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Original Article

Quantitative study of acupuncture manipulation of lifting-thrusting using an needle insertion-measurement system in phantom tissue

Soo-Yoon Lee[1], Young-Nam Son[1], In-hwa Choi[2], Kyung-Min Shin[3], Kap-Sung Kim[4], Seung-Deok Lee[4]

[1]College of Korean Medicine, Dongguk University, Goyang, Republic of Korea
[2]Department of Ophthalmology, Otolaryngology and Dermatology, College of Korean Medicine, Kyung Hee University, Seoul, Republic of Korea
[3]Acupuncture, Moxibustion & Meridian Research Group, Korea Institute of Oriental Medicine
[4]Department of Acupuncture & Moxibustion, College of Korean Medicine, Dongguk University, Goyang, Republic of Korea

Objectives: Quantification, objectification, and standardization of lifting-thrusting manipulation are important issues in traditional Chinese medicine (TCM). The purpose of this study was to quantitatively investigate the difference in the amount of stimulation according to range and frequency among parameters of lifting-thrusting manipulation with the use of a needle insertion-measurement system.
Methods: For quantification of lifting-thrusting manipulation, an acupuncture needle insertion-measurement system was used in phantom tissue. The motor and force sensors of the needle insertion device were connected to the control software. This enabled operation of the lifting-thrusting manipulation and measurement of the acupuncture needle force. The measurement of the acupuncture needle force according to various frequencies (0.25, 0.50, 0.75, and 1 Hz) and ranges of movement (2, 4, 6, 8, and 10 mm) was repeated 10 times.
Results: At a constant frequency of movement, acupuncture needle force according to range of movement (2, 4, 6, 8, and 10 mm) increased with increasing range of movement ($p < 0.05$). At a constant range of movement, acupuncture needle force according to frequency of movement (0.25, 0.50, 0.75, and 1.0 Hz) increased with increasing frequency of movement ($p < 0.05$).
Conclusion: In this study, we conducted a quantitative comparison of the amount of stimulation according to range and frequency, the main parameters of lifting-thrusting manipulation, by using an acupuncture needle insertion-measurement system. Future studies on various manipulations and parameters are warranted to quantify and objectify the amounts of stimulation by acupuncture manipulation.

Key Words : Acupuncture, acupuncture manipulation, de qi, stimulation, needle force

Introduction

Acupuncture manipulation is a needle stimulation technique that is performed to induce a needling sensation after insertion of the needle.[1)] This technique is an important part of acupuncture therapy and is an essential skill for oriental medicine doctors. The amount of needle stimulation that is obtained by acupuncture manipulation is closely related to the therapeutic effect.[2)]

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・Correspondence to : Seung-Deok Lee
Department of Acupuncture & Moxibustion Medicine, Dongguk University Oriental Hospital,
24 Donggu-ro, Ilsandong-gu, Goyang city, Gyeonggi-do, 410-773, Republic of Korea.
Tel : +82-31-961-9122, Fax : +82-31-961-9009, E-mail : chuckman@dongguk.edu

Acupuncture manipulation includes basic manipulation, assistant manipulation, and reinforcement and reducing manipulation.[3] Basic manipulation includes lifting-thrusting manipulation and twisting manipulation,[4] which correspond to transitional motion and rotational motion, respectively. In lifting-thrusting manipulation, the needle is inserted to the appropriate depth followed by repeated up-and-down movements to stimulate the tissues.[5] Different combinations of ranges and frequencies of up-and-down movements affect the amount of stimulation.

However, these parameters are selected according to the practitioner's personal judgment.[6] This heterogeneity results from the absence of a quantifiable indicator of the control of stimulation.[7] Thus, quantification, objectification, and standardization of lifting-thrusting manipulation are important factors in the academic, research, and clinical fields.[8]

Previous studies aimed at quantification and objectification of acupuncture manipulation recorded and analyzed a variety of manipulations and then presented parameters.[2,3,9,10] However, because a quantitative comparison of the amount of stimulation according to variations in the parameters was not performed, the studies were unable to quantify and objectify the acupuncture manipulation.

To perform a quantitative comparison of the amount of stimulation according to the parameters in acupuncture manipulation, a system for quantifying the amount of stimulation by needle is necessary. For this purpose, previous studies have investigated quantitative techniques such as pullout force[11,12] and ultrasound.[13] However, these studies examined the degree of acupuncture needle grasp due to twisting manipulation. RT Davis et al. measured the acupuncture needle motion and force with an acusensor device, but only showed the heterogeneity of acupuncture manipulation.[14]

In this study, we used a needle insertion-measurement system in phantom tissue and performed a quantitative comparison of amount of stimulation according to variations in the parameters range and frequency in lifting-thrusting manipulation.

Methods

1. Phantom Tissue Selection

This study used phantom tissue that had few ethical constraints compared with *in vivo* testing in animals and humans and good reproducibility in the experiments. Phantom tissue that perfectly reproduces the physical properties of human tissue does not currently exist. However, human body-like phantom tissue can be selected depending on the property required in the research.[15] In this study, the selection of the phantom tissue was based on the force acting between the acupuncture needle and tissue. Three acupuncturists each with more than three years' clinical experience selected apple *(unpublished data)* from among 6 candidates (carrot, agar gel, cucumber, sweet potato, ham, and apple) as providing realistic resistance similar to the practitioners' needle sensation of ST 36, an acupoint frequently used in research.

2. Experimental Design

The experiment was performed in a closed lab where the room temperature was maintained at 25°C. For phantom tissue, we purchased apples whose display period was 3 days or less at the local store. The apples were held at room temperature for at least 30 min, and the core and peel were removed to obtain uniform material. Phantom tissue was prepared to fit into a fixed box designed by our research team (2.5*2.5*3(cm)) so that the tissue did not move with the acupuncture needle during the transitional motion. To exclude the puncturing force of the needle on the surface of the phantom tissue and measure only the forces acting in the tissue during the movement, a stainless steel acupuncture needle (gauge, 40; diameter, 0.40 mm; Dongbang

Healthcare Products, Seoul, Korea) was inserted 10 mm into the tissue before the experiment was started. To measure the acupuncture needle force, the needle was fixed at a force sensor (Fig. 1).

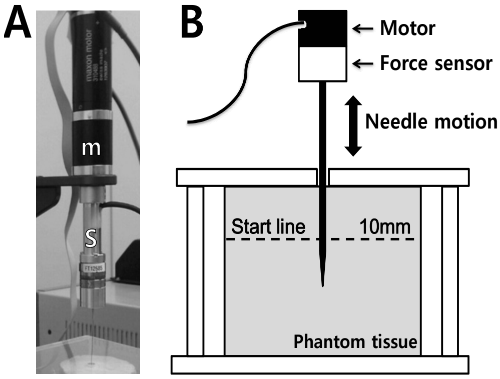

Fig. 1. (A) Photo of motor(*m*), force sensor(*s*), and needle set up. (B) Picture of experimental set up.

This study was designed to compare the difference in amount of stimulation according to range and frequency of lifting-thrusting manipulation. All needling procedures were performed by a computer-controlled needle insertion-measurement system. At a constant frequency, to measure the acupuncture needle force according to the movement range, the movement ranges were set as 2, 4, 6, 8, and 10 mm. The frequency was set as 0.50 Hz, and lifting-thrusting manipulation with a 2-second cycle was repeated 10 times to yield a total movement of 20 seconds. Ten tests were performed for each range. At a constant range, to measure the acupuncture needle force according to the movement frequency, the movement frequencies were set as 0.25, 0.50, 0.75, and 1 Hz. The range was maintained at 6 mm, and the 10-cycle repeats were carried out at each frequency. The total test periods at 0.25, 0.50, 0.75, and 1 Hz were 40, 20, 13.33, and 10 seconds, respectively. The test in each frequency was performed 10 times. The phantom tissue was replaced before each test (Fig. 2).

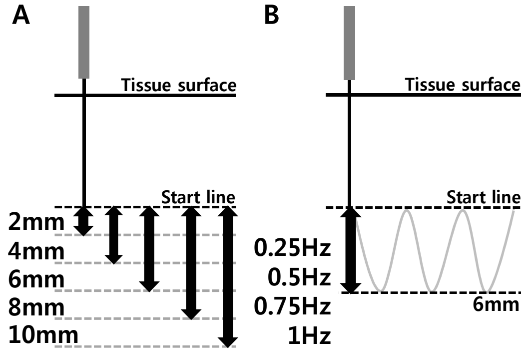

Fig. 2. Setting of parameters in lifting–thrusting manipulation. (A) Range (B) Frequency

3. 6–Axis Force Sensor

A 6-axis force/torque sensor (Nano-17 SI-8-0.05 from ATI Industrial Automation) was attached to the acupuncture needle so that force and torque were measured independently along 6 axes (Fx, Fy, Fz, Tx, Ty, and Tz). Because lifting-thrusting manipulation consists of transitional motion inside the tissue, the acupuncture needle force along the z-axis of the sensor in the same direction as that of the movement of the needle was measured. The needle force (Fz), that is, the force that the needle receives from the tissue according to the action–reaction principle, is identical to the force that the tissue receives from the needle. Thus, the acupuncture needle force (Fz) measured by the sensor was identical to the amount of tissue stimulation produced by the needle performing the lifting-thrusting manipulation. In other words, the amount of stimulation could be obtained by measuring the needle force (Fz) with the force sensor attached to the acupuncture needle.

4. Acupuncture Needle Insertion–measurement System

The total system is divided into three parts; the device part, measurement part, and control part. The device part refers to the needle insertion device in which a motor operates transitional motion of the needle through 1-degree-of-freedom translation stages. The measurement part consists of a 6-axis force sensor. The control part feeds operation commands into the needle insertion device and records the results obtained by the force sensor; it consists of an external control box responsible for control of the device and measurement parts as well as a computer (Windows 8, Pentium PC). The computer software includes Simulink (R2011b 7.8,The Math Works Inc., USA) and Quarc (ver.2.21, Quanser, Canada). When the range and frequency of the movement were entered into them, and the command was passed to the external control box, which controlled the motor. The operation of the motor was controlled by a 500Hz unit. The force exerted on the needle by the tissue was obtained by measuring the force along the z-axis parallel to the movement direction of the acupuncture needle. Data on the position and force of the needle were transmitted to the computer and recorded in 50Hz units. To remove sensor error, the power for the initial 0.1 s was zero-point calibrated.

5. Data Analysis

The experimental results were measured using raw data obtained from 10 repetitive tests and were expressed as the force according to time as shown at Fig. 3. To compare the difference in forces, peak points in each cycle were utilized similarly to the Chae et al.[16] method and they were set to be needle forces. To compare amounts of stimulation according to the movement range and frequency, the average needle force in the 2nd–10th cycle was obtained except the needle force in the 1st cycle with a large difference. The results were expressed as the mean ± standard deviation (SD). The statistical program used for data analysis was STATA/SE (Stata/SE 9.2 for Windows, Stata Corp LP, College Station, TX, USA). A one-way analysis of variance (ANOVA) was used for the statistical process. If the ANOVA was significant, Bonferroni post hoc test was performed, and $P < 0.05$ was considered statistically significant.

Results

1. Needle Force Overtime

The graph of the needle force overtime for 2, 4, 6, 8, and 10 mm movements is shown at Fig. 3; the x-axis represents time (second, s) and the y-axis needle force (Newton, N). The frequency was 0.50 Hz and the total movement time was 20 s for a total of 10 cycles. As 2 s corresponded to one cycle, 0–2, 2–4, and 18–20 s corresponded to the 1st, 2nd, and 10th cycle, respectively. When the range of the movement was 2 mm the needle forces in the 1st–3rd cycles were 0.32 ± 0.03 N, followed by 0.29 ± 0.03 N. After the 3rd cycle, the needle forces were 0.29 ± 0.03 N. When the range of the movement was 4 mm, the forces in the 1st and 2nd cycles were 0.60 ± 0.03 N and 0.55 ± 0.03 N, respectively. Thereafter, the force decreased by 0.01 N, so the force in the 10th cycle was 0.46 ± 0.03 N. When the range of the movement was 6 mm, the forces in the 1st, 2nd, and 3rd cycles were 0.81 ± 0.04 N, 0.75 ± 0.03 N and 0.70±0.02 N, respectively. The value reduced by 0.03 N until the 6th cycle, and then the value reduced by 0.02 N. The value in the 10th cycle was 0.54 ± 0.04 N. When the range of the movement was 8 mm, the forces in the 1st and 2nd cycles were 0.97 ± 0.05 N and 0.87 ± 0.04 N, respectively. Thereafter, the value reduced by 0.05N until the 4th cycle, and then the decline gradually slowed from 0.03N to 0.1N. The value in the 10th cycle was 0.64 ± 0.05 N. When the range of the movement was 10 mm, the forces in the 1st and 2nd

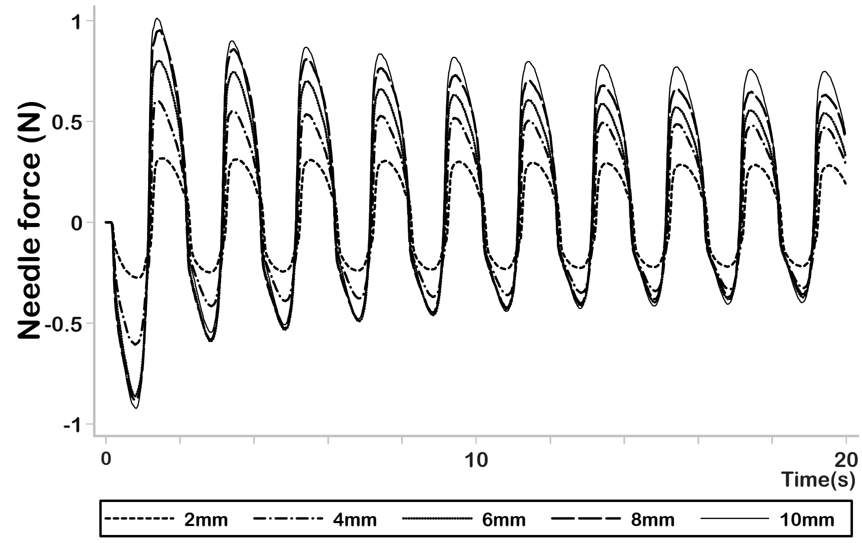

Fig. 3. The needle force overtime at each range. As the cycle elapses, the size of the needle force decreases. (N=10, 0.50Hz, 10 cycles, 20s)

cycles were 1.01 ± 0.07 N and 0.90 ± 0.06 N, respectively. The decrease slowed from 0.03 N to 0.01 N, and the value in the 10th cycle was 0.75 ± 0.05 N.

2. Comparison of Average Needle Force

The needle force in each cycle varies depending on the movement range and increases with increasing movement range (Fig. 3). Comparison of the average needle force among the movement ranges is shown at Fig. 4A. The needle forces in the 2nd–10th cycles were used to obtain the average needle force, excluding the value in the 1st cycle with a large difference in the forces. The needle forces in the 2, 4, 6, 8, and 10 mm range were 0.30 ± 0.03 N, 0.50 ± 0.04 N, 0.63 ± 0.07 N, 0.73 ± 0.09 N, and 0.81 ± 0.07 N, respectively. There were significant differences in the needle force among 2, 4, 6, 8, and 10mm. In addition, the needle force increased with increasing movement range. Figure 4B shows a graph comparing the average needle force among movement frequencies. The movement forces for frequencies 0.25, 0.50, 0.75, and 1 Hz were 0.39 ± 0.06 N, 0.63 ± 0.07 N, 0.70 ± 0.11 N, and 0.90 ± 0.09 N, respectively. There were significant differences in the needle forces among 0.25, 0.50, 0.75, and 1 Hz. In addition, the needle force increased with increasing movement frequency.

Discussion

The purpose of this study was to perform a quantitative comparison of amounts of stimulation according to range and frequency, parameters of lifting-thrusting manipulation, with the use of an acupuncture needle insertion-measurement system in phantom tissue.

The needle force overtime in each cycle did not remain constant for 10 cycles, and decreased as the movement cycle elapsed (Fig. 3). The decrease slowed as the movement cycle progressed. Generally, the degree of the decrease was large in the 1st–3rd

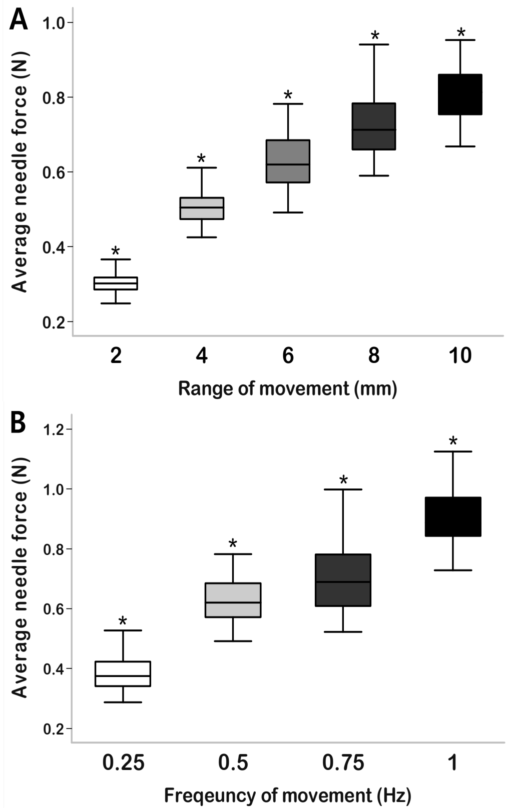

Fig. 4. Comparison of needle forces according to the movement range and frequency
(A) There was significant difference in needle forces according to the range. (B) There was significant difference in needle forces according to the frequency. N=10, 2~10th cycle. Values are at the mean ± SD; *p <0.05.

cycle, and converged to 0–0.1 N after the 5th cycle. This means that repeated lifting-thrusting manipulation in the same region cannot generate the same amount of stimulation from the beginning to the end of movement. The needle force of transitional motion after insertion of the acupuncture needle in the tissue is the sum of the cutting force at the tip of the acupuncture needle and the friction force acting along the acupuncture needle body.[17] If lifting-thrusting manipulation is repeated in the same site, tissue cutting and subsequent tissue relaxation can occur.[18] As a result, cutting force and friction force decrease, which lead to decreases in the needle force.

To perform a quantitative comparison of amount of stimulation according to movement range, we compared the mean of needle force of all cycles, except the first cycle with a large difference among needle forces (Fig. 4A). When the movement frequency was constant (0.50 Hz), the needle force increased with increasing movement range. Because the needle force is identical to the amount of tissue stimulation by the acupuncture needle, the amount of tissue stimulation increased with increasing movement range, based on the results of Fig. 4A. The needle force increases with increasing needle penetration depth in the tissue at the same penetration rate.[19] As the displacement of the needle increases, the area of friction between the acupuncture needle and the tissue increases, resulting in increased friction force. Similarly, at a constant movement frequency, the displacement rate of the needle increases with increasing range. For one down-and-up movement per second, the 2 mm movement range results in a 4-mm displacement per second and the 10 mm movement range results in a 20-mm displacement per second. The area of friction between the acupuncture needle and the tissue increases with increasing movement range. This explains why needle force increases with increasing range and why amount of stimulation also increases with increasing range. At a constant movement range (6 mm), the needle force increased with increasing frequency (Fig. 4B). This agrees with previous findings that needle force increases with increasing rate of the needle insertion (into the same depth)[15] and that in most friction models, the size of the friction force increases with increasing rate.

To investigate the difference in amount of stimulation by parameter of lifting-thrusting manipulation, we selected phantom tissue rather than animal or human tissue. For human tissue, the insertion force varies depending on the type of tissue such as skin, muscle, fat, or connective tissue. Further, there are differences in the same type of tissue among individuals.[14,20] For animal tissue, the required force varies depending on the kind of animal, individual, tissue sampling site, and ambient temperature.[21] For *in vivo* testing in animals or humans, local tissue reactions caused by the acupuncture needle stimulation (eg twitch, contraction) affect needle force. Therefore, the utilized phantom tissue showed relatively small difference in the results according to the object, site and ambient temperature and was more reproducible compared to the human body and animals.

Acupuncture is a kind of physical stimulation causing an electrical signal in the tissue. The subsequent activation of thick nerve branches blocks the pain gate or inhibits pain perception in the brain.[22] Acupuncture manipulation is a needle stimulation technique. If the tissue does not receive continuous physical stimulation from the acupuncture needle, the adaptation mechanism of the receptor reduces or eliminates the frequency of action potentials.[23] Thus, the nerve signals caused by the acupuncture manipulation play an important role in acupuncture therapy.[24] In addition, the acupuncture manipulation has roles and values that cannot be replaced by electro-acupuncture, due to its unique sense of *de qi* and afferent nerve fibers.[25]

Amplitude and duration of the action potentials generated in the receptors are influenced by the stimulation intensity. Sensory stimulation can also cause an inhibitory potential. Accordingly, it is estimated that different amounts of stimulation represent different physiological effects.[26] If there is a difference in the amounts of stimulation by the acupuncture needle, different treatment effects are expected. Thus, control of the amount of stimulation of acupuncture manipulation is essential to improve the efficacy of acupuncture therapy.[2]

Just as the amount of current is controlled in electro-acupuncture to achieve stimulation beyond threshold, the amount of stimulation of acupuncture manipulation can be controlled through different combinations of parameters such as range and frequency to obtain the desired effect. For quantification, objectification, and standardization of acupuncture manipulation, we need to perform a quantitative comparison of how the amount of stimulation varies according to variations in the parameters. However, there has been little research comparing the amount of stimulation according to parameters.

In summary, we performed a quantitative comparison of the amount of stimulation according to the range and frequency, the main parameters of the lifting-thrusting manipulation, by using a needle insertion-measurement system. As a result, it was shown that at a constant frequency, the amount of stimulation increased with increasing range and that at a constant range, the amount of stimulation increased with increasing frequency.

Furthermore, if we accumulate data on the amount of stimulation according to various manipulations and parameters on the basis of the quantification method presented in this study and perform regression analysis on the data, we can predict and control the amount of stimulation. In addition, the selected parameter with high correlation can be developed as the parameter useful for prediction and control of the amount of stimulation.

Through this study, we can improve the reproducibility of lifting-thrusting manipulation in the academic, research, and clinical fields and contribute to the objectification and standardization of lifting-thrusting manipulation. Further, the result can be used for developing acupuncture practice models enabling application of the desired amount of stimulation by controlling parameters or for developing acupuncture practice devices for applying set amounts of stimulation to the tissue.

In the future, we will be able to investigate the appropriate amount of stimulation for the *de qi* reaction according to tissue type or acupuncture point by using the quantification principle of the acupuncture manipulation presented in this study. Also, we will be able to perform a study that presents the amount of stimulation of the acupuncture manipulation appropriate for treatment purpose.

1. Conflict of interest statement

The authors do not have any conflicts concerning this paper.

2. Acknowledgements

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