Muscle Stiffness and Elasticity Related to Physical Therapeutic Modalities

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The purpose of this study was to quantitatively assess treatment effect of physical therapy on experimentally-induced masseter muscle fatigue by two parameters of muscle stiffness and elasticity. Three physical therapeutic modalities inducing electroacupunture stimulation therapy(EAST), Microwave diathermy and low-level laser therapy(LLLT) were compared.

10 healthy volunteers with normal occlusion (mean age of 26.3±1.16 years, M:F=1:1) were participated in this study. All subjects were asked to chew gum on the right side until they felt pain(more and VAS 5 (0 to 10)) and their masseter muscles were examined with a tactile sensor in order to evaluate changes of stiffness and elasticity according to gum chewing and three physical therapeutic modalities. Subjective discomfort or pain was self-estimated by VAS as well. Unilateral gum chewing increased stiffness and decreased elasticity only on the chewing side but VAS increased on the both sides($p<0.05$). EAST or Microwave diathermy greatly decreased stiffness and VAS and increased elasticity($p<0.05$) but LLLT did not exhibit significant difference.

From the results of this study, it is concluded that both EAST and Microwave diathermy have favorable effect on stiffness and elasticity of muscles and pain relief while effect of LLLT is not reliable. In addition, experimental unilateral gum chewing compromises stiffness and elasticity of masseter muscles only the chewing side while subjective discomfort or pain can be felt on the both sides.

Key words : Physical therapy, EAST, Microwave diathermy, LLLT, Stiffness, Elasticity

I. INTRODUCTION

One of the most common orofacial pain conditions is temporomandibular disorders (TMD) which comprises all disturbances associated with the function of masticatory system.[1] Treatment options of TMDs include patient education and self-care, cognitive intervention, physical therapy, orthopedic appliances, pharmacologic therapy, occlusal therapy, and surgery.

Physical therapy is well recognized as an effective,[2] conservative and is routinely used in TMD therapy.[3] A number of physical therapeutic modalities are used to manage pain and dysfunction in patients with TMD and include thermotherapy, coolant therapy, electroacupuncture, transcutaneous electrical nerve stimulation(TENS), and low level laser therapy(LLLT).

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Electroacupuncture is a modified form of the traditional acupuncture. It employs an electrical current to provide a noxious stimulus to an acupuncture point, having the same effect of inducing the release of endorphin into the peripheral circulation, which effectively block the transmission of noxious impulses and thus reduce the sensation of pain.[4)]

Microwave diathermy as one of deep heat therapy has thermal and mechanical effects on the target tissue resulting in an increased local metabolism, circulation, extensibility of connective tissue and tissue regeneration.[4-5)] Its beneficial effects for the patients with TMD include improvement of pain, swelling and range of motion.

Laser is a relatively recent treatment modality in the field of physical therapy. LLLT have biostimulating and analgesic effects through direct irradiation without causing thermal response.[4-6)] Several studies have investigated the efficacy of LLLT therapy in TMD.[7-9)] In spite of some studies demonstrating its clinical effect on TMD, there still existed question of its efficacy

Many researchers investigated the effectiveness of physical therapies by means of variable methods including visual analogue scale(VAS), pain pressure threshold(PPT), range of motion(ROM) and electromyography(EMG). Kim *et al.*[10)] reported that combination treatment of EAST and ultrasound decreased VAS and PPT values and Chung *et al.*[11)] used PPT to show the effects of TENS and EAST. Lee *et al.*[12)] demonstrated the effects of Microwave diathermy and ultrasound using a EMG. While condition of muscle itself has been conventionally evaluated by EMG, a tactile sensor system has been recently tried for this purpose. Through frequency change occurring when the sensor probe of the system met the muscle to be evaluated, its stiffness and elasticity can be conveniently calibrated in real time, which suggests that the tactile sensor can more accurately reflect muscle fatigue than conventional methods.[13)]

The the purposes of this study were to quantitatively assess therapeutic effectiveness of physical therapy on experimentally-induced masseter muscle fatigue by two parameters of muscle stiffness and elasticity and, thus, to compare commonly-used physical therapeutic modalities including electroacupuncture stimulation therapy (EAST), Microwave diathermy and LLLT. It was also evaluated difference in muscle stiffness and elasticity between chewing and non-chewing sides due to unilateral gum chewing.

Ⅱ. MATERIALS AND METHODS

1. Tactile sensor system

A tactile sensor system[14)] used for this study was Venustron®(Axiom Co. Ltd., Japan) as seen in Fig 1. 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.

2. Subjects

10 volunteers(M:F=1:1) were participated in this study. Their mean age was 26.3±1.16 years old. All

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

of them had normal occlusion with Class I occlusion. To minimize the influence on muscle to be evaluated, followings were excluded; those with malocclusion including bimaxillary protrusion, anterior open bite and anterior deep bite; those with TMD; those with tenderness to muscle palpation; those with missing teeth except 3rd molars or extensive bridge-work; those with serious dental caries and periodontal diseases. Other systemic musculoskeletal disorders and dermatologic disease were also excluded. Informed consents for participation in this study were obtained from all the subjects.

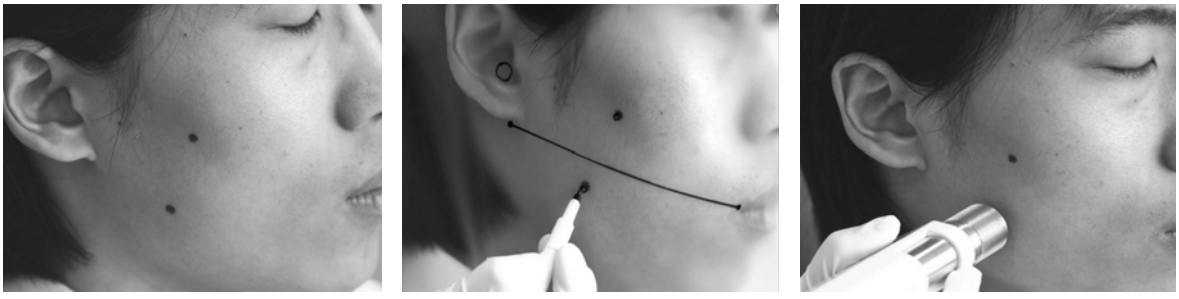
3. Procedure

Muscle examinations with a tactile sensor were performed on anterior and inferior portions of the masseter muscle. Each subject was in seated position at the dental chair with a headrest and anterior and inferior masseter muscle was identified by manual palpation and then two measurement spots were marked with a pen. For the experiment reproducibility in consecutive examination with an interval of a day, ala-tragus line and the two measurement spots of masseter muscle for each subject were transferred to a transparent paper(Fig. 2-A, B).

Prior to gum chewing, the two spots selected for evaluation of masseter muscle were examined bilaterally with a tactile sensor while the subjects were asked to be relaxed (baseline data, Fig 2-C). To induce muscle fatigue experimentally, the subjects were instructed to chew gum(Excellent breath, Taiyo Co. Japan) at right side with a velocity of 2 times per second until he or she felt pain (more than 5 of VAS ranging from 0 (no pain) to 10 (the worst pain)) and the chewing time was recorded.

Muscle stiffness and elasticity was measured right after gum chewing(0 min after chewing) and the examination was repeated after having rest period of 15 minutes (15 min after chewing), which were used as control for comparison of therapeutic effect with three physical treatments to be followed. Rest period of 15 minutes resulted from that the longest time of physical therapy to be compared(i.e., EAST) was supposed to be 15 minutes.

During the following three days, the subjects were asked to chew gum for the time previously recorded and given three physical treatments (EAST, Microwave diathermy and LLLT) respectively in random manner. Muscle examination was done before and after physical treatment and the subjective discomfort or pain was also recorded by VAS. In order to reduce muscle fatigue due to repeated chewing, each experiment was performed with an interval of a day and the subjects were instructed to avoid other chewing during an hour prior to the experiment.



A B C

Fig. 2. Measurement procedure. A) marking at anterior and inferior masseter muscle with a pen, B) marking the ala-tragus line and measuring points on a transparent paper, C) examination of stiffness and elasticity using a tactile sensor.

Physical therapies were done as conventional method. EAST(Pulse later PG-8, Ito Co. Japan) were done for 15 minutes at the aforementioned two muscle spots on the masseter muscle bilaterally with 3 Hz. Microwave diathermy(PM-800, Ito Co. Japan) were applied to the masseter muscle of the chewing side for 8 minutes at 80W and LLLT(Densbiolaser SD-201B Dong Yang medical Co. Korea) at the two spots with 13Hz for 2 min each.

4. Statistical analysis

Muscle stiffness and elasticity between chewing and non-chewing sides was compared with paired t-test. A comparison among three physical therapies were assessed with ANOVA and Multiple Comparison t-tests. P-values of less than 0.05 were interpreted as significant. All the analyses were performed with SPSS windows program(ver 12.0).

Ⅲ. RESULTS

Table 1 shows the changes of the muscle stiffness on the chewing and non-chewing sides after gum chewing and physical therapy. The higher value of stiffness indicates decrease of stiffness of target material and the lower value does increase of that. Significant difference among the groups was found only in the chewing side($p<0.05$). The stiffness measured at 0 min and 15 min after gum chewing increased significantly compared with that before chewing both on the anterior and inferior masseter muscles($p<0.05$), which decreased significantly after application of EAST or Microwave diathermy($p<0.05$). The muscle stiffness after LLLT showed reduced values (that is, increase of stiffness) compared with that before chewing and

Fig. 3. Changes of muscle stiffness after gum chewing and physical treatment.

Table 1. Comparison of muscle stiffness after gum chewing and physical treatment.

		Before chewing	0 min after	15 min after	EAST	Microwave diathermy	LLLT	ANOVA
Chewing side	Ant. Masseter	0.655 ± 0.149 *(a,b,c)*	0.380 ± 0.148 *(a,d,e)*	0.404 ± 0.095 *(b,f,g)*	0.733 ± 0.162 *(d,f,h)*	0.715 ± 0.192 *(e,g,i)*	0.486 ± 0.127 *(c,h,i)*	p=0.000
	Inf. Masseter	0.739 ± 0.213 *(J,k,l)*	0.387 ± 0.096 *(j,m,n,o)*	0.431 ± 0.108 *(k,p,q,t)*	0.786 ± 0.144 *(m,p,r)*	0.773 ± 0.187 *(n,s,t)*	0.541 ± 0.124 *(l,o,q,r,s)*	p=0.000
Non-chewing side	Ant. Masseter	0.577 ± 0.123	0.565 ± 0.131	0.550 ± 0.087	0.599 ± 0.149	0.599 ± 0.112	0.564 ± 0.102	p=0.922
	Inf. Masseter	0.632 ± 0.101	0.590 ± 0.090	0.611 ± 0.084	0.616 ± 0.073	0.609 ± 0.072	0.632 ± 0.101	p=0.895

Significant difference existed between the same alphabets.($p<0.05$, Multiple Comparison t-tests)

after EAST or Microwave diathermy and it was not significantly different from 0 or 15 min after chewing ($p<0.05$)(Fig 3).

It was indicated in Table 2 how elasticity of the masseter muscle related to gum chewing and physical treatment. Like the stiffness, significant difference among the groups was found only in the chewing side($p<0.05$). The muscle elasticity decreased after gum chewing, which lasted even after rest period of 15 minutes, but recovered after EAST or Microwave diathermy($p<0.05$). Elasticity of masseter muscle after application of LLLT demonstrated still decreased values compared with that before chewing and after EAST or Microwave-diathermy($p<0.05$) although the values became higher than that right after chewing($p<0.05$)(Fig. 4).

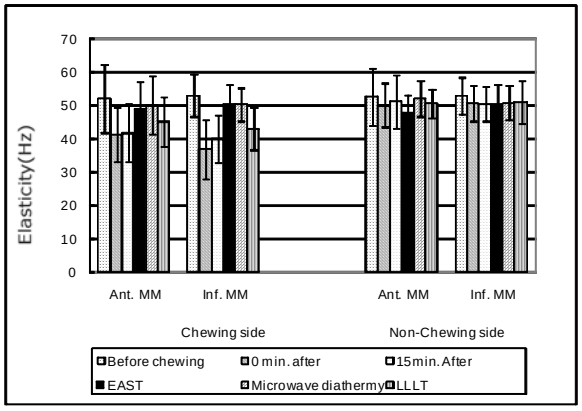


Fig. 4. Changes of muscle elasticity after gum chewing and physical treatment.

Table 3 indicates difference of muscle stiffness and elasticity between chewing and non-chewing sides. Difference of stiffness measured at 0 and 15 min after gum chewing between both sides showed negative values, indicating significant increase on the chewing side compared with non-chewing side($p<0.05$). Although significant difference between both sides still existed after EAST or Microwave diathermy($p<0.05$), this results was due to considerable decrease of stiffness on chewing side, which suggests favorable treatment effect of the two treatment. On the contrary to them, decrease of stiffness on the chewing side after LLLT was not significant. No obvious finding was found for difference of elasticity between chewing and non-chewing sides in this study.

In comparison of therapeutic effectiveness among three treatment methods, as showed in Table 4, significant difference of stiffness and elasticity were found between EAST and LLLT, and between Microwave diathermy and LLLT on the chewing side($p<0.05$). There was no significant difference

Table 2. Comparison of muscle elasticity after gum chewing and physical treatment.

		Before chewing	0 min after	15 min after	EAST	Microwave diathermy	LLLT	ANOVA
Chewing side	Ant. Masseter	51.907 ±10.224 *(A,B,C)*	41.315 ±8.003 *(A,D,E)*	41.683 ±8.624 *(B,F,G)*	49.133 ±7.895 *(D,F,H)*	50.012 ±8.471 *(E,G,I)*	44.934 ±7.374 *(C,H,I)*	p=0.000
	Inf. Masseter	52.949 ± 6.436 *(J,K,L)*	36.855 ±8.833 *(J,P,Q)*	39.972 ±7.104 *(K,R,S)*	50.281 ±5.903 *(O,R,T)*	50.271 ±5.052 *(P,S,U)*	42.890 ±6.278 *(L,Q,T,U)*	p=0.025
Non-chewing side	Ant. Masseter	53.238 ±4.996	52.137 ±8.136	52.438 ±5.229	53.924 ±4.513	53.137 ±5.516	54.200 ±6.864	p=0.969
	Inf. Masseter	51.805 ±4.254	50.420 ±5.291	50.289 ±5.163	51.494 ±5.038	50.699 ±5.144	50.759 ±6.409	p=0.984

Significant difference existed between the same alphabets ($p<0.05$, Multiple Comparison t-tests)

Table 3. Difference of muscle stiffness and elasticity between chewing and non-chewing sides.

		Before chewing	0 min after	15 min after	EAST	Microwave diathermy	LLLT
△Stiffness	Ant. Masseter	0.078 ±0.202	-0.185 ±0.205	-0.146 ±0.138	0.134 ±0.156	0.116 ±0.142	-0.078 ±0.126
	Paired t-test	*p=0.253*	*p=0.019*	*p=0.009*	*p=0.024*	*p=0.030*	*p=0.084*
	Inf. Masseter	0.107 ±0.223	-0.203 ±0.138	-0.180 ±0.138	0.170 ±0.138	0.164 ±0.185	-0.052 ±0.112
	Paired t-test	*p=0.164*	*p=0.001*	*p=0.003*	*p=0.004*	*p=0.021*	*p=0.177*
△Elasticity	Ant. Masseter	-3.588 ±10.159	-6.352 ±12.843	-4.181 ±13.891	-7.360 ±4.623	-4.211 ±9.358	-5.890 ±13.752
	Paired t-test	*p=0.692*	*p=0.154*	*p=0.366*	*p=0.001*	*p=0.188*	*p=0.209*
	Inf. Masseter	-2.967 ±7.776	-9.430 ±11.550	-9.245 ±6.675	-1.213 ±6.070	-0.428 ±4.725	-7.869 ±6.580
	Paired t-test	*p=0.258*	*p=0.03*	*p=0.001*	*p=0.543*	*p=0.781*	*p=0.004*

△=values of chewing side - values of non-chewing side.

Table 4. Comparison of physical therapeutic effect on muscle stiffness and elasticity

		Chewing side		Non-Chewing side	
		Ant. Masseter	Inf. Masseter	Ant. Masseter	Inf. Masseter
EAST* vs Microwave diathermy§	ΔStiffness	0.018± 0.148	0.013±0.119	0.000±0.062	0.007±0.025
	p-value	*0.710*	*0.738*	*1.000*	*0.406*
	ΔElasticity	-2.362±6.100	1.725±7.254	0.787±6.119	-0.205±1.443
	p-value	*0.252*	*0.471*	*0.694*	*0.664*
EAST* vs LLLT§	ΔStiffness	0.247±0.141	0.245±0.109	0.035±0.175	0.023±0.045
	p-value	*0.000*	*0.000*	*0.269*	*0.148*
	ΔElasticity	-1.746±13.790	2.983±9.196	-0.276±4.068	-0.265±4.857
	p-value	*0.040*	*0.002*	*0.835*	*0.867*
Microwave diathermy* vs LLLT§	ΔStiffness	0.229±0.136	0.232±0.207	0.035±0.047	0.016±0.049
	p-value	*0.000*	*0.006*	*0.055*	*0.337*
	ΔElasticity	0.616±10.276	1.258±4.741	-1.063±5.24	-0.060±4.556
	p-value	*0.046*	*0.000*	*0.537*	*0.968*

△=values after * - values after §.

Table 5. Changes of VAS after gum chewing and physical treatment.

		Before chewing	0 min after	15 min after	EAST	Microwave diathermy	LLLT
Chewing side	VAS	0.00 ±0.00	6.40 ±0.84	4.70 ±0.68	1.75 ±1.17	2.30 ±0.95	4.20 ±0.79
	p-value		*0.000*	*0.000*	*0.004*	*0.000*	*0.000*
Non-chewing side	VAS	0.00 ±0.00	2.10 ±2.08	0.80 ±1.62	0.00 ±0.00	0.00 ±0.00	0.70 ±1.34
	p-value		*0.011*	*0.153*	*1.000*	*1.000*	*0.132*

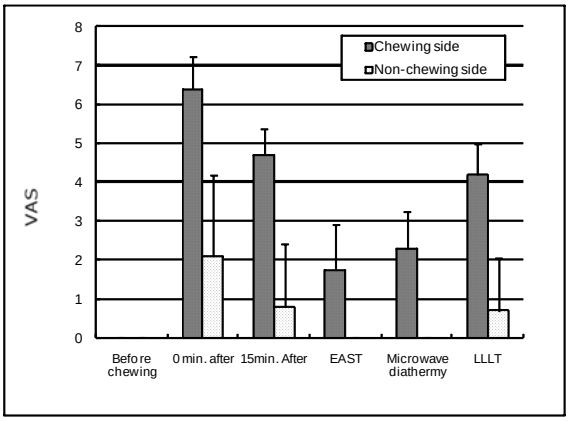


Fig. 5. Change of VAS after gum chewing and physical treatments.

between EAST and Microwave diathermy($p>0.05$). Table 5 shows the change of VAS related with gum chewing and physical therapy. VAS values reported by the subjects increased after gum chewing not only on the chewing side but also on the non-chewing sides, though VAS values on the chewing side was even higher than the non-chewing side. Significant decrease of VAS values for the chewing side was observed after EAST or Microwave diathermy on the chewing side ($p<0.05$), while LLLT did not exhibit noticeable decrease. EAST showed the best effect on pain relief(Fig. 5).

Ⅳ. DISCUSSIONS

A number of physical therapeutic modalities are used to manage pain and dysfunction in patients with TMD and this study was designed to compare their therapeutic effect on the masseter muscles. Out of variable physical therapeutic modalities, electro-acupuncture stimulation therapy(EAST), Microwave diathermy and LLLT were selected to be compared because they are commonly used for TMDs in clinical setting but each has different mechanism of action.

EAST is a modality based on gate control theory and its analgesic action is probably at the entry region in the central nerve system and the supraspinal level.[15] It includes the release of endogenous opioids and other neuromodulatory substances.[16-17] Chung *et al.*[11] reported that EAST can influence on the peripheral sensory nerves and be an effective method to relive pain of orofacial region. Carlson[18] also reported reduced pain intensity of tension type headache patients following acupuncture.

Microwave diathermy is a deep heat therapy modality that uses a magnetron to produce high-frequency electromagnetic energy that is converted heat within the body.[5] There are many evidences showing thermal and mechanical effect of Microwave diathermy on target tissue, resulting in an increased local metabolism, circulation, extensibility of connective tissue regeneration. Microwave diathermy is used especially for pain

relief and muscle extension.[18] According to a study by Lee *et al.*[12] deep heating therapies such as Microwave diathermy and ultrasound decreased pain and masseter muscle activity, so that increased range of motion in the TMD patients.

LLLT is also suggested in the management of TMD through its analgesic, anti-inflammatory, and biostimulating effects. Even though the mechanism of analgesic effect of low-level laser is not well understood, increased pain threshold through alteration of neuronal stimulation and firing pattern and inhibition of the medullary reflexes are thought to be involved.[19,20] Olavi *et al.*[21] reported that LLLT decreased the pain threshold of trigger points on orofacial region in wave length of 940nm. Bezzuur *et al.*[22] indicated that GaAlAs laser irradiation increased regeneration of skeletal muscle pain.

Muscle condition related to gum chewing was evaluated by two parameters of muscle stiffness and elasticity in this study. The muscle stiffness significantly increased on the chewing side just after gum chewing, which was still found at 15 min after gum chewing. The elasticity also changed in the same manner except that it was decreased. It postulated an increase of calcium concentration outside of the sarcopalsmic reticulum possibly due to mechanical rupture of either the sarcoplasmic reticulum or of the muscle cell membrane. A sufficient increase in calcium would maximally activate actin and myosin.[23] After applying EAST or Microwave diathermy, favorable changes of stiffness and elasticity occurred on the chewing side, which was thought to be due to improved blood circulation and extensibility. On the other hand, LLLT effect on muscle fatigue was slight, which can be explained by that LLLT has little thermal and blood circulation effect. Hansen[10] and Callio *et al.*[11] exhibited that LLLT were no effect on chronic orofacial pain or pain after wisdom tooth extraction. According to Gam *et al.*,[24] there is no scientific evidence to show that LLLT can penetrate deeper structure and several studies analysed lead them to conclude that LLLT is not effective in musculoskeletal syndromes(Table 1, 2).

In this study, there were little change of stiffness and elasticity of the masseter muscle on the non-chewing side, which resulted in significant side-to-side difference($p<0.05$)(Table 3). Although several studies indicated compromised masticatory efficiency and occlusal force in most patients with unilateral TMD, it is likely that experimental gum chewing affected only the chewing side. The difference between the chewing and non-chewing sides was relieved after application of all three physical treatment including EAST, Microwave diathermy and LLLT. Although significant side-to-side difference was also found after EAST or Microwave diathermy, this discrepancy is thought to be because excellent effect of EAST and Microwave diathermy decreased greatly stiffness on the chewing side, leading to the lower stiffness than the non-chewing side. Decreased elasticity due to gum chewing on the chewing side was also relieved after EAST or Microwave diathermy, exhibiting no significant side-to-side difference. On the while, significant difference after applying LLLT can be explained by decreased elasticity on the chewing side, suggesting lack of its therapeutic effect.

When pain and discomfort after gum chewing was evaluated by VAS, increased VAS value was found on the chewing side. VAS values on the non-chewing side right after chewing was somewhat increased as well, in spite of no significant difference in stiffness and elasticity of the masseter muscle.(Table 1,2 and 5) The VAS values significantly decreased after EAST or Microwave diathermy but there was still significant difference on the chewing side as compared with those before chewing. On the while, decrease of VAS values after LLLT was not noticeable, which were not quite different from the value at 15min after gum chewing. This finding indicates that VAS values related to gum chewing and physical treatment changed in a similar manner to muscle stiffness and elasticity. EAST showed more favorable effect on VAS values than Microwave diathermy although there was no significant difference of muscle stiffness and elasticity.

From the results of this study, it is concluded that both of EAST and Microwave diathermy have favorable effect on muscle stiffness and elasticity and pain relief but effect of LLLT is not reliable. In addition, experimental unilateral gum chewing compromises stiffness and elasticity of the masseter muscles only the chewing side while subjective discomfort or pain can be felt on the both sides. A further study needs to be performed in patients with masticatory muscle disorders.

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국문요약

물리치료에 따른 근육의 경도와 탄성도 비교

단국대학교 치과대학 구강내과학교실

김 성 환 · 김 미 은

본 연구는 근육의 경도와 탄성도를 측정하여 교근 피로에 대한 물리치료의 효과를 정량적으로 평가하고자 하였으며, 측두하악장애 치료에 가장 흔히 사용되는 물리치료이면서 작용기전은 서로 다른 세 가지 치료법인 전기침자극치료(EAST), 극초단파(Microwave diathermy), 저수준레이저치료(LLLT)의 효과를 비교 하였다.

실험을 위하여 건강한 20대 지원자 10명을 선정하여, 교근의 전부와 하부의 근육 경도와 탄성도를 촉각센서로 측정하였다. 실험적으로 교근 피로를 유발하기 위해 피검자가 VAS (0 to 10) 5 이상의 통증을 느낄 때까지 껌을 씹게 하여 근육 변화를 조사하였으며 치료 없이 15분간의 휴식을 준 다음 다시 검사하여 물리치료 후의 효과 비교를 위한 대조군으로 사용하였다. 하루 간격으로 사흘에 걸쳐 동일한 시간 동안 껌을 씹게 한 다음, 물리치료 한 가지씩을 매일 시행하였으며 3가지 물리치료법의 적용 순서는 무작위로 하였다. 껌 저작 전, 직후, 15분 후, 각각의 물리치료 시행 후에 근육 경도와 탄성도 측정과 함께 피검자들이 느끼는 근육의 피로도를 VAS로 평가하도록 조사하였다.

실험 결과, 저작측에서만 껌 저작 직후와 15분 후에 근육경도의 증가와 탄성도의 감소가 관찰되었으며 ($p<0.05$) 비저작측에서는 유의한 차이가 없었으나 VAS는 저작측과 비저작측 모두에서 증가하였다($p<0.05$). 껌 저작으로 인해 변화되었던 근육경도와 탄성도는 전기침자극치료나 극초단파 치료 후에 효과적으로 회복되고 VAS가 감소했으나($p<0.05$) 저수준레이저 치료 후에는 유의한 변화를 보여주지 않았다.

이상의 결과로 보아, 편측 저작은 저작측 근육의 경도를 증가시키고 탄성도는 감소시키는 반면, 비저작측에서는 변화가 없는 것을 알 수 있다. 또한 전기침자극치료와 극초단파치료는 모두 근육의 경도를 감소시키고 탄성도를 증가시켜 근육의 피로를 감소시키는데 효과적인 치료법인데 반해 저수준레이저치료의 효과는 미약한 것으로 판단된다.

주제어 : 물리치료, 전기침자극치료, 극초단파, 저수준레이저, 근육경도, 근육탄성도