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Kinetic Modeling of the Hyoid Movement Revealed Co-Contraction of Protractor and Retractor Muscles

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Background
The hyoid bone movement is essential for safe and effective swallowing. The muscles that exert forces on the hyoid bone during swallowing can be categorized into three groups according to the direction of force; Forward ("Protractor" muscle group), downward ("Depressor") and back-upward ("Retractor") muscle groups. The aim of this study was to establish and validate a kinetic model of hyoid movement during swallowing based on the Results of hyoid motion analysis.

Methods
A total of 8 healthy adults were recruited and underwent the videofluoroscopic swallowing study (VFSS) with the simultaneous surface electromyography (sEMG) recording. A thin liquid of diluted barium sulfate of 2 mL was administered to the participants. The antero-inferior margin of the hyoid bone was digitized and the Results were calculated using in-house MATLAB script and Statistics Toolbox (R2014b; MathWorks, Natick, MA, USA). The sEMG was recorded with the reference electrode attached on the chin and the active electrode on the submandibular area, which was expected to be over the suprahyoid muscles. The sEMG and VFSS data were synchronized using a cue signal at the start of recording. The synchronization of the VFSS images and sEMG was achieved by a simultaneous signaling through custom-made printed circuit board. A kinetic model was made with the following assumption: (1) the linear elasticity modulus of the protractor/retractor/depressor of 0.0231/0.0173/0.0347, (2) a constant 1 to 1 ratio of repulsive to attractive linear modulus, (3) when a force vector is calculated at a moment, the force is assumed to have been generated by combination of possible minimal forces of 3 muscle groups at the moment.

Results
The model showed consistent earlier recruitment of the retractors as compared to the protractors (Fig 1). The difference between onset latency of the EMG bout and the modeled protractors was 0.532 s (95% CI, 0.265-0.798). Rather, the onset latency difference between the sEMG and the retractors was much smaller (0.225; 95% CI, 0.086-0.363). The peak of sEMG coincided with the peak activity of the retractors, but not with the protractors (Fig 2).

Conclusion

Synchronized EMG and kinetic modeling of the hyoid movement revealed the co-contraction of the protractors and retractors at the beginning of swallowing. Surprisingly enough, the maximal exertion of the suprahyoid muscles occurs at the maximal retractor activity. More complex kinetic modeling with incorporation of co-contraction and eccentric contraction should be needed.

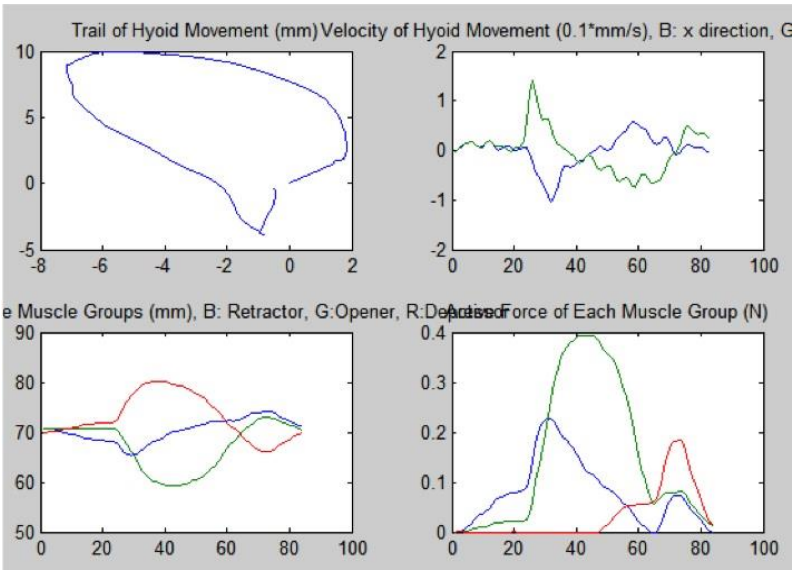

Figure 1. The sequential processes of the kinetic modeling of hyoid movement during swallowing. Upper left. A Trail of the hyoid movement during swallowing. Upper right. Velocity of the hyoid bone during swallowing (blue, horizontal movement; grean, vertical movement). Lower left. The calculated changes in the length of each muscle group. Lower right. The active muscle force calculated from the length change in (blue, retractor; green, protractor; red, depressor)

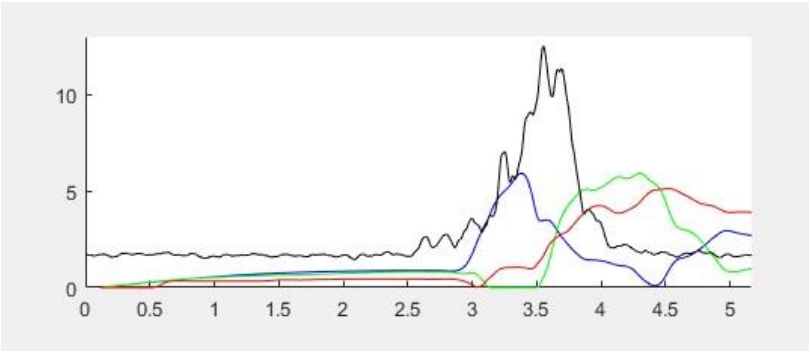

Figure2 The modeled muscle activities (blue, retractor; green, protractor; red, depressor) and the measured sEMG (black). The modeled peak activity of the retractors coincides with the measured peak sEMG activity.

Onset latency	sEMG	Retractor	Depressor	Protractor
No.1	2.227	2.367	2.400	2.467
No.2	1.947	2.283	2.967	2.817
No.3	1.989	2.300	2.767	2.833
No.4	0.432	0.517	0.583	0.850
No.5	2.435	2.683	2.650	2.717
No.6	3.099	3.217	3.383	3.900
No.7	2.523	2.883	3.050	3.500
No.8	3.184	3.833	3.667	4.067
Peak latency	sEMG	Retractor	Depressor	Protractor
No.1	2.663	2.900	2.883	2.900
No.2	2.451	2.850	3.517	3.350
No.3	2.537	2.867	3.483	3.300
No.4	0.591	0.633	0.633	1.333
No.5	3.183	3.000	4.017	4.117
No.6	3.551	3.683	4.450	4.250
No.7	3.552	3.383	4.500	4.300
No.8	3.792	3.983	4.633	4.583

Onset latency and peak latency of sEMG and kinematic modeling of each muscle group.