Clinical Biomechanics 120 (2024) 106347

Contents lists available at ScienceDirect

Clinical Biomechanics

journal homepage: www.elsevier.com/locate/clinbiomech

Is the cadaveric model valid for examining orthopaedic manual therapy techniques? A cross-sectional comparative study in vivo and in vitro

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ARTICLE INFO

Keywords:
Ankle joint
Manual therapy
Mobilization
Cadaveric model

ABSTRACT

Background: Cadaveric models are sometimes used to test the effect of manual techniques. We have not found any studies comparing the effect of tibiotarsal joint distraction on cadaveric models versus live models for clinical use. The aim was to compare the effect on tibiotarsal joint distraction movement when applying three force magnitudes of tibiotarsal axial traction technique force between a cadaveric model and volunteers. In addition, to compare the magnitude of force applied between the cadaveric model and volunteers. Finally, to assess the reliability of applying the same magnitude of force in three magnitudes of tibiotarsal axial traction force.
Methods: A cross-sectional comparative study was conducted. Sixty ankle joints were in open-packed position and three magnitudes of tibiotarsal axial traction technique force were applied. Tibiotarsal joint distraction movement was measured with ultrasound.
Findings: No differences were found in applied force or tibiotarsal joint distraction between volunteers and cadavers in each magnitude of force ($p > 0.05$). The application of the technique showed moderate reliability for detecting low forces in both models. For medium and high force, it showed good reliability in the in vitro model and excellent reliability in the live model.
Interpretation: The amount of distraction produced in the tibiotarsal joint was similar in volunteers and cadavers. The cadaveric model is a valid model for testing and investigating orthopaedic manual therapy techniques. The force applied was similar in the two models. Medium and high force detection showed good reliability, while low force showed moderate.

1. Introduction

Cadaveric models are widely used in research as a substitute for basic research with volunteers (Barg et al., 2016). According to the levels of evidence, they are at the bottom of the evidence hierarchy pyramid (Chloros et al., 2023). Their justification is that the tests to which these cadaveric specimens must be subjected cannot be tested on volunteers (Estébanez-de-Miguel et al., 2020; Iliescu et al., 2021).

In manual therapy, in vivo models help test the clinical effect of a treatment or technique. In vitro models are used in basic research when it is not possible to subject the volunteer to invasive measurements or experimental stress mechanisms (Estébanez-de-Miguel et al., 2020; López-de-Celis et al., 2020). These in vitro (cadaveric) models can be questioned because they do not exhibit the same contractile characteristics, blood circulation or even elastic properties since a live subject, as preservation procedures can affect tissue behaviour (Boyd et al., 2013; Klop et al., 2017).

One of the differences we observed with the cadaveric model is the absence of muscle activation, which can increase the separation between the articular surfaces because there is no muscle tone to resist the traction force.

In orthopaedic manual therapy, the use of translatory mobilization

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https://doi.org/10.1016/j.clinbiomech.2024.106347
Received 2 May 2024; Accepted 11 September 2024
Available online 13 September 2024
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techniques proposed by Kaltenborn is widely used. Their translatory joint mobilization techniques puts the capsular ligament tissue under tension. The tightness of capsular-ligament tissue depends on the magnitude of the translatory joint mobilization force (Do Moon et al., 2015; Estébanez-de-Miguel et al., 2019a; Estébanez-de-Miguel et al., 2020). Low forces (Grade I) are performed before eliminating the slack of the capsulo-ligamentous tissue and are used to relieve symptoms (Do Moon et al., 2015; López-de-Celis et al., 2022). Middle forces (Grade II) are performed until the relaxation of the capsule-ligamentous tissues is completely eliminated and are used both for pain relief and muscle relaxation. Finally, high forces (Grade III) are performed by surpassing the elimination of slack, that is, increasing the tension in the capsulo-ligamentous tissue. High forces are used to increase joint mobility and improve function by elongating the capsulo-ligamentous structures (Do Moon et al., 2015; Estébanez-de-Miguel et al., 2018; Estébanez-de-Miguel et al., 2019b). The effect of these techniques has been previously investigated both in cadaveric models (Bueno-Gracia et al., 2020; Estébanez-de-Miguel et al., 2019a; Estébanez-de-Miguel et al., 2020), and in volunteers (Guerra-Rodríguez et al., 2021; López-de-Celis et al., 2022; López-de-Celis et al., 2023). Depending on the grade of tension applied to the tissue, a differentiated clinical effect is attributed to it (Estébanez-de-Miguel et al., 2018; Estébanez-de-Miguel et al., 2019b).

The tibiotarsal axial traction technique (TATT) is one of the most frequently used techniques for ankle mobility dysfunction. TATT is used clinically to relieve symptoms or to improve mobility in ankle joint (Davenport et al., 2010; Marrón-Gómez et al., 2015; Zordão et al., 2021). Similar to other joint mobilizations, TATT can be applied at low (Powden et al., 2017) or high speed (Zordão et al., 2021). A tibial fixation is recommended during its execution to focus its effect on the ankle joint. TATT is also used in magnetic resonance imaging (MRI) to improve visualisation of articular cartilage (Jungmann et al., 2015; Lee et al., 2017), and in ankle arthroscopy to create a surgical space (Altbuch et al., 2020; Unangst and Martin, 2015). Frequently, a strap is used to generate a traction force (Altbuch et al., 2020; Jungmann et al., 2015).

Previous studies that analysed manual therapy techniques have examined the amount of separation between joint surfaces when applying traction techniques on other joints, such as the hip or shoulder (Estébanez-de-Miguel et al., 2019a; Guerra-Rodríguez et al., 2021; López-de-Celis et al., 2022; López-de-Celis et al., 2023). There are studies on the minimum distraction space required for applying arthroplasty techniques at the ankle (Fragomen et al., 2014). However, there are no studies that analysed the effect of the technique on the ankle joint. On the other hand, the influence that muscle activation may have on the amount of joint separation achieved during the application of joint traction techniques is unknown.

Therefore, the main objective of this study was to compare the amount of distraction of the tibiotarsal joint during the clinical application of the tibiotarsal axial traction technique (TATT) with three different force intensities (low, medium and high) between an cadaveric model and volunteers. Secondary objectives were (1) to compare the intensity of force applied during TATT between the cadaveric model and volunteers and (2) to assess the reliability in the amount of force applied during TATT.

2. Methods

2.1. Participants

The research involved a sample of volunteers without tibiotarsal pathology and a sample of cadaveric specimens. Sixty ankles were analysed (30 in vivo and 30 in vitro). The sample was similar to other studies whose objectives and methodology were similar (López-de-Celis et al., 2022; López-de-Celis et al., 2023; Witt and Talbott, 2018). The study's statistical power was estimated to be greater than 95 %.

Healthy volunteers were recruited from volunteer of the Universitat Internacional de Catalunya. Inclusion criteria comprised volunteers over 18 years of age who provided informed consent. Exclusion criteria included: 1) a history of orthopaedic injuries in the tibiotarsal joint requiring surgical intervention, 2) presence of pain in the tibiotarsal joint, 3) history of orthopaedic injury in the lower extremity (fractures, grade II or III sprains), 4) history of grade I sprain requiring treatment in the last six months, and 5) diagnosis of ligamentous hypermobility or Ehlers-Danlos syndrome.

Cadaveric specimens were collected from the body donation service of the Universitat Internacional de Catalunya. The inclusion criteria were not presenting deformities or scars compatible with previous surgery in the lower leg. Cadavers were thawed at room temperature for a minimum of 36 h before use in the study.

Ethical approval for this study was obtained from the Research Ethics Committee of the Universitat Internacional de Catalunya (CER. FIS-2023 – 08). All procedures adhered to the principles outlined in the Declaration of Helsinki 1975, revised in Fortaleza 2013.

2.2. Experimental procedures

A cross-sectional comparative study design was conducted employing a repeated measures design to analyse amount of tibiotarsal joint distraction using the TATT with three force magnitudes (low, medium and high). The primary variable under investigation was the amount of tibiotarsal joint distraction. As a secondary variable, the magnitude of the TATT force applied in low, medium and high conditions was also recorded.

The different volunteers, or cadavers, were organised for experimentation on different days. The measurements were performed in a single sesión. After assessing the inclusion and exclusion criteria, the socio-demographic characteristics of the volunteers and the cadaveric sample were documented. Subjects were placed supine, with the foot outside the table and a cushion under the knee. A belt above the malleolus was used to fix the tibia and a tibiotarsal strap was used to perform the mobilization (Fig. 1A).

All TATTs were performed by the same physical therapist (with over 25 years of clinical experience). A second physical therapist (with more

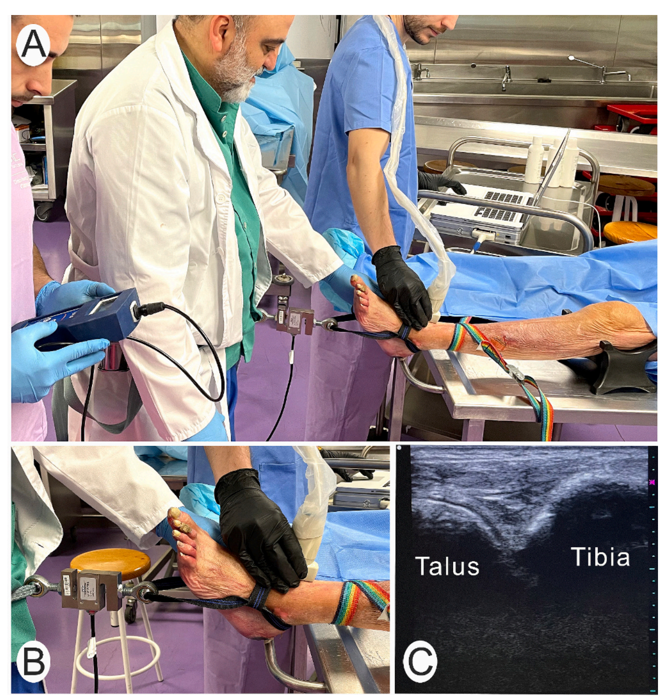

Fig. 1. **A)** Experimental set-up. **B)** Tibiotarsal traction strap, digital force gauge and transducer position at the anterior part of the ankle joint. **C)** Ultrasound image of tibia and talus at rest as baseline.

than 8 years of expertise in the field) performed musculoskeletal ultrasounds. A third evaluator recorded the value of the applied force for each level of force (low, medium and high) as depicted in Fig. 1A.

A mobilization belt was placed around the pelvis of the first evaluator to execute the TATT. The belt was attached to the tibiotarsal traction strap, with a dynamometer (475,055 Digital Force Gauge; Extech, Boston, USA) positioned between them to gauge the force applied at different levels (low, medium and high) (Fig. 1A-B). The evaluator was unaware of both the applied force values and the ultrasound images.

The tibiotarsal joint was positioned in a resting position (10° of plantar flexion and a mid-position between the inversion and eversion movement). For volunteers, specific instructions were given to maintain a relaxed position of their lower extremities. Then, the evaluator applied axial traction to the ankle joint with three different intensities for force, following the Kaltenborn degrees of joint mobilization.

A 40 mm linear transducer (USTTL01, 12 L5) connected to a portable ultrasound machine (US Aloka Prosound C3 15.4) was used for the ultrasound assessment. The Aloka Prosound device operates from 2 MHz to 12 MHz. The images were taken at a frequency of 12 MHz, which represents an axial resolution of 0.5 mm to 1 mm. The transducer was positioned longitudinally on the ventral and slightly medial aspect of the tibiotarsal joint, targeting the joint line (Fig. 1A-B). The transducer was adjusted until the ultrasound image showed the joint line. Measurements were conducted at the three force intensities during the application of the TATT. The tibiotarsal distance was delineated, in each single ultrasound picture, representing the shortest line (in millimeters) from the most distal upper point of the tibia to the perpendicular line extending from the highest point of the talus, as illustrated in Fig. 1C.

An ultrasound baseline image was captured with zero force as a reference, and subsequent images were taken when applying low, medium, and high forces. These images were stored in the ultrasound machine and later subjected to measurements.

Additional ultrasound images were taken at the points when the physiotherapist identified the achievement of each of the three force magnitudes or Grades. The low-force TATT point was determined when the physiotherapist verbally indicated reduced joint looseness. The medium-force TATT image was captured when noticeable resistance, referred to as the "first stop", was initially encountered. The high-force TATT image was taken when maximum tissue resistance occurred. This sequential process was repeated twice with a 30-s rest between repetitions. The average distance recorded in the two trials was used for statistical analysis.

Before the study, two assessments were performed on five volunteers with the same characteristics as the study sample to determine the intra-observer reliability of the ultrasound image measurements. (Table 1). The ultrasound measurements showed excellent reliability.

Table 1
Outcomes of ultrasound measurements of axial movement of talus.

Magnitude of force	Trial 1	Trial 2	$ICC_{3,1}$	95 % CI	SEM	MDC_{95}
	Mean ± SD	Mean ± SD				
Zero-force	0.91 ± 0.20	0.92 ± 0.20	0.996	0.972; 1.000	0.11	0.32
Low-force	1.05 ± 0.19	1.05 ± 0.19	0.993	0.937; 0.999	0.21	0.58
Medium-force	1.15 ± 0.19	1.15 ± 0.21	0.995	0.954; 0.999	0.15	0.42
High-force	1.25 ± 0.18	1.24 ± 0.20	0.992	0.931; 0.999	0.24	0.67

Abbreviations: SD: Standard deviation; $ICC_{3,1}$: Intraclass Correlation Coefficient, 95 %CI: 95 % Confidence Level, SEM: Standard Error of Measurement, MDC_{95}: Minimum Detectable Change at the 95 % confidence level.

2.3. Statistical analysis

IBM SPSS Statistics for Windows, Version 20.0. (Armonk, NY: IBM Corp.) was used for all statistical analyses. Descriptive statistics, including mean and standard deviations or number and percentage, were computed to characterize the demographic features of the sample. The Shapiro–Wilk test was used to determine non-normal distribution of quantitative data. Initial homogeneity was tested with the chi-squared test for qualitative variables and the student *t*-test for qualitative variables. For the comparative analysis of the differences in the axial movement of the talus in each magnitude of TATT force applied in each group and the difference between the force applied in each magnitude in each group, the student's t-test or Mann-Whitney *U* test was used, according to the normal distribution of the variable.

The intra-rater reliability of force application across the three magnitudes of TATT force was evaluated using the intraclass correlation coefficient ($ICC_{3,1}$), standard error of measurement (SEM), and the minimal detectable change at the 95 % confidence level (MDC95 %). In interpreting $ICC_{3,1}$, values exceeding 0.75 were deemed indicative of high reliability. Values below 0.5 suggested poor reliability, while those between 0.5 and 0.75 indicated moderate reliability. Values ranging from 0.75 to 0.9 indicated good reliability and values surpassing 0.90 signified excellent reliability.

3. Results

Thirty tibiotarsal joints were examined from sixteen volunteer (nine male, seven female) and thirty tibiotarsal joints from sixteen cadavers. Among the volunteer, two limbs were excluded because of previous surgery and a history of grade II sprains. In the group of the cadavers, the sample consisted of 16 bodies; two right limbs were excluded because of scarring compatible with previous surgery. The demographic characteristics of the sample are shown in Table 2.

Table 3 shows the distance achieved while applying the TATT for the three force intensities and the differences between the volunteer and donor groups. It also shows the amount of force applied at each level and the differences between groups.

Tibiotarsal joint distraction was significantly greater when high-force traction was applied in both groups (3.6 ± 1.6 mm cadavers, 3.7 ± 0.8 mm volunteers). In the low force magnitude, the difference ranged between 1.1 ± 0.7 mm for cadavers and 1.3 ± 0.6 mm for volunteers and for the medium force magnitude between 2.6 ± 1.4 mm for cadavers and 2.8 ± 0.8 mm for volunteers. The mean differences in tibiotarsal joint distraction movement were similar, with a difference between groups of about 0.1 mm (High-force) and 0.2 mm (Low and Medium force). No statistically significant difference between groups was reached in tibiotarsal distraction at any magnitude of applied force ($p > 0.05$). No statistically significant differences were reached in the force applied in the different magnitudes ($p > 0.05$). (Table 3).

The intra-rater reliability of the applied force was analysed for the different magnitudes in each sample between the first and second applications. The reliability of the low force was moderate in both groups

Table 2
Demographic characteristics.

	Cadavers	Volunteers
	Mean ± SD or n (%)	Mean ± SD or n (%)
Age (year)	69.2 ± 15.7	24.3 ± 5.6
Sex		
Men	8 (50 %)	9 (53.3 %)
Women	8 (50 %)	7 (46.7 %)
Lower Extremity		
Right	14 (46.7 %)	15 (50 %)
Left	16 (53.3 %)	15 (50 %)

Abbreviations: SD, standard deviation; n, number

Table 3
Outcomes of each group and their difference in distraction compared to Zero-force and the magnitude of force applied.

	Cadavers	Volunteers	Mean difference	*p*-value
Tibiotarsal joint distraction from Zero-force				
Low-force	1.1 ± 0.7 mm	1.3 ± 0.6 mm	-0.2 mm	$p = 0.110$
Medium-force	2.6 ± 1.4 mm	2.8 ± 0.8 mm	-0.2 mm	$p = 0.585$
High-force	3.6 ± 1.6 mm	3.7 ± 0.8 mm	-0.1 mm	$p = 0.626$
Magnitude of force				
Low-force	50.1 ± 11.8 N	54.4 ± 12.8 N	−4.3 N	$p = 0.244$
Medium-force	145.2 ± 24.8 N	149.5 ± 27.5 N	−4.2 N	$p = 0.531$
High-force	190.1 ± 27.6 N	189.3 ± 31.4 N	0.8 N	$p = 0.757$

TATT: Axial tibiotarsal traction mobilization; N, Newtons; mm, millimeters

(ICC = 0.535 cadavers; ICC = 0.640 volunteers), while the reliability for medium (ICC = 0.807) and high forces (ICC = 0.869) was good at the cadaveric group and excellent (ICC = 0.916 medium-force and high-force) in the volunteer group respectively (Table 4).

4. Discussion

This study compared the amount of distraction produced in the tibiotarsal joint during the application of three magnitudes (low, medium and high) of TATT between a cadaveric models and volunteers. No significant difference was found between groups.

The amount of force applied for each force intensity was similar between the cadaveric models and volunteers. A maximum difference of 4.3 Newtons was observed but the difference was not statistically significant. The reliability to apply the three different force intensities was moderate for the low force both for volunteers and cadavers while the reliability for the medium and high forces was good in the cadavers and excellent in the volunteers. The reliability of the degree of movement detection has been evaluated in other studies, showing good to excellent intra-observer reliability (Courtney et al., 2010; Courtney et al., 2016; Estébanez-de-Miguel et al., 2018; Estébanez-de-Miguel et al., 2019a; Maher et al., 2010; Park et al., 2015; Vermeulen et al., 2006) in agreement with our study.

The mean age of the cadaveric sample was older than that of the volunteers. Although the thawing process was 36 h and similar studies showed no differences in tissue condition, some stiffness of the tissue, possibly due to the difference in age of the sample cannot be ruled out.

Previous studies showed that the integrity of tissues in cadavers is preserved with a single cycle of freezing and thawing. However, the integrity of the tissues decreases with each cycle beyond the first (Boyd et al., 2013; Huang et al., 2011; Klop et al., 2017). In our study, the cadaveric model underwent at most one cryopreservation cycle. The results of the present study lead us to believe that the tissue properties in joint distraction behaviour are similar in the cadaveric model and volunteers, which agrees with previous research.

In our study, TATT at high force magnitude achieved a tibiotarsal distraction between 3.6 and 3.7 mm, and at medium force magnitude, the values ranged between 2.6 and 2.8 mm. In other clinical applications, such as MRI imaging studies, sustained traction is applied, similar to the technique we applied in our study, to separate the articular surfaces and better visualise the joint. An 8–10 kg weight performs the traction, somewhat lower than average force magnitude (Baer et al., 2006; Jungmann et al., 2015; Lee et al., 2017). The separation values achieved range from 0.6 mm^{20} to 1.2 mm^{21}, consistent with the force applied in our study. In another clinical application, such as ankle arthroscopy, it is also necessary to generate a gap at the tibiotarsal joint, and it has been observed that to obtain a minimum distraction distance, this should be about 5.8 mm at the tibiotarsal joint (Fragomen et al., 2014) with higher application forces than those presented in our study. This distance is greater than that achieved with the maximum force traction in our study. However, our forces are intended to tighten the capsulo-ligamentous tissue and decrease intra-articular pressure but not to completely separate the articular surfaces.

Other studies that have analysed the effect of traction on other joints have obtained values of 0.79 mm to 3.72 mm of joint surface separation, similar to those obtained in this study (López-de-Celis et al., 2023; Witt and Talbott, 2016). This significant gain may be due to the increased mobility of the joint.

The values of force application in cadavers were similar to values in volunteers, ranging from 0.8 to 4.3 N. Interestingly, the lowest difference was found within the high force application. One possible reason is that the high force is applied until a marked resistance of the tissue is felt, being an easy point to identify by the clinician. On the contrary, in the application of low or medium intensity forces, the tissue can still elongate and no clearly identifiable resistance is felt. The fact that there is no difference between the two groups could suggest that the behaviour of the tissue is similar.

One of the main differences between the two groups lies in muscle tone, which is nonexistent in cadavers. However, neither the amount of distraction produced in the tibiotarsal joint nor the amount of the applied force were statistically diferent between groups. This suggests that the involvement of muscle tone is negligible to achieve joint surfaces distraction if the volunteer remains relaxed. This agrees with the study by Estébanez-de-Miguel et al. (Estébanez-de-Miguel et al., 2020), where muscle tissue tension was observed not to affect axial hip traction.

The main limitation of this study is the discrepancy in the age of the volunteers and cadavers. This discrepancy may cause some differences in the tissues, resulting in slight differences in the distraction produced at the tibiotarsal joint and in the applied force values. In addition, the sample of volunteers reported no previous pathology, but we cannot be sure of this in the cadavers as we do not know the expected history. We were only guided by the external signs of possible surgical intervention.

Table 4
Reliability of forces of each group.

Magnitude of force	ICC	95 % CI of $ICC_{3,1}$	SEM	MDD
Forces Cadavers				
Low-force	0.535	0.195; 0.754	8.17	22.65
Medium-force	0.807	0.626; 0.904	6.82	18.91
High-force	0.869	0.745; 0.935	5.30	14.70
Forces Volunteers				
Low-force	0.640	0.123; 0.848	5.72	15.87
Medium-force	0.916	0.833; 0.959	3.34	9.26
High-force	0.916	0.830; 0.960	3.69	10.23

Abbreviations: $ICC_{3,1}$: Intraclass Correlation Coefficient, 95 %CI: 95 % Confidence Level, SEM: Standard Error of Measurement, MDC_{95}: Minimum Detectable Change at the 95 % confidence level, ATT: Axial titiotarsal traccion mobilization.

5. Conclusion

The amount of distraction produced by the TATT in the tibiotarsal joint was similar in volunteers and cadavers. The cadaveric model could be a valid model for testing and investigating orthopaedic manual therapy techniques. The force applied was similar in the two models. Medium and high force detection showed good reliability, while low force showed moderate.

Funding disclosures

The authors declare that this study has not received any funding.

CRediT authorship contribution statement

Carlos López-de-Celis: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Jacobo Rodríguez-Sanz:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Segi Gassó-Villarejo:** Writing – review & editing, Writing – original draft, Visualization, Investigation. **Elena Bueno-Gracia:** Writing – review & editing, Writing – original draft, Methodology. **Max Canet-Vintró:** Writing – review & editing, Writing – original draft, Investigation. **Elena Estébanez-de-Miguel:** Writing – review & editing, Writing – original draft, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability statement

The datasets generated and analysed during this study are publicly available at the following link: https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/VIMLHB

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