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Original Article

Quantitative Comparison of Acupuncture Needle Force Generation According to Diameter

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ABSTRACT

Background: Various factors can alter the efficacy of acupuncture treatment, such as the location of points, manipulations, depth of insertion, needle retention time, and needle type. In this study, the effect of needle diameter on the efficacy of acupuncture treatment was quantitatively evaluated.
Methods: Five acupuncture needles of different diameters used in clinical practice were compared. Force on the porcine tissue phantom was measured using a sensor. Lifting-thrusting and twisting-rotating movements were performed using a needle insertion-measurement system. After repeated measurements, force magnitude was calculated and compared. Following this, we correlated needle diameter and force magnitude during lifting-thrusting and twisting-rotating movements.
Results: The force magnitude was significantly altered between needle diameters during lifting-thrusting movements, as shown by a significant positive correlation between needle diameter and force magnitude. In contrast, there was no difference in force magnitude with different needle diameters during twisting-rotating movements.
Conclusion: Needle diameter can significantly affect stimuli and force magnitude dependent upon the type of manipulation. Research into the effect of other needle type characteristics and stimulation method is necessary to fully elucidate the role of acupuncture needle choice in treatment efficacy.

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Introduction

Acupuncture is a type of physical stimulation that can affect the nervous system via a blockage of the route, or sensation of pain, in a thick bundle of nerves by inducing electrical signals to the tissue [1]. Acupuncture has been effective at treating a variety of diseases, based on the stimulation of specific acupuncture points [2]. Depending on the level of stimulation, the treatment effect will also vary; therefore, to maximize the efficacy of acupuncture as a stimulus therapy, accurate diagnosis, proper selection of acupuncture points and treatment areas, and proper adjustment of the stimulus rate is required [3].

Different stimulation methods, such as manipulations or electro-acupuncture, the number of acupuncture points, depth of insertion, needle retention time, and the type of acupuncture needle will impact the degree of stimulation [4]. In addition, the diameter and surface characteristics of the acupuncture needle may also change the degree of stimulation.

Previous studies have shown that treatment efficacy increases with the use of manipulations [5,6]. In addition, the expression of neuronal nitric oxide synthase and norepinephrine were altered with acupuncture depth [7]. Studies have also shown that acupuncture points in white mice differ relative to the pain caused by the use of manipulations [8].

However, there are few studies assessing the impact of the thickness, length, composition, and shape of the needle, which is a significant characteristic of acupuncture itself, on treatment efficacy and stimulus. Previous studies have measured the impact of needle tip shape [9] and acupuncture surface [10,11], which measured the quality and stability of the needle. A further study compared the difference in muscle fatigue recovery relative to needle thickness; however, did not include any quantitative assessment of stimulus

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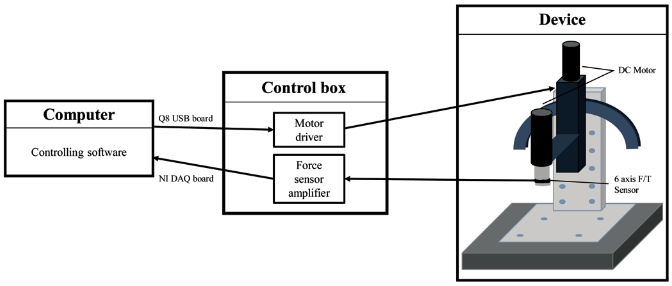

Fig. 1. Operating procedures for the needle insertion-measurement system. The range and frequency of movements are controlled by software. A motor moves the acupuncture needle to the porcine tissue phantom. The sensor attached to the acupuncture needle records the needle–tissue interaction force.

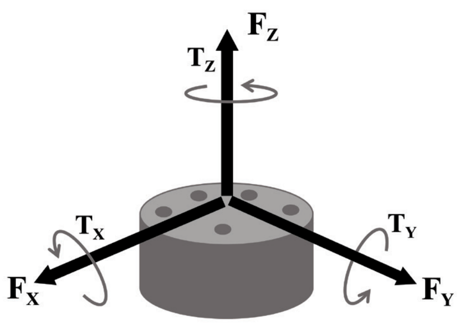

Fig. 2. The directions of the 6-axis of force/torque detected by the sensor. The force Z axis for the lifting-thrusting and the torque Z axis for the twisting-rotating.

rates with thickness [12]. Therefore, in this study, we quantitatively measured needle force generated by the interaction between the acupuncture and tissue using the needle insert-measurement system using needles with different diameteSrs.

Materials and Methods

Needle insertion-measurement system

The needle insertion-measurement system consisted of 3 components: motor, control, and input. The motor component enabled measurement of the upper and lower, rotary, and left-right movement of the needle. The input component was Simulink (R2017b 9.3, MathWorks Inc., USA) and Quarc (ver. 2.21, QUANSER, Canada) software that could command the motor component to move via an external control box (Fig. 1). A sensor (Nano-17, ATI Industrial Automation, Garner, NC, USA) was connected between the motor and needle, which measured the force/torque generated between the porcine tissue phantom and needle, and was recorded by the control component via computer. The sensor used in this study was a 6-axis F/T sensor that measured force and torque independently on the 6 axes (Fig. 2). In this study, depending on the direction of movement, the Fz and Tz axes measured lifting-thrusting and twisting-rotating movements, respectively.

Acupuncture needle

The acupuncture needles (Dongbang Healthcare Products, Seoul, Korea) used in this study were stainless steel with varying diameters of 0.20 mm, 0.25 mm, 0.30 mm, 0.35 mm, and 0.40 mm (Fig. 3). The length of the needles was consistently 40 mm.

Porcine phantom

Porcine tissue was selected as the phantom due to its similar characteristics to human tissue [13]. The tissue was sourced from Korea within 10 days after death. The phantom was fixed to a container to minimize movement during the experiment. To reduce the impact of the phantom's deformation, the experimental time for a single tissue sample was limited to 10 minutes.

Experimental design

The experiment was carried out by applying needles to a 1.5 cm acupuncture depth into the phantom. Acupuncture was performed according to the 5 different diameters, and basic lifting-thrusting and twisting-rotating. Lifting-thrusting movements were created by a vertical motor at an amplitude and frequency of 5 mm and 1 Hz, respectively. Twisting-rotating movements were created by a rotary motor at an amplitude and frequency of 180° and 0.2 Hz,

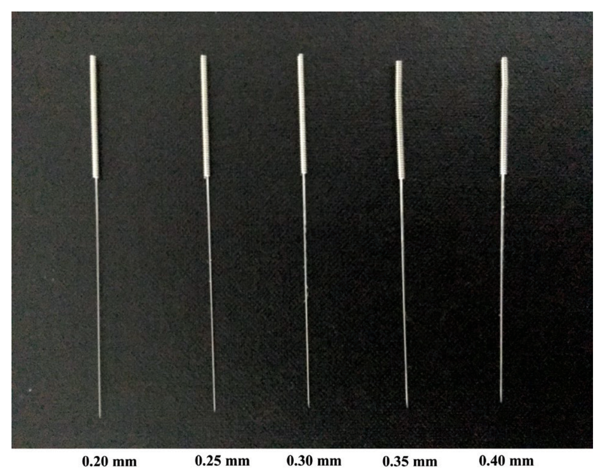

Fig. 3. The 5 different diameters of acupuncture needle.

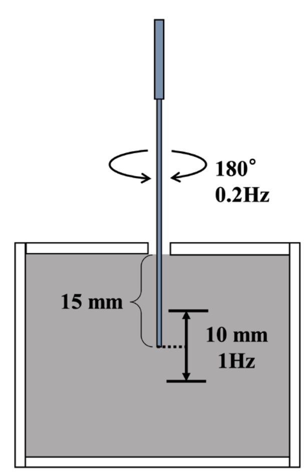

Fig. 4. Schematic of lifting-thrusting and twisting-rotating movements.

respectively (Fig. 4). These movement parameters were chosen according to previous studies [14,15].

Data processing

Fifteen lifting-thrusting or twisting-rotating movements were performed in a row for 1 trial. Ten repetitions were performed for each diameter in this study, excluding the initial insertion force movements performed (up to the 3) and inertia force movements (second from last) at the end of the trial. The frictional force (Fz) in the z-axis, created by the vertical motion of the needle, was measured in lifting-thrusting movements. The torque (Tz), created by the rotation motion of the needle, was measured during twisting-rotating movements.

Statistical analysis

SAS 9.4 (SAS Institute Inc., Mary, North Carolina 27513, USA) software was used to analyze the data. One-way ANOVA was used to compare the lifting-thrusting and twisting-rotating forces between different needle diameters. Tukey's HSD was used for post-hoc analysis between specific pairs of measurements. Data were considered statistically significant if $p < 0.05$. Correlations between needle diameter and force/torque were calculated using Spearman's rank-order correlation and regression test.

Results

Force differences according to needle diameter

Lifting-thrusting

Fig. 5A shows the changes in force during lifting-thrusting, depending on needle diameter. The largest and smallest forces were created by 0.40 mm and 0.20 mm needles, respectively, with force increasing as the diameter of the needle increased. Furthermore, there was a statistically significant 3-fold difference in the force generated between the smallest and largest needle diameter (Table 1).

Twisting-rotating

Fig. 5B shows the changes in forces recorded during twisting-rotating, depending on needle diameter. There were no statistically significant differences between the forces generated with different needle diameters (Table 2).

Table 1. The Needle Force Generated During the Lifting-thrusting Movements with Different Diameter Acupuncture Needle Diameters.S

	0.20 mm[1]	0.25 mm[2]	0.30 mm[3]	0.35 mm[4]	0.40 mm[5]	ANOVA p	Tukey's HSD
Max	0.16 ± 0.04	0.24 ± 0.04	0.29 ± 0.05	0.41 ± 0.10	0.48 ± 0.06	< 0.05*	1 < 2 < 3 < 4 < 5
Min	-0.11 ± 0.03	-0.13 ± 0.04	-0.16 ± 0.04	-0.21 ± 0.05	-0.29 ± 0.04	< 0.05*	1 < 2 < 3 < 4 < 5

Data are presented as mean (N) ± SD.
* A significant statistical difference with $p < 0.05$.

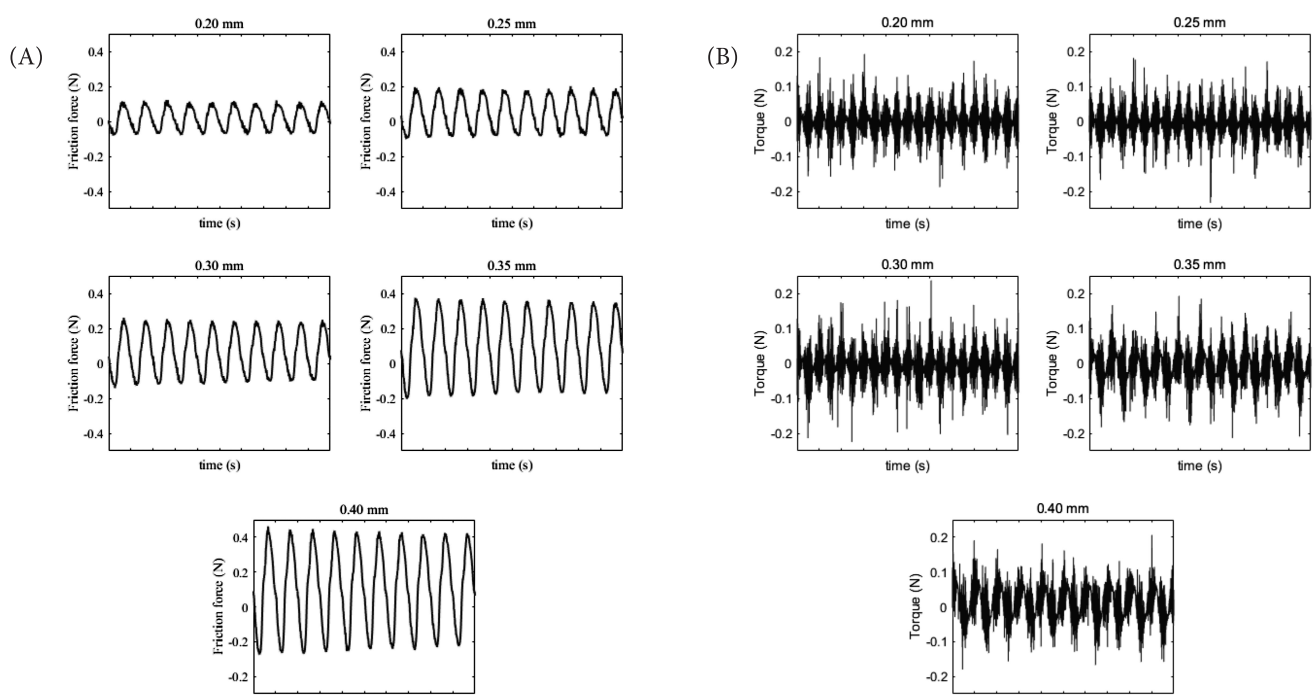

Fig. 5. (A) Force changes over time in lifting-thrusting movements. Changes in force Z-axis friction. (n = 10, 1 Hz, 10 cycles).
(B) Torque changes over time in twisting-rotating movements. Changes in torque Z-axis friction. (n = 10, 0.2 Hz, 10 cycles)

Table 2. The Needle Force Generated During the Twisting-rotating Movements with Different Diameter Acupuncture Needle Diameters.

	0.20 mm[1]	0.25 mm[2]	0.30 mm[3]	0.35 mm[4]	0.40 mm[5]	ANOVA p	Tukey's HSD
Max	0.55 ± 0.14	0.57 ± 0.16	0.57 ± 0.22	0.58 ± 0.16	0.58 ± 0.17	0.49	-
Min	-0.57 ± 0.18	-0.57 ± 0.17	-0.59 ± 0.18	-0.60 ± 0.18	-0.60 ± 0.22	0.55	-

Data are presented as mean (N) ± SD.
* A significant statistical difference with $p < 0.05$.

Table 3. Correlation Between the Needle Force Generated during Lifting-thrusting Movements and the Diameter Acupuncture Needle.

Maximum value	The force during movements	Acupuncture needle diameter	Minimum value	The force during movements	Acupuncture needle diameter
The force during movements	1		The force during movements	1	
Acupuncture needle diameter	0.8985*	1	Acupuncture needle diameter	- 0.8245*	1

* A significant statistical difference with $p < 0.05$.

Table 4. Correlation Between the Needle Force Generated During Twisting-rotating Movements and the Diameter Acupuncture Needle.

Maximum value	The force during movements	Acupuncture needle diameter	Minimum value	The force during movements	Acupuncture needle diameter
The force during movements	1		The force during movements	1	
Acupuncture needle diameter	0.0485	1	Acupuncture needle diameter	– 0.0509	1

* A significant statistical difference with $p < 0.05$.

Correlation between needle diameter and force

Lifting-thrusting

When the maximum value generated during lifting-thrusting was analyzed according to the diameter of the needle, a strong positive correlation was obtained (r = 0.8985, $p < 0.05$). Also, at the minimum value, there was a strong negative correlation (r = –0.8245, $p < 0.05$; Table 3). Regression analysis showed that that needle diameter significantly affects the force generated during lifting-thrusting (maximum: R2 = 0.7731; minimum: R2 = 0.6652).

Twisting-rotating

There was no significant correlation between the magnitude of force and needle diameter at the maximum and minimum values (maximum: r = 0.0485, $p = 0.2786$; minimum: r = –0.0509, $p = 0.2555$; Table 4).

Discussion

This study sought to quantitatively assess the impact of needle diameter on force generation in acupuncture. We found that there was a significant association between increased force generation and increased needle diameter when lifting-thrusting movements were being performed. The "Miraculous Pivot [16]" said: if a disease is deep-rooted, a long needle should be used, which is typically thicker. This indicates that needle selection according to diameter is an important factor to be considered based on disease symptoms. Furthermore, the "Plain Questions [17]" said: different acupuncture characteristics correspond to different disease indications.

Acupuncture is known to be a physical stimulus that affects the nervous system to prevent pain [1]. Stimulation strength, amplitude, and duration can impact sensory stimulation and cause inhibitory potential [18,19]; therefore, different stimuli can exert different physiological or treatment effects. Furthermore, details of needling, including different hand manipulations, are important for controlling the stimulus. Liu et al [6] and Xu et al [20] have reported that treatment efficacy varies with the presence or absence of hand manipulation, whereas Kong et al [21] argues that treatment effects vary with the type of hand manipulation. In addition, Lee et al [7] has observed changes in plasma substrates according to acupuncture depth.

The selection of manipulation and depth of insertion are the most representative methods for controlling stimulation rate, however, STRICTA criteria for interventional reporting in clinical trials suggests that detailed information on diameter, length, manufacturer, and material type should be assessed as well as manipulation, location of the point, depth of insertion, duration of insertion, and needle stimulation method [22]. This is because these needle characteristics may affect factors such as the amount of stimulus from the needle itself.

Thus, this study was conducted to compare the amounts of physical stimuli generated between the acupuncture needle and the porcine tissue phantom model during lifting-thrusting and twisting-rotating movements in different needle diameters. We chose needle diameters that were in clinical use to ensure that our results would be relevant in practice.

The lifting-thrusting and twisting-rotating methods are the most widely used methods for assessing changes in stimulation [23]. We selected the porcine tissue phantom model as it has similar characteristics to human tissue and has been used in previous studies [13].

When the needle is applied to the porcine tissue, the forces generated by the interaction with the phantom due to the lifting-thrusting or twisting-rotating movements may be considered to reflect the magnitude of the stimulus felt during acupuncture treatment. Furthermore, the maximum and minimum values measured can be understood as the magnitude of the maximum force measured according to the direction of progress or rotation of the needle.

The results of this study showed that the magnitude of needle force varied significantly with the needle diameter in the lifting-thrusting, but not twisting-rotating. There was a strong correlation and predictive value with the maximum and minimum values, indicating that the needle diameter increased the production of stimulation. Conversely, there was no significant difference when twisting-rotating was performed, indicating that needle diameter does not induce any change in stimulus during twisting-rotating actions. These results can be explained by formulae reported in Jiang et al [24] and Reed et al [25], which express the forces between the needle and tissue.

The interaction with the tissue when the acupuncture needle is inserted vertically can be classified according to stiffness, cutting, and friction forces [26]. However, Son et al [27] argues that the only force experienced from the tissue is friction force. Jiang et al [24] describes the amount of friction force generated when the needle is perpendicular to the phantom tissue as follows:

$$f_{\text{friction}} = -\frac{\mu D}{2}\frac{0.65E_2}{1-v_2^2}\sqrt[12]{\frac{E_2(\pi D)^4}{E_1 l(1-v_2^2)}}h$$

where D = needle diameter of needle, μ = coefficient of friction between f_{friction} force needle and tissue, E_1 and E_2 = Young's moduli (modulus of elasticity) between the needle and tissue, v_2 = Poisson ratio (strain) of tissue, and h = depth of insertion

This equation shows that an increase in needle diameter also increases the friction force caused by the lifting-thrusting of the needle; therefore, the greater the amount of force that the needle receives from the tissue.

For twisting-rotating movements, Reed et al [25] expresses the torsional force of the needle as follows:

$$\mathrm{T} = \left[\mathrm{T}_C + \mathrm{T}_{brk} - T_{C*\exp}(-cv|\omega|)\right] + f_\omega$$

where T = torque, T_c = coulomb friction torque, T_{brk} = breakaway friction torque, cv = coefficient, w = relative velocity, and f_w = viscosity friction coefficient.

This equation shows that torque, which results from an interaction between tissue and needle during rotational motion, is affected by the relative velocity between the tissue and needle; however, the needle diameter in this study does not affect the relative velocity of the needle.

Taken together, our results indicate that the diameter of the acupuncture needle should be considered in addition to factors such as manipulations, depth of insertion, and acupuncture points. In particular, we have confirmed that increased diameter of acupuncture needles should be considered as a way to influence the strength of the stimulus when using manipulations, such as reinforcement and reduction using speed.

The use of porcine tissue phantom to represent human tissue, and the use of only 1 axis for analysis in the study of the movement of the needle as determined by the needle insertion-measurement system, made it possible to identify the factors that affected the interaction with the porcine tissue phantom that may occur during acupuncture treatment. We expect this study to be the basis for further investigations into assessments of the movement of acupuncture needles quantitatively.

Conflicts of Interest

The authors have no conflicts of interest to declare.

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