1843: ESCUDE AND AVCI *ET. AL.* REVISITED: COCHLEAR MICROANATOMY FROM A DATABASE OF 1099 EARS

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Introduction

As well detailed by Escudé 2006 and further explored by Avci 2014 (and others), the human cochlea shows considerable variability in size and morphology. Understanding cochlear microanatomy is crucial for performing less traumatic cochlear implant insertions, developing less traumatic electrode arrays and insertion guidance systems for cochlear implantation. One of the key goals with the development of our Nautilus system was to create an automatic segmentation of the patients' cochlea from CT images, to facilitate pre-surgical planning. The output of the system is a series of measurements of the cochlea that have been pooled and analyzed for a better understanding of cochlear morphology. The results of the analysis of 1100+ cochlear are presented here.

Objectives

The aim of this study was to evaluate the correlation of all the parameters that are generated by the Nautilus system from the entire database of cochlear segmentation (1100 ears). We sought to identify which microanatomical parameters were correlated to each other, and the strength of their correlation. Additionally, for the purpose of electrode development, we evaluated the 90th and 10th percentiles of the sizes of the Scala Tympani. With this it becomes apparent what is the maximum dimensions of an electrode array that would fit in the great majority of cochlea (90%) in a given angular location. Furthermore, we have questioned whether A is the most beneficial measurement to use for the evaluation of cochlear size.

Methods

A total of 590 patients undergoing various treatments at the Institut Universitaire de la Face et du Cou, Nice, France, from 2008 to 2013 were included in this retrospective study. Preoperative temporal bone CT scans were obtained for each patient, constituting a dataset of 1099 CT images comprising 560 right and 539 left scans. The acquired images were of varying quality, with voxel resolutions ranging from [0.187 × 0.187 × 0.250] to [0.316 × 0.316 × 0.312] mm3. These images were then uploaded and processed by the Nautilus system which processed the images automatically, generating the cochlear view, intracochlear segmentations and various clinically relevant cochlear parameters. Figure 1 depicts different parameters that Nautilus extracts from each image. Once all the images had been processed, an export bundle was prepared with the following characteristics for analysis: cochlear and ST models, cochlear size, shape, duct lengths and cross-sectional measurements.

Statistical Analysis

A histogram of the cochlear parameters extracted by Nautilus such as **volume**, **A**, **B**, **height**, **lateral wall (LW) length**, the **wrapping factor** and **roller coaster** height was generated using 50 bins. Based on the mean and the standard deviation of the parameters, Gaussian curves were plotted on top of the histograms. Correlation analysis was performed via visual inspection of scatter plots and the calculation of the Pearson correlation coefficient between the aforementioned parameters, as well as between parameters A, B and the LW length at various cochlear angles. A regression curve was fitted to the correlation data by the ordinary least squares method.

Analysis of ST height, area and radius was performed up to a cochlear angle of 705°. The mean, standard deviation, 10th and 90th percentile of the ST angular data were calculated based on the data points falling within ±15° of every 30° ST angle, e.g., the metadata at 90° were based on individual data points between 75° and 105°. Global metrics defining cochlear size and shape such as A, B, volume and duct lengths were also evaluated. Statistical t-tests with Holm–Sidak correction were performed to analyze the results. A *p*-value of <0.05 was considered significant. A correlation analysis was also performed to determine the relationship between different parameters.

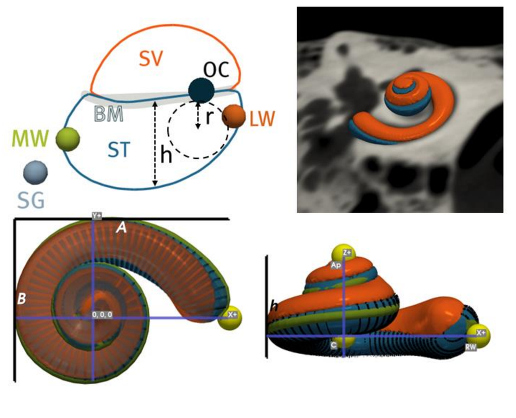
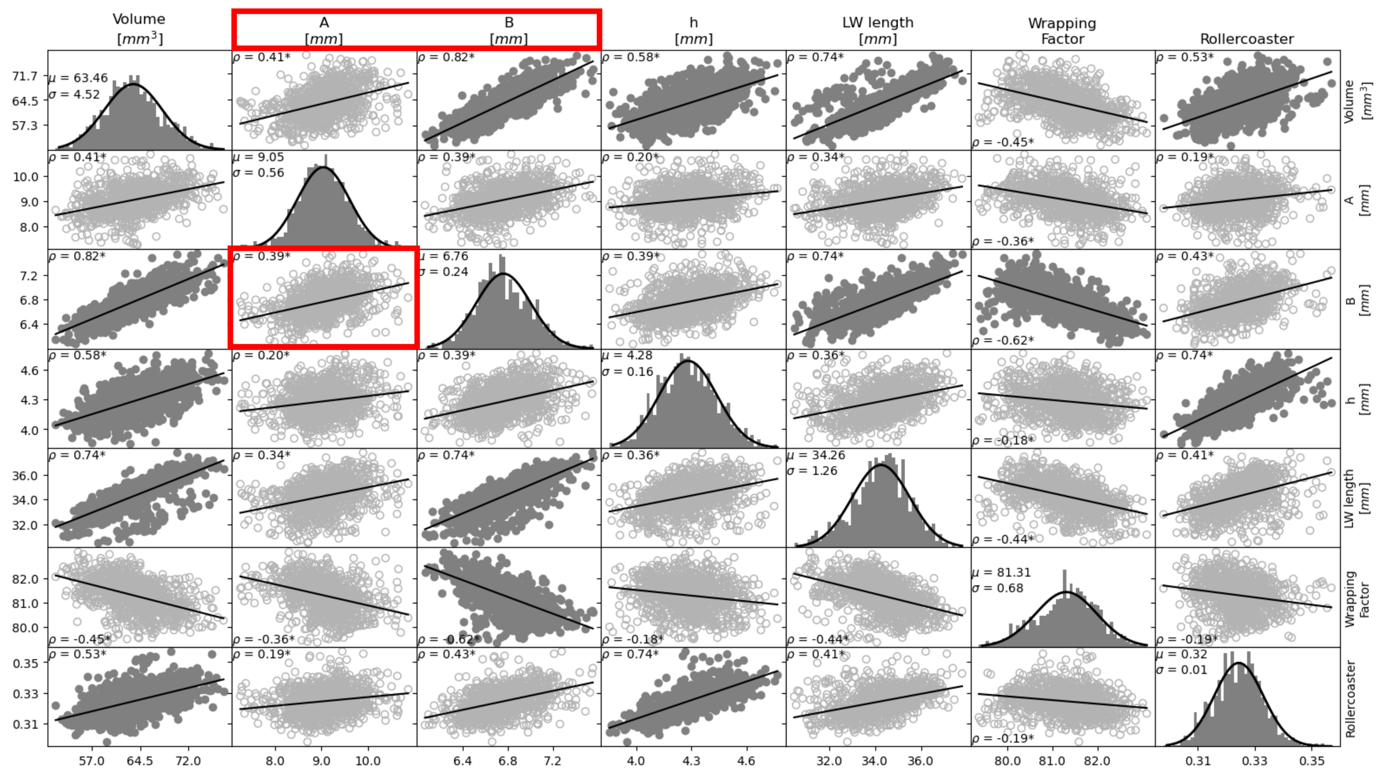


Fig. 1 – Main characteristics exported by Nautilus

1. Correlating A | B vs the rest

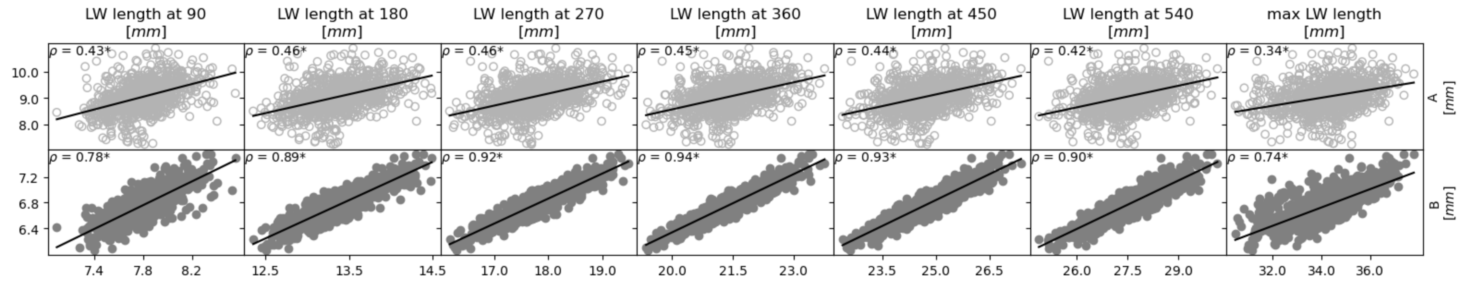


Escude *et.al.* 2006 proposed the measurement A as the line originating from the center of the round window to the lateral wall, through the modiolus. B was proposed as the perpendicular line, through the modiolus, to A. A was then used to estimate the insertion depth angle of a given electrode array by its length in mm. Cochlea were then classified into medium (avg A) and small or large (avg ± 2 std).

Now that we have access to a series of additional measurements of the cochlea, and a much larger dataset, we sought to revisit the use of A and B as a proxy for other cochlear microanatomies. When we correlate A to B we see a weak correlation of $p = 0.39$. Furthermore, A is not strongly correlated ($p \leq 0.05$) to any of the other metrics.

B, on the other hand, showed a strong positive correlation with LW length ($\rho = 0.74$, $p < 0.05$) and strong negative correlation with the wrapping factor ($\rho = -0.62$, $p < 0.05$). Unsurprisingly, cochlear B was only weakly correlated to cochlear height ($\rho = 0.39$, $p < 0.05$) and roller coaster parameter ($\rho = 0.43$, $p < 0.05$), as these parameters are related to a dimension orthogonal to the plane where cochlear B was measured.

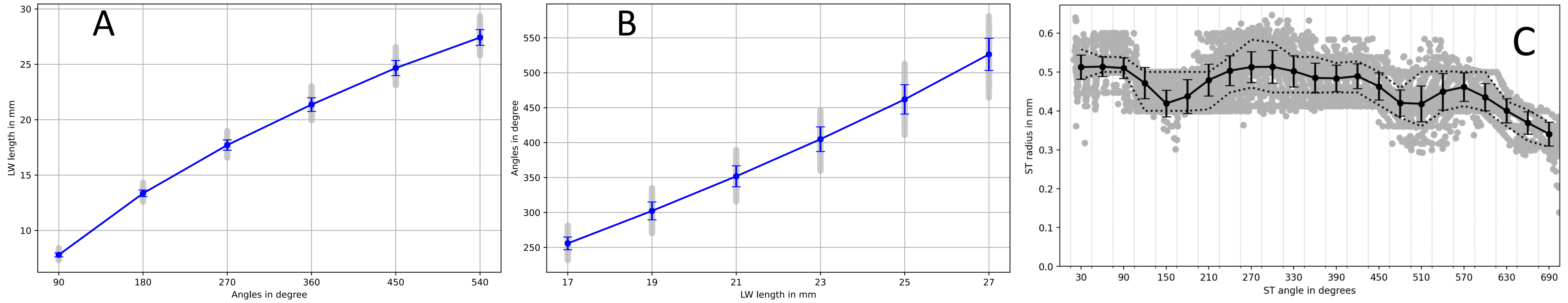
Additionally, when plotted against the length in mm along the LW corresponding to different angular depths of insertion, we can see a strong correlation for B ($\rho=0.78 \leq B \geq 0.94$) at every 90° of insertion depth.



2. Evaluating depth of insertion of LW arrays

The Scala Tympani varies is size and shape along its trajectory from the base to the apex. From a cochlear implant perspective, it is important to evaluate the available space for a given electrode array at a given depth. As highlighted by Avci *et. al.* 2014, the microanatomy of the cochlea has large implications for the development of electrode arrays, as we try to minimize insertion trauma as much as possible. Therefore, we have evaluated the spread of LW length for a given insertion depth (fig. A), the spread of angular depth for a given LW distance (fig. B) and the largest radius possible for a given insertion angle (fig. C).

As many surgeons today target a specific angular insertion depth, to preserve residual hearing or for surgical preference, we decided to first visualize the variability of mm insertion depth for different insertion angles, at every 90°. The variability greatly increases as depth increases (avg±std) from 7.8±0.4 mm at 90° to 27.5±1.0 mm at 540°. An even more exaggerated spread is seen when visualized from fixed mm depth of insertion to angular variability, as seen in B. The variability follows the same trend, increasing (avg±std) from: 255.4±11.2 at 17 mm to 524.9 ±28.3 at 27 mm of Lateral Wall insertion depth. Finally, if we evaluate the maximum sized array that would fit at a given depth (fig. C) we can see that the radius (half the diameter) fits well an electrode of 0.8mm, up to about 450°, after which the shape of the scala becomes less rounded and quickly tapers off from there.



Discussion

The lack of correlation of the measurement A to most of our microanatomical measurements was surprising. One key aspect is that Nautilus does not automatically segment the round window, but estimates is based on the machine learning algorithm's training. So there may be an inherent error in the calculation of A. However, given the manual nature of its measurement in standard practice (including in Escude 2006) we do not believe this to be the cause of the lack of correlation.

The strong correlations with B make sense from our perspective as B is taken purely from the spiral section of the cochlea. As the "decaying spiral" begins around 90°, it would make sense that measurements related to the spiral function would be correlated, such as wrapping factor and LW length. The lack of correlation to the rollercoaster function for both A and B leads one to assume that the Z axis changes, or trajectory changes, of the scala are not more random and not a function of cochlear shape. Interestingly, rollercoaster was correlated to volume (size) of the cochlea and we believe that this finding should be investigated further.

The LW vs Angle of insertion data are not radically different, but it is valuable to see how well they confirm the data from Avci et.al. 2014, lining up almost exactly to their 360° and 540° in fig. 11. As our electrodes are 25 mm long, we focused on that data range for development with a spread of 460.9±25.5 mm.

Conclusions

- We find that the A measurement of the cochlea is poorly correlated to other microanatomical measurements.
- We have found that B, the perpendicular line to A, correlates well to multiple cochlear microanatomical measurements. We suggest that, for better evaluation of cochlear size and geometry, B be used as the standard measure.
- Variability in the Z axis, rollercoaster, was seen to be strongly correlated to the cochlear volume (size). We believe that, given the importance of scalar trajectory on electrode insertion dynamics, this correlations should be further investigated.
- Our dataset reinforces the LW vs Insertion Angle vs Maximum Radius data from Avci et.al. 2014

References

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