EXPERIMENTAL APPROACH FOR SKIN DISPLACEMENT WITH KINESITHERAPY APPLICATION

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ABSTRACT
Introduction: Pathological changes in the subcutaneous connective tissue can be detected through inspection and palpation. The mobility of the superficial and deep skin layers can be assessed by attempting to displace the skin or by forming a skin fold. The present study aimed to develop an experimental model and create a prototype for measuring skin displacement (SKD) with the application of kinesitherapy. Methodology: The experimental procedure included three stages. As a result, a device for measuring SKD was created, allowing for separate measurements of both hands. The accuracy of the measured skin displacement is 0.5 mm, determined by the use of the Chronojump displacement sensor. Results and Conclusions: Based on the obtained results, several key conclusions were drawn. An experimental approach for assessing SKD in the context of kinesitherapy was developed, and a dedicated experimental bench for measuring SKD was constructed. Calibration and verification of the device were completed through testing with twenty-two real patients, focusing on the L5 spinal zone. All participants exhibited a statistically significant increase in SKD on the right side of the spine. The quantitative data related to SKD have strong kinesitherapeutic and clinical applications and may contribute to the development of a mathematical model describing the mechanical behavior of the skin.

Keywords: *experimental bench for skin displacement, calibration, verification*

INTRODUCTION

Studying how skin behaves under different loads is essential for improving various medical and cosmetic procedures—such as plastic surgery, skin grafting, wound healing, and tissue expansion. The skin is one of the largest and most important organs in the human body. It protects against harmful microorganisms and chemicals, as well as excessive water loss (Lakhani et al., 2021).

The skin consists of three main layers: the outer layer (epidermis), the middle layer (dermis), and the inner layer (subcutaneous tissue). Of these, the dermis plays the greatest role in skin strength and resilience. It contains collagen and elastin fibers, along with a ground substance composed mainly of water and special molecules known as proteoglycans (Lakhani et al., 2021; Kwon et al., 2021).

Elastin fibers provide flexibility and enable the skin to return to its original shape when stretched slightly. Collagen fibers, on the other hand, are engaged under greater loads and are primarily responsible for the skin's strength and durability. They also determine how the skin responds in different directions—a phenomenon known as anisotropy (Lakhani et al., 2021; Baumann et al., 2021).

Palpation is a fundamental method used for therapeutic intervention, diagnosing tissue conditions, and evaluating treatment outcomes in kinesitherapy, massage therapy, osteopathy, and related fields. Analysis of palpation reveals that it involves two types of sensory perception: tactile sensation (touch) and kinesthetic sensation (proprioception). Furthermore, palpation relies both on the therapist's actions and the patient's physiological feedback, which complicates reproducibility (Takeda et al., 2025).

The palpation method is inherently subjective, and most commonly used tests lack standardization and objective, quantitative assessment of skin displacement (SKD) in centimeters. This limits the ability to compare results, evaluate the effectiveness of interventions, and ensure consistent therapist training.

According to the principles of segmental-reflex therapy, functional and structural changes in internal organs (known as primary pathological foci) are reflected through reflex changes in the

superficial tissues—such as the skin, connective tissue, muscles, and periosteum—which form what are called secondary pathological foci. These changes occur along the segmental reflex arc and are accessible to manual manipulation and therapeutic intervention.

In turn, the secondary pathological focus can also exert a negative influence on the affected internal organ via the same segmental reflex arc, thus creating a pathological reflex cycle. Detecting changes in the superficial tissues and eliminating them through appropriate methods and techniques interrupts this cycle and supports the body's recovery processes.

Changes in the subcutaneous connective tissue can be detected through visual inspection and palpation, during which the mobility of the superficial and deep skin layers is assessed either by attempting to displace the skin or by forming a skin fold.

A review of the scientific literature reveals a lack of practical devices capable of objectively measuring SKD and extensibility in a clinical setting. Nevertheless, various experimental approaches exist for studying and analyzing the mechanical properties of the skin. A new vacuum-based measurement device developed, calibrated, and implemented by Lakhani et al. (2021) enables in vivo measurement of the human skin's mechanical stress–strain response in all planar directions using a single test. This device applies an axially symmetric load to estimate the apparent toe moduli and apparent linear moduli in all planar directions. In contrast, traditional elastic modulus measurement systems require multiple tests to account for anisotropy (Deroy et al., 2017; Jacquet et al., 2017; Zhang et al., 2018).

Additionally, two objective methods for assessing tissue deformation (compliance) have been described: one based on vacuum application to measure skin consistency in the spinal region of healthy children and adults (Hogeweg et al., 1993), and another using a compression tissue compliance meter for documenting soft tissue pathology (Fischer, 1987). However, neither device provides information about skin extensibility and mobility, which are typically assessed through palpation by observing SKD (Dosch et al., 2007). On the other hand, Martire et al. (2025) proposed a simulation of an innovative device to determine optimal stiffness for developing a silicone patch capable of measuring skin hardness in a standardized and reliable manner across different anatomical areas and under various conditions. Similarly, Raitt et al. (2024) investigated how a pressure-modulated optical tracking sensor can use compliance control to quantify tissue stiffness and detect margins in samples through dynamic palpation. Despite these developments, there remains a need for a portable device capable of quantitatively assessing SKD in millimeters during palpation. The development of a device that objectively measures skin extensibility and mobility would contribute to the standardization of research in this field, improve data comparability, and enhance the training of young professionals.

This study aims to create an experimental model of an innovative, portable device for objectifying SKD as a diagnostic method used in manual therapies, such as massage, kinesitherapy, and osteopathy.

METODOLOGY

The experimental approach included three stages. First, a drawing prototype was created, on which the main support points of the proposed mechanical device were schematically marked (Figures 1 and 2). When designing this drawing, the following important factors determining the outcome were taken into account:

- convenience and functionality for the person performing the test procedures;
- target area of palpation – the back;
- speed and ease of processing the obtained quantitative data;
- cost-effectiveness of implementation;
- mobility of the device, allowing tests in different locations;
- possibility of conducting tests under energy-independent conditions – prolonged operation using only the laptop's autonomous power supply.

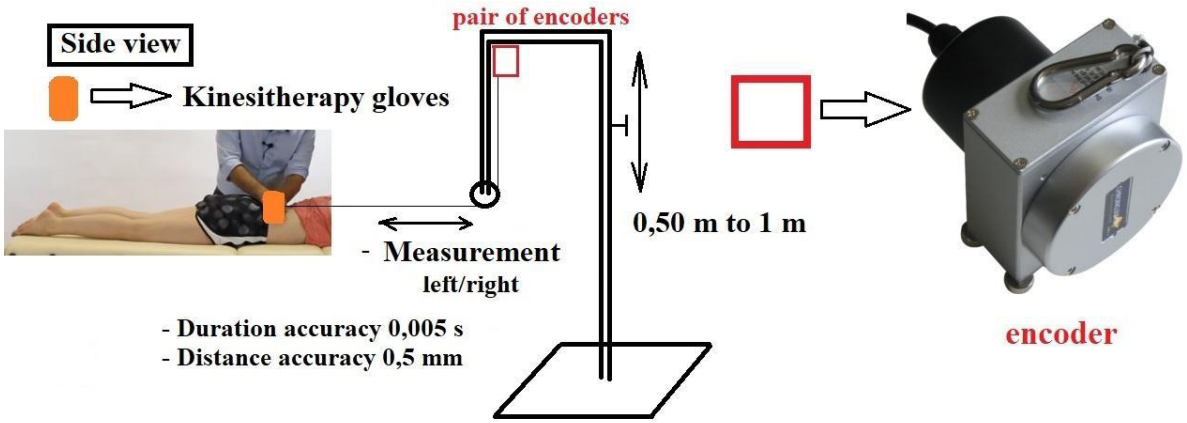

Figure 1. *Scheme of SKD device – side view.*

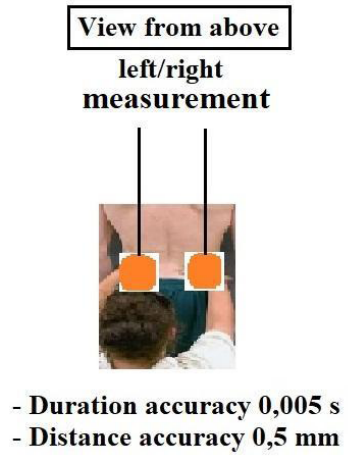

Figure 2. *Scheme of SKD device – view from above.*

The second step in creating the stand involved constructing the planned geometry. During the building process, it was determined that the geometry could be optimized. The final fabricated structure is shown in Figure 3. The two encoders, attached to the base via their magnetic feet, can be raised or lowered depending on the requirements of the current measurement and the patient's anthropometry (Figure 3).

Figure 3. *Experimental geometry in real measurement.*

SKD studies were conducted in six areas shown in Figure 4. The selected areas were chosen to fully cover the entire length of the spine and were near the corresponding vertebrae – T1, T2, T10, L1, L3, L5. In the present study, only the L5 area results were included.

Figure 4. *Measuring zones along the spine.*

The third stage involved calibration and verification of the experimental stand through testing with twenty-two real patients. The measuring module of the proposed system is based on a Chronojump encoder (Chronojump-Boscosystem, Spain). It is attached to the moving operator's glove and measures various biomechanical characteristics of a given movement task. For the purposes of the present experimental approach, only the parameter distance in centimeters was used. If the encoder wire moves at an angle, the data will not be accurate, and the wire may be damaged (Chronojump-Boscosystem, 2023).

An additional comparison was performed using the Mann–Whitney U test, with a significance level of $p < .01$ and a two-tailed hypothesis, due to the small sample size.

RESULTS

SKD was measured in the L5 zone to the left and right of the spine, as shown in Figure 3. The average value of this parameter was obtained from 8 movements in both directions parallel to the spine.

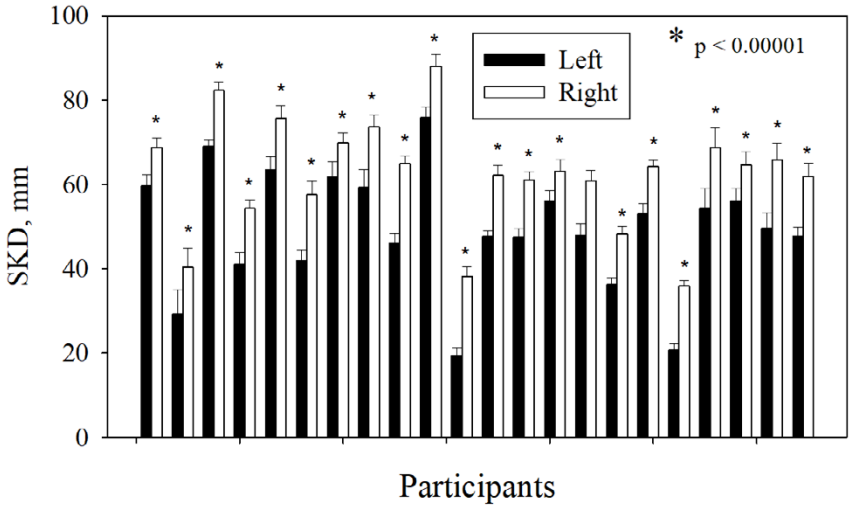

Figure 5. *SKD in zone L5 obtained on the left and right of the spines of 22 participants.*

Table 1. *Percentage increase in SKD on the right versus left L5 area in all participants.*

No	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
%	15	37.6	19.2	32.2	19.2	37.2	13.2	24.2	40.9	16.1	96.9	30.3	28.3	12.7	27	32.9	32.9	21.5	26.4	15.2	33	29.8

The performed Mann-Whitney U test shows that for all participants the right SKD is statistically significant with p-value < .001.

DISCUSSION

Skin structures are arranged in a way that facilitates stretching to support the movement of the human body and serve structural functions that assist joint motion by adjusting the position of the skin, such as the incidental stretch that occurs during movement. Proper skin mobility is essential for efficiency due to the skin's nature as a single, continuous tissue layer covering the entire human body (Choi et al., 2023). Therefore, good SKD in the lumbar area is an important factor for the mobility of the lower lumbar region. Lower values may predispose individuals to a restricted range of motion in the lower back.

The generated forces—normal, tensile, and shear—during SKD are expected to be transmitted via the lumbodorsal superficial fascia to the thoracolumbar fascia, myofascia, muscles, and thoracic, lumbar, and hip arthrofascial complexes, as these structures are interconnected through connective tissues (van Amstel et al., 2022). Conversely, the condition of the underlying lumbodorsal superficial fascia and its connections to the thoracolumbar fascia, myofascia, muscles, and thoracic, lumbar, and hip arthrofascial complexes may influence SKD in that area. It can be hypothesized that impaired function of any of these tissues may reduce normal SKD values.

The results obtained from SKD measurements on both the left and right sides of the spine at the L5 level support the concept that the skin is a crucial organ for transmitting mechanical forces to the underlying anatomical structures. The shear forces generated during palpation in the context of SKD are transmitted through the lumbodorsal superficial fascia to the thoracolumbar fascia, myofascial structures, skeletal muscles, and the arthrofascial complexes of the thoracic, lumbar, and hip regions. These structures are functionally and anatomically interconnected via connective tissue networks (van Amstel et al., 2022; Herlin et al., 2015; Adamietz et al., 2021).

The tangential (shear) forces induce mechanical strain within these fascial and muscular components, potentially modulating their stiffness (van Amstel et al., 2022; Ruttiman et al., 2019). Such changes in tissue stiffness are likely mediated through the activation or inhibition of mechanoreceptors, including proprioceptors, kinesthetic receptors, and certain nociceptors. Consequently, these neurophysiological responses may alter skeletal muscle tone, thereby influencing spinal alignment, pelvic biomechanics, and the range of motion in the hip joint (van Amstel et al., 2022; Maas, 2019).

The higher values observed on the right side in all participants require further investigation. These differences may result from the operator's position, the dominance of the operator's hand, or genuine SKD asymmetry.

CONCLUSIONS

Based on the obtained results, a new experimental approach for skin displacement involving kinesitherapy was developed, along with the construction of a specialized experimental bench for measuring SKD. The stand was calibrated and verified through testing with twenty-two real patients focused on the L5 spinal zone. All participants showed a statistically significant increase in SKD in the L5 zone on the right side of the spine. The obtained values of SKD, together with the reported differences in the left and right of the spine have a diagnostic potential for the assessment of spinal skin dysfunction. Future research is needed to optimize the experimental approach and to elucidate the skin spinal interactions in depth.

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REFERENCES

Adamietz, B., Schönberg, S. O., Reiser, M., Uder, M., Frank, A., & Strecker, R. (2021). Visualization of the epimysium and fascia thoracolumbalis at the lumbar spine using MRI. *Der Radiologe*, *61*, 49–53. https://doi.org/10.1007/s00117-021-00849-9

Baumann, L., Bernstein, E. F., Weiss, A. S., Bates, D., Humphrey, S., Silberberg, M., & Daniels, R. (2021). Clinical relevance of elastin in the structure and function of skin. *Aesthetic Surgery Journal Open Forum*, *3*(3), ojab019. https://doi.org/10.1093/asjof/ojab019

Choi, S. H., Lee, B. J., & Lee, S. Y. (2023). A study on skin mobility according to joint movement: Variations in mobility according to joint motion range and correlation and influence with hydrica composition. *Skin Research and Technology*, *29*(2), e13288. https://doi.org/10.1111/srt.13288

Deroy, C., Destrade, M., Mc Alinden, A., & Ní Annaidh, A. (2017). Non-invasive evaluation of skin tension lines with elastic waves. *Skin Research and Technology*, *23*, 326–335. https://doi.org/10.1111/srt.12339

Dosch, P., & Dosch, M. (2007). Manual of neural therapy according to Huneke. Georg Thieme Verlag.

Fischer, A. A. (1987). Clinical use of tissue compliance meter for documentation of soft tissue pathology. *Clinical Journal of Pain, 3*(1), 23–30.

Herlin, C., Chica-Rosa, A., Subsol, G., Gilles, B., Macri, F., & Beregi, J. P. (2015). Three-dimensional study of the skin/subcutaneous complex using in vivo whole body 3T MRI: Review of the literature and confirmation of a generic pattern of organization. *Surgical and Radiologic Anatomy*, *37*(7), 731–741. https://doi.org/10.1007/s00276-014-1409-0

Hogeweg, J. A., Lemmers, D., & Temmink, P. (1993). Skin compliance: Measuring skin consistency in the spinal region of healthy children and adults. *Physiotherapy Theory and Practice*, *9*(4), 205–214. https://doi.org/10.3109/09593989309036492

Jacquet, E., Chambert, J., Pauchot, J., & Sandoz, P. (2017). Intra- and inter-individual variability in the mechanical properties of the human skin from in vivo measurements on 20 volunteers. *Skin Research and Technology*, *23*, 491–499. https://doi.org/10.1111/srt.12361

Kwon, K., Wang, H., Lim, J., Chun, K. S., Jang, H., Yoo, I., ... Rogers, J. A. (2021). Wireless, soft electronics for rapid, multisensor measurements of hydration levels in healthy and diseased skin. *Proceedings of the National Academy of Sciences*, *118*(5), e2020398118. https://doi.org/10.1073/pnas.2020398118

Lakhani, P., Dwivedi, K. K., Parashar, A., & Kumar, N. (2021). Non-invasive in vivo quantification of directional dependent variation in mechanical properties for human skin. *Frontiers in Bioengineering and Biotechnology*, *9,* 749492. https://doi.org/10.3389/fbioe.2021.749492

Maas, H. (2019). Significance of epimuscular myofascial force transmission under passive muscle conditions. *Journal of Applied Physiology*, *126*(5), 1465–1473. https://doi.org/10.1152/japplphysiol.00631.2018

Martire, M. V., D'Alvia, L., Cortese, L., Del Prete, Z., & Rizzuto, E. (2025). Design of a novel stretchable sensor for systemic sclerosis diagnosis through skin elasticity measurement: A simulation study. In *IEEE Medical Measurements & Applications* (MeMeA) (pp. 1–5). IEEE. https://doi.org/10.1109/MeMeA65319.2025.11067959

Raitt, D. G., Huseynov, M., Homer-Vanniasinkam, S., Wurdemann, H. A., & Abad, S. A. (2024). Soft-tipped sensor with compliance control for elasticity sensing and palpation. *IEEE Transactions on Robotics*, *40*, 2430–2441. https://doi.org/10.1109/TRO.2024.3371691

Ruttiman, R. J., Sleboda, D. A., & Roberts, T. J. (2019). Release of fascial compartment boundaries reduces muscle force output. *Journal of Applied Physiology*, *126*(3), 593–598. https://doi.org/10.1152/japplphysiol.00330.2018

Takeda, H., Kato, F., Kamishima, K., & Iwata, H. (2025). Development of a two-fingered robotic hand capable of reproducing five types of palpation movements. Measurement: *Sensors*, 38, 101846. https://doi.org/10.1016/j.measen.2025.101846

van Amstel, R. N., Jaspers, R. T., & Pool-Goudzwaard, A. L. (2022). Skin displacement as fascia tissue manipulation at the lower back affects instantaneously the flexion and extension spine, pelvis, and hip range of motion. *Frontiers in Physiology*, *13*, 1067816. https://doi.org/10.3389/fphys.2022.1067816

Zhang, J., Cai, L., Wang, T., Tang, S., Li, Q., & Tang, T. (2018). Lithium doped silica nanospheres/poly(dopamine) composite coating on polyetheretherketone to stimulate cell responses, improve bone formation and osseointegration. *Nanomedicine: Nanotechnology, Biology and Medicine*, *14*(3), 965–976. https://doi.org/10.1016/j.nano.2018.01.017

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