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ORIGINAL ARTICLE

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THE EFFECT OF THE THERAPEUTIC WHIRLPOOL ON THE VISCOELASTIC PROPERTIES OF THE SKIN

Tüzün FIRAT[1*], Burcu Semin AKEL[2], Çiğdem Öksüz[3]

ABSTRACT

Purpose: Changes in the skin function after whirlpool application have not previously been investigated. The aim of the study was to investigate the effects of the therapeutic whirlpool on the biophysical properties of the skin in healthy individuals.
Method: 24 healthy individuals (12 women, 12 men) received therapeutic whirlpool for 20 minutes, 5 days per week in every day and 48 hands were evaluated in this prospective cohort study. Skin elasticity, moisture, transepidermal water loss (TEWL), pH and temperature were measured before the first session, after the first session and after the fifth session. The measurements were taken from the palmar and dorsal side of the hand.
Results: On the volar side, the elasticity and the temperature did not change after treatment (p=0.054 and 0.100). TEWL and pH increased while the moisture decreased after the first session (p<0.016). The pH was also high after the last session (p=0<001). On the dorsal side, the moisture did nod change (p=0.105). TEWL increased after first session and decreased after last session (p<0.016). The pH increased soon after the first session and after the 5th session (p<0.016). The elasticity decreased after the first session (p<0.016). Lastly, the temperature was found to decrease between 2nd and 3rd measurements (p=0.033).
Conclusion: According to our results, whirlpool leads the loss of the skin barrier function in healthy individuals and the skin should be protected soon after therapeutic whirlpool. Electrophysical agent applications such as electrical stimulation to be applied after whirlpool should be planned carefully.
Keywords: Whirlpool Baths, Water Loss, Insensible, Skin, Temperature

ÖZET

Amaç: Girdap banyosu uygulamasından sonra cilt fonksiyonlarındaki değişiklikler daha önce araştırılmamıştır. Çalışmanın amacı, sağlıklı bireylerde terapötik girdap banyosunun cildin biyofiziksel özellikleri üzerindeki etkilerini araştırmaktı.
Yöntem: Bu prospektif kohort çalışmasında 24 sağlıklı bireye (12 kadın, 12 erkek) haftada 5 gün, her gün 20 dakika boyunca terapötik girdap banyosu uygulandı ve 48 el değerlendirildi. Cilt elastikiyeti, nem, transepidermal su kaybı (TESK), pH ve sıcaklık ilk seanstan önce, ilk seanstan sonra ve beşinci seanstan sonra ölçüldü. Ölçümler elin palmar ve dorsal tarafından alındı.
Sonuçlar: Volar tarafta, elastikiyet ve sıcaklık tedaviden sonra değişmedi (p=0.054 ve 0.100). İlk seanstan sonra nem azalırken TESK ve pH arttı (p<0.016). Son seanstan sonra da pH yüksekti (p=0<001). Elin dorsal tarafında nem değişmedi (p=0.105). TESK ilk seanstan sonra arttı ve son seanstan sonra azaldı (p<0.016). pH ilk seanstan hemen sonra ve 5. seanstan sonra arttı (p<0.016). Elastikiyet ise ilk seanstan sonra azaldı (p<0.016). Son olarak, sıcaklığın 2. ve 3. ölçümler arasında azaldığı görüldü (p=0.033).
Sonuç: Sonuçlarımıza göre girdap banyosu, sağlıklı bireylerde cilt bariyer fonksiyonunda kayba yol açmaktadır. Terapötik girdap banyosundan hemen sonra cilt korunmalıdır. Girdap banyosu sonrası uygulanacak elektrik stimülasyonu gibi elektro fiziksel ajan uygulamaları dikkatle planlanmalıdır.
Anahtar Kelimeler: Girdap Banyosu, Deri Sıcaklığı, Su Kaybı, Hidroterapi

[1]Professor, Hacettepe University, Faculty of Physical Therapy and Rehabilitation, Hand Surgery and Rehabilitation Unit, 06100, Ankara, Türkiye

[2]Professor, Istanbul Kultur University, Faculty of Health Sciences, Department of Physiotherapy and Rehabilitation, İstanbul, Türkiye

[3]Professor, Hacettepe University, Faculty of Health Sciences, Department of Occupational Therapy, 06100, Ankara, Türkiye

*Corresponding author e-mail: tuzun@hacettepe.edu.tr

INTRODUCTION

Heat therapy is the application of heat to the body resulting in increased tissue temperature. Physiological effects of heat therapy include pain relief, increases in blood flow and metabolism, and increased elasticity of connective tissue. Superficial modes of heat therapy include hot water bottles, heat packs, heat wraps, hot towels, paraffin, steam, and therapeutic whirlpool (1).

Of these, therapeutic whirlpool has additional effects than other heating methods due to pressurized hot water and constant heat level. Whirlpool show its physiological effects through conduction and convection (2). The transfer of heat is a result of the conduction process. The physiological process results with sweating of the tissue, increasing blood circulation and metabolic heat and heat dissipation via hair above the skin surface (3). Although it is not practical as hot packs, hot towels, hot water bottles; therapeutic whirlpool have an advantage over other methods for increasing ROM due to the ability to perform motion during the heating process while still allowing for an even distribution of heat (4). Moreover, therapeutic whirlpool acts like an analgesic agent; it relaxes muscle spasm, relieves joint pain and stiffness, facilitates exercise, and is also used for wound care to remove necrotic tissue (5, 6). In all physiological therapeutic processes, the skin is an important interface and the function of the skin is necessary for the thermal effect to occur.

Skin behavior after heat therapies have been investigated in a few studies. Igaki et al, investigated the skin heat conduction under moist and dry heat conditions to confirm the influence of moist heat on the skin and subcutaneous region. The stratum corneum started swelling and thickened immediately after 0.5 min of exposure to moist heat, and this swelling continued thereafter. In contrast, no change was noted in the thickness of the stratum corneum under the dry heat condition (7). Similarly, Petrofsky et al showed that skin moisture was significantly changed with an increase of 43.7% after moist heat application (8). In another study of Petrofsky et al, skin moisture and temperature were evaluated after whirlpool. The skin moisture did not change after application. However, when they applied a plastic barrier to the skin, skin moisture increased significantly (9).

The skin's barrier is the frontline in stopping the infiltration of harmful agents and infectious pathogens (10). The outermost layer of the skin serves as a protective barrier, blocking harmful environmental substances, bacteria, and viruses from entering the body, while also preventing water loss from the skin's surface (11). In order for the skin barrier to function, it is important to know the viscoelastic properties of the skin. Biophysical measurements of the skin include moisture, temperature, trans-epidermal water loss (TEWL), pH and elasticity are important techniques for investigating skin’s viscoelastic function in vivo (3, 12-14). These techniques also provide information about the barrier function of the skin. TEWL which is an indirect measure of skin permeability used to assess stratum corneum integrity and barrier function in health and disease (15). Skin moisture also plays an important role in maintaining healthy skin, with lack of moisture causing dryness and making the skin less supple (16).

Although whirlpools are well-known thermal agents affecting the subcutaneous tissue and deeper layers, changes in the skin function after whirlpool application have not previously been investigated. The aim of this study was to determine the effects of the therapeutic whirlpool on the biophysical properties of the skin. We hypothesized that skin function altered after therapeutic whirlpool.

METHODS

The study was conducted at Hacettepe University, Faculty of Physical Therapy and Rehabilitation. All participants signed an informed consent form prior to participation.Senior class university students from the Faculty of Physical Therapy and Rehabilitation were included to the study. The study was announced in the faculty with posters, the ones interested and volunteered to the study contacted one of the researchers. They were all informed about the study and evaluated to be sure if they were eligible according to inclusion criteria. Subjects with a history of diabetes, heat or cold intolerance, Raynaud’s phenomenon, sleep disorders and peripheral nerve

pathology were not included in the study. A brief medical history was taken from each subject to note conditions that might affect autonomic function. Twenty-six voluntary students (12 male, 14 female) volunteered to the study; two female subjects did not meet the inclusion criteria. At last, 24 healthy students with an age range of 21-24 years participated in the study. The 48 hands of the 24 subjects were evaluated.

Subjects were instructed to limit strenuous physical activities including running 4 hours before their appointment to minimize variations in body temperature caused by the effects of exercise. Before the first measurement, they were rested for 30 minutes at the experiment room in a seated position with their hand and forearm uncovered for achieving dry skin conditions and acclimatization. During the measurement of skin properties, the subjects sat in front of the investigator with their arm resting on the table. Skin tests were performed at 20-22°C and with 20-40% room humidity.

Immersion in a warm whirlpool was done by asking the subjects to place both their forearms and hands in a whirlpool tub maintained at 43°C for approximately 20 min in one session. This immersion was repeated 5 consecutive days in a week to see the cumulative effect of the whirlpool treatment session (17, 18). Thus, the study was conducted between Monday and Friday. The temperature was closely monitored with a battery-operated digital thermometer. The water temperature was checked prior to the immersion for each subject. Kuligowski et al. reported in 1998 that warm whirlpool application can be performed at 35.0ºC and 43.3ºC (19). In the current literature, applications are mostly performed at 35.0ºC - 40.0ºC. However, the applications are on disease groups such as distal radius fracture, flexor tendon injuries, knee osteoarthritis, pressure ulcers and systemic sclerosis (20-24).To our knowledge, there is no study conducted on healthy individuals. Since our study was conducted on healthy individuals, we performed an application at the upper limit of the temperature range mostly applied in the current literature.

Biophysical measurements of the skin include moisture, temperature, trans-epidermal water loss (TEWL), pH and elasticity are important techniques for investigating skin function in vivo. These techniques provide information on skin barrier function. A Cutometer MPA 580 (Courage+Khazaka, Cologne, Germany) device was used for measuring skin elasticity, TEWL, moisture, pH and temperature. Different probes were used for each parameter. The skin elasticity measuring principle was based on the suction method. Skin elasticity was evaluated with a Cutometer® MPA 580 (CK Electronics), an instrument to assess the skin's elastic properties using suction and elongation. Using a 2-mm probe, a negative pressure of 450 mbar was applied to the skin for a period of 2 second, followed by a 2 second relaxation time. Portion between the maximum amplitude and the ability of re-deformation of the skin (gross elasticity), the closer the value is to 1 (100%), the more elastic the curve (25). The depth of penetration of the skin into the aperture is determined using a noncontact, optical measuring system (26). The recovery behavior of the skin following suction was evaluated with this reliable method (27). TEWL was assessed based on measurement of the water evaporation amount in a chamber system. The barrier function of the stratum corneum was assessed by measuring TEWL (g/m2h) using the Tewameter® TM 300 (Courage+Khazaka). Higher evaporation values showed more water loss. It’s reliability was shown by Pinnagoda et al (28) . Skin surface hydration (moisture) was determined by Corneometer® CM 825 (Courage+Khazaka) and showed as capacitance value which was displayed in arbitrary units (AU) by the instrument. The equipment was calibrated before each testing according to the manufacturer's instructions. The skin moisture measurement was based on skin capacitance and higher values showed more water content (29). Skin surface pH was measured using the Skin pH Meter® PH 905 (Courage+Khazaka). The pH meter was calibrated daily prior to measurement using two standard buffers at pH 4.0 and 7.0. The electrode was washed with distilled water before each measurement (28). Skin temperature (using Skin-Thermometer ST 500) was measured by Multi Probe Adapter (MPA, Courage + Khazaka electronic GmbH, Germany) (30).

Measurements were performed 3 times: First measurement was performed before the first whirlpool treatment session; second measurement was performed 20 minutes after the first

whirlpool treatment session and third measurement was performed after the fifth treatment session. Skin measurements were taken from the palmar side of the 2nd metacarpophalangeal joint for the volar side, and the dorsal surface of the 1st web space for the dorsal side of the hand (31). Same researcher performed all the measurements which were performed 3 times and mean values were used for the analysis.

Statistical Analysis

Statistical analyses were performed using the IBM SPSS version 20. The variables were investigated using visual (skewness, kurtosis, histogram analysis) and analytical methods (Kolmogorov-Simirnov test and detrended plot analysis) revealed that data distribution was nonparametric. Friedman tests were conducted to test whether there is significant change in skin parameters. Statistical significance value was accepted as lower than 0.05 ($p<0.05$). The Wilcoxon signed rank test was used to test the significance of pairwise differences using Bonferroni correction to adjust for multiple comparisons. After Bonferroni corrections, p value lower than 0.016 was accepted as significant difference.

RESULTS

The values of volar and dorsal skin properties between all measurement results were summarized in Table 1.

Changes in the skin viscoelastic properties on the volar Side of the hand

There were no differences on elasticity ($p=0.054$) and temperature ($p=0.100$) values between the measurements. TEWL values were different between the tests ($p=0.012$). Post-hoc analysis showed that TEWL increased after first session. Similarly, moisture decreased after first session ($p=0<001$). Additionally, skin pH was found higher after first session and at the end of 5th session ($p=0<001$) according to the post-hoc analyses.

Changes in the skin viscoelastic properties on the dorsal side of the hand

There was no difference on moisture on the dorsal side of the hand after treatment ($p=0.105$). Although elasticity showed difference between the measurements ($p=0.003$), post-hoc analysis did not discriminate the difference. TEWL measurements were different between all measurements (1st-2nd, 1st-3rd, 2nd-3rd) according to the post-hoc analyses ($p=0<001$). pH values increased soon after first session and after 3rd session ($p=0.004$). Lastly, temperate was found decreased between 2nd and 3rd measurements ($p=0.033$).

DISCUSSION

Our results showed that skin loses its water content after whirlpool application. In addition to the increased TEWL, the increase in skin pH even after the 5th treatment session is the one of the important results of our study. On the other hand, moisture is decreased after single session of whirlpool application. These findings indicate that the skin barrier function is disturbed after whirlpool application. Dorsal and volar side of the hand showed different features in terms of elasticity and moisture. Skin temperature did not change significantly after application.

Many sectors use whirlpool baths for skin beauty, pedicures or relaxation besides as a physical agent in rehabilitation. Meeker et al have reported that whirlpool baths provide the physiological benefits of heat that can promote healing (17). Self-healing and healing kinetics can be described in terms of viscoelastic behavior. The promoted self-healing can be attributed to the improved flexibility of macromolecules with a proper agent. Hydration reduces the relative portion of linear elasticity compared with viscosity, and results in the swelling of biopolymer (32). In our study skin elasticity showed a little increase right after application only from the dorsal side of the hand. Sar et al. did not find difference between Laser, ultrasound and matrix rhythm therapy in terms of skin elasticity (33). We may say that physical agents used in rehabilitation setting may not influence skin elasticity. The skin temperature did not increase significantly with whirlpool. Although, this is a response of skin during thermoregulation process, we expected little increase in temperature. The unexpected finding on skin elasticity and temperature has questioned the terminology used for heat modalities.

Table 1. Change in skin properties after whirlpool application between measurements.

Side of Hand (N=24)	Parameter	1st measurement X±SD	2nd Measurement X±SD	3rd measurement X±SD	x^2	p
Volar	Elasticity	0.08 ± 0.02	0.07 ± 0.02	0.07 ± 0.02	5.853	0.054
	TEWL	61.64 ± 22.51	71.57 ± 19.94	64.31 ± 22.65	8.792	**0.012**[a]
	Moisture	92.90 ± 21.58	68.99 ± 24.55	77.06 ± 27.01	37.625	**<0.001**[a]
	pH	5.79 ± 0.32	6.19 ± 0.46	6.26 ± 0.51	32.639	**<0.001**[a,b]
	Temperature	29.54 ± 4.25	30.77 ± 3.99	29.07 ± 5.24	4.597	0.100
Dorsal	Elasticity	0.18 ± 0.06	0.20 ± 0.05	0.18 ± 0.06	11.645	**0.003**
	TEWL	16.52 ± 6.88	42.74 ± 41.35	27.02 ± 12.61	52.817	**<0.001**[a,b,c]
	Moisture	33.19 ± 16.62	31.11 ± 9.89	37.50 ± 18.03	4.508	0.105
	pH	5.98 ± 0.33	6.10 ± 0.95	6.23 ± 0.45	11.124	**0.004**[a,b]
	Temperature	31.21 ± 2.14	31.71 ± 2.26	30.02 ± 2.92	6.802	**0.033**[c]

1st measurement: Before whirlpool bath, 2nd measurement: 20 minutes after whirlpool bath on the same day, 3rd measurement: Measurement after 5th session; [a] Difference between first and second assessment (Post-hoc analysis), [b] Difference between first and third assessment (Post-hoc analysis), [c] Difference between second and third assessment (Post-hoc analysis)

Whirlpool is one of the most commonly preferred superficial heat applications in hand rehabilitation used for the treatment of joint stiffness, scars, and adhesions as a hydrotherapeutic method based on the physiological effects of water and this effect is widely attributed to elasticity (34, 35). Whirlpool therapy can increase range of motion by stimulating the muscle spindles and Golgi tendon organ (36). However according to our study it is not accurate to conclude that whirlpool relaxes stiffness via the increased temperature or due to superficial location of target tissue like skin elasticity (34). Studies discuss hot-water immersion following exercise to elicit heat acclimation in athletes (37). It may be beneficial to investigate if whirlpool would activate healing with hydration after exercise. This may provide an implication for rehabilitation protocols. Petrofsky et al. mentioned decreased temperature after whirlpool when the application region was uncovered (9). They found that the application region kept its temperature when it was covered with a plastic moisture barrier before the whirlpool application. Our decreased moisture and increased TEWL values may also explain the consistency in the temperature level. Based upon these findings, it can be hypothesized that keeping the moisture is essential to maintain the temperature of the skin. We can also say that it is not enough to measure only skin temperature to understand the thermo-effect of an agent. TEWL and pH values were consistent in both sides of the hand, therefore gave important findings. These biophysical properties measured in the study play a significant role in maintaining the protective characteristic of the skin. The skin becomes more prone to damage and infection if the acid mantle becomes disrupted or damaged, or loses its acidity (38). TEWL values increase proportionately to the level of damage (39). When the skin's moisture barrier is lost, there is an increase in both the normal bacteria present in the body and pathogenic bacteria (18). These biophysical skin parameter changes would cause the loss of the skin barrier, leading to easier penetration of irritants and more susceptibility to infections. The main finding of our study is increased skin TEWL and pH together with decreased moisture after one and five session of whirlpool application which means skin becomes more prominent to damage or infection.

The pH reflects the molar concentration of hydrogen ions in solution (40). Therefore, the rise in skin pH after whirlpool treatment can be a result of the loss of water content. Skin pH is influenced by many factors including age, sebum, anatomic site, sweat and moisture (18) . It is also reported that increased sweating rate can affect the skin pH (41) . Regardless of the exact reason, it is obvious that the barrier function of the skin is disturbed after whirlpool application, as also supported by increased TEWL values. Petrofsky et al. compared the effect of a dry heat source with two different moisture heat sources on skin temperature and skin blood flow. He found that moisture heat sources including the whirlpool increases the skin temperature more, cause a more rapid drop in skin temperature, and lead to a larger decrease in skin blood flow (9). The larger decrease in the skin blood flow may result in loss of water.

The skin barrier disruption findings have some clinical implications. In a healthy skin these are reversible normal reactions, however in individuals with diabetes, reflex sympathetic dystrophy, and sensitive skin; whirlpool should be used in awareness of its effect on skin properties. It must be also discussed or investigated to use any agent or material that can disturb the skin like splints, vibration, exercise materials, taping right after whirlpool application.

The biophysical response of the volar and dorsal sides of the hand was different after whirlpool application. In our study, it was shown that there was a significant increase in humidity on the volar side of the hand and a decrease in temperature on the dorsal side immediately after whirlpool application. Autonomic functions on the dorsal and volar side of the hand are innervated by different nerves. The difference in the autonomic functions of median and radial nerves may be the reason as the measurements were taken from two different dermatomes. Fırat mentioned that the radial nerve differs from the median and ulnar nerves in terms of motor, sensory and autonomic functions (34). The dense distribution of sweat glands in the palm of hand in contrast with the dorsum can also be one of the causes (35). Therefore, these differences should be taken into consideration when examining the autonomic functions of the hand.

This study emphasized the effects of whirlpool application in only healthy volunteers without any trauma or peripheral nerve lesions involving the hand. The effect of a whirlpool bath on skin properties following trauma should also be noted in the future studies like peripheral nerve injuries which skin water content decreases as a nature of the injury (23, 36). It is a limitation of our study that we could not measure the duration of the changes in skin property to show the longtime effects of whirlpool baths. Another limitation of our study was to not to determine of recovery of the duration moisture and TEWL after whirlpool application.

Our findings should be considered for hand rehabilitation even if our study sample consisted of healthy subjects. Pseudomonas aeruginosa is reported as a highly evolved pathogen that is common cause of nosocomial infections, especially with hydrotherapy (9). On the other hand whirlpools may be contraindicated for clean granulating wounds, epithelializing wounds, migrating epidermal cells, new skin grafts, and new tissue flaps but according to our study results it should also be taken into account that healthy skin can also be open to infection, not only because of hygiene-related problems such as unclean water or tank but also the immediate effect of the whirlpool application on the skin. It should be noted that the reason of infections may not only be the hygiene problems of whirlpool baths but also the change in skin properties including the barrier function. We can conclude that some moisturizing topical agents should be used soon after whirlpool. Moreover, whirlpool generally used before other physical therapy modalities such as neuromuscular electrical stimulation (NMES). But some NMES applications involving galvanic current may be harmful after whirlpool due to decreased water content of the skin. Therefore, we do not recommend using especially galvanic based NMES applications soon after the whirlpool applications.

CONCLUSION

The application of therapeutic whirlpool baths reduces the protective function of the skin. The loss of function seen in healthy subjects in our study suggests that the application should be reconsidered when planning the application in patients with skin involvement (e.g. denervation, complex regional pain syndrome, rheumatological diseases affecting the skin). In addition, it should be considered that

electrophysical agents such as neuromuscular electrical simulation used after the application may have adverse effects on the skin. We believe that some time should be allowed after the whirlpool to preserve the viscoelastic properties of the skin and for other supportive treatments to be appropriate.

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