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Biomechanical Properties of the Skin on the Dorsal Trunk in Young Men

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Abstract: The skin is composed of high molecular weight fibers such as collagen and hyaluronic acid and has a barrier function against mechanical stimulation. On the other hand, the elasticity and viscoelasticity of the skin are essential functional factors in the relationship between skin and body movements. Of the main components of the skin, collagen is involved in shape maintenance and elastin is involved in elasticity. The skin's biomechanical properties differ from site to site due to the content of these components and the arrangement of fibers. The trunk is the largest in the human body, and the trunk's skin affects not only inherent trunk movements but also limb movements. In this study, the skin on the dorsal trunk is divided in detail and the biomechanical properties of each site are compared and examined. Fifteen healthy young men (21.9 ± 0.4 years) participated in the study. The measurement zone was divided into 5 equal parts from the upper end to the lower end, 4 equal parts between the left end and right ends, and 20 (4×5) blocks in total. The measurements of skin biomechanical properties were conducted by using the help of Cutometer[®] MPA 580. The results of this study express a specific distribution of elasticity and viscoelasticity in the skin on the dorsal trunk. Regarding the biomechanical properties of the dorsal trunk, viscoelasticity was significantly lower on the caudal side than on the cranial side and significantly lower on the lateral side than the medial side. There was a tendency for the elasticity to be significantly higher on the lateral sides than the medial side. The findings of this study suggest the relationship between the biomechanical properties of the skin of the dorsal trunk and the movements of the limb as well as trunk movements.

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1. Introduction

The skin is the largest organ in the body; the area of the adult skin is approximately $1.6\text{--}1.9\text{ m}^2$ [1]. The skin is located in the outermost of the body, and it serves as the boundary between the lateral side and inside. Therefore, the skin protects and helps keep humans healthy by guarding the whole body against external mechanical stress, maintaining body fluid balance, regulating body temperature, and sensing organs and immune functions. Protection against

external mechanical stress is done by the reversible deformation mechanism in response to mechanical stimuli such as stretching and compression stress [2]. This mechanism is performed by skin elasticity. The skin can be stretched way above its original size. It can return to its original size, maintaining its original physical properties after being stretched [3–5]. The elasticity of the skin is an important factor in normal joint movement. Therefore, reduced elasticity and extensibility of the skin under pathological conditions is likely to result in limited range of motion. Keloid

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and hypertrophic scars following burn injuries and surgeries affect the elasticity and extensibility of the skin and become limiting factors for joint movement [6, 7]. In animal experiments, decrement in skin extensibility by long-term joint fixation causes a limited range of motion [8].

Thus, when focusing on the relationship between the skin and body movements, it is necessary to understand the biomechanical properties of the skin related to stretching and sliding properties. The skin has a three-layer structure mainly composed of epidermis, dermis, and subcutaneous tissue. The main components are collagen and elastin. Collagen is involved in body shape maintenance, and elastin is involved in elasticity restoration. There are plentiful of these in the dermis. It is known that the arrangement of collagen and elastin is not constant throughout the body and has a specific direction in each body part [12]. Langer line, Wrinkle line, and Relaxed skin tension line, etc., (i.e., skin line) indicate the arrangement and orientation of collagen and elastin. They are used as criterion for skin incision direction to early and neatly recovering surgery wound [13].

The trunk, which is the largest of the body parts, plays an important role in all movements because it is involved in not only the inherent movements of the facet joints and thorax but also the movements of the upper and lower limbs. Likewise, trunk motions have triaxiality movements (flex-extension, lateral bend, and rotation), and the trunk motions are combined for daily activities like walking, lifting, reaching, and so on. Therefore, the skin of the trunk is required to stretch and slide in various directions during body movements. The skin line of the dorsal trunk is different in cranial and caudal levels, and it is arranged diagonally or longitudinally at the thoracic spine level and horizontally at the lumbar spine level [14]. When considering the relationship between limb movements and trunk's skin dynamics, it is expected that upper and lower limb movements are more closely related to the skin on the lateral side of the trunk than on the medial side. In the cranial and caudal level of the trunk, not only is the thoracic spine but the rib cage and scapula are also located on the cranial side, so the extension direction of the skin on the cranial level is different from that on the caudal level. It is thought that the regional difference in the direction in which the dorsal trunk skin is stretched by body movements is associated with differences in

biomechanical properties of the skin between the parts on the dorsal trunk.

Thus, the biomechanical properties of the skin are involved in the dorsal trunk skin dynamics required for trunk inherent movements and limb movements. However, no reports have shown the relationship between the skin biomechanical properties and body movements. Skin line is the direction in which skin elasticity affects broadly in total and does not indicate the difference in biomechanical properties due to the detailed distinction of body parts. Although there are some reports on skin biomechanical properties about age-related changes and lesion sites [15–17], few basic data reported the characteristics of biomechanical properties in the skin site [16]. Thus, the relationship between the biomechanical properties of each skin part and body movements are also poorly understood.

Therefore, in this study, we focused on the skin of the dorsal trunk and measured the biomechanical properties. The reason for choosing the dorsal trunk as the measurement part was that the shape of the trunk is flat, and the measurement zone can be divided quantitatively, which makes it possible to maintain high measuring reproducibility compared to the limbs. The dorsal side was chosen because the range of motion of the trunk in flexion is greater than that in extension, and the dorsal trunk is the part that is stretched during flexion, which is thought to have a stronger effect on skin biomechanical properties than the ventral side. Based on the characteristics of body movements peculiar to the trunk, it was hypothesized that biomechanical properties of the skin are different in each block by dividing the dorsal trunk in detail. Furthermore, since the biomechanical properties of the skin include not only elastic but also viscous elements, it is necessary to study the viscoelastic property that binds these elements. From a kinematic viewpoint, the tension associated with the elasticity of the skin is often noticed, but deformation resistance to mechanical stimuli as a passive tissue is also important. Particularly, since it is necessary to suppress excessive movement of the lumbar region in relation to the preventions of kyphosis and low back pain, fixation and stability to movement are required and it is essential to consider the viscous factor of the skin. Due to improvement in the functions of measuring instruments, this study investigated the skin biomechanical properties to distinguish between elasticity and viscoelasticity.

2. Methods

2.1 Subject

Since the skin biomechanical properties were greatly affected by gender and aging, the subjects of this study were 15 young adult males that had no history of back skin and motor disorders of the trunk to eliminate their effect. The subjects of age were 21.9 ± 0.4 years, the height was 1.7 ± 0.1 m, the weight was 69.8 ± 10.4 kg, and body mass index was 24.0 ± 3.0 . At the start of the experiment, the purpose, method and content of this study were explained to all subjects and consent was obtained to participate in the experiment. The protocol was conducted according to the declaration of the Helsinki Principles and approved by the ethics committee of Teikyo University of science (Approval No. 14041).

2.2 Measurement of skin viscosity and elasticity

The evaluation of skin biomechanical properties was conducted on the dorsal trunk. The measurements were conducted using suction method with the help of Cutometer[®] MPA 580, made by Courage + Khazaka Electronic GmbH in Germany, a probe of 8-mm hole, and 400 mbar of suction per second. The Cutometer[®] is a non-invasive tool by suction method that facilitates analysis and characterization of the functional state of the skin. The measurement environment were controlled (temperature 26 ± 2 °C and humidity ranging $35 \pm 5\%$). At every measurement, the skin biomechanical properties were represented using a curve of deformation according to time. The exploration probe made a vacuum through a suction obtained at constant negative pressure (400 mbar). The curve was recorded by sucking up a section of skin for 2 s and

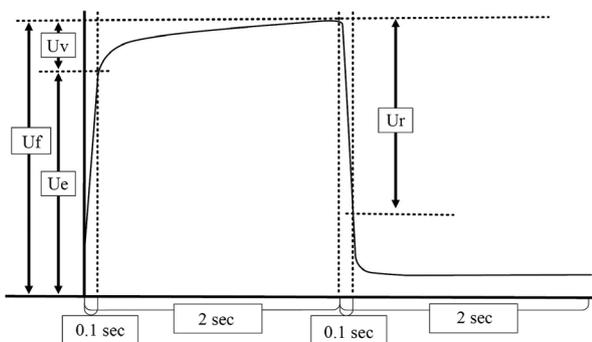


Fig. 1 Skin deformation curve and measurement parameters due to the Cutometer[®]
 Ue: Skin extensibility, Uv: Delayed distension,
 Uf: Final deformation, Ur: Immediate retraction

then releasing the skin for 2 s (Fig. 1). Subjects were in the prone position on the treatment table (Sakai Medical Co., Ltd.), the head and neck were in the median position, and the limbs were in the anatomical position.

The measurement zone was divided into 5 equal parts from the upper end to the lower end, 4 equal parts between the left end and right end, and 20 (4×5) blocks in total, defining the line connecting both acromions at the upper end, the line connecting both iliac crests at the lower end, and the perpendicular line through both iliac crests at the left end and right end (Fig. 2).

The cranial-caudal side of the measurement zone was the first to the fifth rows from the cranial side, and the medial-lateral side were the two rows near the midline on the medial side and the other rows on the lateral side. The measurement was performed four times at random near the center of each block, without placing the probe at the same site. The measurements in this study were performed by the same examiner who was skilled in measuring with the Cutometer[®].

For the analysis of the data measured using the Cutometer[®], R6 and R7 were used. R6, which was calculated by Uv/Ue in Fig. 1 is the ratio of displacement delay to the extension immediately after suction. R6 represented the viscoelasticity of the skin [18]. R7 was calculated by Ur/Uf in Fig. 1 and was the degree of returning to the original position when the

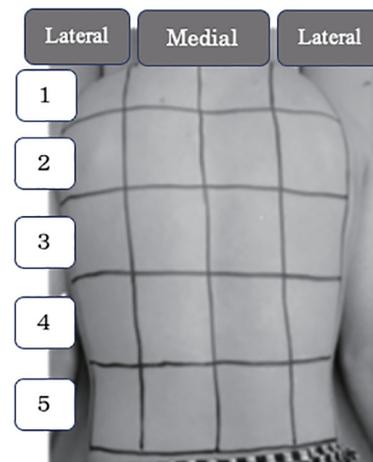


Fig. 2 Measurement zone

The measurement zone is divided into 5 equal parts from the upper end to the lower end, 4 equal parts between the left end and right end, and 20 (4×5) blocks in total, defining the line connecting both acromions at the upper end, the line connecting both iliac crest at the lower end, and the perpendicular line through both iliac crests at the left end and right end.

suction pressure was set to zero in the skin deformed by suction. R7 demonstrated the elasticity of the skin and was used as an index when evaluating changes in skin elasticity with age [18]. In this study, R6 was defined as the viscous resistance value associated with skin stretching, and R7 was defined as the elastic value when the skin shortened. In R6, the higher the value, the higher the viscoelasticity. The closer the value of R7 is to 1, the higher the elasticity (Fig. 1).

2.3 Statistical analysis

Firstly, for R6 and R7, the Shapiro–Wilk test ($p > 0.05$) was performed to confirm the normality of the variables. To analyze the medial side and lateral side, the weighted average values of the left and right sides of the medial side and lateral side were calculated. After that, a two-way analysis of variance (ANOVA) was conducted for the medial-lateral factor, and the caudal-cranial factor in five rows. If a significant main effect was observed on the medial-lateral side, paired t-tests were conducted to compare the difference in mean values ($p < 0.05$), and on the cranial-caudal side, Tukey’s multiple comparison test was conducted to compare the difference in the mean values of five groups ($p < 0.05$). Furthermore, as a measure of the practical relevance of significance, effect size was calculated using η^2 for a two-way ANOVA and Hedge’s g for paired t-tests. SPSS 21.0 (IBM Japan) was employed for statistical analysis and Microsoft Excel was used to calculate each effect size.

3. Results

Tables 1 and 2 project the mean and standard deviation of each block of the dorsal trunk for R6 and R7, which were measured values related to skin biomechanical properties. The results of a two-way ANOVA for R6 and R7 were shown in Tables 1 and 2. As a result, a significant main effect medial-lateral factor was observed for both R6 ($F [1, 140] = 50.05$, $p < 0.001$, $\eta^2 = 0.22$) and R7 ($F [1, 140] = 8.63$, $p < 0.01$, $\eta^2 = 0.06$). Regarding the caudal-cranial factor, the main effect was observed in R6 ($F [4, 140] = 8.58$, $p < 0.001$, $\eta^2 = 0.15$), but not in R7 ($F [1, 140] = 1.52$, $p = 0.199$, $\eta^2 = 0.04$). No interaction was observed in either R6 ($F [4, 140] = 0.76$, $p = 0.552$, $\eta^2 = 0.01$) or R7 ($F [4, 140] = 0.73$, $p = 0.573$, $\eta^2 = 0.02$). The results of paired t-tests for the medial-lateral factor showed that R6 was significantly lower on the lateral side than on the medial side ($p < 0.001$, Hedge’s $g = 1.06$), and R7 was significantly higher on the lateral side than on the

Table 1 R6 mean and standard deviation (SD) by zone

zone	medial	lateral	Mean \pm SD
1	0.46 \pm 0.07	0.35 \pm 0.07	0.41 \pm 0.06
2	0.41 \pm 0.09	0.33 \pm 0.06	0.37 \pm 0.07
3	0.38 \pm 0.08	0.31 \pm 0.09	0.35 \pm 0.10 [†]
4	0.37 \pm 0.05	0.30 \pm 0.07	0.33 \pm 0.06 [†]
5	0.34 \pm 0.05	0.28 \pm 0.03	0.31 \pm 0.04 ^{†‡}
Mean \pm SD*	0.39 \pm 0.06	0.32 \pm 0.05	0.35 \pm 0.05

As a result of a two-way ANOVA for R6, a significant main effect was observed on the medial-lateral factor and the caudal-cranial factor, respectively. Paired t-tests were conducted to compare the difference in mean values of medial and lateral, and * indicates a statistically significant difference, $p < 0.001$. On the caudal-cranial factor, Tukey’s multiple comparison test was conducted to compare the difference in the mean values of five groups, and † indicates a statistically significant difference in zone 1, $p < 0.001$ and ‡ indicates a statistically significant difference in zone 2, $p < 0.01$. No significant interaction between caudal-cranial factor and medial-lateral factor was observed for these variables.

Table 2 R7 mean and standard deviation (SD) by zone

zone	medial	lateral	Mean \pm SD
1	0.69 \pm 0.09	0.74 \pm 0.09	0.71 \pm 0.09
2	0.70 \pm 0.09	0.76 \pm 0.09	0.73 \pm 0.08
3	0.70 \pm 0.08	0.71 \pm 0.08	0.71 \pm 0.08
4	0.70 \pm 0.08	0.71 \pm 0.08	0.70 \pm 0.08
5	0.72 \pm 0.08	0.78 \pm 0.06	0.75 \pm 0.07
Mean \pm SD*	0.70 \pm 0.08	0.74 \pm 0.09	0.72 \pm 0.08

As a result of a two-way ANOVA for R7, since a significant main effect was observed on the medial-lateral factor, paired t-tests were conducted to compare the difference in mean values of medial and lateral, and * indicates a statistically significant difference, $p < 0.01$. No significant interaction between caudal-cranial factor and medial-lateral factor was observed for these variables.

medial side ($p < 0.01$, Hedge’s $g = 0.48$). From the result, it was shown that viscoelasticity was lower and elasticity was higher on the lateral side than on the medial side. Regarding the caudal-cranial factor of R6, the value decreased from the higher part of the dorsal trunk to the lower part. Regarding multiple comparisons of caudal-cranial factor in R6, differences were observed in the combinations of the first and third to the fifth columns ($p < 0.001$ in all pairs), and the second and fifth columns ($p < 0.01$). In these combinations, the caudal region exhibited a

significantly lower value than cranial, indicating that the caudal region had substantially lower viscoelasticity than the cranial region.

4. Discussion

The skin, which covers the entire body, is the largest tissue in the body, and mechanical features such as tension affect body movements. However, although there have been some reports on the overall elastic properties of each body part, such as the Langer line [13], there have been no reports on the biomechanical properties of the skin by dividing the body parts in detail.

To understand the relationship between trunk skin and body movements, we examined the skin mechanical characteristics of the dorsal trunk. On that account, the trunk was divided into five divisions on the cranial side and four divisions on the medial-lateral side, and their skin mechanical characteristics were compared. From the results of this study, the viscoelasticity of the dorsal trunk in the resting position was lower on the caudal side than on the cranial side and lower on the lateral side than the medial side. Regarding elasticity, there was no difference in the cranial direction, and it was higher on the lateral side than the medial side. From the characteristics of the measuring instruments used in this study, "viscoelasticity" indicates velocity-dependent resisting power, and "elasticity" indicates the recovery rate per unit time. Therefore, these results show that the caudal side of the dorsal trunk is easy to change shape, and the lateral side of the dorsal trunk is easy to change shape and return to its original form.

Of the trunk, the joint movement of the lumbar spine has a large range of motion in flexion and extension and few in rotation. However, in the thoracic spine, the range of motion of flexion and extension is minute and the range of motion of rotation is relatively large [19]. These are due to the structural characteristics of the facet joints of the lumbar and thoracic vertebrae. A previous study using magnetic resonance imaging shows that the skin of the lower lumbar spine is displaced compared with the upper thoracic spine when the trunk is flexed [20]. This difference in skin movements at the thoracic and lumbar levels are relevant to this result. In this study, the trunk is divided into five equal intervals in cranial and caudal direction, and the

upper two sections correspond to the thoracic spine (the third section corresponds to the thoracolumbar junction), and the two sections from the caudal side conform to the lumbar spine. Therefore, it is considered that the difference between the cranial side and caudal side in the viscoelasticity of the skin in this result reflects the difference in the joint movement characteristics of the thoracic spine and lumbar spine.

In the horizontal direction, the viscoelasticity was lower, and the elasticity was higher on the lateral side of the trunk than on the medial side. Regarding skin elasticity, a previous study using a device that measures the propagation velocity of sound waves reported that skin elasticity is high in the direction along the Langer line [21]. In Langer line on the dorsal trunk, the running on the lateral side is horizontal, and the results of this study are related to this finding.

This tendency of the distribution of these skin biomechanical properties is suggested to be related to the upper limb reach movement and the upper and lower limb movements in walking, which are the most typical movements in humans. The elastic force of passive tissues, such as the Achilles tendon, is used in repetitive movements such as walking, and it is an important factor from the viewpoint of energy efficiency [22]. Since reaching and walking involve trunk movements, this elastic force of the lateral trunk skin may be regarded as an auxiliary element in kinematics in the repetitive movements of the upper and lower limbs during walking. The low viscoelasticity on the lateral side of the dorsal trunk is related to the ease of movement, and the high elasticity is associated with the ease of returning to the original position (median position) in the movement of the upper limbs in daily activities.

However, the low viscoelasticity on the lateral side of the trunk also indicates easy stretching during body movements than other parts. This seems to be related to the fact that the axilla is a frequent site of scarring. Since it is thought that scarring of a wound, which is the cause of scarring contracture, is related not only to the skin component of the wound site but also to the extension stimulus to the site [23], the ease of the stretch associated with low viscoelasticity is thought to be the cause of scarring. As a clinical example, the surgical wound scar on the axilla after mastectomy for breast cancer is known to cause shoulder joint contracture [24].

The results of this study showed that there is a

specific distribution of elasticity and viscoelasticity in the skin on the dorsal trunk. This result suggests the elasticity and viscoelasticity of the skin on the dorsal trunk are associated with the characteristics of spinal movement and trunk function. Previous studies showing the relationship between body movements and skin dynamics on the trunk reported [20, 25–28]. Other than the trunk, there is a study on skin sliding of the lower limbs due to the lateral movement of the pelvis [10]. It was reported that the characteristics of skin movement associated with the body movements are the effect of the elastic characteristics of each part of the skin [28]. The fact that the skin biomechanical properties differ depending on the site is essential in understanding the meaning of skin biomechanical properties for body movements.

However, it is unclear from this study whether the elasticity and viscoelasticity of the skin has high or low values in the site where joint mobility is high. Additionally, it would be difficult to show how the biomechanical properties of the skin on the dorsal trunk observed in this study affect the three-dimensional characteristics of the joint motion of the trunk. Therefore, exhibition of the fundamental meaning of skin biomechanical properties for body movements as a study should be conducted in the future. It will be possible to examine the functional significance of the biomechanical properties of the skin for body movements by analyzing the degree of skin stretching during various body movements. Moreover, since elasticity and viscoelasticity include not only the degree of stretch of the skin but also the time elements, the fact that there is a specific distribution of these parameters in the skin on the dorsal trunk in this study suggests that it is necessary to examine not only the amount and direction of body movements but also qualitative factors such as exercise speed.

The limitations of this study are that the subjects were healthy adult males. Therefore, it is unknown whether the findings of this study are applicable to females, the elderly, or people with disabilities. In particular, the elderly may differ from the findings of this study because skin composition changes with age. Therefore, it is necessary to clarify these points in future studies.

5. Conclusions

The results of this study express a specific

distribution of elasticity and viscoelasticity in the skin on the dorsal trunk. The viscoelasticity was significantly lower on the caudal side than on the cranial side and significantly lower on the lateral side than the medial side. There was a tendency for the elasticity to be significantly higher on the lateral sides than the medial side. These results show that the shape of the caudal side of the dorsal trunk is relatively easy to change, and the shape of the lateral side of the dorsal trunk is easy to change and return to its original shape. In this study, the fact that the biomechanical properties of the skin on the dorsal trunk were different depending on the site predicts the relationship between the biomechanical properties of the skin and trunk movements as well as the movements of the limb.

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