Biplane ultrasound imaging of lingual motion in chewing

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Background: Ultrasound imaging of the tongue is commonly accomplished with two-dimensional B-mode ultrasound but the tongue is a complex three-dimensional hydrostatic organ. New layouts for phased crystal arrays enable the parallel acquisition of sagittal and coronal slices (Remijn et al., 2015). This study compared lingual chewing movement of two solid textures (almond vs. beef jerky) in sagittal and coronal view planes. The research was exploratory and not guided by specific hypotheses.

Methods: Five females and 4 males (mean age 32 years) participated in the study. The participants sat with their forehead against a drum practice pad (RF-12G, HQ Percussion, Farmingdale, NY) on a cymbal stand (Pearl BC 1030, Pearl Cooperation, Nashville, TN). The participants' chin rested on an ultrasound transducer in a custom-made holder. A Philips X3-1 matrix array transducer with a centre frequency of 5 MHz connected to a Philips iU22 workstation was used for the recordings (Philips Medical, Markham, ON). The video stream was recorded using a VRD-MC6 recorder (Sony Canada, Toronto, ON). The participants in this study chewed two almonds and two pieces of beef jerky.

The ultrasound movies were segmented with Screenblast 3.0 (Sony Canada, Toronto, ON). The tongue surface was traced using a Bamboo tablet (Wacom Technology, Vancouver, WA) and the Ultra-CATS software. The complete processing of the almond bolus was traced. The beef jerky took longer to chew, so tracing was limited to the first and last 10 chewing cycles. The resulting data described the distance between the anchor point and the tongue surface in mm along radiating gridlines in 5° intervals in the sagittal and coronal planes.

Results: To assess measurement reliability, two videos were retraced. Mean errors were 0.6 mm in the coronal and 0.95 mm in the sagittal plane. Mean duration of the beef chew was 30.3 sec (SD 8.5 sec). First ten beef chews took 10.9 sec (SD 1.5 sec), the last ten chews took 10.0 sec (SD 0.74 sec). The mean duration for the almond chew was 15.7 sec (SD 4.2 sec). Cumulative movement at different measurement angles was calculated by smoothing the data with the 3RSSHS algorithm and then adding up the absolute differences between consecutive frames. Table 1 shows the results for the cumulative distances. A repeated measures ANOVA was calculated with the measurement angles and the conditions beef-start, beef-end and almond as the within factors. There was a significant difference for the measurement angles ($F=3.46$, $df=5$, $p<0.05$). Post hoc testing with Tukey-Kramer tests indicated that the posterior tongue at 25° posterior showed a larger amount of movement than the tongue at 25° anterior, 15° left and 15° right (all differences $p<0.05$). The tasks also differed significantly ($F=9.24$, $df=2$, $p<0.01$). Post hoc testing with Tukey-Kramer tests indicated that the chewing of the almonds resulted in a greater cumulative displacement of the tongue than the first and last 10 chews of the beef ($p<0.05$).

Concavity of the coronal tongue was calculated by subtracting the center measurement angle from the average of 15° right and left. Values under -2 were interpreted as convex, values between -2 and 2 as flat, and values over 2 as concave. Table 2 shows the percentages distributions.

Functional associations between different parts of the tongue were evaluated with a principal component analysis with varimax rotation. The resulting first factor explained 54.74% of the variance and comprised all coronal measurement angles between 15° left and 15° right, as well as the sagittal measurement angles between 25° posterior and 0° centre. The second factor explained 34.29% of the variance and comprised sagittal measurement angles from 5° anterior to 25° anterior. Cumulative variance explained by these two factors was 89.03%.

	Coronal 15° left	Coronal 0° centre	Coronal 15° right	Sagittal 25° anterior	Sagittal 0° centre	Sagittal 25° posterior
Beef - first 10 cycles	Mean 202.9 SD 60.4	Mean 198.6 SD 55.7	Mean 213.1 SD 70.1	Mean 180.9 SD 57.1	Mean 212.9 SD 65.7	Mean 247.5 SD 57.9
Beef - last 10 cycles	Mean 205.5 SD 63.9	Mean 233.1 SD 74.8	Mean 204.9 SD 60.9	Mean 200.4 SD 55.9	Mean 247.0 SD 73.43851	Mean 238.0 SD 55.2
Almond	Mean 286.7 SD 96.7	Mean 316.7 SD 122.9	Mean 275.2 SD 88.0	Mean 278.4 SD 114.3	Mean 316.8 SD 132.2	Mean 351.3 SD 134.1

Table1: *Mean cumulative distance travelled in mm.*

	Coronal tongue convex	Coronal tongue flat	Coronal tongue concave
Beef – first 10 cycles	31.5%	55.5%	13.0%
Beef - last 10 cycles	34.6%	53.1%	12.3%
Almond	28.8%	58.5%	12.7%

Table 2*: Percentage distributions of convexity and concavity of the coronal tongue.*

Discussion: The duration data and the distances traveled at different measurement angles showed clear differences between the textures. The motion of the jaw, which is important for chewing, could not be separated from the tongue motion in the image. It was particularly surprising that, in the sagittal plane, the posterior tongue travelled larger distances than the anterior tongue despite the fact that anterior mandibular excursion in chewing is larger than in the posterior mandible.

During chewing, the coronal tongue was mostly flat, sometimes convex, but rarely concave. The tongue has the task of positioning the bolus on the teeth, which is probably better accomplished with a raised center. However, the boli used in the present study were small. A larger bolus may lead to more concavity. The principal component analysis showed that the center and back of the tongue moved independently from the anterior part. The lateral free margins of the tongue clustered with the center and back.

The biplane imaging provided detailed visual information about the complex movement of the tongue in chewing. While speech data can be interpreted with reference to the acoustic signal, chewing data have no such "story-board". More research is needed to develop meaningful outcome measures for typical and disordered chewing.

References

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- Chewing; 3D ultrasound; Methodological research