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Mastoid geometry in a cross-section of humans from infancy through early adulthood with a confirmed history of otitis media☆

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ABSTRACT

Objective: This study describes the changes in mastoid air cell system (MACS) geometry with age in ears with a history of otitis media (OM), without (GR-I) or with (GR-II) middle ear fluid on the CT scan.
Methods: Thirty-seven (74 MACSs) CT scans were selected to approximate 4 MACSs/year between 1 and 18 years. For each MACS, the volume, surface area and surface area/volume ratio were reconstructed using standard procedures. Correlation analysis was used to define the left–right relatedness for the geometric parameters, and regression analysis was used to determine the effect of age on those parameters for each group.
Results: Twenty scans were from female and 17 from males. Fluid was observed in 12 left, 4 right and 10 bilateral MACSs. The MACS volume and surface area of GR-I increased with age, were significantly greater than those for age-matched MACSs in GR-II, but show large variability. Those measures in GR-II were independent of age and a large percentage of these MACS volumes was <5 ml. The surface-area/volume ratio for MACSs in both groups was independent of age and group assignment. The left–right correlations for the three geometric parameters of the MACS were significant for all MACS in the two groups, and for bilateral MACS concordant for group assignment. The left–right correlations for surface area and volume were not significant for bilateral MACSs discordant for group assignment.
Conclusions: These results suggest that: the growth of MACS volume and surface area is genetically programmed but that this is disrupted by long-lasting OM; the effect of OM on MACS growth may depend on the duration and timing of the disease, and the MACS surface area/volume ratio does not explain the effect of MACS volume on the rate of gas exchange between middle ear and blood.

1. Introduction

The mastoid air cell system (MACS) is a highly cellular posterior extension of the middle ear that is continuous in the air-phase with the tympanum. While the function of the MACS is not well established [1], a large number of studies show that MACS volume is inversely related to the frequency of certain pathological conditions of the middle ear including cholesteatoma and otitis media [2–6]. To explain this relationship, researchers have suggested that the MACS is a middle ear pressure-buffer [2], a rate limiter of middle ear pressure change [1] and/or a source of gas that stabilizes middle ear pressure [7–9].

Significant left–right correlations for MACS geometry measured as volume, surface area and the surface area/volume ratio in adults with a wide range of MACS volumes were documented, previously [10] and similar results were reported for children without a history of otitis media over a wide age range [11]. These bilateral symmetries suggest a genetic component for MACS geometry as was proposed for MACS volume by Diamant [12]. However, it is a matter of debate if persons with constitutively small mastoid volumes are "at risk" for middle ear disease or if the presence of middle ear disease stunts MACS development [6,13–18].

Recently, Csakanyi et al. reconstructed MACS volume and surface area from CT scans in a cross-sectional sample of 40 children aged 2.5–17.5 years without a significant history of otitis media and in 56 children aged 2.0–17.0 years with both a history of otitis media and concurrent evidence of that disease [11]. They described a linear increase in MACS volume and MACS surface area to age 7 years, a plateau between 7 and 13 years and then an increase to age 18 years for the disease-free group, but no age-related change in those measures for the group with concurrent otitis media. They also reported that a MACS volume of 5 ml was a reasonable discriminator for the two groups; with the frequency of MACS volumes <5 ml being much higher in the otitis media group.

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While clearly important with respect to demonstrating a difference in MACS volume and surface area between groups of children with and without otitis media over a wide age range, the study by Csakanyi et al. does not directly address whether MACS volume is stunted by otitis media or if smaller MACS volumes predispose to otitis media since children in the otitis media group all had extant disease [11]. In the present study, CT scans for a group of children between the ages 1.5 and 18.2 years with a history of otitis media and without or with observable fluid in the middle ear were analyzed and the MACS volume, surface area and surface area/volume ratios were calculated. The hypotheses tested were: (1) MACS volume and surface area would be less at all ages in those children with extant fluid when compared to those with no observable fluid and (2) the left–right correlations for the geometric parameters of the MACS would be higher in children with the same bilateral disease presentation when compared to those with bilaterally discordant disease presentations.

2. Methods

This study reconstructed and measured MACS volume, surface area and the surface area/volume ratio from CT scans for a cross-sectional sample of infants, children and adolescents with a history of otitis media by chart review and without middle ear fluid (GR-I) or with (GR-II) observable middle ear fluid on the CT scan. A set of CT scans was selected from the collection at the University of Pittsburgh and the medical charts of the subjects were reviewed for any noted abnormalities in the CT scan (other than middle ear fluid) and for a history of otitis media by one of the investigators (CMA). The CT was rejected for inclusion in the study if anatomical abnormalities were detected or if no history of otitis media was recorded in the subject's clinical chart. An attempt was made to obtain 2 scans (4 MACSs)/year between the ages of 1 and 18 years. The study was reviewed and approved by the University of Pittsburgh IRB.

The chosen CT scans included the middle ear and bilateral MACSs and were acquired in the transverse plane using a GE LightSpeed VCT system (General Electric Health Care). The images were obtained using a field of view which included both temporal bones (range 138–180 mm) with a 512×512 matrix. The resolution averaged over the entire sample was 0.032 cm per pixel with a slice thickness of 0.063 cm. From each CT scan, the complete set of transverse images through the bilateral MACSs (superior to inferior) was used for the reconstructions. Using ImageJ software (http://rsbweb.nih.gov/ij/), these sections were imported, and the left and right MACSs and tympanums were identified, segmented out and analyzed. For each MACS, the perimeter and area of all air-cells were calculated, corrected with the appropriate calibration factor, and summed across images. These sums were multiplied by the section interval to yield MACS surface area (cm^2) and volume (ml). This procedure is essentially identical to that used previously to measure MACS volume, surface area and the surface area/volume ratio in adult subjects over a wide range of MACS volumes [10,19].

Each ME was examined for the presence/absence of extant middle ear fluid. One of the primary challenges of automatically

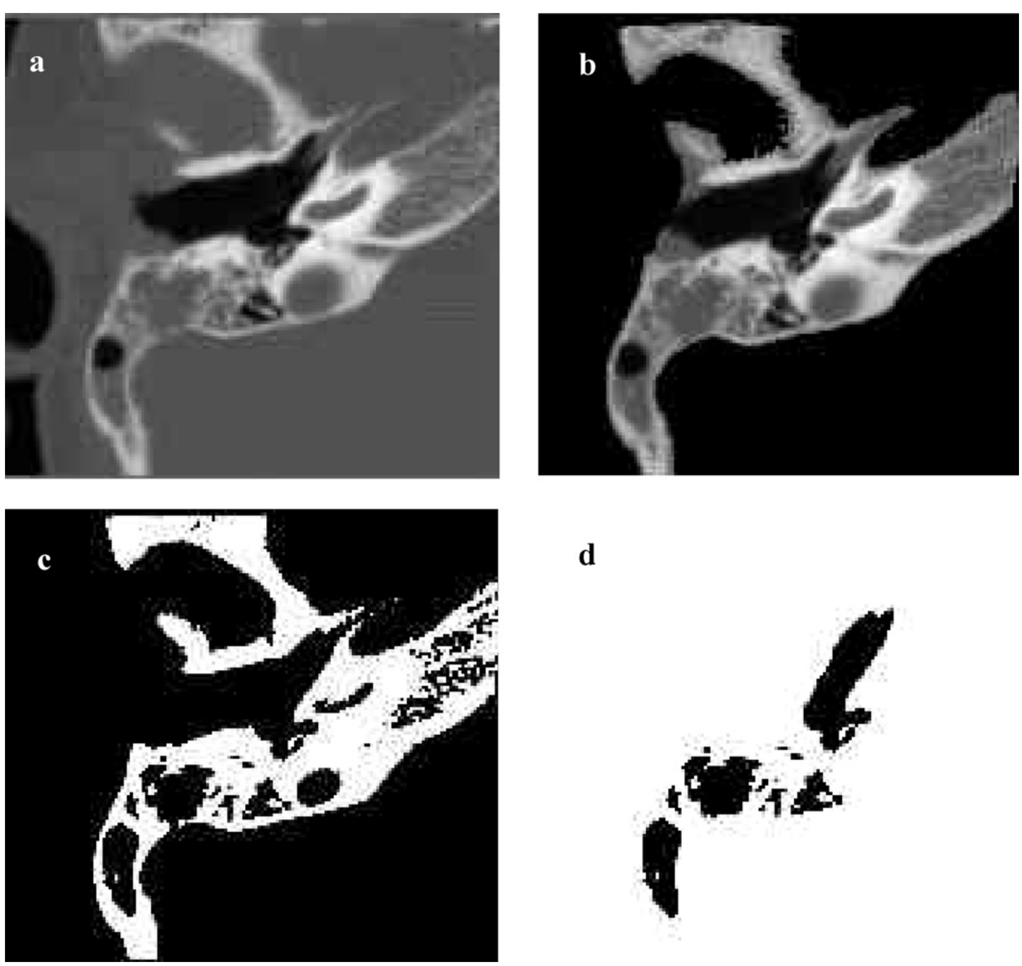

Fig. 1. Illustration of segmenting procedure for isolating MACS air-cells from middle ear effusion and other tissues. (a) Original image of temporal bone, (b) image following masking of temporal bone, (c) interactive contrast enhancement to reduce middle ear effusion intensity toward that of air and (d) binary image used for data extraction.