy.
Method. In the transcanal endoscopic ear surgery group, drilling was performed underwater. A particle counter was used to measure the particle load before, during and after drilling during transcanal endoscopic ear surgery or microscopic ear surgery. The device counted the numbers of airborne particles of 0.3, 0.5 or 1.0 μm in diameter.
Results. The particle load during drilling was significantly higher in the microscopic ear surgery group ($n = 5$) than in the transcanal endoscopic ear surgery group ($n = 11$) for all particle sizes ($p < 0.01$). In the transcanal endoscopic ear surgery group, no significant differences among the particle load observed before, during and after drilling were seen for any of the particle sizes.
Conclusion. Bone dissection carries a lower risk of airborne infection if it is performed using the endoscopic underwater drilling technique.

Introduction

Since the use of high-speed drilling instruments during otological surgery is aerosol-generating, various strategies, such as pre-operative polymerase chain reaction based tests, personal protective equipment and barrier drapes, have been used to reduce the risk of viral transmission during such procedures in the coronavirus disease 2019 (Covid-19) pandemic.[1–3]

If bone drilling is necessary during transcanal endoscopic ear surgery, we routinely perform it underwater.[4] In this method, bone dust and blood are washed out from the surgical field, improving the surgical view under endoscopy. Moreover, endoscopic underwater drilling enables more extensive bone resection within a shorter period than endoscopic non-underwater drilling.[5] Since underwater drilling washes out bone dust and blood from the surgical field, we hypothesised that the levels of aerosols produced by transcanal endoscopic ear surgery are extremely low when the underwater drilling technique is used.

In previous Covid-19 studies of otological drilling, fluorescent droplet deposition in the surgical field was investigated.[1–3] Studies in other fields have attempted to directly measure the levels of airborne particles using a particle counter in the operating room.[6–9] Similar studies of airborne particle levels have been performed in the field of otology,[10,11] but these were cadaveric studies and were not performed in the operating room. Therefore, in this study we aimed to directly measure the levels of airborne particles in the operating room with a particle counter while drilling bone during endoscopic or microscopic ear surgery.

This study compared the particle load generated during bone drilling between transcanal endoscopic ear surgery and microscopic ear surgery. However, the surgical indications for these procedures often differed, and the amounts of bone resected in each group were not comparable. Thus, comparisons were made between non-equivalent procedures. The surgical indications for transcanal endoscopic ear surgery and microscopic ear surgery are described in detail in the Methods section. The limitations of this study are described in the Discussion section.

Materials and methods

This study adhered to the Declaration of Helsinki and was approved by the institutional ethics committee of Osaka Rosai Hospital (register number: 2020-72; principal investigator: the main author). Cases in which otological surgery involving epitympanectomy and/or mastoidectomy was performed using a high-speed drill at our department between 19 June 2020 and 26 February 2021 and in which the intra-operative airborne particle load was investigated were collected. A few cases in which microscopic ear surgery was performed ($n = 2$) were excluded from the study because of the use of electrocautery during the particle load measurement. The patients were divided into two groups: those in whom ear drilling was performed during transcanal endoscopic ear surgery (the transcanal endoscopic ear surgery group, $n = 11$) and those in whom drilling was performed during microscopic ear surgery (the microscopic ear surgery group, $n = 5$) (Table 1).

The transcanal endoscopic ear surgery and microscopic ear surgery had different surgical indications, which are described below. All cases in the transcanal endoscopic ear surgery group involved middle-ear cholesteatoma. A cholesteatoma was defined as being endoscopically accessible when it did not extend beyond the level of the lateral semicircular canal.[12] The transcanal endoscopic ear surgery group consisted of 7 patients who underwent mastoidectomy and 4 who underwent epitympanectomy, and all of these procedures involved underwater drilling.[4] In the microscopic ear surgery group, there were 4 cases of cholesteatoma and 1 case of a middle-ear tumour, which was pathologically confirmed to be an adenoma. The indications for microscopic ear surgery included cholesteatoma and tumours that extended beyond the lateral semicircular canal in the mastoid cavity and were considered inaccessible by transcanal endoscopic ear surgery. In the microscopic ear surgery group, some parts of the surgical procedures were performed with endoscopic assistance, but all mastoidectomy procedures were performed under microscopes via retroauricular incisions. Barrier drapes, such as the OtoTent,[1,2] which suppress aerosols, were not used in any of the microscopic ear surgery procedures. Negative or positive pressure was not used in the operating room in any case.

All patients were pre-operatively confirmed to be negative for Covid-19 based on a polymerase chain reaction test. After January 2021, when the third Covid-19 wave passed through Japan, all anesthesiologists, otolaryngologists, nurses, investigators and healthcare professionals in the operating room wore N95 masks during endotracheal intubation, extubation and otological drilling procedures. People without N95 masks left the operating room during these procedures.

Table 1. Patients' clinical data

Parameter	Transcanal endoscopic ear surgery	Microscopic ear surgery	*P*-value
Patients (*n*)	11	5	
Sex (*n*)			
– Males	8	3	1.000
– Females	3	2	
Age (years)	47.3 ± 22.7	51.2 ± 15.6	0.827
Side of pathology (*n*)			
– Right	5	3	1.000
– Left	6	2	
Surgical procedure (*n*)			
– Epitympanectomy	4	0	0.245
– Mastoidectomy	7	5	
Total surgical time (minutes)	212.8 ± 12.9	286.0 ± 28.4	0.052
Drilling time (minutes)	13.1 ± 5.4	16.5 ± 3.1	0.106

Measurement of airborne particles

A particle counter (Airborne Particle Counter, model: HHPC 3+, Beckman Coulter, Brea, USA) was used to measure particle load.[6] The measurement method of this device is based on the absorption and scattering of laser light by particles. Photodiodes detect these effects and convert them into electrical signals. The airborne particle counter flow rate was set to 2.83 l/minute. Since this device can only measure three types of airborne particles at once, it was set to count airborne particles with diameters of 0.3, 0.5 and 1.0 μm. Each measurement was obtained over a 1-minute period, and was repeated 3 times, with the mean value being adopted as the recorded value. The measurements are expressed in units/l.

The particle load measurement was performed from the opposite side to the surgery, at a distance of 50 cm from the opening of the external acoustic meatus, beyond the screen frame of the surgical field, but as horizontal as possible to the external auditory meatus and as perpendicular as possible to the body axis.

The particle load was measured at three different time-points: before drilling, during drilling and after the drilling. In the pre-drilling period, tympanomeatal flap elevation, tympanic cavity manipulation and cholesteatoma or tumour exposure were performed. In the drilling period, epitympanectomy and/or mastoidectomy was carried out. In the post-drilling period, cholesteatoma and tumour removal, ossicular reconstruction and external auditory canal reconstruction were performed.

The use of electrocautery was minimised during surgery, and it was not used for at least 5 minutes before the measurements. During the drilling period, the measurements started to be obtained at least 1 minute after the start of the drilling.

Surgical time

The drilling time was calculated from the intra-operative video recording. It was defined as the time from the start of the resection procedure to the end of the resection procedure.[5] The start of the resection procedure was defined as the time-point on the video when the drill first touched the bone. The end of the resection procedure was defined as the time-point when the drill was removed from the bone immediately before the cholesteatoma removal procedure was started. The total surgical time was obtained from the patients' surgical records.

Data analysis

The statistical analyses of the results were performed using SPSS® (version 25.0) statistical analysis software. Continuous variables are expressed as mean ± standard error values. Mann–Whitney U test was used to compare the mean values for two groups. The Kruskal–Wallis analysis of variance (ANOVA) test was used to compare the mean values for three groups, and the Bonferroni-Dunn test was used for multiple comparisons testing. Comparisons between groups were performed using Fisher's exact test.

Results

The patients' clinical data are shown in Table 1. The total surgical time tended to be longer in the microscopic ear surgery group (286.0 ± 28.4 minutes) than in the transcanal endoscopic ear surgery group (212.8 ± 12.9 minutes), but the difference was not significant (Mann–Whitney's U test, $p = 0.052$).

The 0.3-μm particle load

In the comparison between the microscopic ear surgery and transcanal endoscopic ear surgery groups, the 0.3-μm particle load during drilling was significantly higher in the microscopic ear surgery group (42.20 ± 14.01 units/l) than in the transcanal endoscopic ear surgery group (3.43 ± 1.56 units/l) (Mann-Whitney's U test, $P < 0.01$) (Figure 1).

In the microscopic ear surgery group, the 0.3-μm particle load observed before (4.94 ± 2.95 units/l), during (42.20 ± 14.01 units/l), and after (9.54 ± 2.32 units/l) drilling differed significantly (Kruskal-Wallis test, $P < 0.05$), and the particle load observed during drilling (42.20 ± 14.01 units/l) was significantly higher than that seen before drilling (4.94 ± 2.95 units/l) (Bonferroni-Dunn test, $p < 0.05$) (Figure 1).

In the transcanal endoscopic ear surgery group, the 0.3-μm particle load observed before (2.88 ± 1.26 units/l), during (3.43 ± 1.56 units/l) and after (4.97 ± 1.54 units/l) the drilling did not differ significantly (Kruskal–Wallis ANOVA test, $p = 0.281$) (Figure 1).

The 0.5-μm particle load

In the comparison between the microscopic ear surgery and transcanal endoscopic ear surgery groups, the 0.5-μm particle load observed during (17.28 ± 5.84 units/l) and after (3.86 ± 1.57 units/l) drilling in the microscopic ear surgery group was significantly higher than those seen during (1.20 ± 0.70 units/l) and after (1.19 ± 0.42 units/l) drilling in the transcanal endoscopic ear surgery group (Mann–Whitney U test, $p < 0.01$ and $p < 0.05$, respectively) (Figure 2).

In the microscopic ear surgery group, the 0.5-μm particle load seen before (1.32 ± 1.10 units/l), during (17.28 ± 5.84 units/l) and after (3.86 ± 1.57 units/l) drilling differed significantly (Kruskal–Wallis test, $p < 0.05$), and the particle load observed during drilling (17.28 ± 5.84 units/l) was significantly higher than that seen before drilling (1.32 ± 1.10 units/l) (Bonferroni-Dunn test, $p < 0.05$) (Figure 2).

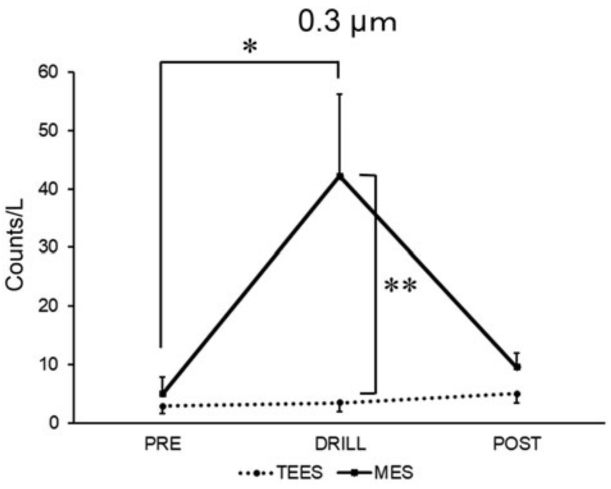

Figure 1. The 0.3-μm particle load. The 0.3-μm particle load observed during drilling was significantly higher in the microscopic ear surgery group than in the transcanal endoscopic ear surgery group (Mann–Whitney U test; $^{**}p < 0.01$). In the microscopic ear surgery group, the 0.3-μm particle load observed during drilling was significantly higher than that seen before drilling (Bonferroni-Dunn test, $^{*}p < 0.05$). PRE = before drilling; DRLL = during drilling; POST = after drilling; TEES = transcanal endoscopic ear surgery; MES = microscopic ear surgery.

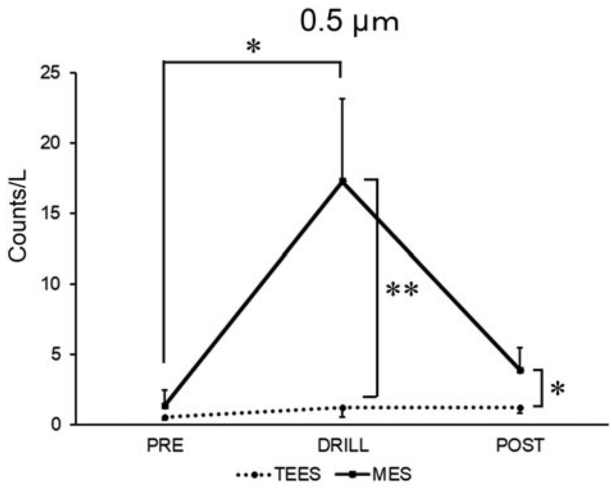

Figure 2. The 0.5-μm particle load. The 0.5-μm particle load observed during and after drilling in the microscopic ear surgery group was significantly higher than that seen during and after drilling in the transcanal endoscopic ear surgery group (Mann-Whitney's U test, $^{**}p < 0.01$ and $^{*}p < 0.05$, respectively). In the microscopic ear surgery group, the 0.5-μm particle load observed during drilling was significantly higher than that seen before drilling (Bonferroni-Dunn test, $^{*}p < 0.05$). PRE = before drilling; DRLL = during drilling; POST = after drilling; TEES = transcanal endoscopic ear surgery; MES = microscopic ear surgery.

In the transcanal endoscopic ear surgery group, the 0.5-μm particle load observed before (0.51 ± 0.23 units/l), during (1.20 ± 0.70 units/l) and after (1.19 ± 0.42 units/l) drilling did not differ significantly (Kruskal–Wallis ANOVA test, $p = 0.377$) (Figure 2).

The 1.0-μm particle load

In the comparison between the microscopic ear surgery and transcanal endoscopic ear surgery groups, the 1.0-μm particle load seen during drilling in the microscopic ear surgery group (12.70 ± 3.73 units/l) was significantly higher than that observed during drilling in the transcanal endoscopic ear surgery group (1.17 ± 0.83 units/l) (Mann–Whitney U test, $p < 0.01$) (Figure 3).

In the microscopic ear surgery group, the 1.0-μm particle load observed before (1.92 ± 1.28 units/l), during (12.70 ± 3.73

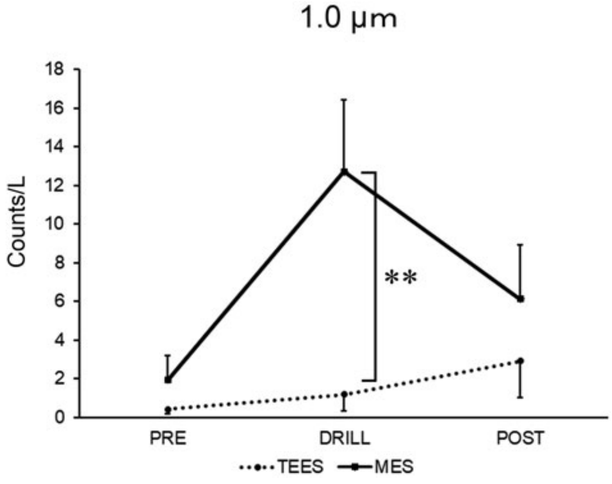

Figure 3. The 1.0-μm particle load. The 1.0-μm particle load observed during drilling in the microscopic ear surgery group was significantly higher than that seen during drilling in the transcanal endoscopic ear surgery group (Mann-Whitney's U test, $^{**}p < 0.01$). PRE = before drilling; DRLL = during drilling; POST = after drilling; TEES = transcanal endoscopic ear surgery; MES = microscopic ear surgery.

units/l) and after (6.12 ± 2.78 units/l) drilling did not differ significantly (Kruskal–Wallis ANOVA test, $p = 0.063$) (Figure 3).

In the transcanal endoscopic ear surgery group, the 1.0-µm particle load observed before (0.42 ± 0.25 units/l), during (1.17 ± 0.83 units/l) and after (2.91 ± 1.91 units/l) drilling did not differ significantly (Kruskal–Wallis ANOVA test, $p = 0.168$) (Figure 3).

Discussion

In this study, the particle load observed during drilling was significantly higher in the microscopic ear surgery group than in the transcanal endoscopic ear surgery group for all particle sizes. The 0.3-µm, 0.5-µm and 1.0-µm particle load seen during drilling were 12-fold, 14-fold and 11-fold higher in the microscopic ear surgery group than in the transcanal endoscopic ear surgery group, respectively ($p < 0.01$). In the microscopic ear surgery group, the particle load observed during drilling was significantly higher than that seen before drilling for particle diameters of 0.3 µm (8-fold higher) and 0.5 µm (13-fold higher) ($p < 0.05$).

The particle load measured around the surgical field in this study was considered to mainly reflect the aerosols generated by drilling because significant increases in the particle load were observed during drilling in the microscopic ear surgery group. This was the first study to quantitatively measure the numbers of airborne particles generated in the operating room during otological surgery and demonstrated that the levels of aerosols produced were extremely low when the endoscopic underwater drilling technique was used. On the other hand, it was confirmed that the levels of aerosols increased during drilling in microscopic ear surgery.

Drilling through the mastoid bone creates significant clouds of droplets and aerosols, which could increase the risk of Covid-19 infecting people in the operating room.[13] Transcanal endoscopic middle-ear procedures are probably less risky than conventional microscopic techniques, particularly since the external auditory canal acts as a natural protective shield from the droplets generated during such procedures.[3] Our transcanal endoscopic ear surgery procedures were performed underwater, and we consider that this markedly suppressed aerosol generation.

Among previous Covid-19-related studies of airborne particle levels, some measured the levels of airborne particles generated in the operating room,[6–9] but in the field of otology there have only been cadaveric studies of this topic, which were not performed in the operating room.[10,11]

Aerosols typically consist of droplet nuclei of less than 5 µm in size.[14] In previous studies, Kirschbaum *et al.*,[6] Patir *et al.*[7] and Ruiz Medina *et al.*[9] measured 6 types of particles (diameter: 0.3–10 µm), and Simpson *et al.*[8] measured 5 types of particles (diameter: 0.3–5.0 µm). The device that we used in this study was similar to that used in the study by Kirschbaum et al.,[6] but our device only measured 3 types of particles (diameter: 0.1, 0.3 and 1.0 µm), which were investigated in this study.

In the previous studies, the particle load decreased in the order of 0.3 to 10 µm.[6,7,9] As described in the Methods section, our device was set to detect particles with diameters of 0.1, 0.3 and 1.0 µm because it can only measure 3 types of particles at once. As can be inferred from previous studies,[6,7,9] there was a possibility that the particle load would have been too small to measure if the measurement target had been set at a particle diameter greater than 1.0 µm. Therefore, particles with a diameter of 1.0 µm or less were subject to measurement.

In our study, the particle load decreased in the same order as was found in the previous studies. The 0.3-µm particle load was found to increase to several tens of millions during total knee arthroplasty[6] and to hundreds of thousands during frontotemporoparietal craniotomy.[7] In a cadaver study, subjecting cow tongues to electrocautery produced tens of thousands of particles with a diameter of 0.3 µm.[9] Our pilot study showed that electrocautery generated thousands of particles with a diameter of 0.3 µm (data not shown). The particle load detected in the present study was lower than the abovementioned levels. Although the particle load measured in this study was low, significant increases in the particle load were observed in the microscopic ear surgery group.

Santarpia *et al.*[15,16] reported that Covid-19 RNA was identified in air samples collected during the initial isolation of 13 patients with Covid-19. This finding raised concerns about the substantial risk of the airborne transmission of Covid-19 among healthcare professionals. Norris *et al.*[11] performed mastoidectomy in cadaveric temporal bones and found aerosolised bone dust in the air during mastoidectomy. Chari *et al.*[10] also conducted cadaveric research and confirmed that airborne particles were generated during mastoidectomy. It remains unknown, however, whether the aerosolised materials produced during ear drilling (e.g., blood, bone dust, and middle-ear and mastoid mucosal tissue and fluid) have the ability to transmit Covid-19 and whether the quantity and size of such particles affect the transmission rate of the disease.

In the current study, the particle load was measured on the opposite side to where the surgeon sat. In a previous study, a significant increase in the number of droplets was observed on the operator's side during microscopic ear surgery.[2] Therefore, the number of particles may have been higher if it had been measured near the operator. However, it is difficult to do this in a clean field during surgery.

- The use of high-speed drilling instruments during otologic surgery is aerosol-generating
- This was the first study to quantitatively measure the levels of airborne particles produced in the operating room during ear drilling
- A particle counter was used to measure the particle load before, during, and after drilling during transcanal endoscopic ear surgery or microscopic ear surgery
- In the transcanal endoscopic ear surgery group, drilling was performed underwater
- The levels of aerosols were extremely low during transcanal endoscopic ear surgery when an underwater drill was used, whereas they were increased during microscopic ear surgery
- Bone dissection carries a lower risk of airborne infection if it is performed using the endoscopic underwater drilling technique

In the present study, the 0.5-µm and 1.0-µm particle load tended to increase in the latter part of the surgery. The use of electrocautery was minimised during surgery, but it was used on some occasions in both the transcanal endoscopic ear surgery and microscopic ear surgery groups. It is suggested that the airborne particles generated by electrocautery may have stayed in the air and increased the particle load in the latter part of the surgery. Also, near the end of the surgery, anaesthesiologists and nurses often came into or left the operating room, resulting in the doors being opened repeatedly. These factors may have affected the particle load in the latter part of the surgery.

It should be noted that the number of cases in the microscopic ear surgery group was small. A few cases involving microscopic ear surgery ($n = 2$) were excluded from the study, because of the use of electrocautery during the particle load measurement. As Covid-19 became more prevalent as the study progressed, the number of otological surgical procedures gradually decreased. Therefore, a limited number of cases was collected. However, although the number of cases was small, a significant difference in the airborne particle load was observed between microscopic ear surgery and transcanal endoscopic ear surgery groups.

In this study, the surgical time tended to be longer in the microscopic ear surgery group than in the transcanal endoscopic ear surgery group because more extensive disease spread necessitates wider excision. There were seven cases in which mastoidectomy was performed during transcanal endoscopic ear surgery (Table 1), in which minimal bone drilling of the external auditory canal was performed to make an access route to the mastoid cavity and remove a cholesteatoma. On the other hand, in the 5 cases in which mastoidectomy was carried out during microscopic ear surgery, a broad region of the mastoid cortex and the lateral air cells were extensively drilled. In this study, the volume of bone drilled was not measured, but it was expected to be much greater in the microscopic ear surgery group than in the transcanal endoscopic ear surgery group. Thus, this study compared particle load between two procedures with different surgical indications and that involved different volumes of drilled bone, which were limitations. However, it was indicated that the use of an endoscopic approach in middle-ear surgery should be advocated whenever the type and extent of the pathology allows it, as was suggested by Anschuetz *et al.*[3]

Conclusion

This was the first study to quantitatively measure the levels of airborne particles produced in the operating room during ear drilling and found that the levels of aerosols were extremely low during transcanal endoscopic ear surgery when an underwater drill was used, whereas they were increased during microscopic ear surgery.

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Competing interests. None declared

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