The non-invasive evaluation of biomechanical coordination during swallowing

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Background: Swallowing is a important and complex physiological behaviour. Any procedural abnormality of the dynamic of swallowing will result in dysphagia and even lower quality of life. However, evaluating the biomechanical coordination during swallowing non-invasively has not yet been achieved. In modern society, it is the pursuit of the clinician to monitor swallowing and evaluate the related functions conveniently and noninvasively for the timely diagnosis of any swallowing defects.

Objective: We intended to characterize the temporal pattern of swallowing behaviour, and determine how these patterns of the tongue and the hyoid are related to and coordinated with the muscle activity with a non-invasive sensing system.

Methods: Fifteen subjects were recruited, and a non-invasive sensing system composed of a pressure sensor, a bend sensor, surface electrodes and a microphone was created to simultaneously monitor tongue pressure (TP), hyoid motion, and surface EMG suprahyoid muscle (SH)/ infrahyoid muscle (IH), as well as take sound recordings, when the subjects swallowed 5 ml of water.

Results: The slight movement of the hyoid occurred first among all of the monitored biomechanical events and most closely to the subsequent SHon. Then, the TPon of Ch.1 appeared with the simultaneous appearances of IHon, TPon of Ch.5 and Ch.4, as well as upward movement of the hyoid, followed by the TPon of Ch.2 and Ch.3. The TPmax occurred before the onset of the stationary phase of the hyoid during swallowing. The offset of the stationary phase of the hyoid, SHoff, IHoff and TPoff appeared without any significant time lags. In addition, there were obvious positive correlations between SHon and T1, SHon and T2, as well as IHon and T2 with moderate correlation coefficients. Moreover, there were significant positive correlations between SHoff and TPoff at Chs. 1-5 and T5 with moderate correlation coefficients. This was also the case between IHoff and TPoff at Chs. 1-5 and T5.

Conclusions: There is a fine-tuned motor pattern and temporal coordination among tongue, hyoid and supra- and infra- hyoid muscles during swallowing in healthy subjects. Also, the non-invasive sensing system has potential as a good candidate for monitoring and evaluating the swallowing.

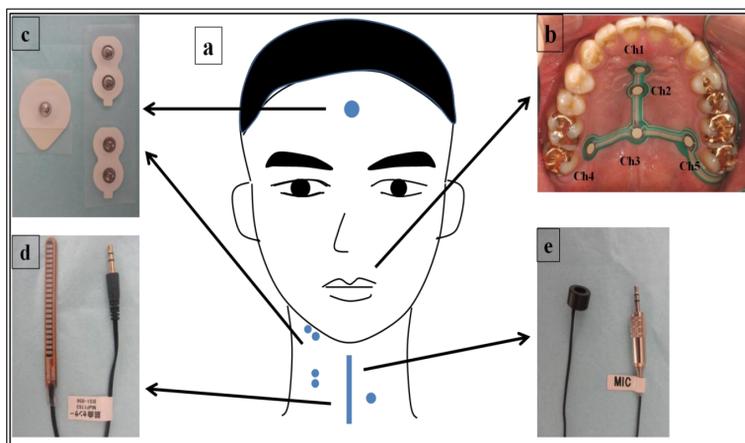**Keywords**: Swallowing; Sensing; Tongue pressure; Hyoid; EMG

Figure 1. Schematic representations of the sensing system and experimental set-up. (a) A subject with tongue pressure sensor sheet, surface electrodes, bend sensor and microphone. (b) Tongue pressure sensor sheet. (c) Surface electrodes. (d) Bend sensor. (e) Microphone.
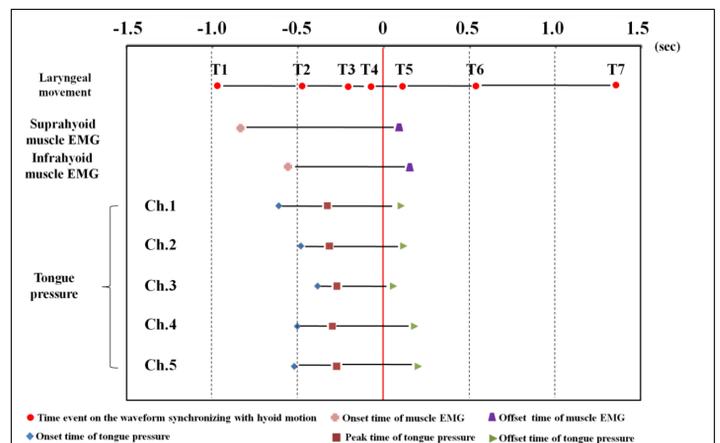

Figure 3. Temporal sequence of biomechanical events during oropharyngeal swallowing. The red line is the swallowing sound that was chosen to be the reference time.

Figure 4. Duration of biomechanical events during oropharyngeal swallowing. DSH, duration of suprahyoid muscle activity; DIH, duration of infrahyoid muscle activity.* p<0.001 v.s. DSH and T1-T5; # p<0.001 v.s. TP of Ch.3; & p<0.005 v.s. DTP of Ch.3.

Table 1. Correlation coefficient of biomechanical events during swallowing

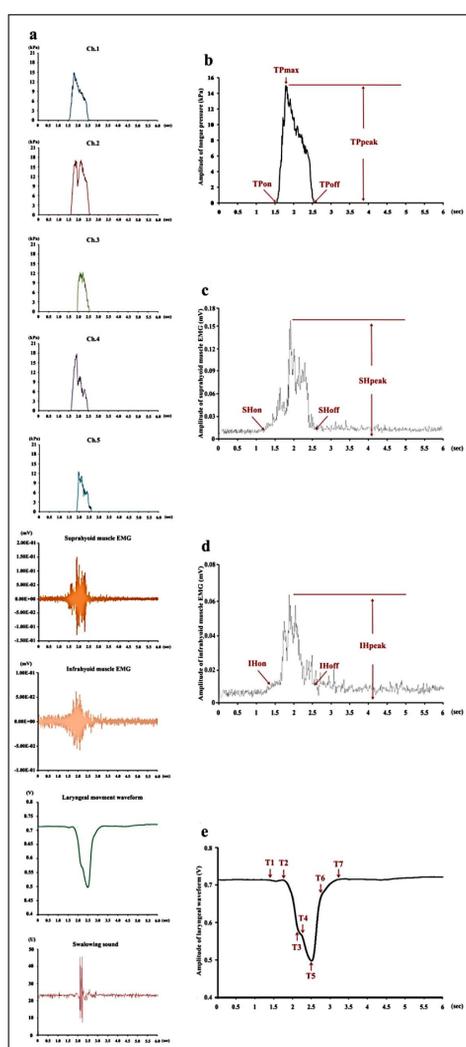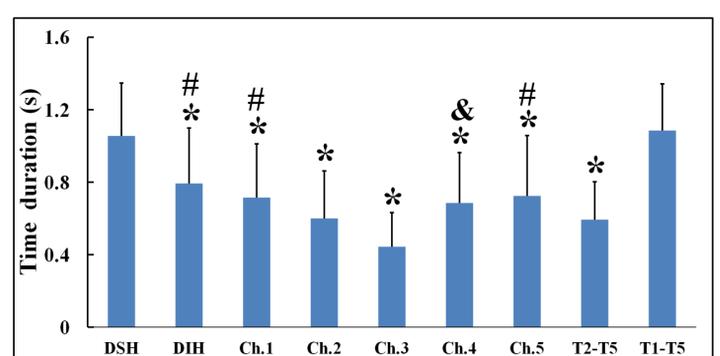| Events of muscle EMG	Events of the tongue pressure and hyoid activity	r	p
SHon	Ch.1 TPon	0.472	0.058
	Ch.2 TPon	0.434	0.064
	Ch.3 TPon	0.415	0.070
	Ch.4 TPon	0.377	0.112
	Ch.5 TPon	0.192	0.206
	T1	0.658	0.002
	T2	0.616	0.008
IHon	Ch.1 TPon	0.543	0.025
	Ch.2 TPon	0.302	0.152
	Ch.3 TPon	0.277	0.175
	Ch.4 TPon	0.252	0.199
	Ch.5 TPon	0.198	0.251
	T1	0.258	0.193
	T2	0.666	0.005
SHoff	Ch.1 TPoff	0.653	0.002
	Ch.2 TPoff	0.594	0.019
	Ch.3 TPoff	0.626	0.008
	Ch.4 TPoff	0.633	0.007
	Ch.5 TPoff	0.613	0.010
	T5	0.694	0.001
IHoff	Ch.1 TPoff	0.656	0.002
	Ch.2 TPoff	0.643	0.003
	Ch.3 TPoff	0.640	0.004
	Ch.4 TPoff	0.580	0.026
	Ch.5 TPoff	0.689	0.010
	T5	0.602	0.010

Figure 2. Representative recordings of the noninvasive sensors. (a) Decomposed graph of waves of tongue pressure, EMG, laryngeal movement and swallowing sound. (b) The data analysis of TPon, TPmax, TPoff and DTP. (d) The data analysis of SHon, SHoff, SHpeak and DSH. (d) The data analysis of IHon, IHoff, IHpeak and DIH. (e) Laryngeal signal waveform and marked time point.