Muscle Stiffness and Elasticity of Masticatory Muscles on Gum Chewing

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Some researchers suggested that tactile sensor system would be useful in evaluating masticatory muscles of TMD patients, but there were few studies on the effects of chewing with time. The aim of this study was to investigate the change of elasticity and stiffness for masseter and temporal muscles of normal subjects before, during and after gum chewing and to obtain the baseline data for further researches on the elasticity and stiffness for masticatory muscles of TMD patients.

Stiffness and elasticity of their anterior temporalis and inferior masseter muscle were measured bilaterally by a tactile sensor system. Each subject was instructed to sit on a chair for evaluation of masticatory muscles. Before operating the sensor, the thickest skin area over anterior temporalis and inferior masseter muscles were selected as the points to be pressed by a tactile sensor, and marked with a pen. While the teeth of subjects were lightly contacted, the probe of the tactile sensor was placed perpendicularly over the marked point over the skin, followed by computer-controlled movement including gently pressing straight down on the muscle for a second and retracting. All subjects were instructed to chew gum (Excellent Breath, Taiyo Co., Japan) bilaterally with a velocity of 2 times per second for 40 minutes after the first measurement had been performed for the baseline data of all subjects. The measurements had been repeated during chewing with 10 minutes of interval and continued for 40 minutes with same interval after chewing. Resultantly, the decrease of elasticity and the increase of stiffness in masticatory muscles can be seen significantly within 10 minutes after chewing and those were maintained during chewing without significant change with chewing time. The elasticity of muscles was recovered within 10 minutes after stopping chewing, but the stiffness was recovered more lately than elasticity by about 10 minutes. Based on these results, it can be concluded that elasticity and stiffness of muscles would be good indicators to evaluate the masticatory muscles objectively, when more supported by further researches.

Key words: Gum chewing, Tactile sensor system, Stiffness, Elasticity, Masticatory muscles

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I. INTRODUCTION

Temporomandibular disorders(TMD) has been classified into three diagnostic categories, (1) cranial bone (including the mandible) disorders (2) TMJ disorders and (3) masticatory muscle disorders and among them the muscle disorders exhibit high prevalence clinically.[1)]

In past years much attention has been drawn to the use of electromyographic (EMG) recordings in the diagnosis and treatment of masticatory muscle disorders.[2,3] It was originally felt that if a painful muscle was in spasm, an increased EMG activity would be recorded from the involved muscle. Although this is likely true for myospasms, studies [4,5,6,7] now demonstrate that muscle pain is often not associated with any significant increase in EMG activity.

Tactile sensory system was developed to measure the stiffness of objects (tactile stiffness) and was used to describe the time course of muscle contraction and relaxation. It was reported that this system can describe the time course of latissimus dorsi muscle contraction and relaxation.[8]

A study had been attempted to investigate whether hardness/softness of oral soft tissue can be used as a parameter in the diagnosis of the function of the oral cavity using a newly developed tactile sensor. It showed that a tactile sensor could be used to detect the properties of the facial muscles associated with expression and mastication during facial activity.[9]

Some researchers[10-13] suggested that tactile sensor system would be useful in evaluating masticatory muscles of TMD patients, but there were few studies on the effects of chewing with time. The aim of this study was to investigate the change of elasticity and stiffness for masseter and temporal muscles of normal subjects before, during and after gum chewing and to obtain the baseline data for further researches on the elasticity and stiffness for masticatory muscles of TMD patients.

Ⅱ. MATERIAL AND METHODS

1. Tactile sensor system

A tactile sensor system[15] employed for this study was Venustron®(Axiom Co. Ltd., Japan) as seen in Fig 1 and 2. The sensor consists of a piezoelastic transducer made of ceramics such as lead zirconate titanate (PZT) and a vibration pickup (made of PZT or polyvinylidene fluoride (PVF2) film) and it is connected to a computer equipped with the appropriate software.

When there is an electric input, the PZT element vibrates at its own inherent resonance frequency. If the sensor probe vibrating in this frequency is pressed against an object, this frequency shifts and the amount of shift in frequency is determined by the object's acoustical impedance, which directly correlated with the hardness/softness of the material. The change in frequency, or Δf is defined

Fig. 1. The tactile sensor system (Venustron®, Axiom Co. Ltd., Japan) used for this study.

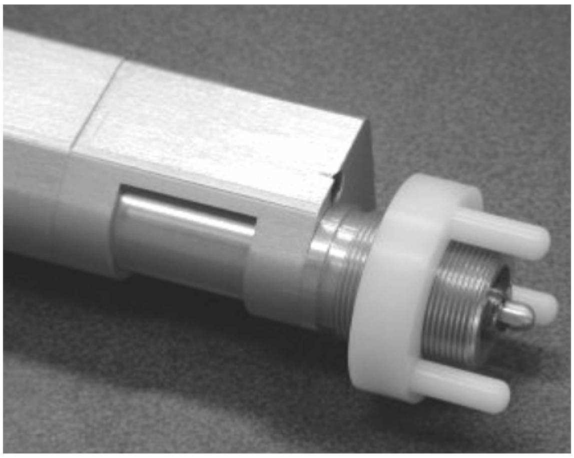

Fig. 2. The tactile sensor tip (arrow) which is placed and moved on the tissue surface to be measured

a b

Fig. 3. The stiffness and elasticity of masticatory muscles were measured using a tactile sensor (a, inferior masseter muscle; b, anterior temporalis muscle)

as the difference between the new frequency, f_x and the initial frequency, f_0, shown as $\Delta f = f_x - f_0$. The initial frequency, f_0 was 57 Hz and the tip diameter of sensor probe was 5 mm in this tactile sensor system.

When the sensor probe is placed over the surface to be measured, measurement begins via the Window's compatible software. A small motor located in the upper end of the probe shaft is activated by the computer, which controls the depression. The sensor tip pushes down on the material once and retracts to provide a continuous stream of simultaneous stiffness, pressure and depression in real time. 200 tactile, pressure and depression data per second are swiftly and sequentially processed and recorded by the computer.

2. Measurement of muscle stiffness and elasticity

The subjects consisted of 20 healthy men who participated voluntarily in this study and their mean age was 23±0.84 years. Stiffness and elasticity of their anterior temporalis and inferior masseter were measured bilaterally by a tactile sensor system.

Each subject was instructed to sit on a chair for evaluation of masticatory muscles. Before operating the sensor, the thickest skin area over anterior temporalis and inferior masseter muscles were selected as the points to be pressed by a tactile sensor, and marked with a pen.(Fig. 3) While the teeth of subjects were lightly contacted, the probe of the tactile sensor was placed perpendicularly over the marked point over the skin, followed by computer-controlled movement including gently pressing straight down on the muscle for a second and retracting.

All subjects were instructed to chew gum (Excellent Breath, Taiyo Co. Japan) bilaterally with a velocity of 2 times per second for 40 minutes after the first measurement had been performed for the baseline data of all subjects. The measurements had been repeated during chewing with 10 minutes of interval and continued for 40 minutes with same interval after chewing.

Muscle stiffness and elasticity right after gum chewing was measured again and the examination was repeated after having rest period of 15 min after chewing.

Prior to commencing the experiments, the examiner of this study performed several measuring exercises to become familiar with the tactile sensor and to determine the amount of depression in the muscles. The distance moved down from skin by the sensor probe was determined as 3 mm in anterior temporalis, and 7 mm in masseter.[13)]

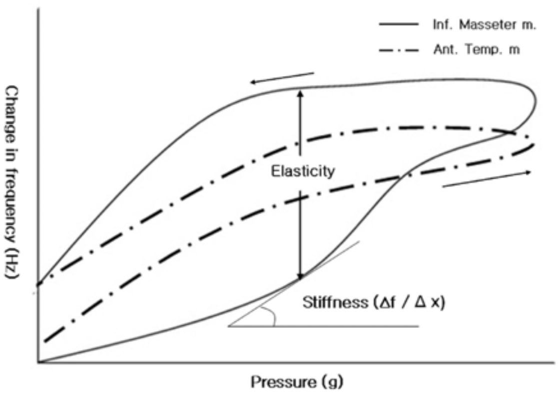

Fig. 4. Hysteresis curves of inferior masseter and anterior temporal muscles showing frequency versus pressure[19]

3. Statistical analysis

Repeated measures 2-way ANOVA was used to evaluate the change of elasticity and stiffness of masseter inferior and temporalis anterior with time after chewing. Multiple comparison t-test was used to investigate the differences among groups. Differences were regarded as statistically significant at $p < 0.01$.

Ⅲ. RESULTS

A hysteresis curve in Fig. 4 is composed of two parts, which are formed when the sensor pushes down (bottom) and then retracts (top).[15] The slope of the tangent of the hysteresis curve ($\Delta f/\Delta x$) is defined as stiffness of the muscle being measured and the distance between the two parts as its elasticity. High scores of elasticity, therefore, means low elasticity of muscles and reversely high scores of stiffness means low stiffness of muscles in this study.

Elasticity of inferior masseter and anterior temporalis was decreased very significantly as soon as chewing gum within 10 minutes as seen in table 1, 2 and Fig. 5. It can be seen also that elasticity of both muscles was significantly recovered as soon as stopping chewing gum within 10 minutes.

Stiffness of inferior masseter and anterior temporalis was reversely increased with high significance as soon as chewing gum within 10 minutes as seen in Table 3, 4 and Fig. 6. The recovery of stiffness for both muscles also can be seen after stopping chewing gum similarly as that of elasticity. However, the recovery of stiffness for both muscles was delayed about 10 minutes compared to that of elasticity as seen Table 4.

The elasticity and stiffness were changed significantly in 10 minutes after chewing gum, but after then they were not changed anymore significantly ($p>0.01$) with chewing time, showing a plateau in graphs. (Table 2, 4 and Fig. 5, 6).

The differences of elasticity ($p<0.05$) and stiffness ($p<0.01$) between between two muscles of inferior masseter and anterior temporalis as well as differences among groups according chewing time($p<0.01$) can be seen in Table 1 and 3.

Table 1. The mean and standard deviations of elasticity measured for inferior masseter and anterior temporalis and the results of repeated measures 2-way ANOVA

	Inf.masseter m.	Ant.temp.m	p-value
BC	64.91±24.53	50.76±20.85	
C10	80.31±28.23	63.21±23.39	
C20	86.62±24.27	66.97±25.20	
C30	88.94±29.05	70.64±19.77	
C40	83.23±22.38	69.21±19.44	p=0.000
A10	69.72±24.87	62.04±16.60	
A20	63.96±23.33	54.58±15.58	
A30	63.68±19.47	53.46±18.41	
A40	60.08±18.92	50.88±20.51	
p-value	p=0.000		p=0.620

*High scores of elasticity means low elasticity of muscle
BC : before chewing
C10~40 : at 10~40 minutes during chewing
A10~40 : at 10~40 minutes after chewing

Table 2. Multiple comparison t-test for elasticity of inferior masseter and anterior temporalis according to time, based on the results of repeated measures 2-way ANOVA

	BC	C10	C20	C30	C40	A10	A20	A30	A40
BC (57.837)									
C10 (71.760)	*								
C20 (76.801)	*								
C30 (79.793)	*								
C40 (76.223)	*								
A10 (65.878)			*	*	*				
A20 (59.273)		*	*	*	*				
A30 (58.568)		*	*	*	*				
A40 (55.484)		*	*	*	*	*			

(　) Mean score (* : p<0.01)

BC : before chewing
C10～40 : at 10～40 minutes during chewing
A10～40 : at 10～40 minutes after chewing

Table 3. The mean and standard deviations of stiffness measured for inferior masseter and anterior temporalis and the results of repeated measures 2-way ANOVA

	Inf.masseter m.	Ant.temp.m	p-value
BC	1.78±0.79	1.58±0.57	
C10	1.33±0.67	1.29±0.49	
C20	1.21±0.59	1.15±0.41	
C30	1.11±0.47	1.09±0.40	
C40	1.13±0.48	1.04±0.35	p=0.000
A10	1.35±0.55	1.38±0.66	
A20	1.60±0.74	1.46±0.62	
A30	1.71±0.73	1.51±0.67	
A40	1.68±0.69	1.55±0.60	
p-value	p=0.033	p=0.940	

* High scores of stiffness means low stiffness of muscle
BC : before chewing
C10～40 : at 10～40 minutes during chewing
A10～40 : at 10～40 minutes after chewing

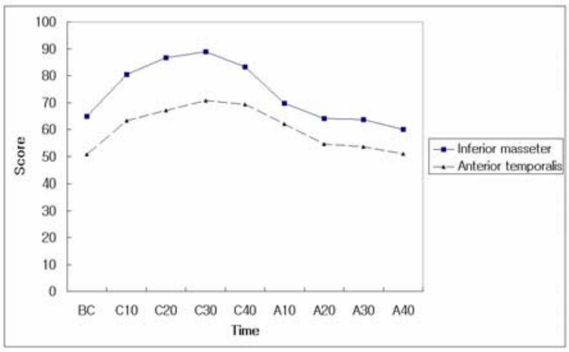

Fig. 5. The linear graph showing the changes of elasticity of inferior masseter and anterior temporal muscles before, during and after gum chewing
* High scores of elasticity means low elasticity of muscle
BC : before chewing
C10～40 : at 10～40 minutes during chewing
A10～40 : at 10～40 minutes after chewing

Table 4. Multiple comparison t-test for stiffness of inferior masseter and anterior temporalis classified according to time, based on the results of repeated measures 2-way ANOVA

	BC	C10	C20	C30	C40	A10	A20	A30	A40
BC (1.680)									
C10 (1.305)	*								
C20 (1.176)	*								
C30 (1.099)	*								
C40 (1.086)	*								
A10 (1.364)				*	*				
A20 (1.530)			*	*	*				
A30 (1.613)		*	*	*	*	*			
A40 (1.614)		*	*	*	*	*			

( ) Mean score (* : $p<0.01$)

BC : before chewing
C10~40 : at 10~40 minutes during chewing
A10~40 : at 10~40 minutes after chewing

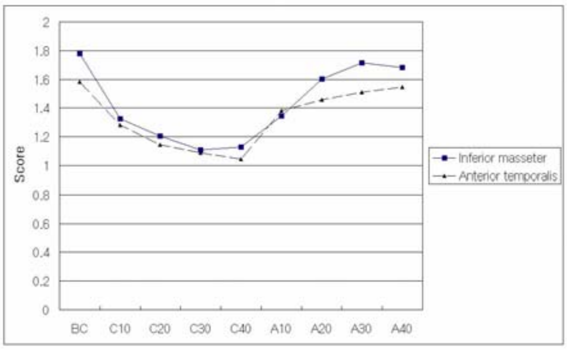

Fig. 6. The linear graph showing the changes of stiffness of anterior masseter and anterior temporal muscles before, during and after gum chewing

* High scores of stiffness means low stiffness of muscle

BC : before chewing

C10~40 : at 10~40 minutes during chewing

A10~40 : at 10~40 minutes after chewing

Ⅳ. DISCUSSION

In cats, increasing the hardness and toughness of the food increases the swallowing thresholds, i.e. the number of chews that are necessary to process the food for swallowing.[14,15] A similar finding has been reported in man,[16] but, in the same report, there was also a group of subjects who did not show a significant increase in the swallowing threshold even when chewing hard food. This variable is also known to be influenced by the occlusal state.[17] The reported variation in responses might therefore be due to the use of natural foods whose properties are hard to control and of subjects with unspecified occlusal states. In this study, commercial gum was used to keep decrease this variation instead of natural food for normal subjects with class I occlusion.

Katayama and Inada[18] reported that the tactile sensor indicated that increases in stiffness and decreases in elasticity of the masseter muscle on the mastication side were proportional to the number of masticatory cycles, which were measured at 0, 50, and 100 cycles. They also showed that there was no pronounced increase stiffness and decrease in elasticity on the mastication side compared with those on the non-mastication side, although some increase in muscle stiffness and decrease in muscle elasticity associated with an increase in the number of masticatory cycles were also observed on the mastication side. In our study all subjects were instructed to chew bilaterally and there were no differences of elasticity and stiffness between both mastication sides. All measurements of both mastication sides, therefore, were included in the sample size.

A myofascial TP is a hyperirritable spot located in a skeletal muscle and/or its associated fascia. Clinical characteristics of an active TP include the presence of a taut band, a jump of the patient when sufficient digital pressure is placed on the TP (jump sign), and referred pain when the pressure is maintained. Another clinical sign is a transient contraction of muscle fibers in the tense band (local twitch response) produced by transverse snapping palpation of the TP.[19,20] The primary purpose of a muscle examination is to identify generalized muscle tenderness and pain and to detect the presence of trigger points. Digital palpation is the most commonly used method of determining the presence of muscle tenderness and pain. Because a healthy muscle is not normally tender to palpation, a painful response to palpation is indicative of an abnormality in the muscle.[21]

Whenever the presence of a TP is suspected, an attempt should be made to reproduce the patient's chief complaints. This can be accomplished by maintaining firm, continuous pressure on the point for several seconds. Because the presence of referred pain from a TP can be confuse both the patient and clinician with respect to identifying and locating the structures involved in causing the pain complaint, diagnostic blocking of a suspected TP is often used.[22] A painful response to palpation is very subjective data, so it would be very difficult for dentists to evaluate exactly the masticatory muscle condition.

A frequency analysis of simultaneously recorded electromyograms (EMG) of the masseter muscle showed a decrease in the higher frequency components. However, this parameter was proportional to the number of mastication cycles in only a small number of the subjects on either the mastication or non-mastication side. EMG was unclear in most of subjects in their study.[23] The results in this study support, as suggested by them, that muscle stiffness and elasticity measured with the tactile sensor more accurately reflect muscle fatigue than conventional parameters. It is also believed that elasticity and stiffness of muscles would be good indicators for dentists to evaluate the masticatory muscles objectively, when supported by further researches.

Ⅴ. CONCLUSION

The decrease of elasticity and the increase of stiffness in masticatory muscles can be seen significantly within 10 minutes after chewing and those were maintained during chewing without significant change with chewing time. The elasticity of muscles was recovered within 10 minutes after stopping chewing, but the stiffness was recovered more lately than elasticity by about 10 minutes. Based on these results, it can be concluded that elasticity and stiffness of muscles would be good indicators to evaluate the masticatory muscles objectively, when more supported by further researches

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국문요약

껌씹기가 저작근의 경도와 탄성도에 미치는 효과

단국대학교 치과대학 구강내과학 교실

원태희 · 김미은 · 김기석

최근 tactile sensor 를 사용하여 근육의 경도와 탄성도를 조사하는 방법이 저작근의 새로운 평가방법으로 제시되고 있다. 본 연구의 목적은 촉각센서를 이용하여 일정시간 껌씹기를 시행전, 중, 후의 저작근의 경도와 탄성도를 조사하여 향후 턱관절 장애 환자의 저작근 평가를 위한 기초자료를 확보하는 데 있다.

건강한 성인 8명을 대상으로 양측 전측두근(anterior temporalis), 하교근(inferior masseter)의 경도와 탄성도를 촉각센서(Venustron II, Axion Co., Japan)를 이용하여 다음과 같이 측정하였다. 피검자들을 unit-chair에 바로 앉힌 상태에서 양측 교근 및 측두근 부위를 촉진을 통해 전 측두근(temporalis anterior), 하 교근(masseter inferior) 두 부위를 펜으로 표시하였다. 실험의 재현성을 위하여 투명한 종이에 ala-tragus line을 표시한 후 두 부위를 투명종이 위에 표시하였다. 편안한 상태에서 촉각센서를 사용하여 양측 하 교근 및 전 측두근의 경도와 탄성도를 측정한 후, 껌(Excellent Breath, Taiyo Co., Japan)을 양측으로 씹게 하여 1초당 2회의 속도로 씹게 하였다. 껌을 40분동안 저작하는 동안 10분, 20분, 30분, 40분에 양측 하 교근 및 전 측두근의 경도와 탄성도를 측정하였다. 그 후 껌을 뱉게 하고 하악의 안정위 상태에서 10분, 20분, 30분, 40분 후 양측 하 교근 및 전 측두근의 경도와 탄성도를 각각 측정하였다. 측정치들을 반복측정 이원분산분석과 다중비교를 통하여 비교하였다.

실험결과 측두근과 교근을 비교 시 탄성도, 경도 모두 교근의 변화가 유의하게 크다. 또한 저작하면 서서히 경도는 증가하며 탄성도는 반대로 감소한다. 탄성도 및 경도는 저작 시 신속히 증가하나 저작 종료 후에는 탄성도만 신속히 회복되나 경도는 약 10분 이상의 일정시간이 지나야 회복된다. 이상의 결과들을 보아 임상적으로 좀 더 다양한 연구와 기초자료가 확보된다면, 저작근의 근육 상태를 평가하는데, 근육의 탄성도와 경도를 조사하는 tactile sensor system은 유익한 기기로서 활용될 수 있을 것이다.

주제어: 껌씹기, Tactile sensor, 경도, 탄성도, 저작근