DETERMINATION OF GEOMETRY PARAMETERS OF THE OSSICULAR CHAIN BASED ON 3D MODELS FROM MICRO-CT-SCANS

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Abstract: *The measuring of the ossicular chain with 3D models from micro-CT-scans enables an accurate description of the malleus-stapes offset, geometry parameters for the development of an anatomically shaped prosthesis and the characterization of the distances and angles from the malleal neck to the stapes head or stapes footplate. In this study a measuring strategy is developed and verified based on 20 cadaveric human temporal bones without signs of chronic otitis media. The comparison of the measurements to results known from other studies, confirm the validity of this approach.*

Keywords: *Ossicular chain, malleus-stapes offset, anatomically shaped prosthesis.*

Introduction

Chronic otitis media is one of the main reasons for an interruption of the ossicular chain and can be surgically treated with tympanoplasty. In this case, a prosthesis is implanted which undertakes the sound transmission from the tympanic membrane or malleal handle (MHa) to the stapes head (SH) or footplate (SF). Of special interest is the malleus-stapes offset since it causes complications during the reconstruction of the ossicular chain when partial ossicular replacement prosthesis (PORP) or total ossicular replacement prosthesis (TORP) is positioned [1]. Another aspect is that an anatomically shaped prosthesis might improve the sound transmission. The size and shape of such a prosthesis can be obtained by the measuring of the ossicles. Furthermore the measuring of the distance and angle between the malleal neck (MN) and the stapes head or stapes footplate are of interest when the malleal head (MHead) is degenerated by an inflammatory process and a prosthesis has to be fixed at the malleal neck. Micro-computed tomography (micro-CT) provides high-resolution anatomical data which can accurately represent finely detailed structures such as the ossicles [2]. After 3D polygonal surface from the segmented data is generated, accurate measurements of locations, distances, and angles can be obtained.

Methods

A total of 20 cadaveric human temporal bones without signs of otitis media were frozen directly after harvesting and trimmed into a cubic form. The micro surgical removal of the incus and the malleal head was done to simulate a progression of the destruction of the ossicles. Three different conditions of the ossicular chain are evaluated: *step 1)* the intact ossicular chain, *step 2)* the ossicular chain missing the incus and *step 3)* missing the incus and the malleus head. A micro-CT scanner (SkyScan 1172, Kontich, Belgium) was then used to obtain volumetric datasets of all temporal bone cubes with ossicular chains in the described conditions. Subsequent to the micro-CT-scan 3D-reconstructions of the ossicular chain were acquired using the program CTan ver.1.5.0 and the measuring of the geometrical details was done with Creo Parametric 1.0.

A) To determine the effect of destruction on the malleus-stapes-head offset it was measured in all three conditions of the ossicular chain. The malleus-stapes-head offset consists of the offset height h_{SH} which is the vertical connecting line between the highest point on the SH P_{SH} and the furthest medial lying point on the malleal handle $P_{M\,med}$ (see Fig. 1). The offset width q is orthogonal to h_{SH} and is the horizontal connecting line. The angle α is the offset angle. In a similar way the malleus-stapes-footplate offset is defined. The difference is that the offset height is measured from $P_{M\,med}$ to a point on the superior surface of the footplate and the axis A_{SH} ($P_{SF\,sup}$) and β is the offset angle. *B)* The measurings of the ossicular chain concerning the development of an anatomically shaped prosthesis are shown in Fig. 1. The stapes height is measured along the axis A_S between P_{SH} the superior
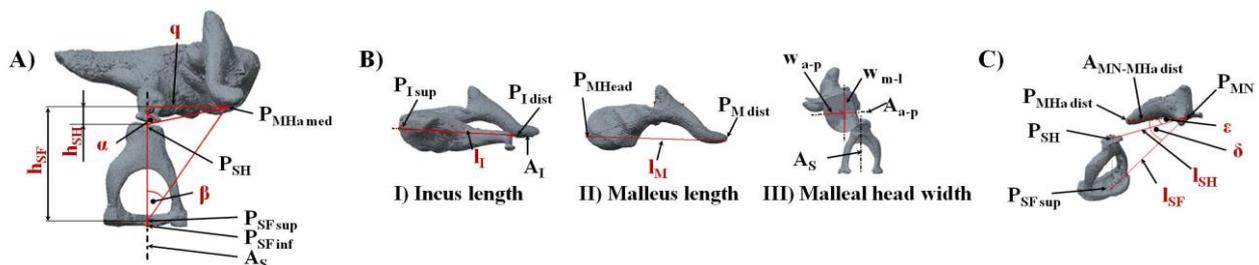

Figure 1: Measuring of *A)* the malleus-stapes offset, *B)* parameters for the development of an anatomically shaped prosthesis and *C)* the distances and angles between the malleal neck and the stapes head or the superior footplate surface.

and inferior surface of the footplate. Between the distal end of the long process of the incus, through which the axis A_I runs centrically, and the superior edge of the incus body the length l_I of the incus is measured along A_I. The total length of the malleus l_M is the connecting line between the tip of the malleal head and the distal end of the malleal handle. In a 1 mm wide measuring range in eleven cross sections the width of the malleal head is measured in the medial to lateral (w_{m-l}) and the anterior to posterior (w_{a-p}) direction. The axis A_S indicates the medial to distal direction and the crura of the stapes define the anterior to posterior direction. Afterwards the maximum widths in both directions can be selected. *C)* The distances l_{SH} and l_{SF} between the malleal neck and the stapes head or footplate are determined between a point P_{MN} on the cutting edge where the malleal head was removed and the points P_{SH} and $P_{SF\ sup}$ (see Fig.1). The axis A_{MN-MHa} is defined by the points $P_{M\ dist}$ and P_{MN} and the angles ε and δ are determined between this axis and the distances l_{SH} and l_{SF} respectively.

Results

A) In some cases a negative offset height was measured when the medial point on the malleal handle was located below the highest point of the stapes head. In the other measurements of the ossicular chain the offset angle remained constant and had a small range. The offset angles α and β for *step 1)* to *step 3)* amount to 80.57 °, 81.60 °, 80.95 ° and 36.77 °, 38.84°, 38.12° respectively. As shown in Fig. 2, the measured offset angle α differs from both transcanal and transtegmenal measurements. The mean value is higher than that of the values known from literature whereas the range is narrower [1] [3].
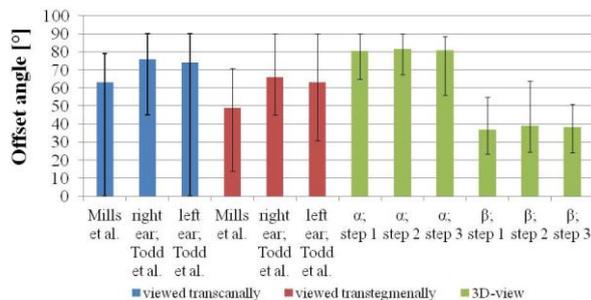

Figure 2: Mean value and range of the transcanally, transtegmenally and in the 3D Model measured offset angle
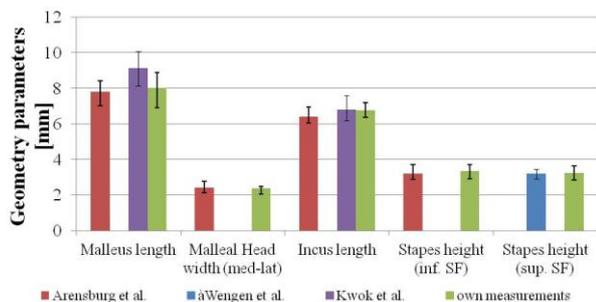

Figure 3: Mean value and range of the geometry parameters concerning the development of an anatomically shaped prosthesis in comparison with parameters known from literature

B) The incus length averages 6.76 mm along with the stapes height to the superior and inferior surface of the footplate with 3.25 mm and 3.34 mm respectively. The mean value of the malleus length amounts to 8.01 mm. The measured width of the malleal head averages 2.37 mm in the lateral to medial direction and 2.13 mm in the anterior to posterior direction. A comparison with measurements from other authors displays the validity of the measurements, since the mean values are similar as well as the ranges as shown in Fig. 3 [4] [5] [6] [7]. *C)* The measurement of the angle ε averages 38.31 °. The mean of the angle δ amounts to 51.19 °, whereas the distances l_{SH} and l_{SF} average 3.96 mm and 5.89 mm. To our knowledge, there is no study so far concerning these parameters.

Discussion

An advantage of the described method is that, in contrast to other approaches, the preparation of the ossicular chain before the micro-CT-scan is not damaging. The comparison of the measurements concerning the parameters for an anatomically shaped prosthesis with results from other authors confirms the validity of the presented approach. Furthermore, the 3D model permits a view from all directions onto the ossicular chain, which allows a more accurate positioning of axes and reference points in the model, as compared to the transcanal or transtegmenal perspective. This fact may also explain the occurrence of a negative offset height in this study, as well as the greater offset angle α. An offset angle greater than 60 ° is critical with regard to force transmission from the malleal handle to the stapes through a PORP. However, all measured offset angles α average about 80 °.

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