Effect of Pressure Loads during Train Ride after Stapedotomy – Case Study

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Case Description

- A patient suffers from otosclerosis
- Stapedotomy with insertion of a Soft CIIP (Heinz Kurz, Dusslingen)
- Postoperative results good like normal
- Discharge after 4th day
- Patient observes changing hearing capabilities:
  - Significant hearing loss changes reproducible by valsalva manoeuvre
- Audiometry in follow up examination shows also significant alternating hearing capabilities
- Revision surgery:
  - Resection of the Soft CIIP
  - Insertion of a Titan K-Piston
- Postoperative results good like normal
- Discharge after 2nd day
- All following examinations show improved and stabilized hearing capacity

Case Analysis

- Evaluation of video records for first and revision surgery:
  - Both implants showed good coupling to the long process of incus.
- Evaluation of audiograms:
  - Both postoperative audiograms are normal. Results at first follow-up examination depend on valsalva manoeuvre.

Pressure Measurements and Evaluation

Measurements have been conducted in both trains.
- The figure below shows the cabin pressure on the ICE train ride from Köln to Mannheim and the IC train ride to Mainz, respectively.
- In the ICE are much higher pressure variations than in the IC
- Low frequent pressure variations stem from altitude changes
- Higher frequent pressure variations are mainly due to tunnel driving
- At the entrance of a tunnel pressure increases intensely and fast, oscillates with lower amplitudes and decreases intensely and fast again at the exit of the tunnel
- Rainbow counting method [2] is used to evaluate the pressure measurements. Typically this procedure is applied to fatigue life calculations of technical systems. Here it is used to analyze the pressure spectrum by counting the number of simple stress reversals and categorizing them according to their magnitude and mean level, see figure left
- It is assumed that swallowing equalizes the absolute pressure in the tympanic cavity to that in the outer ear canal completely. Therefore the mean level of a pressure variation is denoted relatively to the pressure reference level and not to its absolute pressure value
- The tables below show the overall number of load cycles for the ICE and IC train ride from Köln to Mannheim evaluated with and without swallowing

Hypothesis

- After a stapedotomy the ossicular chain including tympanic membrane is significantly more compliant due to decoupling from the annular ring
- Pressure variations during the train ride dislocates the not completely healed up tympanomeatal flap due to microslip which is explained below
- Thus parts tensa of the tympanic membrane is partly loosened
- The partly loose tympanic membrane causes the hearing loss which can be reproducibly compensated by valsalva manoeuvres or other static pressure variations

Conclusions

- The high number of pressure load cycles around considerable high mean levels caused a microslip zone. This area enlarged with increasing number of load cycles leading to an overall dislocation of the tympanomeatal flap. As a consequence, the tympanic membrane was not properly stretched, but partially slack which caused the hearing loss
- Valsalva manoeuvre tensed the partly slack tympanic membrane and thus improved hearing
- Patients should avoid situations for some time after the operation in which higher pressure variations can occur, i.e. like flying, diving, sailing a car door and so on.
- In particular one should avoid situations with a high number of load cycles like travelling in an InterCity Express

References


Acknowledgements

Thanks to our student assistant F. Haag for helping with the data processing.

Below is a table showing the mean level of pressure variation in daPa for different frequencies and time intervals:

<table>
<thead>
<tr>
<th>Frequency [Hz]</th>
<th>125</th>
<th>250</th>
<th>500</th>
<th>1000</th>
<th>2000</th>
<th>4000</th>
<th>8000</th>
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<td>1 - 20</td>
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<td>20 - 40</td>
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<td>40 - 60</td>
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<td>60 - 80</td>
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<td>80 - 100</td>
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<td>&gt;160</td>
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</table>

During a train ride in an ICE the passenger is exposed to a high number of pressure variations at considerable high mean levels, as shown in the measurements. The cause of alternating forces in the contact region between the tympanomeatal flap and the ear canal wall. The effect of those forces is illustrated with a simplified micro-mechanical contact model:

- Initial position: Tympanomeatal flap and ear canal wall is elastically connected. The intermediate layer is represented by single bonds.
- A force deforms the elastic tympanomeatal flap and the elastic intermediate layer. Microslip occurs locally in regions where forces exceed maximum friction.
- Where microslip occurred initial contact points of bonds are changed. Thus the tympanomeatal flap does not return to its initial position and the intermediate layer and the flap under pretension.
- During the next load cycles, microslip is traveling further lateral and microslip area is increasing
- With every load cycle the steps above are repeated and finally lead to an overall dislocation of the tympanomeatal flap although single pressure variations at each load cycle are small.