Validation of *In Vivo* MRI Lingual Volume Measurement Using *Ex Vivo* Models

G. Chi-Fishman[1], R. P. O'Quinn[2], N. S. Geisler[3], R. S. Wade[4], C. K. Hisley[5]

[1]Physical Disabilities Branch, Rehabilitation Medicine Department, Clinical Center, National Institutes of Health, Bethesda, MD, United States, [2]Biomedical Engineering, North Carolina State University, Raleigh, NC, United States, [3]Bioengineering, Oregon State University, Corvallis, OR, United States, [4]Anatomical Services Division, University of Maryland School of Medicine, Baltimore, MD, United States, [5]Diagnostic Radiology, University of Maryland School of Medicine, Baltimore, MD, United States

Purpose

- To validate a method for tongue volumetric measurement as performed on three-dimensional MR images.
- To assess the validity of the validation technique using inter- and intra-operator reliability measurements.

Introduction: As a vital organ unparalleled in its anatomical complexity, the tongue has the versatility to effect regional deformations and positional changes with multiple potential degrees of freedom. Despite an abundance of studies on the tongue and its functions, as well as numerous proposed tongue models over the years, much of the anatomical and biomechanical details of the *in vivo* human tongue remain poorly understood. It is widely accepted that the human tongue is a muscular hydrostat, and as such, volume constancy is its fundamental biomechanical characteristic. Conceptualizing the human tongue as a type of hydraulic system acknowledges the absence of bones and joints in the intrinsic tongue proper. The concept, however, does not address the potential effects of complex interdigitations, biomechanical coupling, or functional synergism of the intrinsic muscle fibers with those of the extrinsic muscles that do have bony origins. A basic question remains: can the human tongue change its volume? To answer this question, a comprehension study is underway, using advanced sagittal 3D MRI technology and post-processing to determine task-induced changes in tongue volume *in vivo* [1]. One of the first steps toward this objective is the validation of our scanning and measurement methods. Lauder and Muhl [2] used a rabbit model to test the reliability of their MRI tongue volumetric measurement technique. This technique was adapted to larger animal and human cadaver tongues in our validation study. The use of *ex vivo* models, if proven adequate for *in vivo* volumetric validation, will provide the methodological foundation to reliably address *in vivo* lingual volume changes or constancy as a function of tongue contraction tasks.

Methods: The *ex vivo* models used included two fresh, unembalmed human donor cranial samples and one freshly slaughtered calf head. After initial preparation, all specimens were subjected to repeated 3D MR scanning of the tongue using various protocols (proton density, T1, T2); normal and maximum resolutions; normal (4 mm) and reduced (1 mm) slice thickness; sagittal, axial, and coronal imaging planes; and GE (Signa 1.5T) and Phillips (Eclipse 1.5T) scanners. Post-processing of 68 MR image series and slice-by-slice segmentation of the tongue from each dataset were performed by two trained, blinded operators using the NIH Medical Image Processing, Analysis and Visualization (MIPAV) software. The operators manually traced the contours of the tongue proper (intrinsic muscles and the genioglossus) on each slice of each image series in randomized order (i.e., mixed imaging planes), and the software generated volume measurements as the sum of the slice-by-slice areas traced. Subsequently, the physical volumes of the tongues were measured using two methods. One method, applied to the male human specimen, involved serial parasagittal sectioning of the head (intended thickness = 4 mm, to match the slice thickness for our *in vivo* sagittal MRI study), followed by digital photography of the individual slices (modeled after the Visible Human Project) [3]. Tongue thickness in each section was determined using a 5-point caliper measurement method. Area measurements of the tongue proper were made from the photographs in MIPAV. The physical volume of the tongue was determined by multiplying each measured area by the corresponding section thickness. A second method involved excising the tongue, measuring mass using a balance, and determining volume using the Archimedes Principle and the density of water. Physical volume of the calf tongue was further verified by density comparison using known tissue composition values for raw beef tongue [4] and the Choi and Okos temperature-dependent density model [5]. All traced, image-based volumes were compared to the physical volumes for each tongue specimen. Statistical analyses were performed with operator, scanner, imaging resolution, and scan plane as factors. Acceptable difference limit was set at 5%.

Results: For two of the specimens, the traced volumes of each operator did not differ significantly from the physical volumes (Fig. 1b & 1c), regardless of imaging plane or resolution. The mean difference was as little as 0.11% for the sagittal datasets and as much as 4.27% for the axial datasets. For the initial specimen (Fig. 1a), the traced volumes were significantly different from the physical volume for the axial (operator 1) and coronal (operator 2) datasets; in the sagittal plane, however, the traced volumes were only -0.35% to -0.53% deviant from the physical volume. Overall intra-operator coefficients of variation improved from 6.18% to 2.23% with training and practice. Inter-operator agreement was good in all cases based on the estimated limits, with no outliers, proportional relationship, notable variation dependence, or systematic error (Fig. 2). The "theoretical" calf tongue density based on published values for the beef tongue and a density model for chemical composition was 1.049 g/cc. Given a measured tongue mass of 398.4 grams, this translated to a "theoretical" volume of 379.67 cc, which was 4.69% different from the computed mean value of 397.49 cc.

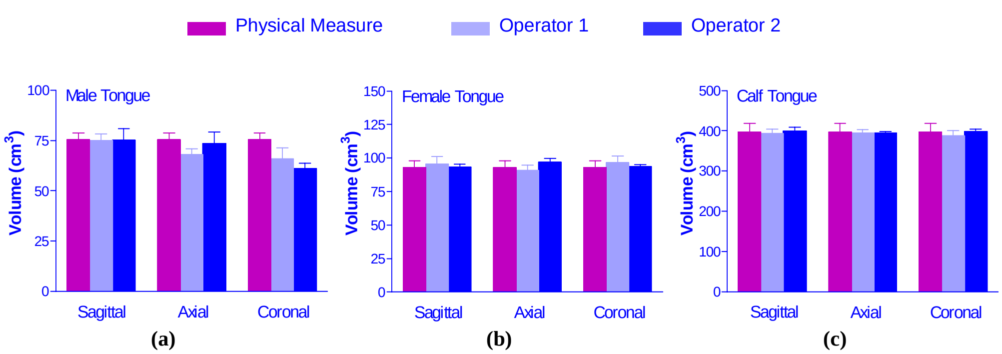

Fig. 1. Traced volumes of two trained operators vs. the physical volumes for each specimen.

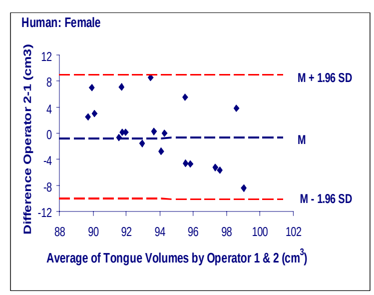

Fig. 2. Representative Bland-Altman plot of operator agreement.

Discussion: Results of this study using *ex vivo* models adequately validated the volumetric scanning and volume measurement methods used in our *in vivo* human MRI project where task-induced changes in tongue volume are examined. The best and most consistent results for each model were found in the sagittal datasets – the chosen imaging plane for our *in vivo* tongue volume study. Although inter-operator agreement was consistently good and intra-operator variations reduced with practice, operator training is crucial to volume measurement accuracy.

References

1. Chi-Fishman G, Miller JL, Butman J. Volumetric changes of the *in vivo* human tongue: Current findings. *Dysphagia* 18(2):151, 2003.
2. Lauder R, Muhl ZF. Estimation of tongue volume from magnetic resonance imaging. *The Angle Orthodontist* 61:175-184, 1991.
3. Spitzer VM, Whitlock DG. *Atlas of the Visible Human Male*. Sudbury, MA: Jones and Bartlett, 1998.
4. Anderson BA, Lauderdale JL, Hoke IM. *Composition of Foods: Beef Products. Handbook Number 8-13*. Washington, DC: USDA, 1986.
5. Choi Y, Okos, MR. Thermal properties of liquid foods – Review. In MR Okos (ed), *Physical and Chemical Properties of Food*. St. Joseph, MI: ASAE, 1986.