Independently-moving hemimandibles in rats allow for symmetrical and synchronous chewing on left and right sides

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Abstract

Chewing is a cyclic activity necessary for mechanical breakdown of food. In vertebrates, chewing happens dominantly on one side or another during one chewing cycle; the side of the mouth is doing the chewing and is called the working side. The balancing side is the opposite side following the movements but not crushing the food. Rat jaw anatomy is unique; they have two independently-moving lower jaw bones called hemimandibles. We used X-ray Reconstruction of Moving Morphology (XROMM) to reconstruct 3D bone motions from X-ray videos coupled with CT scans to examine in vivo skeletal movements during chewing in rats. The data we collected does not support working and balancing side chews that are generally seen in vertebrate chewing. Although the separation of the hemimandibles may suggest asymmetrical chewing, our data indicates symmetrical movements between the left and right sides through translational and rotational measurements. Gape was determined through z-axis rotation (in the mediolateral plane) and other rotations and translations were compared through gape cycles. Overall, there was no evidence of asymmetry between the left and right hemi-mandible chewing nor working-balancing side patterns.

Introduction

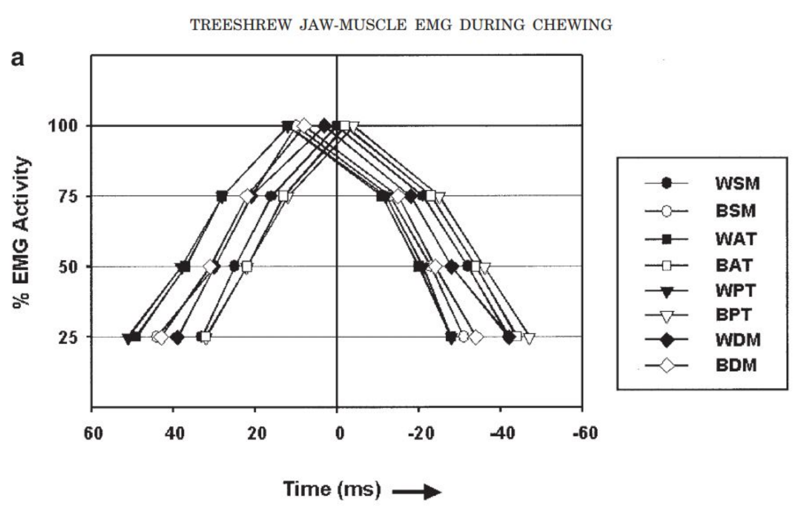

Figure 1. Electromyography data on working and balancing sides. Many vertebrate chewing patterns have a dominant chew side that is doing the actual chewing -- this is called the working side. The opposing balancing side follows the movement but is not crushing food. Electromyography data shows that muscles on either side fire at different times in a working-balancing side system (Vinyard et al. 2005).

Rats (*Rattus rattus*) have unique cranial anatomy. They have two independently-moving jaw bones called hemi-mandibles. Unlike many mammals, they do not have a fused symphysis between the left and right lower jaw (Hiiemae and Houston 1971). In 1975, Weijs observed quickly alternating working-balancing chewing pattern in rats (Weijs 1975). Using X-ray Reconstruction of Moving Morphology (XROMM), we took measurements of the distinct chewing that rats do.

Methods

We used X-ray Reconstruction of Moving Morphology (XROMM) to reconstruct 3D bone motions from X-ray videos coupled with CT scans to examine *in vivo* skeletal movements during chewing in rats. This data was used to animate and quantify motion and through CT scans using Autodesk Maya (Brainerd et al. 2010).

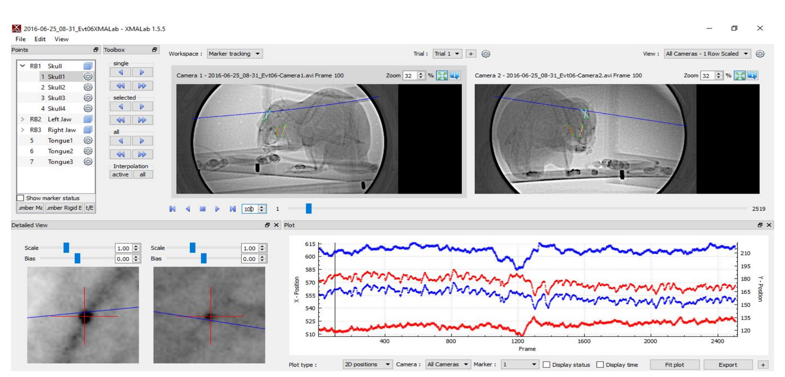

Figure 2. XMALab. Tantalum markers were surgically implanted the rat skull and jaw and X-ray videos were taken of the rat eating pellet food at the University of Chicago. Using XMALab (Knörlein et al., 2016), these points were digitally tracked through two different camera angles. Using this data, we were able to couple it with CT scans to animate *in vivo* movements in Autodesk Maya.

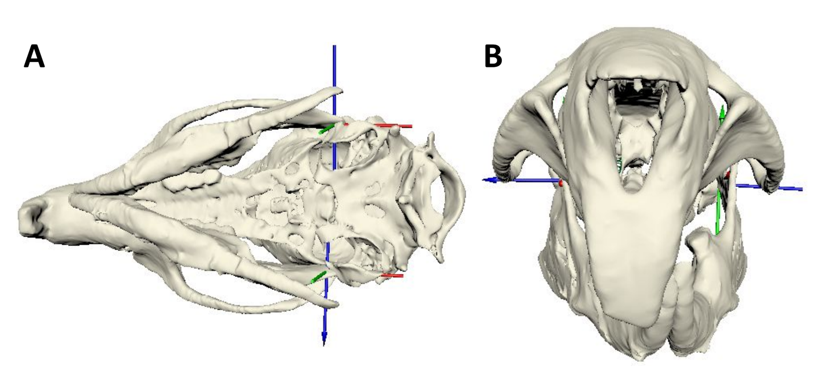

Figure 3. Joint Coordinate System (JCS) Axes. The JCS axes were placed on the temporomandibular joints on right and left sides to measure joint rotations and translations. Axes were aligned using upper molar cusp plane. (A) Ventral view of left and right TMJ JCS axes. (B) Anterior view of left and right TMJ JCS axes. Note that hemimandibles are unfused.

Figure 4. Molar Anatomical Coordinate System (ACS). An ACS can track a single point over time. A lower molar was tracked in respect to the skull. Axes were aligned using an upper molar cusp plane. (A) Lateral right view of molar ACS axes. Jaw is closed at the zero point. (B) Lateral right view of molar ACS axes. Jaw is at peak gape.

Results

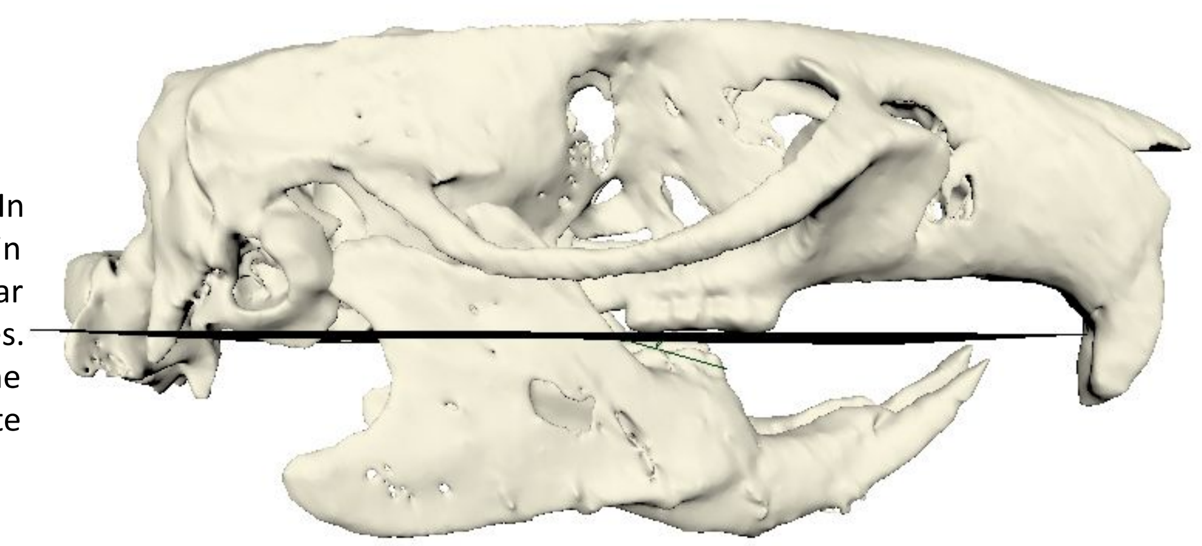

Figure 5. Plane going through upper jaw molar cusps. In order to standardize our data, we created a plane in Autodesk Maya. It went through the upper jaw molar cusps because of the free moving lower hemi-mandibles. This plane standardized the rotation of the axes for the Joint Coordinate Systems and the Anatomical Coordinate Systems.

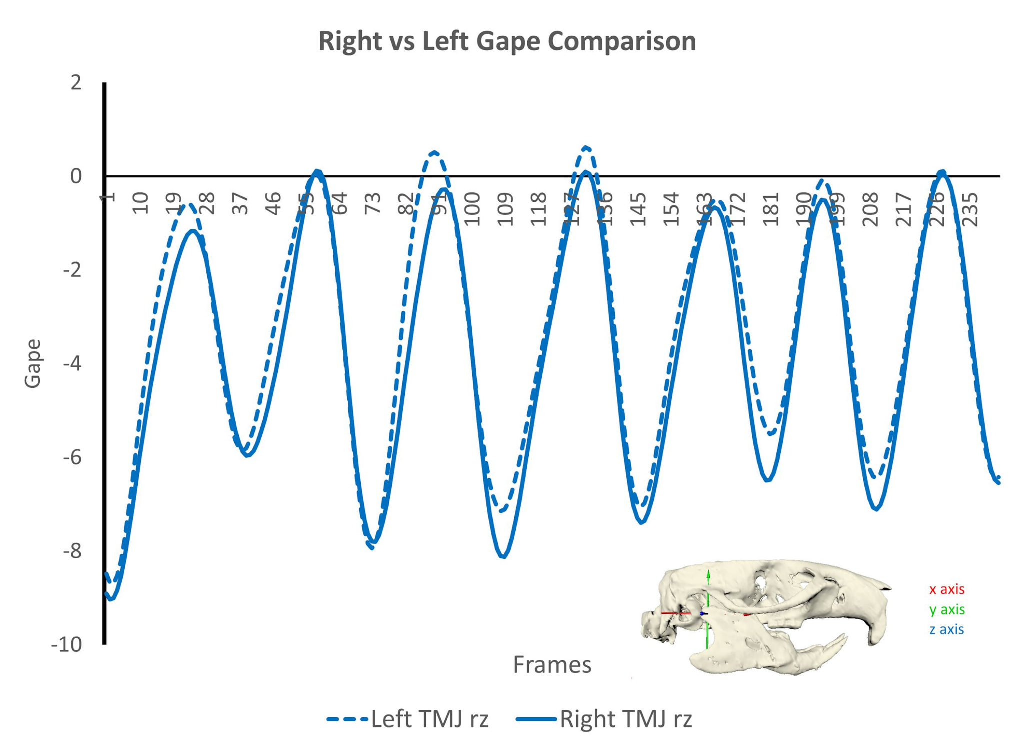

Figure 6. Left versus right gape. Gape, measured through z-axis (mediolateral) rotation on the temporomandibular joint using JCS. Zero point is at jaw close. Positive z-rotation is a closed mouth and negative rotation is an open mouth. The joint rotates synchronously over time.

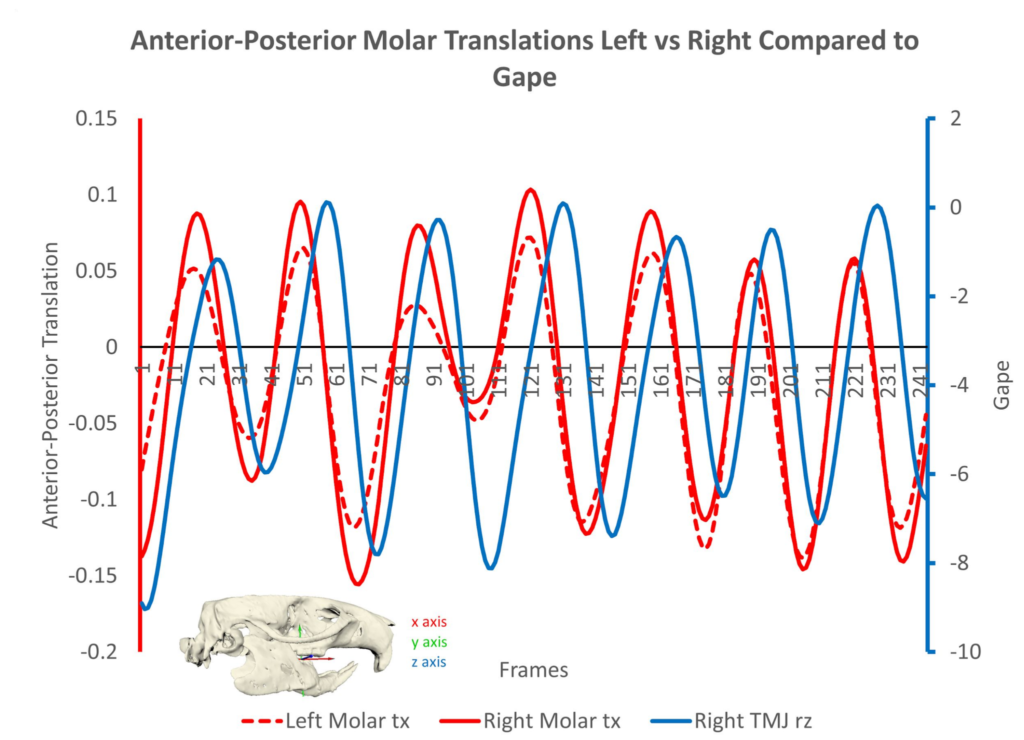

Figure 7. Anterior-posterior molar translations in respect to gape. Translations measured using ACS. When the mouth is opening after a close, there is posterior molar movement. When jaw is closing, there is anterior molar movement. Left and right movements generally synchronous.

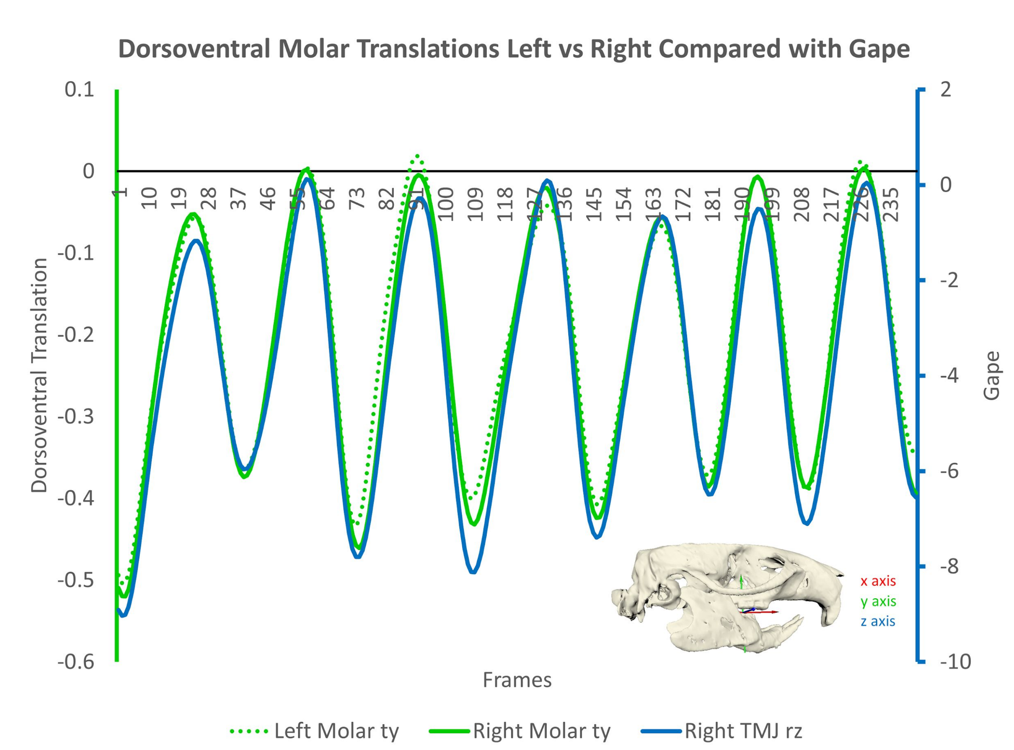

Figure 8. Dorsoventral molar translations in respect to gape. Translations were measured using ACS. As the mouth moves from open to close, the left and right molar synchronously move dorsally. When the mouth opens, the left and right molar synchronously moves ventrally.

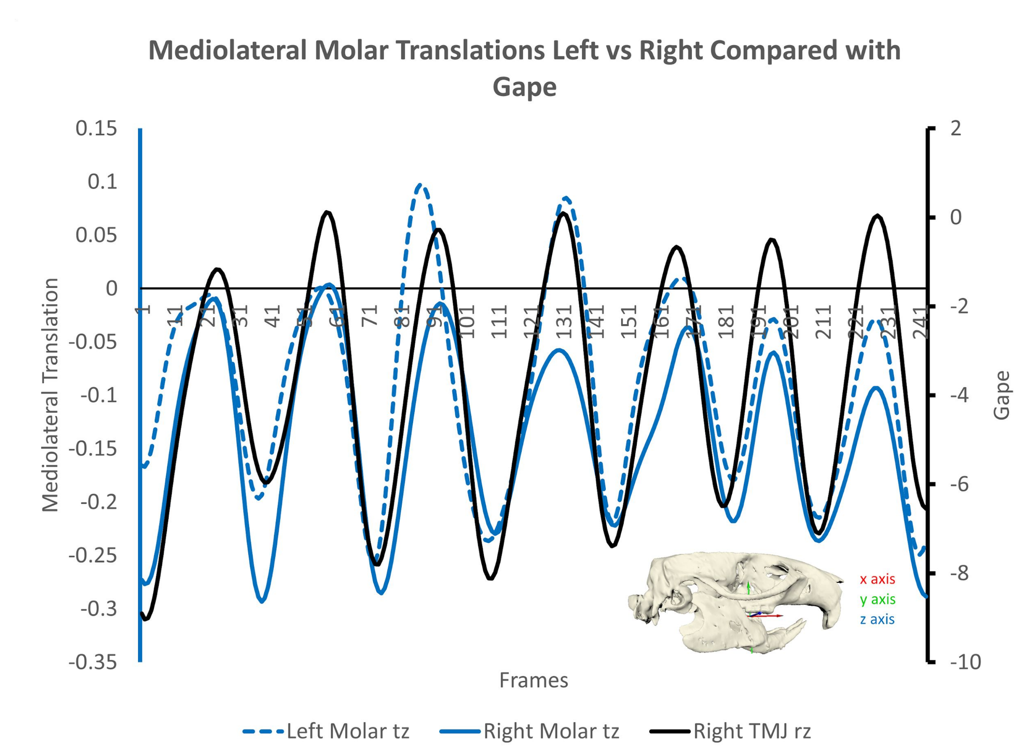

Figure 9. Mediolateral molar translations in respect to gape. Translations were measured using ACS. As the mouth closes, the molars on both sides translate to the right. When the mouth opens, the molars translate to the left. The jaw moves medially and laterally as one unit during chewing.

Discussion

Between the left and the right sides, temporomandibular joint z-axis rotation (mediolateral) occur synchronously (Figure 6). In a working-balancing side masticatory system, these motions would not occur collectively (Vinyard et al., 2005). One side would be moving ahead of the other. Because of the synchronicity of these rotations, our data suggests that the working-balancing side system does not exist in rats.

Dorsoventral and anterior-posterior lower molar movements, in general, were also symmetrical during the chew cycle (Figure 7 & Figure 8). Mediolateral molar movements had symmetrical movements, but at different amplitudes (Figure 9). This suggests that there are whole jaw mediolateral movements.

Figure 10. Plane placement. In Brainerd et al.'s 2010 study on pig mastication, a plane was placed on the lower jaw tooth cusps. Because the hemi-mandibles of a rat are unfused, our plane was placed on the upper jaw molar cusps. This standardized the axes of the coordinate systems.

Future Directions

In the coming months, we will process data from three more rats to find consistencies and discrepancies between individuals.

Analyzing any movements that may occur at the symphysis and investigate other types of animals with similar chewing cycles with fused symphyses.

Hiiemae describes masticatory and ingestion cycles (1971). Using this information, we could look into the movements and differentiate our data into cycles.

Coupling these data with electromyography to see the timing of firing with the symmetrical motions to determine the function of this synchronous system.

Acknowledgments

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Supplemental videos of graphed chewing cycles can be viewed by scanning QR code to the right or by following this link: shorturl.at/opwE7