online © ML Comm
www.jkns.or.kr http://dx.doi.org/10.3340/jkns.2015.57.4.283
Print ISSN 2005-3711 On-line ISSN 1598-7876
J Korean Neurosurg Soc 57 (4) : 283-288, 2015

Clinical Article

The Effectiveness of Infrared Thermography in Patients with Whiplash Injury

Young Seo Lee, M.D.,[1] Sung Hwa Paeng, M.D., Ph.D.,[1] Hooman F. Farhadi, M.D.,[2] Won Hee Lee, M.D.,[1] Sung Tae Kim, M.D.,[1] Kun Su Lee, M.D.[1]

Department of Neurosurgery,[1] School of Medicine, Inje University Busan Paik Hospital, Busan, Korea
Department of Neurosurgery,[2] Wexner Medical Center, Ohio State University, OH, USA

Objective : This study aims to visualize the subjective symptoms before and after the treatment of whiplash injury using infrared (IR) thermography.
Methods : IR thermography was performed for 42 patients who were diagnosed with whiplash injury. There were 19 male and 23 female patients. The mean age was 43.12 years. Thermal differences (ΔT) in the neck and shoulder and changes in the thermal differences (ΔdT) before and after treatment were analyzed. Pain after injury was evaluated using visual analogue scale (VAS) before and after treatment (ΔVAS). The correlations between ΔdT and ΔVAS results before and after the treatment were examined. We used Digital Infrared Thermal Imaging equipment of Dorex company for IR thermography.
Results : The skin temperature of the neck and shoulder immediately after injury showed 1–2°C hyperthermia than normal. After two weeks, the skin temperature was normal range. ΔT after immediately injuy was higher than normal value, but it was gradually near the normal value after two weeks. ΔdT before and after treatment were statistically significant (p<0.05). VAS of the neck and shoulder significantly reduced after 2 week (p=0.001). Also, there was significant correlation between ΔdT and reduced ΔVAS (the neck; r=0.412, p<0.007) (the shoulder; r=0.648, p<0.000).
Conclusion : The skin temperature of sites with whiplash injury is immediately hyperthermia and gradually decreased after two weeks, finally it got close to normal temperature. These were highly correlated with reduced VAS. IR thermography can be a reliable tool to visualize the symptoms of whiplash injury and the effectiveness of treatment in clinical settings.

Key Words : Whiplash injury · Infrared thermography · Visual analogue scale · Thermal difference · Pain.

INTRODUCTION

Whiplash injury is a neck injury caused by sudden forward and backward movements of the head during rear-end automobile collisions like the motion of a whip. It is also called cervical sprain or acceleration-deceleration injury[5]. The term of 'whiplash' was first used in 1928 to describe the mechanism of delayed neck injury after motor vehicle accidents[10]. In more past, it was described as spinal concussion[7]. More severe and chronic status is referred as "whiplash associated disorders"[24]. The incidence of whiplash injury is reported to be 28–834/100000 (person) per year[8]. Whiplash injury is mainly caused by rear-end collision but also resulted from head on/side collision. The injury is observed in 40% of traffic accidents but also found after trauma such as diving accidents. Whiplash injury was found in 38% of passengers but other injuries were reported only in 0.7%. Also, cervical spine soft tissue injuries occurred in 16% of traffic accidents and in 38% of rear-end collisions but they increased to 20% when the seat belt was fasten and decreased to 8% otherwise[19]. Cervical spine soft tissue injuries were mainly occurred after low speed rear-end collisions. However, painful experience secondary to these injuries is subjective and it is difficult to visualize the symptom. There is no diagnostic tool to objectively demonstrate these symptoms yet. Therefore, there is a lack of objective data reflecting pain.

This study aims to objectively visualize the neck and shoulder pain and any improvements before and after the treatment of whiplash injury using visual analogue scale (VAS) and infrared (IR) thermography.

• Received : July 8, 2014 • Revised : November 20, 2014 • Accepted : February 2, 2015
• Address for reprints : Sung Hwa Paeng, M.D., Ph.D.
Department of Neurosurgery, School of Medicine, Inje University Busan Paik Hospital, 75 Bokji-ro, Busanjin-gu, Busan 614-735, Korea
Tel : +82-51-898-4244, Fax : +82-51-890-6144, E-mail : shpaeng@empas.com

MATERIALS AND METHODS

IR thermography was performed for 42 patients who were diagnosed with whiplash injury in our hospital between March 2008 and December 2013 (Table 1). Whiplash injury was diagnosed with symptoms, even though it was normal in imaging study. After 2 week conservative treatment, the results of IR thermography and VAS were compared with immediately ini-

Table 1. Patients data

Case	Sex	Age	Etiology	Initial temperature (°C)				After 2 weeks temperature (°C)				Initial VAS		After 2 weeks VAS	
				Neck (Ant)	Neck (Post)	Shoulder (Rt)	Shoulder (Lt)	Neck (Ant)	Neck (Post)	Shoulder (Rt)	Shoulder (Lt)	Neck	Shoulder	Neck	Shoulder
1	F	45	TA	34.15	34.72	34.41	33.89	33.87	34.6	34.05	34.3	8	8	5	3
2	M	41	TA	29.49	29	28.66	29.12	29	28.61	28.54	28.8	7	7	4	3
3	F	50	TA	30.99	31.53	30.69	31.13	30.77	30.52	30.56	30.79	8	7	3	3
4	M	57	TA	38.93	39.35	38.6	38.04	38.3	38.46	37.58	37.4	8	7	2	2
5	M	57	TA	37.01	36.79	36.68	37.27	36.61	36.49	35.94	36.16	7	8	2	3
6	M	54	TA	32.73	32.72	32.08	32.49	31.24	32.14	31.62	31.75	9	7	3	3
7	F	43	FALL	35.14	34.93	34.71	34.32	33.89	34.06	33.89	33.82	9	8	5	3
8	F	54	TA	34.66	34.28	32.58	32.66	33.82	34.27	31.53	31.76	8	8	5	6
9	F	54	TA	35.42	35.17	32.81	32.87	35.12	34.96	31.76	31.94	7	7	4	6
10	F	32	TA	33.93	33.61	33.1	32.61	31.41	31.66	30.31	30.06	8	7	5	3
11	M	38	FALL	33.55	33.12	31.76	31.27	32	32.5	31	30.89	7	8	3	3
12	F	46	TA	29.56	29.34	33.49	33.13	29.3	29	32.91	33	8	7	4	3
13	F	55	TA	31.74	31.39	31.85	31.33	31.15	30.91	31.1	31.01	7	7	2	2
14	M	53	TA	36.58	36.73	36.19	36.27	36.53	36.32	35.57	35.93	8	8	3	5
15	F	46	TA	32.6	32.7	32.89	32.29	31.99	32.39	31.59	31.84	8	8	3	3
16	F	57	TA	35.99	35.75	33.52	32.84	35.01	35.08	32.75	32.48	8	8	3	2
17	F	33	TA	36.12	36.24	31.48	31.02	35.63	35.83	31	30.92	8	8	3	3
18	M	48	TA	35.49	35.41	33.21	33.21	35.17	34.95	31.79	31.49	7	8	2	6
19	M	58	TA	38.72	39.34	38.47	38.99	38.04	38.04	38.38	38.51	8	8	3	3
20	F	31	FALL	35.72	35.39	34.76	34.53	35.32	35	34.01	34.02	9	9	5	5
21	M	26	FALL	39.68	39.42	39.28	39.04	39.19	39.02	38	38	8	8	3	3
22	M	22	FALL	32.19	32.44	32.44	32	31.34	31.1	31.3	31.34	8	9	3	3
23	M	40	TA	30.99	31.53	30.69	31.14	30.77	30.52	30.56	30.79	8	8	5	3
24	F	47	TA	38.92	39.35	38.6	38.01	38.3	38.46	37.58	37.4	7	7	4	3
25	M	31	TA	37.01	36.79	36.68	37.27	36.61	36.48	35.94	36.16	8	7	3	3
26	F	21	TA	33.23	32.72	32.08	32.49	32.24	32.14	31.62	31.75	8	7	2	4
27	F	51	TA	35.14	34.93	34.72	34.32	33.88	34.06	33.89	33.85	7	8	2	2
28	F	37	TA	34.66	34.28	32.58	32.66	33.82	34.26	31.53	31.76	9	7	3	6
29	M	53	TA	35.42	35.17	32.81	32.87	35.11	34.96	31.76	31.94	9	8	5	6
30	F	34	TA	33.95	33.61	33.1	32.61	31.41	31.66	30.32	30.05	8	8	5	4
31	F	27	TA	33.57	33.12	31.76	31.27	32	32.4	31	30.89	7	7	4	3
32	M	49	TA	29.56	29.34	33.49	33.13	29.3	29	32.91	33	8	7	5	3
33	F	51	TA	31.74	31.39	31.86	31.33	31.15	30.91	31.1	31.01	7	8	3	3
34	F	39	TA	36.58	36.73	36.19	36.27	36.53	36.32	35.57	35.93	8	7	4	3
35	M	28	FALL	32.6	32.7	32.89	32.29	31.98	32.39	31.59	31.83	7	7	2	2
36	M	32	TA	35.99	35.76	33.52	32.84	35.01	35.08	32.75	32.48	8	8	3	3
37	M	46	TA	36.17	36.25	31.48	31.02	35.63	35.83	31	30.92	8	8	3	3
38	M	50	TA	35.49	35.41	33.21	33.21	35.17	34.95	31.79	31.49	8	8	3	5
39	F	28	TA	38.73	39.34	38.47	38.99	38.03	38.03	38.38	38.52	8	8	3	4
40	M	58	TA	35.72	35.39	34.76	34.53	35.32	34.66	34.02	34.01	7	8	2	3
41	F	41	TA	39.69	39.43	39.28	39.03	39.17	39.02	38	38	8	8	3	3
42	F	48	TA	32.19	32.44	32.49	32.5	31.34	32.05	31.3	31.31	9	9	5	6

VAS : visual analogue scale

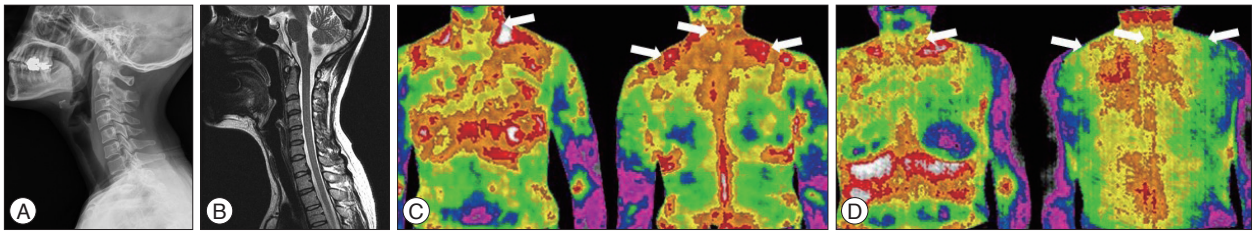

Fig. 1. A 49-year female admitted after in car traffic accident (rear collision), complaining of severe posterior neck pain and shoulder pain, limitation of motion of neck. A : Cervical anteroposterior/lateral X-ray showing straight or kyphotic cervical curvature. B : No abnormality on cervical MRI. C : IR thermography showing 1–2°C thermal elevation than normal value in areas on the neck (34.26, 34.28°C) and shoulder (32.58, 32.66°C) after cervical whiplash injury (VAS 8) (arrows). D : IR thermography showing significantly normal skin surface temperature (neck : 33.82, 33.89°C, shoulder : 31.53, 31.76°C) after 2 weeks management and symmetric state (VAS 4) (arrows). IR : infrared, VAS : visual analogue scale.

Table 2. Thermal difference (ΔT) after whiplash injury

Region (°C*)	Mean±SD (°C)			
	Initial temperature	Mean ΔT† (°C‡)	2 weeks temperature	Mean ΔT†
Neck		0.3±0.16 (0.08±0.56)		0.28±0.19
Ant (32.84±1.35)	34.71±2.72		33.99±2.82	
Post (32.55±1.4)	34.64±2.81		34.03±2.81	
Shoulder		0.38±0.2 (0.14±0.4)		0.16±0.10
Right (31.88±1.47)	33.91±2.57		32.04±2.61	
Left (32.56±1.38)	33.76±2.62		33.08±2.63	

*Normal temperature : normal skin temperature value[29], †Average of the absolute value for thermal difference of each cases, ‡Thermal difference in normal group[29]

tial assessment after injury (Fig. 1).

IR thermography was performed in a room without supply of light and heat. The room with consistent airflow and a low humidity was used for IR thermography. The test was performed without light and heat and the room temperature was maintained at 23–25°C (recorded by the thermometer installed the room or the thermometer of the heating system). We used Digital Infared Thermal Imaging equipment of Dorex company for IR thermography. Subjects kept for about 15–20 minutes without upper garments so that they could accommodate the room temperature and eliminate abnormal thermal differences. All patients were conservatively treated for 2 weeks after initial whiplash injury (bed rest and NSAIDs).

The thermal differences (ΔT) of the anterior and posterior neck and the right and left shoulder were compared to evaluate the symmetry and to obtain basic data. Then the changes in thermal difference (ΔdT) before and after treatment were analyzed. The normal control thermal values were referred to the previous study[29]. Neck and shoulder pain was assessed using VAS immediately after the injury and after 2 week conservative management and the change in difference (ΔVAS) was analyzed. Data was analyzed by paired t-test and bivariate correlation test using SPSS 20 (SPSS Inc., Chicago, IL, USA). Significance was determined when *p* value was less than 0.05.

RESULTS

There were 19 male and 23 female patients and the mean age was 43.12 years (range; 21–58 years). There were 36 cases of traffic accidents and 6 cases of trauma. ΔT of the anterior and posterior neck and the right and left shoulder, and ΔdT in thermal differences before and after treatment were analyzed. In addition, VAS of neck and shoulder immediately after the injury and after 2 week conservative management was measured and ΔVAS were analyzed.

IR thermography results (ΔT & ΔdT)

The initial skin surface temperature was 34.71±2.72°C at the anterior neck, 34.64±2.81°C at the posterior neck, 33.91±2.57°C at the right shoulder and 33.76±2.62°C at the left shoulder. On the completion of 2 week conservative management, the skin surface temperature was 33.99±2.82°C at the anterior neck, 34.03±2.81°C at the posterior neck, 33.04±2.61°C at the right shoulder and 33.08±2.63°C at the left shoulder. The skin temperature of the neck and shoulder immediately after injury showed 1–2°C hyperthermia than normal. After two weeks, the skin temperature was almost normal.

ΔT of the anterior and posterior neck and the right and left shoulder immediately after the injury were 0.3±0.16°C and 0.38±0.2°C, and those after the conservative treatment were 0.28±0.19°C and 0.16±0.10°C, maintaining the symmetry. They didn't exceed the criteria (ΔT<0.5) for test errors or pathologic conditions and were found to be significant (Table 2).

ΔdT was 0.72±0.56°C at the anterior neck, 0.62±0.44°C at the posterior neck, 0.87±0.57°C at the right shoulder and, 0.71±0.57°C at the left shoulder. These changes were statistically significant (p<0.05) (Table 3).

The thermal difference after immediately injury is higher than normal value, but it gradually decreased after two weeks.

VAS results (VAS & ΔVAS)

VAS for neck pain was 7.86±0.65 immediately after trauma and was reduced to 3.43±1.06 after conservative management. VAS for shoulder pain was 7.69±0.6 initially but was also reduced to 3.52±1.23 after conservative management (Fig. 2). VAS of the neck and shoulder were significantly reduced after 2 week and were statistically significant (p=0.001) (Table 4).

Also, Bivariate correlation analysis showed that there was significant correlation between ΔdT of the neck and shoulder and ΔVAS in VAS before and after the treatment (the neck; r=0.412, p<0.007) (the shoulder; r=0.648, p<0.000) (Fig. 3).

Table 3. Changes in thermal difference immediately after whiplash injury and after 2 week conservative management (ΔdT)

	Mean±SD (°C)	p*
	ΔdT†	
Neck (Ant.)	0.72±0.56	0.000
Neck (Post.)	0.62±0.44	0.000
Shoulder (right)	0.87±0.57	0.000
Shoulder (left)	0.71±0.57	0.000

*Wilcoxon signed-rank test<0.05, †Average of the absolute value for change in thermal difference before and after treatment

Table 4. VAS results immediately after whiplash injury and after 2 week conservative management (ΔVAS)

	Mean±SD	p*
	ΔVAS	
Neck	4.43±0.97	0.001
Shoulder	4.17±1.23	0.001

*Wilcoxon signed-rank test<0.05. VAS : visual analogue scale

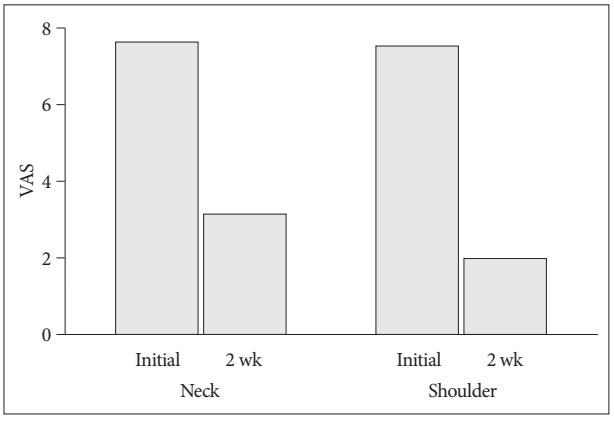

Fig. 2. Changes in VAS after whiplash injury. VAS : visual analogue scale.

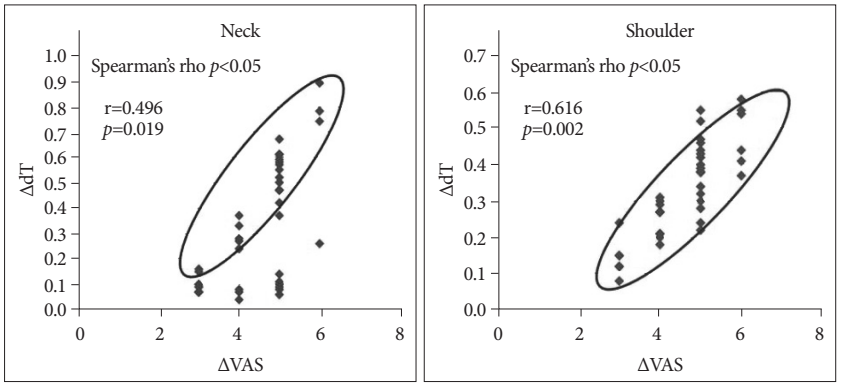

Fig. 3. Correlation analysis between changes in thermal difference and VAS before and after treatment (ΔdT & ΔVAS). VAS : visual analogue scale.

DISCUSSION

With advances in technology and emergency treatment, the diagnosis of whiplash injury has been increasing. Symptoms of whiplash injury are variously reported from simple neck pain to radiating arm pain[28]. However, patients are often undiagnosed or misdiagnosed with ruptured cervical disk even with more specific investigations. This reveals the limitation of diagnostic tools for whiplash injury. It was reported that abnormality was started to show on electromyogram 2 weeks after the injury and then investigations were usually commenced. Thermography is a useful tool to visualize and quantify the symptoms of whiplash injury by measuring skin surface temperature[19]. It is expected that patients will understand better about their condition and any improvement when the imaging is shown. It is also considered to be safer because it doesn't require ionized radiation.

On thermography of a healthy individual without injury, the thermal difference of the anterior and posterior neck and that of the right and left shoulder are trivial, showing symmetric distribution. In a person with injury, there are significant thermal differences. Based on this idea, thermography was developed and first used for the diagnosis of breast cancer[15]. Thermography is a useful tool that provides objective guidelines for the diagnosis and treatment of pain and the effectiveness of thermography has been evaluated in several studies[1,22]. Wexler[27] first utilized thermography to evaluate pain, there were cold areas on the affected side of the patients with traumatic cervical syndrome and abnormal skin surface temperature related to spinal problem was identified as hypothermia. The majority of traumatic cervical syndrome was sprain in his study.

In studies with myofascial pain syndrome, it was reported that trigger points on thermography could be appeared as either 5–10 cm of hot spots or cold spots[14]. Furthermore, some studies reported that there were no thermal differences of both sides. Despite of that, it is generally accepted that areas of pain are usually shown as hot spots and areas of nerve damage are detected as hot spots during the acute phase and cold spots during the chronic phase. The diagnostic sensitivity of thermography was high when trigger points were detected as hot spots[9,11,14].

Our study was conducted with patients with whiplash injury who complained neck pain and shoulder pain

only. Previous studies on the natural history of whiplash injury are mostly small retrospective studies. During a collision, the 6th cervical vertebral body extends upwards as the body moves upwards and the segments above the 6th cervical vertebrae flex at first, creating S-shape. Then the upper segments extend. Extension and flexion are worst 50–100 ms and 100–200 ms after a collision. The lowest collision speed which can cause whiplash injury is estimated to be 8 km/hr. In a head-on collision, the driver's torso and head snap forward and the neck flexes. The movement of head is decelerated by the neck, and the occipitoatlantal joint and the 6th cervical vertebrae are involved in the deceleration force. Then the head and the neck extend due to the elastic force of the occipital and cervical structures. At this point cervical hyperextension cause tissue damages[9,12,20]. It is important fact that neck is passively moved regardless the direction of the shock. Due to this passive movement, cervical muscle loses an opportunity to prepare for the shock and acquires injury secondary to eccentric contraction[4]. Sixty percent of the whiplash injury symptoms are neck pain and headache originated from cervical spine and 50% of them are occurred at the 2–3th cervical vertebrae[17,24].

There have been a number of studies about the mechanism of whiplash injury which help understand the symptoms. In fact, hot spots were detected on the affected area on thermography immediately after whiplash injury[19]. It was estimated that the thermal increase was resulted from inflammation, local vasodilation and the secretion of chemical messengers [substance P, calcitonin gene-related peptide, nitric oxide (NO)] from nerve endings in response to painful stimuli[3].

Inflammatory sites are always shown as a hot spot. Acute inflammation facilitates the secretion of substance P from nerve endings and increases vasodilation and vascular permeability escalating the effects of nerupeptides such as bradykinin and histamine. This inflammation-induced activation aggravates the inflammation itself and pain. In addition, local perfusion is increased by NO produced by nerve stimulus or humoral factors and regulatory chemical messengers, resulting in an increase of skin surface temperature[2]. This means that the degree of high temperature indicating the acute inflammation reflects the intensity of the vicious cycle of pain. Therefore, during this period, anti-inflammatory agents and steroids will be effective to manage the symptoms and local anesthetics or radiofrequency nerve block can be administered to stop the vicious cycle of pain[13,18,21].

Generally, mild and moderate whiplash injury improves after 2 week conservative management with cervical brace, which alleviates the symptoms and helps the recovery, and the administration of anti-inflammatory agents and analgesics[6]. The prognosis has been inconsistently reported. Some reported that patients were completely recovered whereas others reported that the symptoms continued for several years. Compensation neurosis may be accompanied and some even files for a lawsuit[23]. In this case, visualization of changes in skin surface temperature at painful areas using thermography will help provide the evidence of suffering and any improvement as well as establish treatment plans.

Likewise there were no abnormalities in diagnostic imaging studies in our study. Once diagnosed with whiplash injury, the subjects were treated with absolute rest, anti-inflammatory agents and steroids. After 2 weeks, the symptoms were improved in most of the patients. To objectify subjective symptoms and any improvements, thermography was used. On thermography, skin surface temperature was becoming lower to the normal and symmetric imaging was created. We established treatment plans and follow-up based on the thermography results.

However, there were some limitations in our study. The first limitation is possible selective bias secondary to limited selection of patients. The observation period was short because the subjects were selected from in-patients and the sample size was also not many because there were few patients with only whiplash injury, because this study was conducted in a university hospital where more complex patients are dealt with. In addition, patients with grade 1–2 whiplash injury (Quebec classification) were only included in this study. This selection criterion was determined because it is difficult to perform thermography and to communicate with patients if there are severe cervical injuries causing other organ damages. So, we took a long time to recruit patients.

The role of IR thermography is still limited as a diagnostic tool because it is doubtful that thermography is able to identify the entire characteristics of neurogenic dysfunction and disability. The significance of this study is that subjective pain (expressed in VAS score) was objectively quantified with thermography (the comparative analysis of thermal differences before and after the treatment) under the same condition for a certain period of time. In this study, bias from asymmetric distribution was eliminated because the average thermal differences of the anterior and posterior neck and the right and left shoulder were about 0.16–0.3°C which did not exceed 0.5°C[16,25,26]. Furthermore, the thermal differences measured after 2 week treatment were very close to the normal skin surface temperature ($\Delta T<0.3°C$)[26]. Therefore, it was judged that thermography was performed according to the standard guidelines. The changes (ΔdT) of thermal differences greater than 0.5°C in this study were also found to be significant. Thus, comparing thermal differences using thermography will aid the understanding and evaluation of pain and undefined painful condition and it can be used in the case of a lawsuit. It is also expected that combined use with VAS will also assist the evaluation and quantification of treatment.

CONCLUSION

The skin temperature of sites with immediate whiplash injury is hyperthermia and gradually decreased after two weeks, it got close to normal temperature. These are highly correlated with reduced VAS. Symptoms of whiplash injury are highly varied

and some of them are not yet pathophysiologically explained. Although it seems that IR thermography is non-specific and has limited benefits, it can be used as a useful evaluation tool in undefined painful disorders such as whiplash injury because it is able to show objective data about pain experience and improvement.

• Acknowledgements

This work was supported by a grant from research year of Inje University in 2013.

References

1. Ammer K, Schartelmueller T, Melnizky P : Thermal imaging in acute herpes zoster or post-zoster neuralgia. **Skin Res Technol 7** : 219-222, 2001
2. Anbar M : **Quantitative Dynamic Telethermometry in Medical Diagnosis and Management.** Florida : CRC press, 1994, pp13-35
3. Anbar M, Gratt BM, Hong D : Thermology and facial telethermography. Part I : history and technical review. **Dentomaxillofac Radiol 27** : 61-67, 1998
4. Barnsley L, Lord S, Bogduk N : The pathophysiology of whiplash in Malanga GA (ed) : **Spine : State of the Art Reviews**. Philadelphia : Hanley & Belfus, 1998, pp209-242
5. Bogduk N : The anatomy and pathophysiology of whiplash. **Clin Biomech (Bristol, Avon) 1** : 92-101, 1986
6. Bogduk N : Treatment of whiplash injuries in Malanga GA (ed) : **Spine : State of the Art Reviews**. Philadelphia : Hanley & Belfus, 1998, Vol 12, pp469-483
7. Breasted JH : **The Edwin Smith Surgical Papyrus. Published in facsimile and hieroglyphic transliteration with translation and commentary in two volumes.** Chicago : The University of Chicago Press, 1930
8. Cassidy JD, Carroll LJ, Côté P, Lemstra M, Berglund A, Nygren A : Effect of eliminating compensation for pain and suffering on the outcome of insurance claims for whiplash injury. **N Engl J Med 342** : 1179-1186, 2000
9. Chen HB, Yang KH, Wang ZG : Biomechanics of whiplash injury. **Chin J Traumatol 12** : 305-314, 2009
10. Crowe HD : **Whiplash injuries of the cervical spine in proceedings of the section of insurance negligence and compensation law**. Chicago : American Bar Association, 1928, pp76-84
11. Fischer AA : Documentation of myofascial trigger points. **Arch Phys Med Rehabil 69** : 286-291, 1988
12. Grauer JN, Panjabi MM, Cholewicki J, Nibu K, Dvorak J : Whiplash produces an S-shaped curvature of the neck with hyperextension at lower levels. **Spine (Phila Pa 1976) 22** : 2489-2494, 1997
13. Gunzberg R, Spalski M : **Whiplash injuries : current concepts in prevention, diagnosis and treatment at the cervical whiplash syndrome**. Philadelphia : Lippincott-Raven, 1998, pp283-291
14. Kwon OJ, Yu KS, Lee YG : Trigger points : clinical implications of digital infrared thermographic imaging. **J Korean Acad Rehabil Med 15** : 527-533, 1991
15. Lawson R : Implications of surface temperatures in the diagnosis of breast cancer. **Can Med Assoc J 75** : 309-311, 1956
16. Lim KJ : Pain and Thermography. **J Korean Pain Soc 17 (Suppl)** : S29-S35, 2004
17. Lord SM, Barnsley L, Wallis BJ, Bogduk N : Chronic cervical zygapophysial joint pain after whiplash. A placebo-controlled prevalence study. **Spine (Phila Pa 1976) 21** : 1737-1744; discussion 1744-1745, 1996
18. Lord SM, Barnsley L, Wallis BJ, McDonald GJ, Bogduk N : Percutaneous radio-frequency neurotomy for chronic cervical zygapophyseal-joint pain. **N Engl J Med 335** : 1721-1726, 1996
19. Paeng SH, Jung YT, Pyo SY, Kim MS, Jeong YG : Is the use of digital infrared thermal imaging useful in whiplash injury? **Korean J Spine 6** : 274-279, 2009
20. Panjabi MM, Cholewicki J, Nibu K, Grauer JN, Babat LB, Dvorak J : Mechanism of whiplash injury. **Clin Biomech (Bristol, Avon) 13** : 239-249, 1998
21. Pettersson K, Toolanen G : High-dose methylprednisolone prevents extensive sick leave after whiplash injury. A prospective, randomized, double-blind study. **Spine (Phila Pa 1976) 23** : 984-989, 1998
22. Pochaczevsky R, Wexler CE, Meyers PH, Epstein JA, Marc JA : Liquid crystal thermography of the spine and extremities. Its value in the diagnosis of spinal root syndromes. **J Neurosurg 56** : 386-395, 1982
23. Smith J, Everett CR : Prognosis after whiplash-related injury in Malanga GA (ed) : **Spine state of the Art Review**. Philadelphia : Hanley & Belfus, 1998, pp287-300
24. Spitzer WO, Skovron ML, Salmi LR, Cassidy JD, Duranceau J, Suissa S, et al. : Scientific monograph of the Quebec Task Force on Whiplash-Associated Disorders : redefining "whiplash" and its management. **Spine (Phila Pa 1976) 20 (8 Suppl)** : 1S-73S, 1995
25. Uematsu S : Symmetry of skin temperature comparing one side of the body to the other. **Thermol 1** : 4-7, 1985
26. Uematsu S, Edwin DH, Jankel WR, Kozikowski J, Trattner M : Quantification of thermal asymmetry. Part 1 : Normal values and reproducibility. **J Neurosurg 69** : 552-555, 1988
27. Wexler CE : Thermographic evaluation of trauma (spine). **Acta Thermographica 5** : 3-10, 1980
28. Zhang HY, Cho BY, Kim HS, Cho YE : Thermo-graphic diagnosis of whiplash injury with/without radiculopathy. **Key Eng Mater 321-323** : 845-848, 2006
29. Zhang HY, Kim YS, Cho YE : Thermatomal changes in cervical disc herniations. **Yonsei Med J 40** : 401-412, 1999