# Finite-element models of the newborn outer and middle ear

Royan Jafari[1], Hamid Motallebzadeh[1,2], W. Robert J. Funnell[1]
[1]McGill University, Canada [2]California State University (Sacramento), USA

## Introduction

Hearing problems are among the most common birth defects, and all newborns should have their hearing screened [1].

Unfortunately, current screening methods lead to high numbers of false positives, that is, babies who fail the screening test but who do not actually have a permanent hearing impairment that requires treatment. Wideband tympanometry promises to provide valuable information about transient conditions in the middle ear, but it is not yet well understood.

Computational models are an important tool in analyzing complex systems. To help in understanding and improving hearing screening, we have created finite-element (FE) models based on image segmentation of clinical X-ray CT scans of a 1-day-old [2], the age at which newborn hearing screeing is often done, and of a 22-day-old [3–6], an age at which audiological follow-up may occur after a failed screening test. It is difficult to make out details in the CT scans. To guide the image segmentation of the CT scans, we have serial-section histological images for a different 1-day-old ear and for a 3-week-old ear.

Here we describe how we estimate the orientation differences between CT and histology slices, and how we use that information in segmenting the CT images. We also present preliminary simulation results from the FE models.

## Methods

Locally developed software [7] for image segmentation (Fie), FE model generation (Fad) and model viewing (Thrup'ny).
Free and open-source software for CT volume manipulation (3D Slicer [8]) and FE simulation (FEBio [9]).

## Results

Figs. 1 and 2 show slices in which the malleus head and incus body are visible. In both CT and histology, more soft tissue is visible in the middle-ear in the 1-day-old ear than in the older ear. Because the slice orientation is different for the histology than for the CT scans, different structures are seen along with the malleus and incus.

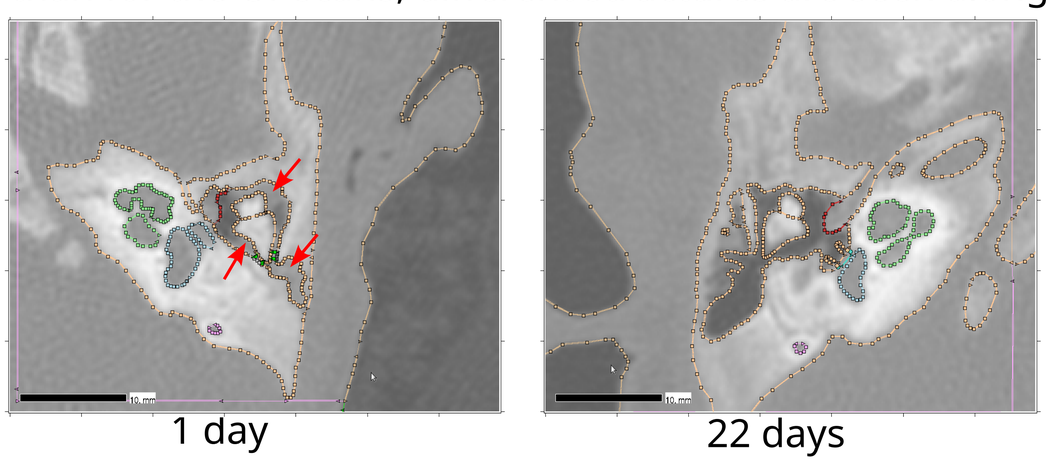


*Fig. 1. CT slices from 2 newborn ears, viewed in Fie, showing the malleus and incus. Note opacity in air spaces of 1-day-old*

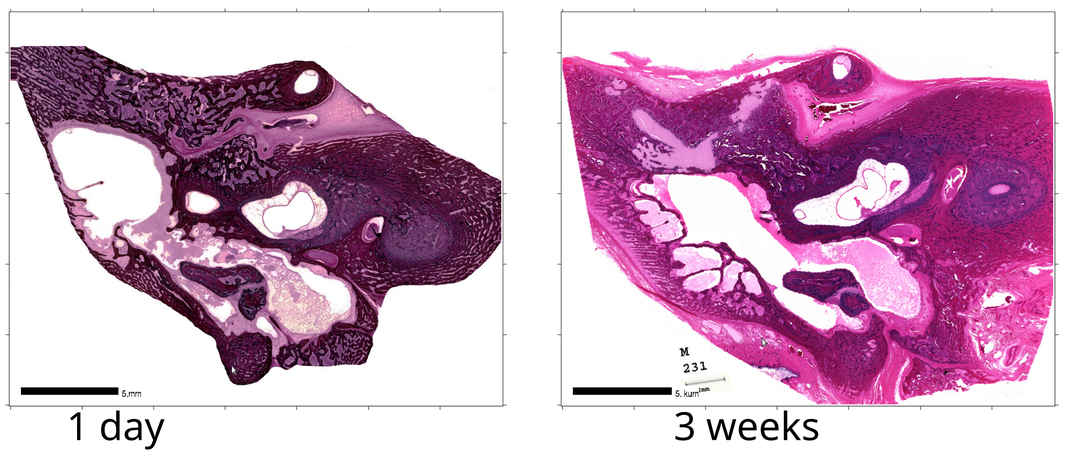


*Fig. 2. Histological sections from 2 newborn ears (different from the ones in Fig. 1), viewed in Fie (segmentation lines not displayed).*

Fig. 3 shows models of the older ear reconstructed from a CT scan (left) and from histology slices (right). The histology-based model is very rough because of slice misalignment and distortion, but it is adequate for the purpose. Both models are viewed along the *z* axis, illustrating the different orientations of the slices in the two modalities. The CT-based model was then aligned (manually and approximately) with the histology-based model. The *x*, *y* and *z* rotations were recorded and then applied in Slicer (Fig. 4). The stapes, cochlea and other structures in the red panel now have the same orientation as in the histology (Fig. 5) and are easier to recognize than in the original CT images.

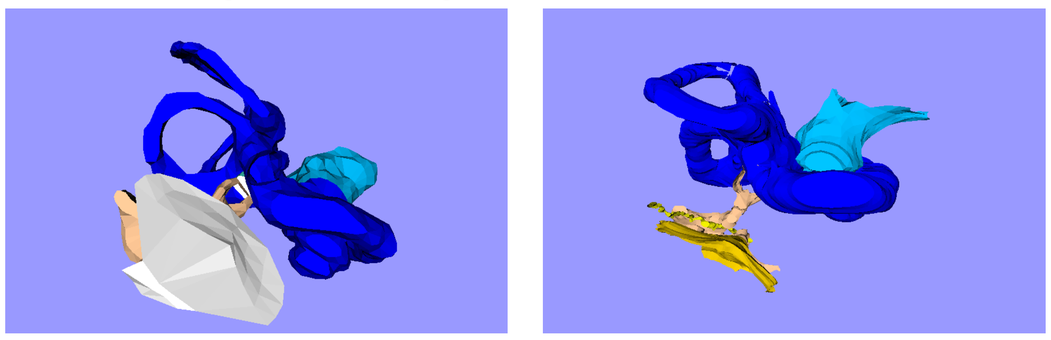

*Fig. 3. 3D models of 22-day ear from CT (left) and 3-week ear from histology (right), viewed in Thrup'ny.*

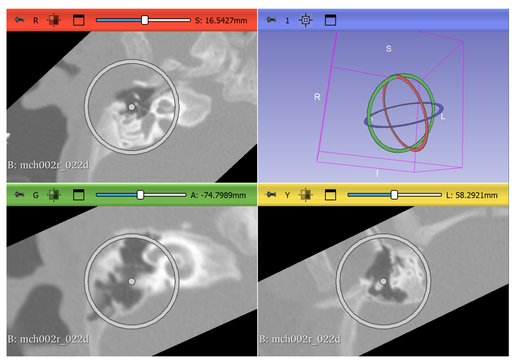

*Fig. 4. CT volume viewed in Slicer, after rotations to match histology slices.*

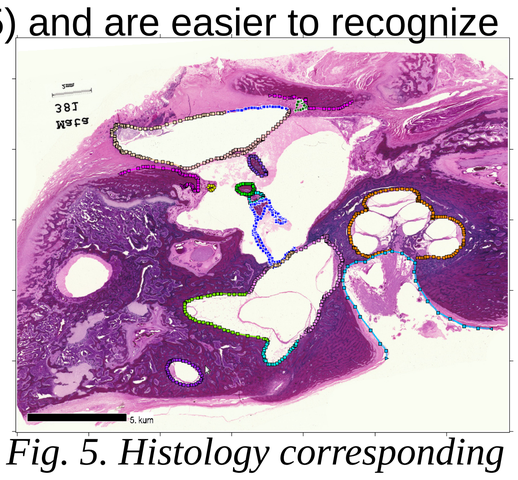

*Fig. 5. Histology corresponding to the red panel in Fig. 4.*

Fig. 6 shows part of a slice of the CT volume after it has been rotated to show a cross-section of the manubrium. The tympanic membrane has also become easy to recognize. Its position has been indicated by manually added markers that can then be imported into Fie and used to guide segmentation of the nonrotated CT volume.

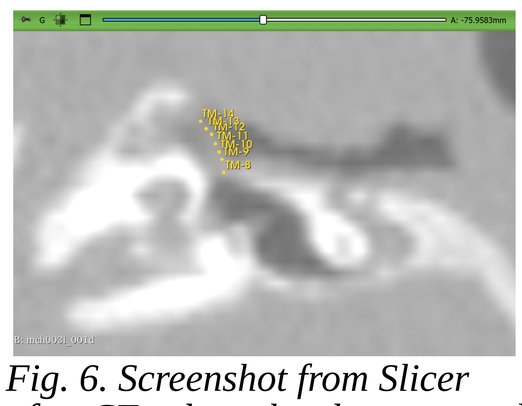

*Fig. 6. Screenshot from Slicer after CT volume has been rotated to clearly show the manubrium*

Fig. 7 shows very preliminary simulated point-displacement results for the 1-day-old model [2] and published volume-displacement results for the 22-day-old model [6]. The main resonance of the 1-day-old model is at a reasonable frequency but is too sharp; the model does not yet include the ear canal or the middle-ear air cavity.

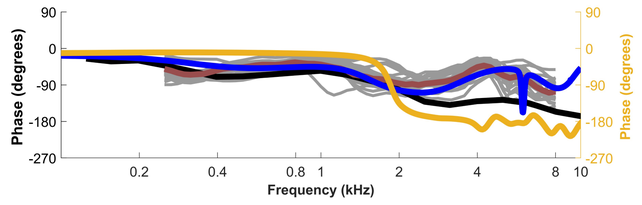


*Fig. 7. Maximum TM displacement for 1-day-old model (orange)[2], TM volume displacement for 22-day-old model (blue) and measured data (grey, black and red)[6]*

## Conclusion

Adjusting for slice orientation greatly increases the value of histology images when creating FE models based on CT images. FE models like these will help in interpreting wideband tympanometry in the context of hearing screening.

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