

# Towards an Interactive Morphological Analysis of Structural Changes Related to Meniere's Disease

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## Abstract

We present an intuitive prototype environment for the interactive manipulation, exploration and annotation of structural and functional data associated with the study of Meniere's Disease (MD). Through the integration of advanced algorithms for segmentation and registration, and the exploitation of commodity based graphics hardware, these systems provide new opportunities to handle the high-resolution data sets emerging from various imaging modalities. Through the increased availability of these systems and the integration of emerging multimodal and multiscale data, a more comprehensive and systems approach to the study of structural data from Meniere's disease patients is emerging.

## Introduction

Expansive advances in image processing and computational power have provided new opportunities to visually analyze and quantify morphologic studies associated with MD.

These include:

- New digital scanners to process large numbers of histologic slides into coherent records that can be used for 3D reconstruction
- Continued improvements in clinical imaging that provides new opportunities for in vivo surveillance of the disease process and of treatment regiments
- New segmentation and registration algorithms to integrate multimodal and multiscale data sets
- Expansive computational power to efficiently handle the large data records associated in these studies
- The exploitation of low-cost graphics accelerator cards to visualize the interaction with large data and make these technologies more widely available

## Background and Significance

Originally, endolymphatic hydrops was considered the hallmark of MD histopathology. Others have debated the significance of this histologic finding specifically to MD. Alterations in the stria vascularis, endolymphatic duct and sac, vestibular aquaduct, the vestibular end organs themselves as well as structures outside the otic capsule have also been associated with temporal bones studied from individuals with clinical MD [1,2]. All these potential sites have been primarily analyzed in two-dimensions with very few exceptions. Many authors are reporting on multimodal studies that seek to correlate structural representation with pathologic function [3,4,5].

Through the integration of novel image processing algorithms [4] and more cost-effective and available computational/visualization power, powerful capabilities to gain new insight and quantification of the morphological impact of the pathology are emerging.

## Methods

Current in vivo scanning provides spatial resolutions in computed tomography (CT) of 0.27 x 0.27 x 0.5mm and magnetic resonance (MR) of 0.3 x 0.3 x 0.3mm (3Tesla). In MR, higher field magnets (>7T), are becoming increasingly available commercially, and are delivering voxels <100micron<sup>3</sup> in size in vivo. Ex vivo resolution with micro CT provides resolution of 35 micron<sup>3</sup>. Histologic data can now be processed with commercial systems with automatic digital scanning of large numbers of sections and provide images in <10micron<sup>3</sup> sizes at astounding resolutions of up to 100,000 x 80,000 lines of resolution. Histologic sections acquired in isotropic fashion are ideal for 3D reconstructions.

We have been developing computational environments that integrate unique image processing algorithms for segmentation, registration and visualization of these multimodal and multiscale data to facilitate a more comprehensive systems approach to the study of various disease pathologies. In addition, we have been developing surgical simulation environments that would allow for importing these data and exploring them in intuitive ways, including dexterous techniques that emulate surgical procedures[6] (Figure 3).

These environments provide the following interactive functions:

- Ability to register serial histologic sections automatically
- Ability to load registered data sets and perform operations simultaneously
- Morphometric analysis and annotation, including distance, angles, and volumes
- Registration, playback and three dimensional analysis of follow-up (4D) data

## Discussion

We have presented on recent developments in 3D reconstruction for structural analysis of multimodal and multiscale data sets used in the study of MD. Through improved processing of tissue specimens, specifically with respect to section alignment, lighting, and uniform staining, these techniques will produce more accurate three-dimensional renderings of individual structures. Additionally, capturing of histologic images at various magnifications will allow for investigation of cellular and subcellular structures in three-dimensions, and thus support a more integrated systems approach of pathogenesis. Ultimately, as histologic data and image data are merged into multimodal volume data sets, in vivo scanning can be better correlated with clinical pathology.

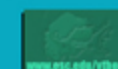
Because all the clinical data sets mentioned above are optimized for reconstruction, they can be used for follow-up in vivo surveillance of treatment, and can also be imported into emerging surgical simulations (Figure 3). Subsequently, preoperative assessment and surgical planning on patient specific data can be achieved.

## Acknowledgements

We would like to thank Dr. Kim Powell Ph.D. of the Cleveland Clinic Foundation for the microCT data, and Dr. Joseph Nadol, M.D. of the Massachusetts Eye and Ear Infirmary for the serial histologic sections.

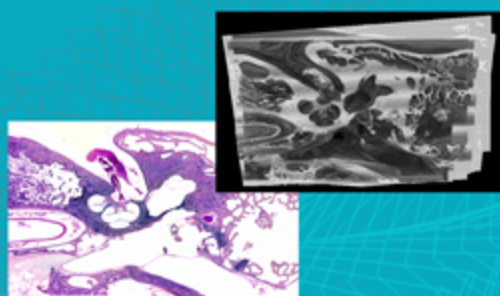
## References

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- [6] [www.osc.edu/vtbone](http://www.osc.edu/vtbone)



## Results

Figure 1 Image for Harvard slide and reconstruction



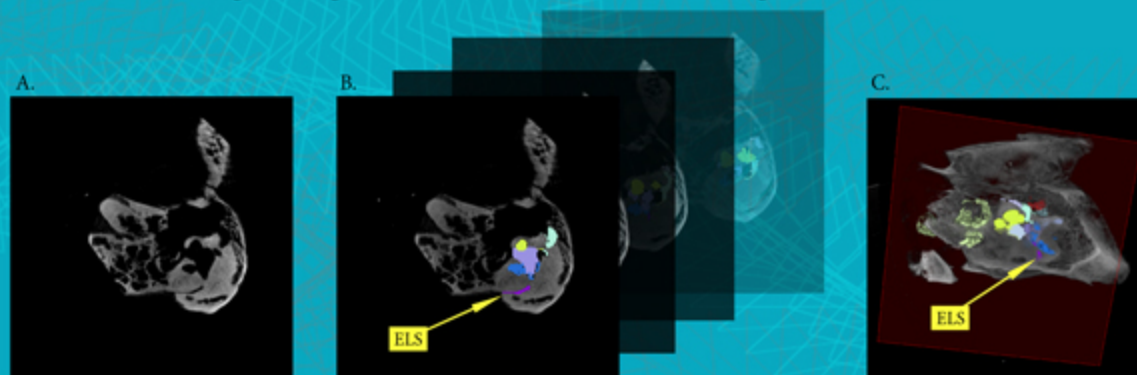
The purpose of serial slide registration is to reconstruct the sample in 3-dimensions. The 3D structure allows us to correlate feature changes, visualize structure geometry and relationship, and make quantitative measurements, all across multiple slides.

The algorithm used include the following high level steps:

- Subsample images for efficiency.
- Correct for color variations.
- Extract principle orientation for registration initialization.
- Register successive slides in pair-wise fashion using Mutual Information Registration (Insight Segmentation and Registration Toolkit)

1 Axial sections through a human temporal bone was obtained at 20micron thickness with section retrieved every 5th section. Image data obtained by scanning individual slides at standard microscopic scanning power (data provided by Joseph Nadol, MD at the Massachusetts Eye and Ear Infirmary Temporal Bone Bank).

Figure 2 Image of MicroCT with section, stack of sections segmented and volume



- A. Axial section through temporal bone specimen using microCT acquisition.  
 B. Image stack of segmented axial sections (Segmentation can be performed on 2D sections in any plane or in 3D with use of a haptic interface).  
 C. Rendered image of volume data generated from axial sections. A clipping plane (red) had been applied to demonstrate segmented structures within the volume.

Carotid artery	Facial Nerve Canal	IAC-Nerve	Malleus	SupSSC
Cochlea	Greater Petrosal Nerve	Incus	PosSSC	Vestibule
Endolymphatic Duct	IAC	LatSSC	Stapes	

Figure 3 Virtual surgical approach to the endolymphatic sac (ELS).

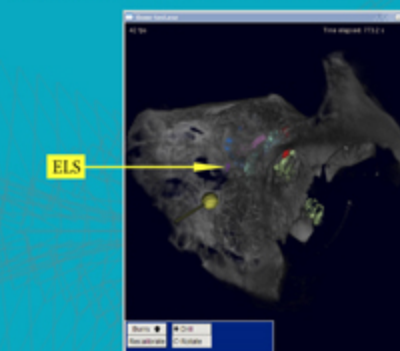


Image from dissection simulator showing exposure of ELS and other segmented structures.