



Original Article

Quantification of the parameters of twisting-rotating acupuncture manipulation using a needle force measurement system

Ye-Ji Han^a, Soo-Yoon Yi^a, Yoon-Joo Lee^a, Keun-Ho Kim^b, Eun-Jung Kim^{a,c},
Seung-Deok Lee^{a,c,*}

^a College of Korean Medicine, Dongguk University, Gyeongju, Korea

^b Division of Constitutional Medicine Research, Korea Institute of Oriental Medicine, Daejeon, Korea

^c Department of Acupuncture and Moxibustion, College of Oriental Medicine, Dongguk University, Gyeongju, Korea

ARTICLE INFO

Article history:

Received 11 September 2014

Received in revised form

4 March 2015

Accepted 10 April 2015

Available online 5 May 2015

Keywords:

needle force measurement system
quantification
twisting-rotating acupuncture
needle manipulation

ABSTRACT

Background: To date, much research has been conducted to measure needle manipulation quantitatively and objectively. This study was performed to quantitatively measure the differences in the amount of stimulation caused by various rotation frequencies and angles in twisting-rotating acupuncture needle manipulation.

Methods: The torque Z force exerted on a tissue was measured at various rotation frequencies and angles by rotating a needle with a needle force measurement system attached to a needle insertion tissue model.

Results: The results show that with rotation frequency at 60°, the torque Z force increased significantly from 0.023 Nmm to 0.118 Nmm as the rotation angle increased ($p < 0.05$). In addition, the torque Z force was significantly increased from 0.082 Nmm to 0.292 Nmm when the rotation angle increased from 60° to 180° at 0.15 Hz. ($p < 0.05$). A strong linear positive relationship between the torque Z force and rotation angle or frequency was obtained [Pearson correlation coefficient (r) > 0.88 ; $p < 0.001$].

Conclusion: The change in needle-tissue interaction force by rotating angles showed a tendency to be higher than those by rotation frequency. Further quantitative research on various manipulations will be required for a standardized education on manipulation and stimulation as well as on needle model development to become possible.

© 2015 Korea Institute of Oriental Medicine. Published by Elsevier. This is an open access article under the CC-BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

1. Introduction

Acupuncture therapy changes the amount of neuropeptides and neurotransmitters released by activating nerve branches, while also promoting the stimulation of nerve receptors.¹

The more the neurotransmitters are released and the longer their application time, the larger and longer lasting are the generated synaptic potentials.^{2,3}

Most of the potential receptors are excitatory, prompting depolarization, but the application of sensory stimulation can

* Corresponding author. Dongguk University International Hospital, 814 Siksa-dong, Iilsandong-gu, Goyang-si 411-773, Korea.

E-mail address: chuckman@dongguk.edu (S.-D. Lee).

<http://dx.doi.org/10.1016/j.imr.2015.04.003>

2213-4220/© 2015 Korea Institute of Oriental Medicine. Published by Elsevier. This is an open access article under the CC-BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

sometimes be inhibitory, triggering hyperpolarizing potential receptors. Thus, the amount of stimulation should be adjusted to control the excitability and inhibitability of the sensory system.³

The stimulation amount is an important factor impacting the therapeutic effect, as acupuncture is a treatment that uses the stimulation method. Because different amounts of stimulation cause different physiological effects, the practitioner must decide how much stimulation should be used.⁴ Because of its subjective uncertainty, differences in stimulation may occur when an acupuncturist performs needle manipulation.^{5,6} Studying the relationship between the stimulation amounts caused by needle manipulation and their effects, as well as examining the functions and the roles of acupuncture, can contribute to the development of clinical guidelines and improve the effectiveness of the treatment.

When performing research on the relationship between the needle stimulation amount and its effects, it is necessary to objectify, quantify, and standardize the stimulation data according to the stimulation method.⁷

The term “needle manipulation” includes various needle techniques that are used to initiate De Qi after the needle has been inserted.⁸ The types of needle manipulation are basic manipulation, assistant manipulation, and reinforcing-reducing manipulation.⁶ The basic manipulation type can be subcategorized into lifting–thrusting manipulation and twisting–rotating manipulation.⁹

In twisting–rotating manipulation, one of the most commonly used manipulations,⁸ acupuncturists insert needles to a certain depth and rotate them.⁵ The most basic practice is a bidirectional rotation performed at various frequencies and angles to increase the therapeutic effects.¹⁰

When performing twisting–rotating manipulation with reinforcing–reducing methods, the practitioner performs the reinforcing method by rotating the needles while pushing the thumb forward, whereas the reducing method is practiced by rotating the needles while pulling the thumb back. In the reinforcing method, the needles are rotated gradually after De Qi, with small twisting angles and slow rotations over a short manipulation time. In the reducing method, the needles are rotated strongly, with large rotating angles and fast rotations over a longer manipulation time.¹⁰

A quantitative and objective study on acupuncture needle manipulation is ongoing that contains three parts. First, a practitioner performs needle manipulation using an acupuncture manipulation detector.^{11–20} Second, the differences in the physical reactions of the patients are measured quantitatively.^{7,21,22} Third, a system is developed¹ that will allow needle manipulation to be practiced objectively and quantitatively.

The Shanghai University of Traditional Chinese Medicine developed a device that can quantitatively measure the needle manipulation performed by a practitioner,²⁰ and a similar measuring device has been developed in the United States.²³ These devices measure parameters such as frequency, range/angle, and duration in real time during the needle manipulation.

Needle insertion was performed using the needle force measuring system, which is more objective and reproducible

than insertion by a subjective practitioner. The stimulation applied to the tissues is the same as the force on the acupuncture needle's body, and by measuring the rotation force applied to the needle, we can objectively quantify the amount of stimulation exerted on the tissues.

In previous studies on twisting–rotating manipulation, the rotation angle and the duration and frequency of the twist needling were set as parameters.²⁰ This study used the rotation angles and the frequency as parameters, and the differences in the stimulation amounts caused by these parameters were quantitatively measured by the needle force measurement system. Based on this system, the stimulation difference was examined. During the reinforcing method, the needles are rotated gradually with small twisting angles (60° and 90°) and slow rotations (0.05 Hz and 0.1 Hz). In the reducing method, the needles are rotated with large rotating angles (120° and 180°) and fast rotations (0.15 Hz and 0.20 Hz).

The aim of this study is to quantitatively compare the amount of stimulation according to variations in the parameters' range and frequency during twisting–rotating acupuncture needle manipulation. A needle-insertion measurement system in phantom tissue was used for the quantitative comparison.

2. Methods

2.1. Quantitative measurement of stimulation through the needle force measurement system

Using a motor generating reducing–reinforcing manipulation and a tissue container holding tissues, a stable twisting–rotating manipulation movement was reproduced.⁶ The rotation angles and frequency were set by the software used. Based on the settings of this software, the motor creates a rotational motion, and the sensor attached to the needle holder measures the needle–tissue interaction force and torques. The computer used to control the system and measure the output was a Pentium personal computer (Intel, Santa Clara, CA, USA) with a Windows 8 Operating System (Microsoft, Redmond, VA, USA; Fig. 1).

The entire system consists of a needle insertion device that drives the rotational motions, a control device, and a computer. The needle insertion device has two motors, which are responsible for the vertical and rotational motions, along with a six-axis sensor. The motor is connected to a motor driver in the control device that dictates the motor's force, and the location information is provided by the software through the Q-8 universal serial bus board. The sensor is connected to a force sensor amplifier, and the data are passed to a National Instruments data-acquisition board in the computer (Fig. 2). The six-axis F/T sensor (Nano-17, ATI Industrial Automation, Garner, NC, USA) is mounted on the handle of the needle to measure the instantaneous force and torque across the six axes (F_x , F_y , F_z , T_x , T_y , and T_z) that were felt by the physicians during the needle insertion. An ATI Nano-17 force sensor has full-scale force (z axis) of 35 N, force resolution of 1/160 N, full-scale torque of 250 mNm, and torque resolution of 1/32 mNm.²⁴ In this study, T_z was measured in the center-axis direction of the rotational motion (Fig. 3).

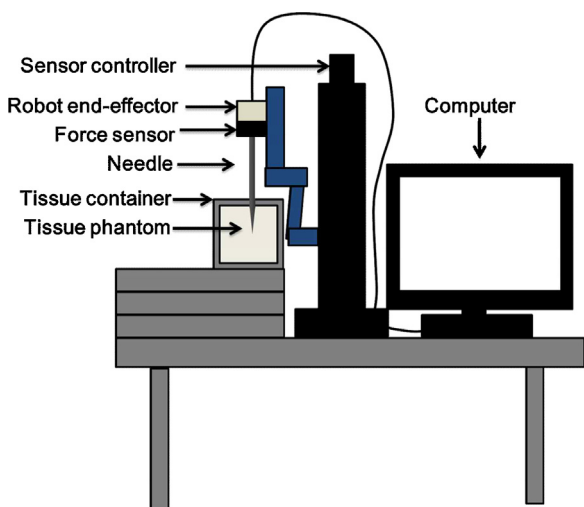


Fig. 1 – The experimental setup and data collection of the needle force measuring system. The tissue model is suspended in a tissue container, and small holes in the container allow the needle to pass through.

2.2. Software

Simulink (MathWorks, Natick, MA, USA) and QUARC (Quanser, Markham, ON, CA) were used as analysis software, and the amplitude, frequency, rotation angle, rotation rate, and rotation direction of the needle could all be controlled by the software. Through a MATLAB (MathWorks) application, the motor driver was controlled in 500-Hz increments. The needle’s location and force information were sent to the computer from each motor and sensor, and the data were recorded at 50-Hz increments.

2.3. Materials

The experiment was designed using a cucumber needle insertion tissue model. Fresh cucumbers, displayed at the store and no longer than 3 days old, were used and stored at room temperature. To minimize any marginal errors caused by a movement of the cucumber, the model was fixed inside a container. To avoid changes to the tissue characteristics caused by evaporating moisture, the experimental time for each tissue model was limited to less than 5 minutes. We performed the experiment with the cucumber model because it is easy to obtain, not harmful, and not stationary. In addition, it has been

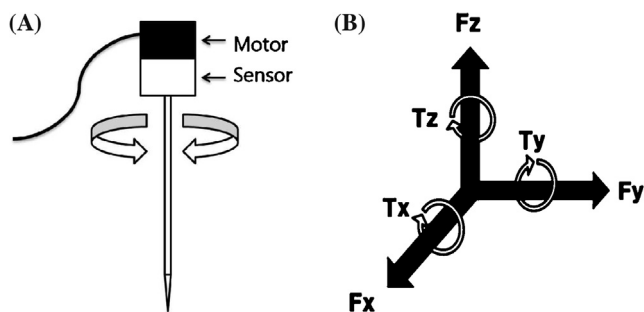


Fig. 3 – (A) The six-axis force torque sensor and needle and (B) the directions of the six axes of force and torque detected by the motion and force sensor. The needle and force Z axis are parallel.

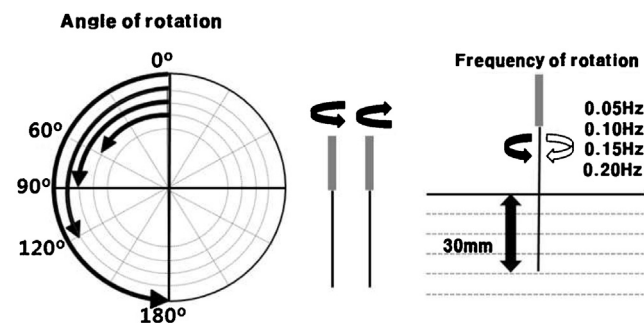


Fig. 4 – Schematic diagram of the needle rotation.

founded that the feeling of inserting a needle into cucumber is similar to the feeling of inserting a needle into human tissue.²⁵ Each rotation was performed on various parts of the cucumber, because repeated rotation of a needle in the same region may significantly reduce the resistance produced by the fibrotic tissues of the cucumber.

2.4. Experimental protocol

A stainless steel needle (gauge, 40; diameter, 0.40 mm; Dong-bang Healthcare Products, Seoul, Korea) was inserted into the needle–tissue model at a depth of 3 cm from the surface (Fig. 4). After insertion, the needle was rotated clockwise at a defined angle and then returned to its original position through a counter-clockwise motion. The parameters were set as shown in Table 1, and 10 cycles were performed and measured for each parameter (Table 1). With a rotation angle set to 60°, the

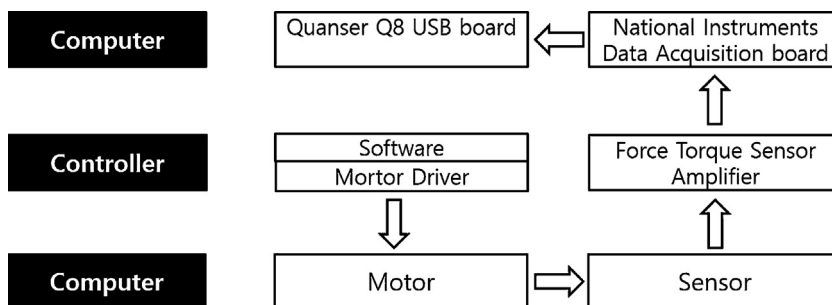


Fig. 2 – Schematic diagram of the system’s structure. USB, universal serial bus.

Table 1 – Needle rotation parameters, including rotation angles (60°, 90°, 120°, and 180°) and rotation frequency (0.05 Hz, 0.10 Hz, 0.15 Hz, and 0.20 Hz)

Angle (°)	Frequency (Hz)	Angle (°)	Frequency (Hz)
60	0.05	120	0.05
60	0.10	120	0.10
60	0.15	120	0.15
60	0.20	120	0.20
90	0.05	180	0.05
90	0.10	180	0.10
90	0.15	180	0.15
90	0.20	180	0.20

rotation frequencies were varied to 0.05 Hz, 0.10 Hz, 0.15 Hz, and 0.20 Hz, and the torque (T_z) was measured as a function of time. This was repeated for rotation angles of 90°, 120°, and 180°. Then, the rotation frequency was set to 0.05 Hz, and the torque (T_z), displacement, velocity, and accelerated velocity were measured at rotation angles of 60°, 90°, 120°, and 180°. These measurements were repeated for frequencies of 0.10 Hz, 0.15 Hz, and 0.20 Hz.

2.5. Data processing

The maximum and minimum values of the torque Z force for each parameter were calculated from the observed data, and then the minimum torque Z force was deducted from the maximum. We defined this force amplitude (FA) as an absolute value equal to the difference between maximum and minimum torque forces ($FA = \max T_z - \min T_z$). For each variable, the FA was calculated for each cycle, and then for comparison, the average of the FAs of 10 cycles was used as the amount of stimulation the tissue received.

2.6. Data analysis

For data analysis, the statistics program Stata/SE (Stata/SE 9.2 for Windows, StataCorp LP, College Station, TX, USA) was used. The experimental results are indicated as the mean \pm standard error of the mean. Analysis of variance was used for statistical analysis, and when the difference was considered significant the Bonferroni method was applied.

Data were then examined by Pearson correlation (r) analysis to determine which variables had high degrees of correlation. A value of $p < .05$ was accepted as statistically significant.

3. Results

3.1. Effect of the rotation angle

The results obtained using the cucumber tissue model for the torque Z force measurement, which quantitatively measured the stimulation caused by twisting–rotating needle manipulation based on rotation frequencies and angles, are described in the following section.

Greater torque was observed as the rotation angle increased between 60°, 90°, 120°, and 180°, as shown in the time–torque graph (Fig. 5). When the rotation frequency was 0.05 Hz, the FA increased from 0.023 N mm to 0.115 N mm as

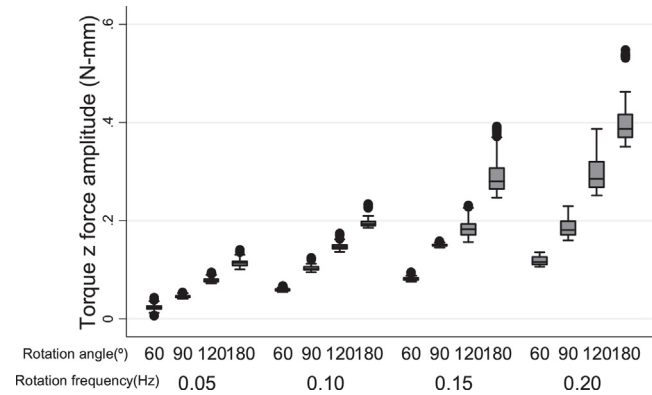


Fig. 5 – Torque Z force amplitude. We defined this as force amplitude (force amplitude = $\max T_z - \min T_z$). The means are significantly ($p < 0.05$) different between the different needle rotation angles. The box plots indicate the median (central horizontal line), interquartile range (box limits), range (whiskers, up to 1.5 times the upper and lower quartiles), and outliers (scattered dots, more than 1.5 times the interquartile range from the median).

the rotation angle increased from 60° to 180°. At a rotation frequency of 0.10 Hz, the FA exerted on the tissues increased from 0.059 N mm to 0.197 N mm as the rotation angle increased. At a frequency of 0.15 Hz, the FA increased from 0.082 N mm to 0.292 N mm as the rotation angle increased, and at 0.20 Hz, the FA increase was from 0.118 N mm to 0.404 N mm, with $p < 0.05$ (Table 2 and Fig. 6). The average FA was 0.282 N mm, 0.485 N mm, 0.708 N mm, 1.008 N mm for rotation angles of 60°, 90°, 120°, and 180°, respectively. A twofold increase in rotation angle results in approximately 230% increase in tissue–needle interaction.

Pearson correlation coefficient was estimated to quantify the strength of the association between FA and rotation angles. Correlation coefficients between these parameters were 0.9603 in 0.05 Hz, 0.9355 in 0.1 Hz, 0.9303 in 0.15 Hz, and 0.8822 in 0.2 Hz ($p < 0.001$).

3.2. Effect of the rotation frequency

At a constant rotation angle, the FA increases at faster rotation frequencies, as shown in the time–torque graph. When the angle was 60°, the FA exerted on the tissue increased from 0.023 N mm to 0.118 N mm as the rotation frequency increased from 0.05 Hz to 0.20 Hz. At 90°, as the rotation frequency increased from 0.05 Hz to 0.20 Hz, the FA applied to the tissues increased from 0.045 N mm to 0.186 N mm. When the angle was 120°, the FA increased from 0.79 N mm to 0.297 N mm as the rotation frequency increased from 0.05 Hz to 0.20 Hz. At 180°, the FA increased from 0.115 N mm to 0.404 N mm as the rotation frequency increased from 0.05 Hz to 0.20 Hz (Table 3 and Fig. 7). The average FA was 0.262 N mm, 0.508 N mm, and 1.005 N mm for rotation frequencies of 0.05 Hz, 0.1 Hz, and 0.2 Hz, respectively. A twofold increase in rotation frequency results in approximately 195% increase in tissue–needle interaction force.

Table 2 – Needle torque measured during needle motions at various rotation angles (60°, 90°, 120°, and 180°) and frequencies (0.05 Hz, 0.10 Hz, 0.15 Hz, and 0.20 Hz)

Rotation frequency (Hz)	Torque Z force amplitude (N·mm)			
	60°	90°	120°	180°
0.05	0.023 ± 0.006	0.045 ± 0.003	0.079 ± 0.005	0.115 ± 0.009
0.10	0.059 ± 0.003	0.104 ± 0.007	0.148 ± 0.009	0.197 ± 0.012
0.15	0.082 ± 0.005	0.150 ± 0.003	0.184 ± 0.018	0.292 ± 0.038
0.20	0.118 ± 0.009	0.186 ± 0.019	0.297 ± 0.036	0.404 ± 0.051

The results are shown as the mean ± standard error of the mean.

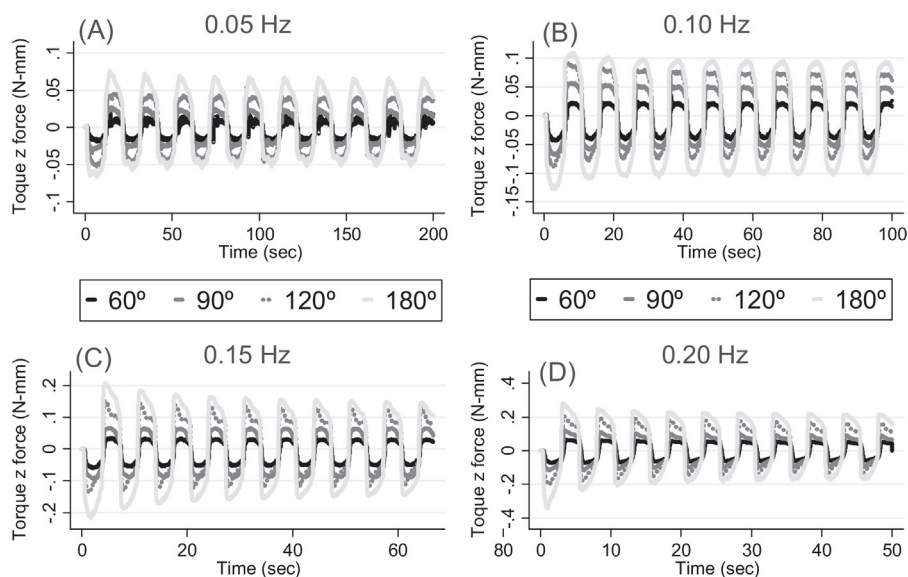


Fig. 6 – A graph of the time-dependent torque Z force as the needle rotates at either 60°, 90°, 120°, or 180°. The rotation frequency was fixed in each experiment: (A) 0.05 Hz, (B) 0.10 Hz, (C) 0.15 Hz, and (D) 0.20 Hz.

When the rotation angle is constant, a faster rotation frequency decreases the time required to reach peak torque, as shown in the time-torque graph (Fig. 8). At a constant rotation angle, the rotation frequency increases as the torque increases for the same displacement, as shown in the displacement-torque graph (Fig. 9). From the frequency-torque graph, it can be observed that a stronger torque is applied when the rotation frequency increases at a constant rotation angle (Fig. 10). Correlation coefficients between these parameters were 0.9269 at 60°, 0.9182 at 90°, 0.9623 at 120°, and 0.9291 at 180° ($p < 0.001$).

4. Discussion

The twisting-rotating manipulation is one of the manipulation techniques used in acupuncture, and refers to the rotational motion of the needles around an axis.¹⁰ Needle manipulation is an important factor influencing the therapeutic effect of acupuncture,²⁰ and different treatment results can be obtained based on the amount of stimulation applied during manipulation.²⁶ Thus, an objective, standardized, and quantified study should be performed that can produce consistent therapeutic effects through needle manipulation.

Table 3 – Needle torque measured during needle motions at various rotation frequencies (0.05 Hz, 0.10 Hz, 0.15 Hz, and 0.20 Hz) and angles (60°, 90°, 120°, and 180°)

Parameters	Torque Z force amplitude (N·mm)			
	0.05 Hz	0.10 Hz	0.15 Hz	0.20 Hz
60°	0.023 ± 0.006	0.059 ± 0.003	0.082 ± 0.005	0.118 ± 0.009
90°	0.045 ± 0.003	0.104 ± 0.007	0.150 ± 0.003	0.186 ± 0.019
120°	0.079 ± 0.005	0.148 ± 0.009	0.184 ± 0.018	0.297 ± 0.036
180°	0.115 ± 0.009	0.197 ± 0.012	0.292 ± 0.038	0.404 ± 0.051

The results are shown as the mean ± standard error of the mean.

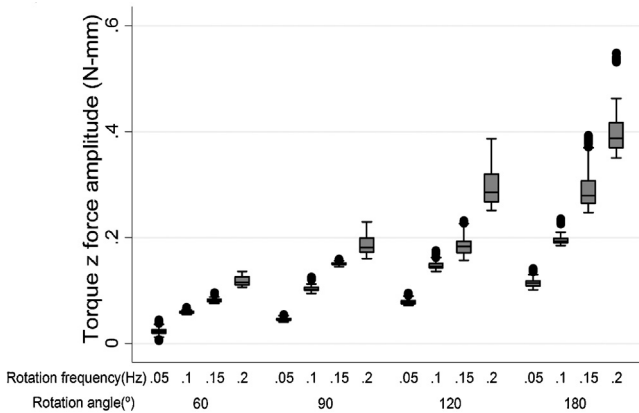


Fig. 7 – Torque Z force measurements. The means between the different needle rotation speeds are significantly ($p > 0.05$) different. The box plots indicate the median (central horizontal line), interquartile range (box limits), range (whiskers, up to 1.5 times the upper and lower quartiles), and outliers (scattered dots, more than 1.5 times the interquartile range from the median).

This study attempted to use the needle force measurement system to quantitatively measure the differences in the amount of stimulation caused by different rotation angles and frequencies. At a constant rotation frequency, a greater torque is caused when the rotation angle increases from 60° to 180°. The FA also increased along with the increase in the rotation angle at all of the frequencies measured.

We can define the amount of stimulation applied to the tissues as an impulse (I)

$$I = Tz \times \text{freq} \tag{1}$$

The impulse exerted on a tissue can be calculated by multiplying the torque on the tissue surface with the needle

rotation time (t). Therefore, the integral value in the time–torque Z force graph can be interpreted as the impulse that the tissues receive, which increases as the rotation angle increases.

This result coincides with the definition of torque ($\tau = \text{torque}$) described in a study by Reed,²⁷ who stated that torque is the multiplication of viscosity (b) and the rotation angle (θ) at a steady rotational motion. To reduce the margin of error, our experiment was repeated 10 times, but the results showed that the torque and the rotation angles were not directly proportional. This is because the needles were not inserted completely perpendicularly to the tissues, and there was therefore a slight difference between the angle of the needle tip inserted deeply into the tissues and the rotation angle of the needle handle sensed by the needle force measurement system.

In previous studies, acupuncture practitioners performed the twisting–rotating manipulation using both the reinforcing method, with needles rotating in small angles, and the reducing method, with needles rotating in larger angles. The results of those studies were analyzed by the acupuncture manipulation information analyzing system, which revealed that the stimulation amount was greater when using the reducing method.¹⁸ In the comparative analysis of two twisting–rotating manipulations of the same frequency but with different rotation angles, it was reported that the body temperature rose when the rotation angle was small and dropped with a larger rotation angle.²¹ Moreover, the linear analysis showed a greater voltage at a greater rotation angle.¹⁰ The animal study confirmed that the rotation angles in twisting–rotating manipulations affect the tissue responsiveness of connective tissue cells.^{5,28}

This research is the first study to have experimentally confirmed that the amount of stimulation on tissues increases as the rotation angle increases during twisting–rotating manipulation. Previous studies using the practitioners’ subjective acupuncture sensation claimed that the stimulation amount

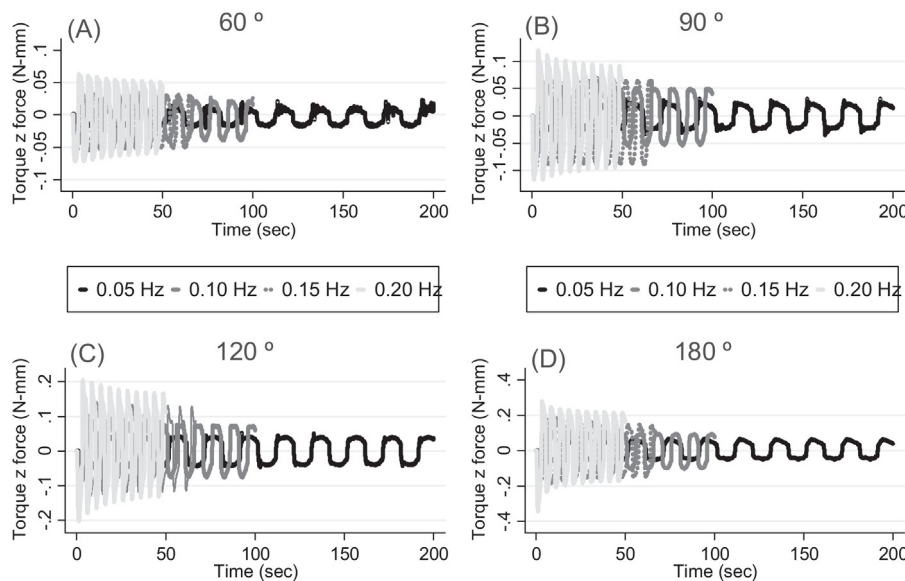


Fig. 8 – Graph of the time-dependent torque Z force as the needle rotates at 0.05 Hz, 0.10 Hz, 0.15 Hz, or 0.20 Hz. The rotation angle was fixed in each experiment: (A) 60°, (B) 90°, (C) 120°, and (D) 180°.

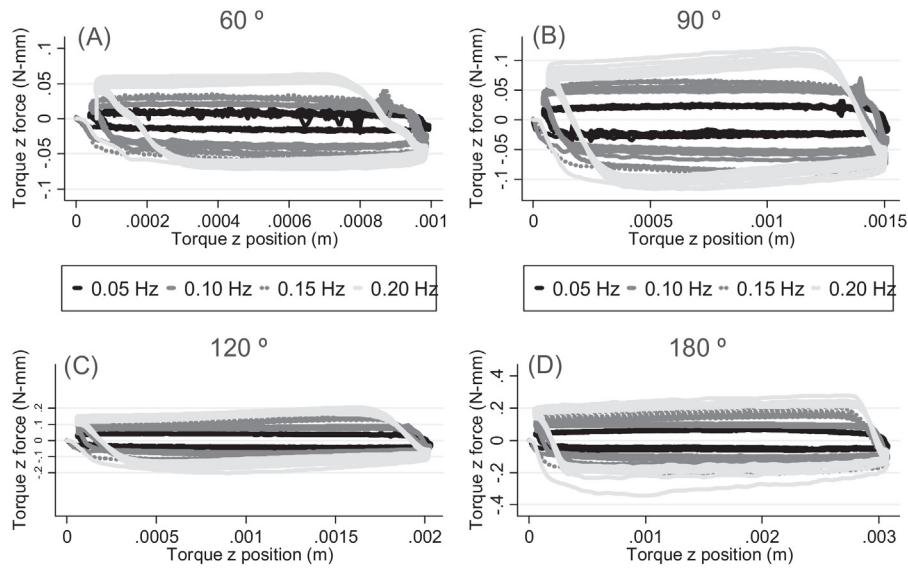


Fig. 9 – Graph of the position-dependent torque Z force as the needle rotates at 0.05 Hz, 0.10 Hz, 0.15 Hz, or 0.20 Hz. The rotation angle was fixed in each experiment: (A) 60°, (B) 90°, (C) 120°, and (D) 180°.

increased as the rotation angles increased,¹⁸ and our objective study supports this result. Thus, we believe that an objectification of the subjective acupuncture sensation will be possible in the future through an acupuncture sensation measurement system.

When the rotation angle was constant, the FA increased as the frequency increased from 0.05 Hz to 0.20 Hz. This result can be understood through the following equation, which Armstrong used to describe the friction of rotating objects.²⁹

$$T = [T_c + T_{brk} - T_c \cdot \exp(-c_v |\omega|)] + f_v \omega \tag{2}$$

where T is friction torque, T_c is Coulomb friction torque, T_{brk} is breakaway friction torque, c_v is coefficient, ω is relative velocity, and f_v is viscous friction coefficient.

In Eq. (2), ω indicates the relative velocity between the tissues and a needle. Thus, the rotational force increases in accordance with the increase in relative velocity.³⁰

In a comparative analysis of two different twisting-rotating manipulation methods with the same rotation angle but with different rotation frequencies, it was reported that the body surface temperature was lower at a higher frequency.²¹ Another study that evaluated the acupuncture manipulation information analyzing system showed that when the reinforcing method was performed with a slow rotation and

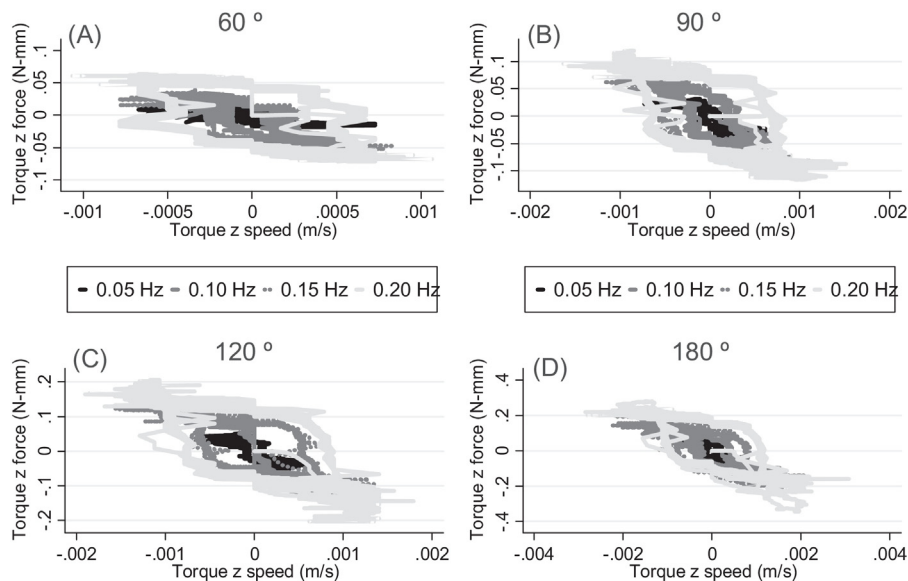


Fig. 10 – Graph of the speed-dependent torque Z force as the needle rotates at 0.05 Hz, 0.10 Hz, 0.15 Hz, or 0.20 Hz. The rotation angle was fixed in each experiment: (A) 60°, (B) 90°, (C) 120°, and (D) 180°.

the reducing method was performed with a faster rotation, the reducing method caused a greater amount of stimulation.¹⁸ In studies using rotation directions, frequencies, intervals of manipulation, and specific acupoints as parameters, it was found that a slower rotation frequency, as well as other parameters, was more effective during the reinforcing method.³¹

This study experimentally demonstrated that the amount of tissue stimulation increased as the rotation frequencies increased and suggested the possibility that the acupuncture sensation could be objectified through the needle force measurement system.

Acupuncture and moxibustion textbooks³² largely define twisting–rotating manipulation with reinforcing–reducing methods as follows:

- A left rotation is performed with the reinforcing method, whereas a right rotation is performed with the reducing method.
- No distinction is made between left and right rotations when the rotation angle is small; instead, a lower force with a gradual and slow insertion providing short stimulation is defined as the “reinforcing method,” whereas a fast insertion with a larger rotation angle and a larger force causing a longer manipulation time is defined as the “reducing method.”

In this study, different rotation frequencies and angles were set as parameters, and their results were quantitatively measured and compared. From the results, it can be concluded that the amount of stimulation applied is greater at larger angles. In other words, the reducing method provides a greater amount of stimulation than the reinforcing method does, which was also confirmed through an objective measurement system.

However, the amount of stimulation caused by a left turn versus a right, which is considered in acupuncture to be one of the significant factors, was not compared because the tissue model used did not display any needle grasp³³ in reaction to the rotation of the needle.

In an earlier phase of the study, an animal tissue model was also considered, but the deviation among the tissues was so large that the animal model was excluded. Animal tissues are often made up of different components, and even within the same body area, there are tissues with more fat, for example.

A direct insertion into a human body was excluded due to the following reasons. It is difficult to control all movements during 10 cycles of needle insertion and measurement because of variables such as breathing or muscle contractions, and there are also individual differences in the depth of subcutaneous tissues and flesh density. In addition, even within the same body, the amount of stimulation varied due to the location of the acupuncture point on ST36.

Cucumber is known to have a similar acupuncture sensation as a human, and it shows fewer differences caused by friction between different body areas and the needle inserted. Therefore, this study was conducted using cucumbers as the needle insertion tissue model. Any element that may affect the friction between a needle and the tissue, such as the needle's thickness or the insertion depth during

reinforcing–reducing twisting–rotating manipulation, still needs further research.

This study measured the amount of stimulation with regard to the needle rotation frequency and rotation angle. This is the first study to quantify the amount of applied stimulation using an objective measurement system based on twisting–rotating manipulation control parameters, as opposed to subjective acupuncture sensations. Additional quantitative research on the way in which stimulation is impacted by different parameters and various manipulations is recommended. Based on such future research, standardized education on stimulation and on needle insertion models for manipulation will be developed.

After performing a quantitative measurement and comparative analysis of acupuncture stimulation using the needle force measurement system at various rotation angles and frequencies, we arrived at the following conclusions:

The amount of stimulation applied to tissues during twisting–rotating manipulation increases as the rotation frequency increases from 0.05 Hz to 0.2 Hz at 60°, and the needle–tissue interaction FA changed from 0.023 Nmm to 0.118 Nmm. In addition, the amount of stimulation to a tissue increased from 0.082 Nmm to 0.292 Nmm when the rotation angle increased from 60° to 180° at 0.15 Hz.

A strong linear positive relationship between FA of needle–tissue interaction and the angle or frequency was found.

This paper takes the first approach, that is, quantitatively measuring the differences in the amount of stimulation caused by various acupuncture needle manipulation. In the future study, Pearson correlation coefficients and linear regression will be calculated to find out whether frequency or amplitude of needle movement is the most important factor for the interaction force between tissue and needle.

By measuring the needle–tissue interaction, the power required in acupuncture manipulation according to the change of rotation speed is measured. The result confirms the necessity of more needle manipulation force as the rotation speed gets faster. The required force increases with not only the rotation speed but also the needle–tissue contact area, the thickness of the needle, and is inversely related to the thickness of the handle used for operating it. In the future, further research for additional verification is required.

Conflicts of interest

All contributing authors declare no conflicts of interest.

Acknowledgments

This research was supported by the “2013 KIOM Undergraduate Research Program” funded by Korean Institute of Oriental Medicine, South Korea. The authors are especially grateful to members of the Department of Acupuncture and Moxibustion (Dongguk University) for their help with this work.

REFERENCES

1. Hao W, Zhu X, Zhang H, Tian B. Study on a mechanical acupuncture instrument with computer aided controlled. *Conf Proc IEEE Eng Med Biol Soc* 2005;4259–62.
2. Kandel ER, Schwartz JH, Jessell TM. *Principles of neural science*. New York: McGraw-Hill; 2000:415.
3. Lundy-Ekman L. *Neuroscience: fundamentals for rehabilitation*. 3rd. St. Louis, MO: Saunders Elsevier; 2007:31.
4. Hu Y-e, Yang H-y. Study of acupuncture manipulation parameter based on data mining technique. In: *7th Asian-Pacific Conference on Medical and Biological Engineering, Springer*. 2008.
5. Langevin HM, Bouffard NA, Churchill DL, Badger GJ. Connective tissue fibroblast response to acupuncture: dose-dependent effect of bidirectional needle rotation. *J Altern Complement Med* 2007;13:355–60.
6. Tian B, Yang H. The engineering research and development of acupuncture manipulation instrument based on the motion control. In: *Third International Symposium on Information Processing (ISIP 2010)*. 2010:559–62.
7. Zheng Z, Liu Y, Guo Y, Guo Y, Wang C, Wang J, et al. Preliminary exploration of research method for studying the influence of acupuncture manipulations on electrical signals of spinal dorsal root nerve in rats. In: *Sixth International Conference on Natural Computation (ICNC 2010)*. 2010:509–13.
8. Huang T, Zhang W, Jia S, Tian Y, Wang G, Yang L, et al. A transcontinental pilot study for acupuncture lifting-thrusting and twisting-rotating manipulations. *Evid Based Complement Alternat Med* 2012;2012:157989.
9. Mackereth PA, Maycock P. Needling techniques for acupuncturists: basic principles and techniques. *Complement Ther Clin Pract* 2012;18:1–129.
10. Wang CH, Xu JM, Zhang TT. Study on twirling reinforcing-reducing manipulation based on the parameter figure of the acupuncture manipulation apparatus. *Zhongguo Zhen Jiu* 2009;29:723–5 [Article in Chinese].
11. Ding G, Shen X, Dai J, Liu H, Yao W, Li X. Research and development on the dynamic system for detecting the force of acupuncture needle during the acupuncture process in the clinical practice of traditional Chinese medicine. *Sheng Wu Yi Xue Gong Cheng Xue Za Zhi* 2003;20:121–4 [Article in Chinese].
12. Tangyi L, Huayuan Y, Xunjie G. Development of model ATP-I acupuncture manipulation parameter determination apparatus. *Zhongguo Zhen Jiu* 2003;11:668–70.
13. Yang HY, Liu TY, Kuai L, Gao M, Hu ZC. Research on real-time data collection and demonstration system for acupuncture manipulation. *Zhong Xi Yi Jie He Xue Bao* 2006;4:311–4 [Article in Chinese].
14. Liu TY, Kuai L, Yang HY, Gao M. Preliminary research on the standardization of acupuncture manipulation. *Zhongguo Zhen Jiu* 2008;28:356–8 [Article in Chinese].
15. Huayuan Y, Gang X, Jing L, Zhuicheng H, Tangyi L. Real-time signal procession of acupuncture manipulation and identification research on AR parameter model. In: *IEEE International Symposium on IT in Medicine and Education (ITIME'09)*. 2009:86–90.
16. Yang H, Liu Y, Gao M, Yin H, Hu Z. Research on real-time collection of acupuncture manipulation parameter and teaching demonstration system. In: *WRI World Congress on Software Engineering (WCSE'2009)*; 2009. pp. 434–6.
17. Hu Y, Yang H, Liu T. Design and implementation of the platform for clustering analysis on acupuncture manipulation parameters. *Sheng Wu Yi Xue Gong Cheng Xue Za Zhi* 2010;27:991–4 [Article in Chinese].
18. Liu TY, Yang HY, Kuai L, Ming G. Classification and characters of physical parameters of lifting-thrusting and twirling manipulations of acupuncture. *Zhen Ci Yan Jiu* 2010;35:61–6 [Article in Chinese].
19. Wang X, Wang K, Li X, Wu L, Guo Y. Research progress of needle-type transducer and its application in traditional Chinese medicine. *J Clin Acupunct Moxibustion* 2010;12:68–71.
20. Yin'e H, Huayuan Y, Tangyi L. Study on cluster analysis of acupuncture-manipulation parameters. *World Sci Technol* 2011;13:59–63.
21. Ping L, Wei G, Fang W. Influence of needling zusanli with twirling reinforcing and reducing manipulation on skin temperature of epigastrium. *Gianjin J Tradit Chin Med* 2002;4:51–4.
22. Li WM, Chen YB, Wang XY. Characteristics of peripheral afferent nerve discharges evoked by manual acupuncture and electroacupuncture of “Zusanli” (ST 36) in rats. *Zhen Ci Yan Jiu* 2008;33:65–70 [Article in Chinese].
23. Davis RT, Churchill DL, Badger GJ, Dunn J, Langevin HM. A new method for quantifying the needling component of acupuncture treatments. *Acupunct Med* 2012;30:113–9.
24. Bebek O, Hwang MJ, Cavusoglu MC. Design of a parallel robot for needle-based interventions on small animals. *IEEE ASME Trans Mechatron* 2013;18:62–73.
25. Han Y-J, Jo S, Son Y-N, Lee S-Y, Kim K-S, Lee S-D. Comparative study of needle sensations in ST36 and 6 models with quantifying measurement system. *Acupuncture* 2013;30:87–94.
26. Li ZG, Wu MM, Liu CZ. Progress of researches on acupuncture manipulation and its quantification. *Zhen Ci Yan Jiu* 2010;35:78–81 [Article in Chinese].
27. Reed KB. Compensating for torsion windup in steerable needles. *Proc IEEE RAS EMBS Int Conf Biomed Robot Biomechatron* 2008;2008:936–41.
28. Langevin HM, Bouffard NA, Badger GJ, Churchill DL, Howe AK. Subcutaneous tissue fibroblast cytoskeletal remodeling induced by acupuncture: evidence for a mechanotransduction-based mechanism. *J Cell Physiol* 2006;207:767–74.
29. Armstrong B, de Wit CC. Friction modeling and compensation. In: *The Control Handbook*. CRC Press; 1995, quoted in Hasson CJ. Neural representation of muscle dynamics in voluntary movement control. *Exp Brain Res* 2014;232:2105–19.
30. Asadian A, Patel RV, Kermani MR. Compensation for relative velocity between needle and soft tissue for friction modeling in needle insertion. *Conf Proc IEEE Eng Med Biol Soc* 2012;2012:960–3.
31. Yang HY, Zhong XH, Liu TY, Kuai L, Gao M. Impact of different emulated acupuncture-needle manipulations on blood pressure and myocardial angiotensin II content in spontaneous hypertension rats. *Zhen Ci Yan Jiu* 2008;33:186–90 [Article in Chinese].
32. Beijing College of Traditional Chinese Medicine. *Essentials of Chinese acupuncture*. Beijing, China: Foreign Language Press; 1980.
33. Langevin HM, Churchill DL, Wu J, Badger GJ, Yandow JA, Fox JR, et al. Evidence of connective tissue involvement in acupuncture. *FASEB J* 2002;16:872–4.