Kinematic and Mechanical Analysis of the Ankle Rotating-Traction-Poking Manipulation

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Abstract

Background: In China, the ankle rotating-traction-poking manipulation (RTPM) has been used to increase range of movement and reduce pain in patients with lateral ankle sprains. But no research so far has quantitatively analyzed the kinematic and mechanical data of RTPM therapy. Therefore, the purpose of the present study was to analyze the kinematics and mechanics of RTPM technique.

Methods : A total of 60 volunteers who had ankle sprains participated in the study. A single physiotherapist specializing in RTPM worked with each of the subjects. Motion capture technology, self-developed mechanical gloves, and a data synchronization device were used to acquire kinematic and mechanical data during the RTPM.

Results : The mean maximum force of the thumb, index finger, and middle finger during the rotating was 18.89 N, 10.26 N, and 9.51 N, respectively, that of the traction force was 18.61 N, 13.25 N, and 8.33 N, respectively, and that of the poking force was 26.5 N, 8.61 N, and 10.62 N, respectively. The average time of rotating for six circles was 11.36 s. The average linear velocity of rotating was 58.28 mm/s, and that of traction-poking was 23.81 mm/s. The average linear acceleration of rotating was 0.43 mm/s ^{2} , and that of traction-poking was 0.54 mm/s ^{2} . The average displacements of traction and poking were 36.94 mm and 22.44 mm, respectively. The average angle of traction and poking were 23.27° and 22.76°, respectively.

Conclusions : The RTPM can be repeatable for clinical application, and also has features of gentleness, rhythmicity, and continuity.

1. Background

Lateral ankle sprains (LAS) are some of the most common musculoskeletal injuries. The rate of LAS ranges from 15% to 20% of all sports injuries [1]. Approximately 32%–74% of patients who suffer LAS develop chronic ankle instability [2,3], which presents with pain, recurrent ankle sprains, decreased neuromuscular control, weakness, an impaired sense of joint position, and diminished performance of functional activities [4]. The most common injury mechanism is a combination of inversion and adduction of the foot in plantarflexion. This injury mechanism can cause damage to the lateral ankle ligaments. Injury of the anterior talofibular ligament and calcaneofibular ligament leads to anterolateral rotary instability and tilting of the talus [5].

According to severity, ankle ligament sprains are divided into three grades [6]: Grade I (mild) - ligaments stretched mildly without macroscopic rupture or joint instability; Grade II (moderate) - ligaments stretched with a partial rupture - there is moderate pain, swelling, functional limitations, and mild to moderate instability. Typically, patients also present with symptoms of difficulty with weight bearing. Grade III (severe) - ligaments stretched with a complete ligament rupture, which presents with severe pain, swelling, hematoma, and significant functional impairment.

Some therapeutic methods have been recommended: surgery, immobilization, cold compresses, and functional treatments with bandages, braces, balance training, and manual therapy. Most authors have suggested non-surgical treatment for LAS [7]. Research has shown that manual therapy following LAS leads to superior early dorsiflexion range compared with a traditional exercise intervention alone [8, 9]. In a study, a caudal talocrural joint manipulation led to a significant plantar load distribution change [10]. Mechanical joint alternation and altered postural control may result in this change.

Ankle manipulation has a long history of use in Chinese medicine. At the present, Sun's ankle rotating-traction-poking manipulation (RTPM) is representative [11]. Physical therapists commonly use this kind of passive joint manipulation to increase range of movement and reduce pain in patients with LAS. Rotation manipulation can relax the spastic, curled, twisted muscular ligaments. Traction manipulation can temporarily widen the joint space to reset the position of the joints, such as the tibiotalar and talofibular joints. Poking manipulation can promote absorption of hematoma and rehabilitate the dorsiflexion range of motion. In recent studies, RTPM has been proven by large multi-center randomized controlled clinical trials for the treatment of Grade I and Grade II LAS. As shown in Table 1, compared with RICE (rest, ice, compression, elevation) therapy, RTPM could effectively improve pain, swelling degree and the Takakura ankle score in patients with acute ankle sprian, and has a stable long-term effect [12, 13]. RTPM can relieve pain and improve range of motion by improving the instability of the rotational talus, adjusting torsion of ligaments and other neurophysiological or mechanical mechanisms [14].

This technique pays attention to the operational principles of "gentleness, rhythmicity, and continuity", which requires skill but still lacks uniform clinical standards. Physical therapists only summarize the crucial operation according to abstract description or their own clinical experience, which leads to blindness and randomness. This results in inconsistent efficacy and safety that impedes the generalization of the RTPM technique. Consequently, it is significant to quantitatively analyze the kinematics and mechanics of RTPM therapy. Motion capture technology is mainly used to analyze foot gait in the ankle field [15], and to quantify cervical and lumbar manipulations [16, 17]. No research so far has involved the RTPM technique. The aim of our study was to measure the three-dimensional kinematic and mechanical parameters during RTPM and summarize its operating characteristics.

2. Methods

From June 2017 to June 2018, all 60 patients with ankle sprains were enrolled from the orthopaedic clinic of Wangjing Hospital, Chinese Academy of Chinese Medicine Science (CACMS). All participants had no fracture or dislocation on ankle X-rays and no complete ligament rupture on magnetic resonance imaging (MRI). The subjects included 15 females and 45 males aged 18–27 years. A physical therapist who specialized in the RTPM and operated this techniques in previous RCTs with extensive clinical experience participated in this experiment. The study was reviewed by the Medical Ethics Committee of Wangjing Hospital of the CACMS (No.WJEC-KT-2015-014-P002). All patients provided written informed consent for the public use of their treatment data and related pictures.

2.1 Instrumentation

2.1.1 Kinematic Instrumentation. The digital motion capture system comprised 14 fixed camera shots (Prime13 type, 1.3 million pixels, Optitrack Corp., USA) and six movable camera shots (Prime13 type, 4.1 million pixels, Optitrack Corp., USA).

2.1.2 Mechanical Instrumentation. Mechanical gloves were developed by the Orthopedic Technology Laboratory of CACMS and the Beijing Institute of Technology (BIT). These gloves had built-in mechanical sensors, gyroscopes, and accelerometer modules, which could measure the force, direction, acceleration, and other mechanical parameters of each finger (Figure 1).

2.1.3 Data Synchronization Acquisition Device. A kinematic and mechanical data synchronization acquisition device was developed by the Orthopedic Technology Laboratory of CACMS and Beijing Institute of Technology. This system used a Zigbee module with a long transmission distance and a fast sampling speed to communicate, which ensured the synchronous acquisition of mechanical gloves and motion capture system, and avoided the systematic errors caused by asynchronous acquisition.

2.1.4 Software. Kinematic software mainly included Optitrack eSync 2 synchronization software, Motive: Body1.10.1 Final software, and Visual 3D professional software (Developed by Natualpoint Inc.). The former two can derive and collect the trail of any marker point in the RTPM operation, and the latter can calculate the motion angle. The mechanical software was independently developed by the Beijing Institute of Technology.

2.2 RTPM Operation. The subjects were manipulated in a supine position (Figure 2), The specific methods were performed as follows:

1. Rotating manipulation: the operator rotated the injured ankle in six circles with a mild traction force with the help of an assistant.
2. Traction manipulation: the operator and assistant applied moderate traction force with a varus ankle position.
3. Poking manipulation: the operator's thumb poked and pressed the injured lateral ligaments with a valgus ankle position under a moderate traction force.

2.3 Procedures. This study was carried out at the Orthopedic Technology Laboratory of CACMS. The operator wore mechanical gloves and adjusted the position of the sensor and the tightness of the gloves, and then fixed the marker points on the glove surface. To avoid the interference of marker points and ensure the conciseness and continuity of the motion trail during manipulation procedures, after repeated attempts, we removed the marker points on the participant's ankles (see Figure 3a, b, c), and simplified the marker points on the operator's hands (see Figure 3d, e, f). Finally, a total of six marker points were placed on the mechanical gloves worn by the operator. The specific placement was as follows (see Figure 3d, e, f): one point was on the radial side of the first metacarpophalangeal joint. One point was on the radial side of the second metacarpophalangeal joint, and one point was on the radial side of the second proximal interphalangeal joint. The placement of marker points on the left and right hands was symmetrical.

A bed was placed in the center of the test site. The participant was placed in position on the uninjured side with the lower third of the shin out of the bed. Then we performed a calibration of the apparatus and initialization of the software. The doctor operated the RTPM. The digital motion capture system and mechanical gloves tracked and saved the data of the whole process.

2.4 Experimental Observation Parameters. The observation parameters were as follows: (1) Mechanical parameters: The maximum force of the thumb, index finger, middle finger, ring finger, and little finger through the RTPM procedures. (2) Kinematic parameters: (a) The time of the rotating, traction, and poking stages, (b) the displacement of the traction and poking stages, (c) the angle of the traction and poking stages, (d) the linear velocity and linear acceleration through the RTPM procedures.

3. Results

3.1 Force-Time Curve of the Fingers. Figure 4 represents the force-time curve on each of the fingers of the operator's hands collected by mechanical sensors, in which the abscissa represents the time and the ordinate represents the force. This whole curve consists of two repeated RTPM procedures and implies the following features: (1) The a-b and c-d stages are rotating procedures. The frequency, period, and force of this stage are always at a stable level, which shows that the rotating manipulation has the characteristics of uniformity, stability, and continuity. The b-c and d-e stages are traction-poking procedures. This part is more flexible and there is no pause at the junction of these two manipulations, which indicates that the traction-poking manipulation is also stable and continuous. (2) The whole curve shows that the thumb exerts the greatest force during manipulation, followed by the index finger and the middle finger. The ring finger and the little finger exert an extremely small force, which only plays an auxiliary role in supporting the ankle. In addition, the peaks of thumb force alternate with the index finger and the middle finger, which indicates that the operator alternatively exerts force on the thumb with the index finger and the middle finger during the rotating operation.

3.2 Mechanical Data Analysis. As shown in Table 2, the thumb exerts the maximum force during the whole process of the RTPM. The force of the index finger is similar to the middle finger. The data of the ring finger and little finger are negligible due to being extremely small.

3.3 Kinematic Data Analysis. Table 3 presents the time, linear velocity, and linear acceleration of RTPM. (1) The average time of rotating for the six circles was 11.36 s, with an average of 1.9 s per circle. The average time of the traction-poking manipulation was 3.42 s. (2) The average linear velocity of rotating was 58.28 mm/s, and that of traction-poking was 23.81 mm/s. The linear velocity of rotating was greater than traction-poking. (3) The average linear acceleration of rotating was 0.43 mm/s^2, and that of traction-poking was 0.54 mm/s^2.

The displacement and angle of the traction-poking manipulation are shown in Table 4. It is difficult to extract the key points during the rotating process because the angle and displacement are continually changing. Thus, only the data on displacement and angle of the traction-poking manipulation were extracted. The average displacements of traction and poking were 36.94 mm and 22.44 mm, respectively. The average angles of traction and poking was 23.27° and 22.76°, respectively. The three-dimensional coordinate system is established in the space of the ankle. The direction of the toe is defined as the X-axis, the direction of the parallel leg is the Y-axis, and the direction of vertical upward is the Z-axis. The displacement plane of the traction-poking manipulation is in the X-Z plane.

4. Discussion

Manual therapeutic methods are a major feature and advantage of orthopaedics in traditional Chinese medicine. It is particularly important to inherit and develop these clinically effective methods. The development trend for manipulation is gradually changing from a simple empirical mode to a quantitative, objective, digital, and precise mode. In this way, physical therapists can refer to the strength, frequency, time, displacement, angle, and other parameters during manipulation [18]. Therefore, by quantifying the manipulation technique, summarizing the mechanical and kinematic parameters, and forming the operational criteria, not only can the physical therapists have evidence to follow, but this has great significance for teaching and popularization of clinical manipulation.

At the present, the quantification of manipulation procedures is mostly limited to single analysis of mechanics or kinematics, or a phased study of both [19]. Although this method can also achieve the purpose of manipulation quantification, it takes more time and increases the subjective errors of researchers during both operations. In this study, the kinematic and mechanical data synchronization acquisition system was developed to ensure the synchronous acquisition of mechanical gloves and motion capture system data, which improved the efficiency of the experiment. To our knowledge, no similar synchronous data acquisition device has been used in previous studies. In addition, the self-developed mechanical gloves were more suitable for the clinical practice of the RTPM. These innovative instruments also add new contents and provide new ideas for the quantitative measurement technology of manipulation.

Motion capture technology was proposed by psychologist Johansson in a Moving Light Display experiment in the late 1970s [20]. This technology is a commonly used tool in biomechanical research that has been proven to be helpful in understanding complex human motion [21]. The accurate fixed scheme of marker points is the key to the success of the experiment. The initial marker points sticking scheme in this study was more complex (see Figure 3a, b, c), including the patient's ankle and the operator's hands. However, the motion trail obtained in the pre-experiment process was disordered and interrupted due to the following reasons: (1) Superfluous marker points: the movement range of each step of the RTPM is small and complex. When the number of marker points fixed by the operator's hands and the subject’s ankle was excessively large, it tended to cause interference. (2) Inappropriate fixed position of the marker points: the overlap and shelter of some marker points between the operator's hands and patient's ankle resulted in some of them not being captured. (3) Instability of the marker points: marker points were fixed mainly by a magic sticker with firmness that was unstable. In the process of the RTPM, magic stickers collided with each other and caused marker points to drop, which affected the consistency of the motion trail. Therefore, on the basis of the original marker point fixing scheme, we changed and simplified the plan (see Figure 3d, e, f). The final motion trail was concise and continuous, which could meet the kinematic analysis requirements for the RTPM.

With regard to the quantitative results, the mean maximum force of the thumb, index finger, and middle finger during rotating was 18.89 N, 10.26 N, and 9.51 N, respectively, with a traction force of 18.61 N, 13.25 N, and 8.33 N, respectively, and a poking force of 26.5 N, 8.61 N, and 10.62 N, respectively. Compared with previous studies that included similar kneading and pressing manipulations [22], the force of the fingers in the manipulation process obtained in our experiment was smaller. The reason for this difference may be: previous studies measured the mechanical data directly on the force platform. In our study, the object of manipulation was patients with an ankle sprain, which meant that the operator's finger force could not be large. This also indicated that the RTPM is based on the operational principle of "gentleness and softness".

The standardization of manipulation should be based on safety. According to the biomechanical study of the ankle ligament in cadavers, it is found that the ultimate damage load of the ankle ligaments is greater than 100 N [23]. The maximum force of the finger in this study was 34.72 N, which was much less than the load that causes damage to the ankle ligaments. Therefore, the RTPM technique is safe from this perspective.

The manipulation of traction and poking puts the ankle in passive varus and valgus, respectively. The displacement and angle of traction manipulation are larger than that of poking. This result is consistent with the physiological characteristics of the range of motion of the ankle, which has greater varus than valgus. The varus and valgus of the ankle are mainly performed by the subtalar joint. Owing to individual differences, studies reporting on this range are inconsistent. Grimston [24] recorded the valgus and valgus motion angles of the subtalar joints in subjects of different ages. The results showed that the valgus and valgus angles were 22.6 and 12.5 degrees, respectively. Guo [25] reported that the subtalar joint was in 10–15 degrees varus and 5–10 degrees valgus. The angle of ankle motion measured in our experiment was larger than other studies, which may be due to the following reasons: the angle measured in our experiment was derived from the whole ankle joint and its subsidiary structure, not the subtalar joint alone. In addition, the motion angle in our study was measured under passive motion, while in other studies it was measured under active motion.

The thumb, index finger, and middle finger exerted the main force in the RTPM. In the rotating operation, the thumb, index finger, and middle finger exerted force in an alternating fashion. The frequency and period of this force were rhythmic, uniform, and at a stable level. After the rotating operation, the traction and poking operation were performed. These three manipulations were in constant motion without a pause. The RTPM technique also reflected the features of rhythmicity and continuity.

5. Conclusions

The self-developed mechanical gloves and data synchronization acquisition device are beneficial for the biomechanical study of manipulation. The RTPM skill has features of gentleness, rhythmicity, and continuity after obtaining and analyzing the kinematic and mechanical data. This quantitative parameters and characteristics will help beginners to quickly master the skill of RTPM.

Abbreviations

RTPM: Rotating-traction-poking manipulation; LAS: Lateral ankle sprains; CACMS: Chinese Academy of Chinese Medicine Science; BIT: Beijing Institute of Technology; MRI: magnetic resonance imaging

Declarations

Ethics approval and consent to participate

The study was reviewed by the Medical Ethics Committee of Wangjing Hospital of the China Academy of Chinese Medical Sciences with the number: WJEC-KT-2015-014-P002.

Participants were consented using the approved informed consent document before their enrollment into the study.

Consent for publication

Not applicable.

Availability of data and materials

The data sets analysed during the current study are available from the corresponding author on reasonable request.

Competing Interestst

The authors declare that they have no conflicts of interest.

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Authors'contributions

GJH and ZLG was involved in obtaining the grant, designing the study. GCY and WBJ was involved in the data collection and writing the protocols. LJ and LJG was involved in designing kinematic and mechanical instrumentations. FMS supervised all the phases of this research project. All authors participated throughout the writing process and have read and approved the final version.

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Tables

Table 1. Changes in VAS score, Swelling degree, Takakura ankle score between RTPM group and RICE group

Groups	Time	N	VAS (mm)	Swelling degree (cm)	Takakura score
RTPM group	Before treatment	54	6. 37±1. 68	7. 19±0. 64	41.19±13.97
	After the first treatment	54	4. 39±1. 55**△	7. 06±0. 62**△	52.44±16.56△
	After the second treatment	54	2. 50±1. 56**△	6. 92±0. 60**△	67.70±16.00**
	After the third treatment	54	1. 30±1. 54**	6. 78±0. 58**△	81.87±17.09**
	Three months after the whole treatment	54	0. 69±1. 81**	6. 71±0. 58**	93.00±16.66**
RICE group	Before treatment	52	6. 24±1. 64	7. 16±0. 78	43.58±10.11
	After the first treatment	52	4. 88±1. 35**	7. 18±0. 84**	46.48±12.72
	After the second treatment	52	2. 98±1. 02**	7. 03±0. 77**	64.17±10.17
	After the third treatment	52	1. 73±1. 16**	6. 88±0. 75**	79.02±9.31**
	Three months after the whole treatment	52	0. 65±1. 01**	6. 80±0. 74**	92.61±6.56**

Compared with before treatment, **P<0.01; Compared with the control group, △P<0.05.

Table 2. Maximum force of each finger

	sample size	Rotating (N)	Traction (N)	Poking (N)
Thumb	60	18.89±5.39	18.61±6.60	26.50±8.22
Index finger	60	10.26±4.42	13.25±5.23	8.61±4.67
Middle finger	60	9.51±4.84	8.33±4.83	10.62±5.67

Table 3. Time, Linear velocity, Linear acceleration of RTPM

	sample size	Rotating	Traction-Poking
Time (s)	60	11.36±1.37	3.42±0.69
Linear velocity (mm/s)	60	58.28±8.86	23.81±4.19
Linear acceleration (mm/s2)	60	0.43±0.03	0.54±0.06

Table 4. Displacements and angle of traction-poking manipulation

	sample size	Traction	Poking
Displacements (mm)	60	36.94±11.11	22.44±8.45
Angle (°)	60	23.27±6.70	22.76±5.94

Figures

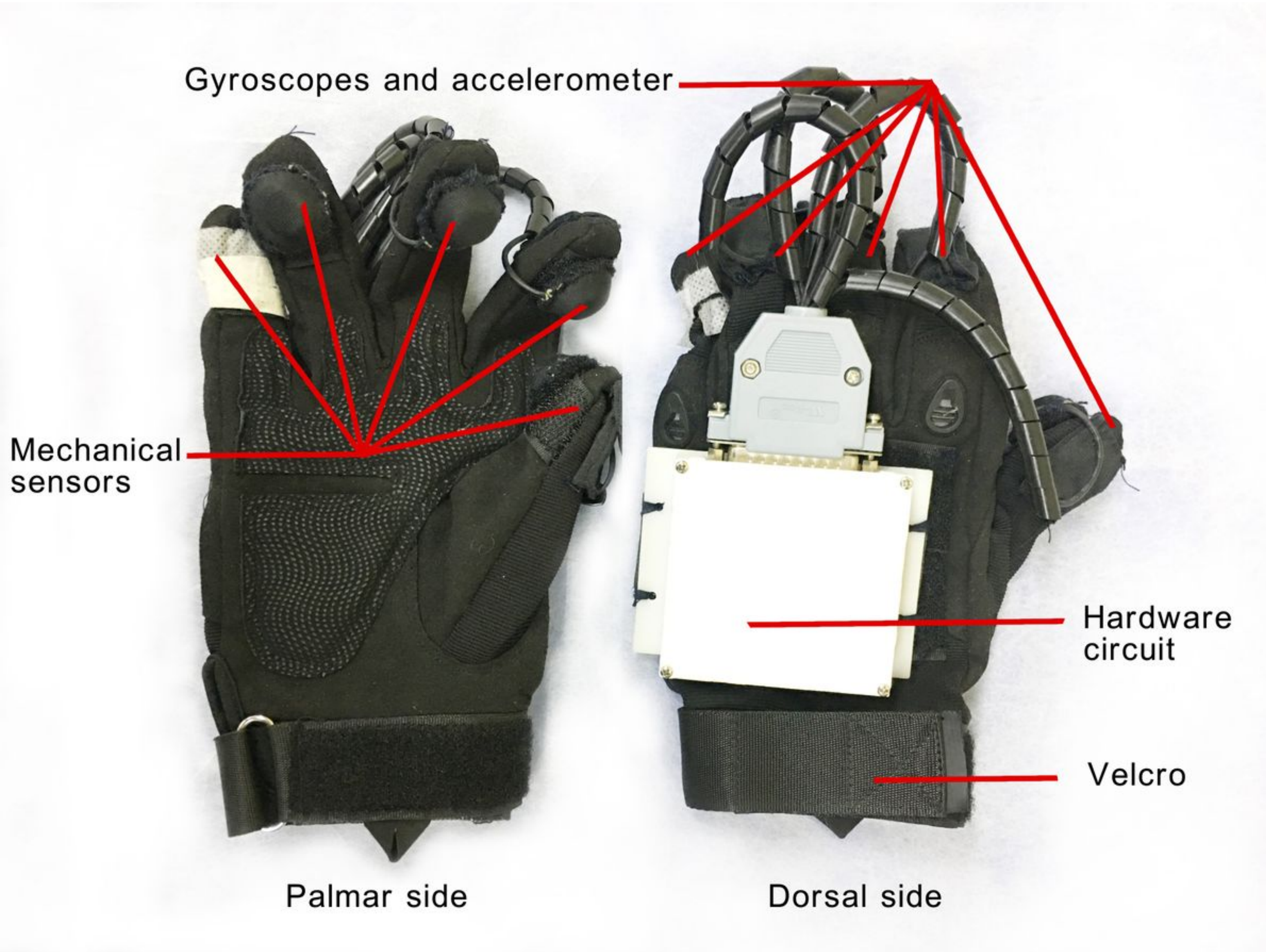
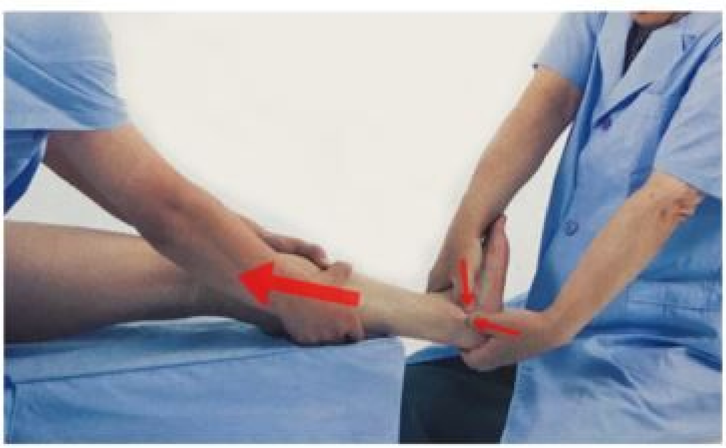


Figure 1

Mechanical gloves.

(a)

(b)



(c)

Figure 2

Illustration of the RTPM. (a) Rotating manipulation, (b) traction manipulation, (c) poking manipulation using the thumb.

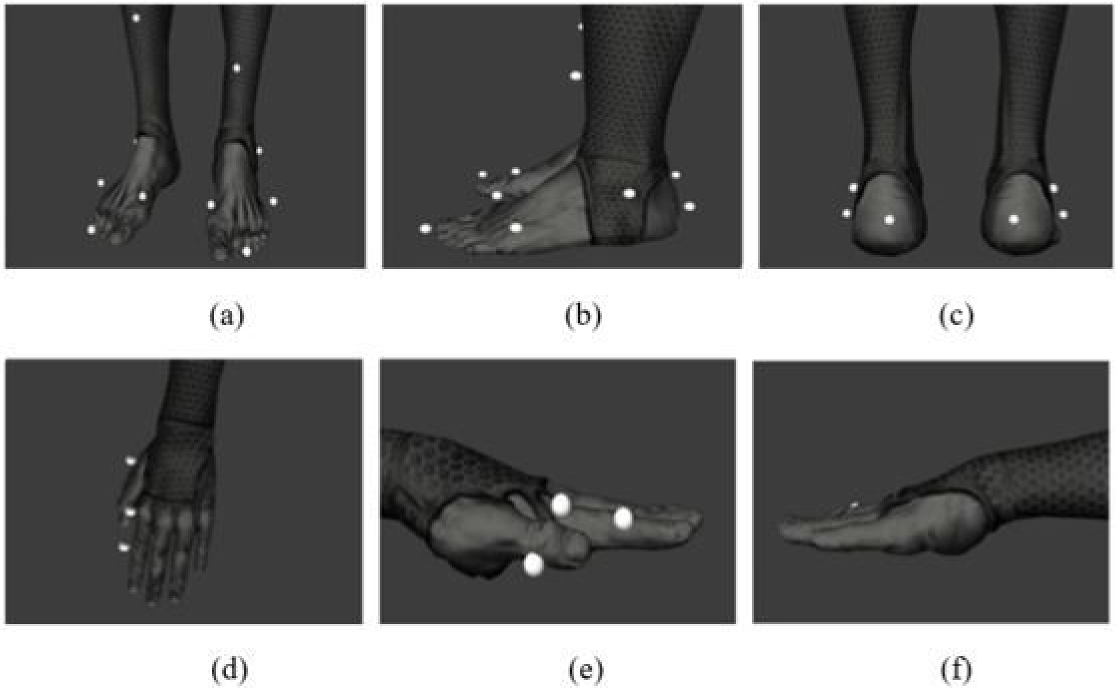


Figure 3

Placement of marker points. (a), (b), (c) show placement of the marker points on the ankle in the original scheme. (d), (e), (f) show placement of the marker points on the hand in the final scheme.

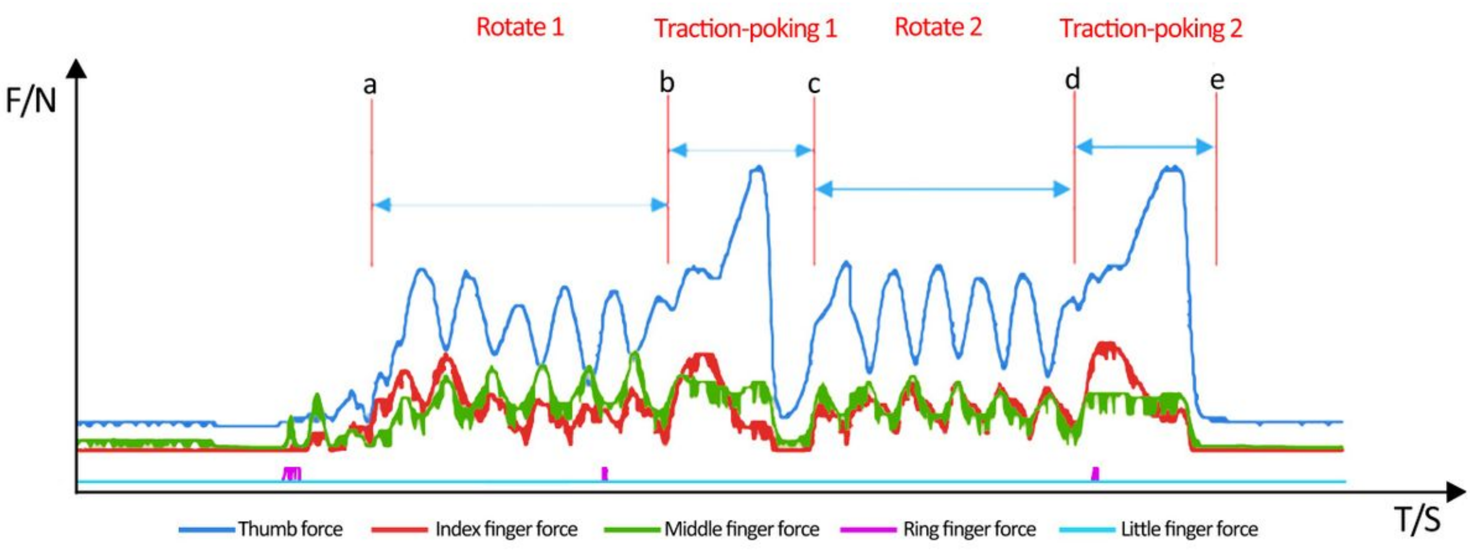


Figure 4

Force-time curve of the fingers

Supplementary Files

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- Dataofkinematicandmechanicalanalysis.xls