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Tibial anterior compartment compressibility in healthy subject, measured using compression sonography

Helen Anwander[a,*], Livia Büchel[a], Fabian Krause[a], Klaus Siebenrock[a], Timo Schmid[b]

[a] Department of Orthopaedic Surgery and Traumatology, Inselspital, Bern University Hospital, University of Bern, Switzerland
[b] Department of Orthopaedic Surgery and Traumatology, Valais hospital, Martiny, Switzerland

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ABSTRACT

Introduction: Compression sonography has been introduced for non-invasive measurement of compartment compressibility and possible diagnostic tool for acute or chronic compartment syndrome in studies using human cadavers and animal models.

To date, standard values in healthy subjects are not yet defined. The aim was to define standard compartment compressibility values in healthy human subjects and to assess the reliability of this measurement method.

Methods: In 60 healthy volunteers, using ultrasound, the diameter of the tibial anterior compartment was measured while applying no pressure, 10mbar and 80mbar of external pressure. A pressure manometer on the ultrasound head was used to monitor the externally applied pressure. Compartment compressibility ratio (R_{0-80}, respectively R_{10-80}) was calculated as following: The delta of the compartment diameter with high and low external pressure, divided through the diameter with low external pressure. In 10 volunteers, two examinators conducted each two measurements to assess the reliability.

Results: Mean compartment compressibility ratio R_{10-80} was 15.9% ±3.6 (range: 7.2 – 22.2). Mean compartment compressibility ratio R_{0-80} was 18.2% ±5.0 (3.0 – 32.1). There was no significant correlation with lower leg circumference, height, weight, BMI, gender, hours of sport per week and type of sport (e.g. weightlifting/ cardio).

For R_{10-80}, intraobserver ICC 2.1 was 0.89 for an experienced observer and 0.79 for a non-experienced observer. Interobserver ICC 2.1 was 0.78. For R_{0-80}, intraobserver ICC 2.1 was 0.71 for the experienced and 0.56 for the unexperienced observer. Interobserver ICC 2.1 was 0.59.

Discussion: In healthy volunteers between 18 and 50 years of age, mean compartment compressibility ratio R_{10-80} was 15.9% ±3.6, independent of demographic factors and sport activity. Application of 10mbar instead of 0mbar increased image quality. Subsequently, R_{10-80} showed lower standard deviation and both higher intraobserver and interobserver reliability than R_{0-80}. Using R_{10-80}, this measurement method is reliable with very high intra- and interobserver correlation.

Introduction

Lower leg compartment syndrome is defined as increased intracompartmental pressure leading to decreased tissue perfusion. Undiagnosed and untreated, compartment syndrome results in tissue ischemia and necrosis and is limb threatening. Diagnosis of acute lower leg compartment syndrome is clinical with the leading symptom pain out of proportion. The five cardinal signs for compartment syndrome include pain, pallor, paresthesia, paralysis, and pulselessness [1]. To verify the clinical diagnosis, intracompartmental pressure can be measured. Normal resting muscle intracompartmental pressure is 0–4 mmHg, pressure of 30 mmHg and above is considered critical [2]. Instead of an absolute value, the delta pressure (ΔP), defined as the diastolic blood pressure minus the intracompartmental pressure, has become generally accepted [3]. The most common method to measure intracompartmental pressure is by placing a needle, connected to a pressure monitor, in the compartment.

However, this invasive technique is painful and yields risks such as infection and bleeding [4]. Furthermore, soft tissue herniation into the needle and saline injections into the compartment can cause falsely high or low readings [5]. Next to measurement of

* Corresponding author at: Inselspital University Hospital Bern: Inselspital Universitatsspital Bern, Switzerland.
E-mail address: Helen.anwander@insel.ch (H. Anwander).

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direct intracompartmental pressure, newer methods to diagnose an acute compartment syndrome such as intramuscular partial pressure of oxygen [6] and near-infrared spectroscopy [7] have been introduced, but lack a reliable threshold and are not yet established [8]. There is still a lack of consensus in the area of the diagnosis [3].

Increased intracompartmental pressure correlates with muscle stiffness [9]. Dickson et al. [10] assessed an noninvasive hardness measuring device to assess the muscle stiffness in patients with compartment syndrome but found low specificity. Recently, compression sonography has been introduced as potential non-invasive alternative to diagnose compartment syndrome [11,12]. Compressibility describes the amount of volume change that occurs when a confining stress is applied. In this setting, compartment compressibility is defined as the change of muscle diameter due to applied pressure. The diameter of the muscle compartment can be measured using ultrasound. The applied pressure can be monitored using a pressure manometer mounted on the ultrasound head. Feasibility of this method has been shown in vitro models [13], human cadavers [12] and living animals [5]. A correlation between rising intracompartmental pressure and decreasing compartment compressibility (defined as decreasing change of diameter due to application of a specified extrinsic pressure) has been shown [5]. Sellei et al. [11] found in a pilot study with 6 patients with compartment syndrome significantly lower compressibility in the affected leg than in the contralateral healthy leg. Marmor et al. [14] applied compression sonography on 52 patients with a tibia fracture and found higher pressure required to flatten the anterior compartment fascia in patients with compartment syndrome. In a cadaver model, the pressure needed to flatten the bulging superficial compartment fascia correlated to the muscle compartment pressures [15].

However, to date, standard values of compartment compressibility of the lower leg using compression sonography in healthy subjects are unknown.

The aims of this study are i) Define standard compartment compressibility values in healthy subjects assessed by compression sonography. ii) Correlate compartment compressibility values to age, gender, body mass index (BMI) and sport activity. iii) Assess intra- and interrater reliability of compartment compressibility measurement using compression sonography.

Methods

This is a descriptive, cross-sectional study with data sampled from healthy volunteers. A total of 120 lower legs in 60 healthy volunteers (30 men and 30 women) were included in the study to obtain the normative compartment compressibility in the anterior compartment without an underlying compartment syndrome.

Inclusion criteria were healthy volunteers aged between 18 and 50 years old and signed informed consent. Exclusion criteria were previous surgery to or fracture of the lower leg, peripheral arterial or venous disease, history of compartment syndrome, limb anomalies and general muscle disorder. All tests were conducted between September and October 2020. Mean age of the volunteers was 30 ± 6.1 years, range: 19 - 49 (Table 1). The majority of the volunteers were medical students, doctors or secretaries. Data was complete in all 60 volunteers and no person had to be excluded due to incomplete data. In addition to demographic data, sport activity was assessed, including hours of sport activity per week, the Tegner score [16,17] and differentiation between weight lifting and endurance.

Ethical approval by the local ethic board was achieved and informed consent of all volunteers was obtained prior to conduction of the measurements.

Table 1
Demographic data.

Parameter	Values
Age	30.0 ± 6.2 (19 – 49)
Gender (% male)	50
Height (cm)	175 ± 8.8 (159 – 198)
Weight (kg)	71.3 ± 12.2 (53 – 105)
BMI (kg/m^2)	23.2 ± 2.9 (18.2. – 36.4)
Circumference lower leg (cm)	38.3 ± 3.4 (33.2 – 50.9)
R_{0-80}	18.2 ± 5.0 (3.0 – 32.1)
R_{10-80}	15.9 ± 3.6 (7.2 – 22.2)

Continuous numbers are expressed by mean ± standard deviation (range). R_{0-80} = Compartment compressibility ratio using 0mmHG for baseline measurement, R_{10-80} = Compartment compressibility ratio using 10mmHG for baseline measurement.

Compartment compressibility measurement

Volunteers were in supine position on an examination table. The examiner and the ultrasound device were positioned on the right side of the volunteer. Both lower legs were undressed and placed with the knee in 30° flexion and the foot flat on the table. Volunteers were in a relaxed position with no deliberate muscle activation of the lower legs. The level with the widest diameter of the lower legs was marked and the circumference measured. All measurements were conducted at this level. The widest diameter was chosen instead of an absolute value, e.g. 15 cm below the knee, as an absolute value would not take in consideration the absolute height of the volunteer. One examiner conducted all examinations to exclude potential observer bias. In 10 subjects, two examiners conducted each two measurements in both legs to assess the intrarater and interrater reliability. One examiner was trained and experienced in ultrasound examinations, while the other examiner had only limited experience in ultrasound examinations.

Measurements were conducted using an ultrasound device from Philips, model Affiniti 50 G. A linear ultrasound probe (12 – 5 MHz) was placed at the marked level medial to the lateral tibia cortex with the probe in a horizontal position compared to the orientation of the lower leg. The probe was positioned displaying the lateral tibia cortex and the interosseus membrane with the connection point of tibia and interosseous membrane in the center (Fig 1a-c). The diameter of the tibial anterior compartment was measured as the distance between the connection point of tibia and interosseous membrane and the superficial muscle fascia on a line perpendicular to the probe. This distance was measured 1) without external pressure applied, and 2) with 10mbar and 3) with 80mbar external pressure (Fig 2). The applied external pressure was monitored using Veinpress system which was mounted onto the ultrasound probe (Fig 3). Veinpress system consists of a translucent silicon membrane connected to a pressure meter (VeinPress 2014, VeinPress GmbH, 3110 Muensingen, Switzerland). The Veinpress system was zeroed to atmospheric pressure before beginning the measurements.

Compartment compressibility calculation

Compartment compressibility ratio (R_{0-80}) was calculated as following:

Backspace The delta of the compartment diameter with high external pressure (80mbar) and no (0mbar) external pressure, divided through the diameter with no external pressure. For R_{10-80}, the calculation was conducted analog with high (80mbar) and low (10mbar) external pressure. The resulting compartment compressibility ratio was reported in percent.

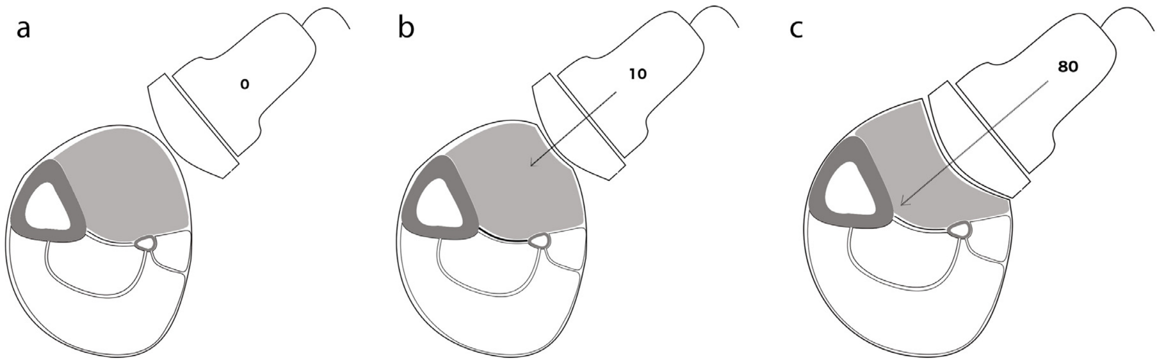

Fig 1. Ultrasound probe placement on the lower leg, displaying the tibia and the interosseous membrane. Measurments were conducted with 0, 10 and 80mbar.

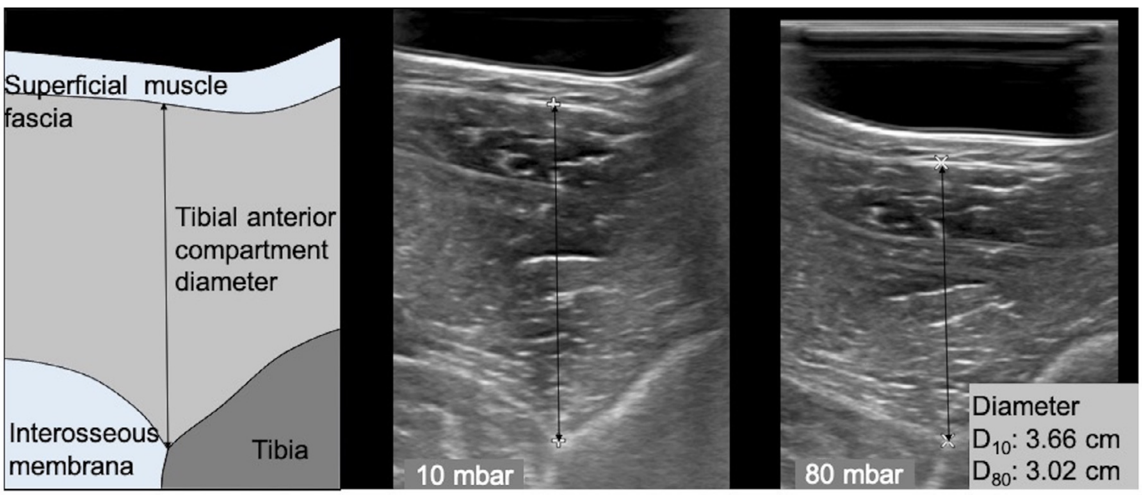

Fig 2. Measurement of the anterior tibial compartment diameter.

Fig 3. Veinpress system is mounted onto the ultrasound probe to monitor the applied external pressure.

Statistical analysis

Power analysis:

The published compartment compressibility of the anterior compartment in healthy humans is 17.95% (SD + /−5,4) [11]. We aimed for a 95% confidence interval of 2%. With a standard deviation of 5.4, the sample size calculated was 81. We increased the total number to 120 lower legs/ 60 participants.

All parameters were first tested for normal distribution using Kolmogorov-Smirnov test. Parameters with normal distribution were displayed as mean ± standard deviation with the range in parenthesis. Frequencies were compared using the Pearson's chi squared test. The compressibility ratio was compared with age and BMI using linear regression.

To assess the reliability of the compartment compressibility ratio measurement, two independent raters conducted the measurements two times in 10 volunteers. The reliability was determined by using the two-way random intraclass correlation coefficient (ICC 2,1) assuming single measurement and absolute agreement. Statistical significance was defined as a p-value ≤ 0.05. SPSS Statistics (Version 25) was used for all statistical analyses.

Results

Mean compartment compressibility ratio R_{10-80} was 15.9% ±3.6 (range: 7.2 – 22.2). Mean compartment compressibility ratio R_{0-80} was 18.2% ±5.0 (3.0 – 32.1) (Table 1). R_{10-80} was below 10.5% in 9 legs (7.5%) in 5 volunteers (8.3%). R_{10-80} values in the right leg (16.8 ± 3.3) were higher than in the left leg (15.0 ± 3.8; $p = 0.005$). The difference between the right and left leg was −1.8% ± 3.3 (−6.1 – 9.5).

Values between both legs correlated with $R = 0.567$, $p = 0.000$. R_{10-80} did not correlate with age, height, weight, BMI, lower leg circumference and hours of sport/week and type of sport (weight lifting versus endurance). No difference was found between men (15.6% ± 3.7) and women (16.3 ± 3.6, $p = 0.299$) A significant but weak correlation of R_{10-80} was found with the Tegner score (R: −0.319, $p = 0.013$).

For R_{10-80}, intraobserver ICC 2.1 was 0.89 for an experienced observer and 0.79 for a non-experienced observer. Interobserver

Table 2
Reliability of tibialis anterior compartment compression sonography.

Compressibility ratio	Observer	ICC 2,1	*P-value*
R_{0-80}	Experienced observer	0.706	0.000
	Unexperienced observer	0.556	0.005
	Interobserver	0.593	0.000
R_{10-80}	Experienced observer	0.894	0.000
	Unexperienced observer	0.794	0.000
	Interobserver	0.784	0.000

R_{0-80} = Compartment compressibility ratio using 0mbar for baseline measurement, R_{10-80} = Compartment compressibility ratio using 10mbar for baseline measurement, ICC 2,1 = two-way random intraclass correlation coefficient, assuming single measurement and absolute agreement.

ICC 2.1 was 0.78. For R_{0-80}, intraobserver ICC 2.1 was 0.71 for the experienced and 0.56 for the unexperienced observer. Interobserver ICC 2.1 was 0.59 (Table 2).

Additionally, we found a strong correlation between lower leg circumference and BMI (R: 0.850, $p = 0.000$) and weight (R: 0.792, $p = 0.000$). There was also a weak correlation of lower leg circumference with age (R: 0.251, $p = 0.006$) and height (R: 0.290, $p = 0.001$).

Discussion

Compression sonography presents a novel non-invasive method for assessing compartment pressure. Whereas different studies could proof the feasibility of the method in models, human cadavers [12] or living animals [5], very little data are available about standard values in healthy human subjects. To our knowledge, the presented study is the first to report these standard values in an adequate sample of healthy volunteers.

A mean compartment compressibility ratio R_{0-80} of 18.2% ± 5.0 (3.0 – 32.1) was found in our study group comprising 120 lower legs in 60 healthy volunteers. Sellei et al. [11] used the same technique to measure the compressibility ratio of the tibial anterior compartment of both lower legs in a small sample of 6 patients suffering from unilateral compartment syndrome. They found a compartment compressibility ratio R_{0-80} of 17.95% ± 5.4 in the healthy leg, corresponding well with the values found in the presented study.

In our study group of 60 healthy volunteers, we found a mean compartment compressibility ratio R_{10-80} of 15.9% ±3.6 (range: 7.2 – 22.2).

No relevant correlation with age, height, weight, BMI, gender and lower leg circumference was found. Higher values were found in the right leg compared to the left leg. We did not assess which was the dominant leg of the volunteers, subsequently we were not able to assess a possible correlation between the compressibility and the dominance of the leg. The measurements were all conducted in a standardized manner with the observer always sitting on the right side of the volunteer and conducting the measurement first on the right leg and then on the left leg. Subsequently the difference in values between the right and left leg could be due to a measurement bias. The side difference might be induced by the standardized setting with the observer always sitting on the right side of the volunteer during all measurements leading a different angle of application of compression between the two sides.

Sellei et al. suggest a cut off at 10.5%. In our study group, this cut off would have led to a specificity of 92%. However, the sensitivity can only be defined in comparison to pathological values. Comparing both legs and tacking a cut off at 5% difference, 11 volunteers were false positive, leading to a specificity of 81.7%. Taking both, a cut off of below 10.5% as total value and a difference of 5% or more, no volunteer was false positive.

During pilot testing, ultrasound imaging with 0mbar of external pressure decreased skin contact and thus image quality, leading to difficulties when defining the measurement points for the $R_{0-80.}$ Application of 10mbar increased image quality and simplified the definition of the measurement points and we therefore decided to additionally measure the R_{10-80}.

The R_{10-80} showed an excellent intrarater reliability in an experienced observer and a high interobserver reliability as well as a high intraobserver reliability in an unexperienced observer. R_{10-80} showed both higher intraobserver and interobserver reliability than R_{0-80}.

Furthermore, the R_{10-80} exhibited a smaller standard deviation and a smaller range compared to the R_{0-80}. Consequently, we recommend using the measurements with 10 and 80mbar and we conclude this technique is reliable for application in a clinical setting even with unexperienced ultrasound examiners.

Intraobserver reliability was comparable with the values published by Marmor et al. [15] assessing the pressure needed to flatten the bulging superficial compartment fascia, interobserver reliability was slightly superior in our study (0.78 compared to 0.65).

Limitations: The main limitation is that in this study only healthy volunteers were included, subsequently no statement can be made about cut-off values in a pathological situation. As our volunteers were all healthy and without pain, volunteer were able to relax and put the leg in a standardized position. In a clinical setting assessing a potential compartment syndrome, measurements can be more challenging, as patients will be in discomfort and the leg may be unstable due to a fracture. Further, the anatomy may be altered after lower leg trauma e.g. due to a fracture.

In our study we included only volunteers between 18 and 50 years. Subsequently normal values for children and older patients may differ from our findings.

Conclusion

In healthy volunteers between 18 and 50 years of age, mean compartment compressibility ratio R_{10-80} was 15.9% ±3.6, independent on age, gender, BMI and lower leg circumference. Interrater and intrarater reliability is high for R_{10-80}. Application of 10mbar instead of 0mbar during the baseline measurement improved inter- and intrarater reliability.

Level of evidence

Level III

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