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The effect of ankle position on intracompartmental pressures of the leg

Ayak bileği pozisyonunun bacakta kompartman içi basınca etkisi

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Objectives: We investigated differences in the intracompartmental pressures (ICP) of the leg in relation to various positions of the ankle joint in patients with chronic exertional compartment syndrome (CECS).

Methods: The study included 16 patients (10 males, 6 females; mean age 30±9 years, range 16 to 48 years) actively involved in various sports. Intracompartmental pressures were monitored with the use of slit catheters connected to a pressure transducer in 28 anterior and 14 deep posterior compartments before and after exercise during the following positions of the ankle joint: relaxed-resting, passive plantar flexion, neutral, and passive dorsiflexion. Alterations in ICP were assessed with reference to that measured in the relaxed-resting position of the ankle.

Results: Significant increases in ICP were observed in both anterior and deep posterior compartments during dorsiflexion of the ankle, being 9.1±10.6 mmHg ($p=0.0001$) and 8±10.3 mmHg ($p=0.001$) in the anterior compartment, and 6.4±4.4 mmHg ($p=0.0001$) and 7.2±4.3 mmHg ($p=0.001$) in the deep posterior compartment before and after exercise, respectively. No significant increases were found in other positions of the ankle ($p>0.05$). While the lowest values of ICP were noted in the relaxed-resting position, plantar flexion of the ankle was associated with decreased ICP pressures.

Conclusion: Dorsiflexion of the ankle increases ICP significantly in both anterior and deep posterior compartments. The results of this study may have clinical implications for the conservative management of both CECS and tibial fractures.

Key words: Ankle joint; compartment syndromes/diagnosis/physiopathology; knee joint; leg; posture; pressure; tibial fractures.

Amaç: Kronik egzersize bağlı kompartman sendromu (KEBKS) olan olgularda ayak bileğinin değişik pozisyonlarına bağlı olarak bacakta kompartman içi basınç farklılıkları araştırıldı.

Çalışma planı: Çalışmaya çeşitli dallarda aktif olarak spor yapan ve klinik olarak KEBKS tanısı konan 16 hasta (10 erkek, 6 kadın; ort. yaş 30±9; dağılım 16-48) alındı. Ayak bileğinin dinlenme, pasif plantar fleksiyon, nötral ve pasif dorsifleksiyon pozisyonlarında, 28 ön ve 14 derin arka kompartmanda egzersiz öncesinde ve sonrasında kompartman içi basınçlar (KİB) basınç transdüserlerine bağlı yarık kateterler kullanılarak izlendi. Basınç değişimlerinde ayak bileğinin dinlenme pozisyonundaki KİB değeri referans olarak alındı.

Sonuçlar: Ayak bileği dorsifleksiyonda iken, hem ön hem de derin arka kompartmanların KİB'lerinde anlamlı artış saptandı. Bu değerler ön kompartman için egzersiz testi öncesinde 9.1±10.6 mmHg ($p=0.0001$), egzersiz testi sonrasında 8±10.3 mmHg ($p=0.001$); derin arka kompartman için egzersiz testi öncesinde 6.4±4.4 mmHg ($p=0.0001$), egzersiz testi sonrasında 7.2±4.3 mmHg ($p=0.001$) idi. Ayak bileğinin diğer pozisyonlarında görülen KİB değişimleri anlamlı farklılık göstermedi ($p>0.05$). En düşük KİB değerleri ayak bileğinin dinlenme pozisyonunda ölçülürken, plantar fleksiyonun basınçta düşüşe neden olduğu görüldü.

Çıkarımlar: Ayak bileğinin dorsifleksiyon pozisyonunda hem ön hem de derin arka kompartmanların KİB'lerinde anlamlı artış meydana gelmektedir. Bu çalışmanın sonuçları KEBKS ve tibial kırıkların konservatif tedavisinde klinik anlamda yol gösterici olabilir.

Anahtar sözcükler: Ayak bileği eklemi; kompartman sendromu/tanı/fizyopatoloji; diz eklemi; bacak; postür; basınç; tibia kırığı.

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Acute compartment syndrome (ACS) commonly occurs after injuries of the leg or forearm, but may also occur in the arm, thigh, foot, buttock, hand, and abdomen.[1] Approximately 63% of all compartment syndromes involve the leg compartments, caused primarily by tibial shaft fractures (40%) and soft tissue injuries without fractures (23%). The most commonly used criterion for diagnosing this condition is the "delta" (Δ) pressure (diastolic blood pressure minus intracompartmental pressure) less than or equal to 30 mmHg.[1,2]

Chronic exertional compartment syndrome (CECS), often an overuse sports injury,[3] results from abnormally elevated intracompartmental pressures (ICP) during exercise or shortly thereafter.[4] The first patient reported was a soccer player with bilateral leg pain caused by exercise.[5] The diagnosis is primarily clinical, and is confirmed by objective measurements. Current criteria include, in the presence of appropriate clinical findings, a pre-exercise resting pressure greater than 15 mmHg and/or a 1-minute post-exercise pressure greater than 30 mmHg, or a 5-minute post-exercise pressure greater than 20 mmHg.[6]

Data on the effect of ankle position on ICPs of the leg are sparse, with only a few published studies involving healthy volunteers.[7-9] We investigated differences in ICPs of the leg in relation to various positions of the ankle joint in patients with CECS.

Patients and methods

Patients

The study included 16 patients (10 males, 6 females; mean age 30±9 years; range 16 to 48 years) with a clinical diagnosis of CECS. We measured the ICP in 28 anterior (14 patients) and 14 deep posterior (7 patients) compartments. All the patients were actively involved in various sports. All the patients gave written informed consent to participate in the study. The experimental protocol was approved by the East London and The City Local Research Ethics Committee.

Evaluation of ankle range of motion

The first part of the study involved determining the range of movement of the patients' ankle joints. With the patient supine on the couch and the knee extended, a straight line was drawn on the lateral aspect of the leg joining the head of the fibula with the tip of the lateral malleolus. The angles of the ankle joint were measured in the relaxed-resting position and full active plantar and full active dorsiflexion positions. The goniometer's center was on the tip of the lateral malleolus. One arm of the goniometer was kept still and parallel to the above-mentioned line, while the other arm was moved to measure the ROM.

Intracompartmental pressure monitoring

After obtaining the range of motion measurements in both ankles, a 17G catheter was inserted bilaterally into the involved compartment under sterile conditions and local anesthesia. A slit catheter was introduced through this into the relevant compartment and connected with a Medex MX860 pressure transducer (Medex Inc., Carlsbad, USA).

The insertion point for the deep posterior compartment was 12 cm proximal to the medial malleolus and 1.5 cm posterior to the posteromedial surface of the tibia. For the anterior compartment, it was 10 cm distal to the tibial tuberosity and 1.5 cm lateral to the anterior tibial crest.

After inserting the slit catheters, the transducers were connected to a personal computer equipped with the programme for dynamic pressure monitoring and the first set of the measurements were obtained.

The hardware included the signal conditioning box, analogue-to-digital (AD) converter (PC74) card, and the computer with its peripherals. The range of expected pressures was 0 to 100 mmHg, with a bridge voltage of five volts and output voltage range of the transducer 0 to 2.5 mV. This requires an amplification of 500 times for a full-scale deflection of five volts. The signal from the transducer is input to a differential amplifier of a gain of five, on the signal conditioning board. The output is then further amplified by a factor of 100 by the programmable gain of the PC74, which is also configured in the differential input mode.

The first part of the software was concerned with the patient data. The second part was essentially the data acquisition, where the AD card acquired the data at a frequency of 30 Hz to be stored in a file specified by the user. The data, at the same time, were scaled and displayed on the screen in real time.

The patients lied supine on the coach with their knees extended and the ankle in the relaxed position. The patients were asked to be completely relaxed, and we waited for the ICP to reach a plateau. After reaching this plateau, the tracing was calibrated to a value of zero. In this way, the ICP tracing for the relaxed-resting position of the ankle was zero, and all the recorded pressures thereafter were in fact the pressure difference (positive or negative) from the relaxed position. Then, asking the patient again to be as relaxed as possible, the investigator placed the patient's feet in full plantar flexion, waiting for the ICP to reach a plateau, and recorded 10 seconds of this plateau tracing. The same procedure was repeated in the passive full dorsiflexion of the feet. At the final stage, the patient's feet were placed in two custom-built frames which kept the ankle at 90° (neutral) to measure ICP in the neutral position of the ankle.

This part of the study lasted approximately one minute. The patient afterwards proceeded to the protocol of ICP monitoring used in our setting, consisting of seven cycles of 60-second running on the spot and 30-second rest sitting on the couch, while the ICP of the relevant compartment was monitored continuously.

After this, the first part of the study was repeated in exactly the same fashion, monitoring the pressures in exactly the same positions of the ankle with the patient having performed the test exercise. This part also lasted approximately one minute, after which the slit catheters were removed, sterile bandages were placed at the insertion sites and the patients were discharged from the clinic with instructions to avoid vigorous exercise for the next couple of days.

Statistical analysis

The data were collected in the form of continuous ICP tracings which were then scanned using a Scan Magic 600 CP scanner (Hewlett Packard, California, USA) and magnified three times. From these magnified scanned tracings, the ICPs (i.e. the pressure differences from the relaxed-resting position) were obtained (Fig. 1).

For statistical analysis, we used the MINITAB 13.0 statistical software (MINITAB Inc 2000, Pennsylvania, USA). To ascertain whether our data followed a normal distribution, we used the Colmogorov-Smirnov test. The 1-sample Student's t-test was used for values which followed normal distribution and 1-sample sign test was used for non-parametric values. Significance was set at $p<0.05$.

Results

There were no neurovascular complications or infections secondary to catheter insertion. The participants experienced only mild discomfort during the procedure.

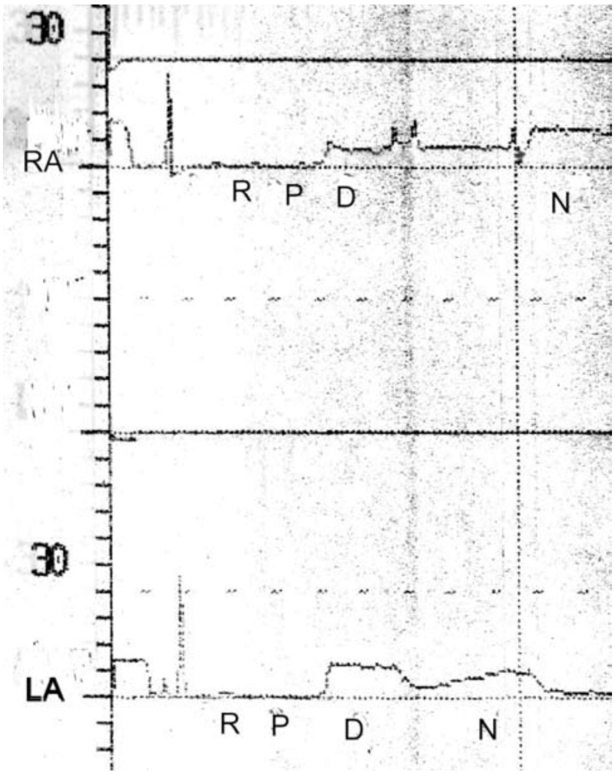

Fig 1. Intracompartmental pressure tracings of a patient for the anterior compartment in relaxed-resting (R), plantar flexion (P), dorsiflexion (D), and neutral (N) positions of the ankle joint.

Range of motion measurements of the ankle joint yielded the following mean values for the right feet: 36.1°, 50.6°, and 2.5° for resting-relaxed, plantar-flexed, and dorsi-flexed positions, respectively. The corresponding values for the left feet were 34.6°, 49°, and 2.3°. The mean dorsiflexion was 2.4±4.6° and the mean plantar flexion was 49.8±9.6°. In the resting-relaxed position, the ankle was held at 35.4±9.1° of plantar flexion. These values were in agreement with those reported by previous studies, which suggest that, with the knee extended, ankle dorsiflexion is close to 0°.[10]

The ICPs of the patients in various positions of the ankle with reference to the resting pressure calibrated to zero (differences from the resting pressure) are shown in Table 1 and 2.

With the ankle dorsiflexed, there were statistically significant elevations in the ICP in both the anterior and deep posterior compartments. These values were 9.1±10.6 mmHg (p=0.0001, %95 CI 2.9-10.5) and 8±10.3 mmHg (p=0.001, %95 CI 3-10) before and after the exercise test, respectively, for the anterior compartment. The corresponding pressures for the deep posterior

Table 1. Alterations in the intracompartmental pressures (mmHg) with relation to the relaxed-resting position for the anterior compartment (14 patients)

		Before exercise			After exercise		
Patient	Side	Plantar	Neutral	Dorsal	Plantar	Neutral	Dorsal
1	Left	3	4	8	-2	0	10
	Right	6	-2	9	-2	1	4
2	Left	-2	9	22	1	8	6
	Right	1	5	15	-2	-1	8
3	Left	-3	1	2	-4	-2	3
	Right	-1	24	30	1	15	26
4	Left	-1	8	10	1	-1	10
	Right	0	11	7	2	0	4
5	Left	-2	-2	-4	0	-4	-1
	Right	-1	0	0	-2	-1	-1
6	Left	2	-4	4	3	-5	3
	Right	0	-8	2	-1	-6	0
7	Left	-1	-3	4	0	-2	3
	Right	1	-6	2	2	-4	1
8	Left	2	4	8	1	4	7
	Right	-1	0	15	-2	0	12
9	Left	-2	6	16	-3	5	13
	Right	0	5	12	-1	4	13
10	Left	8	0	6	8	1	8
	Right	3	3	-2	1	-1	-8
11	Left	0	1	6	1	4	24
	Right	1	0	7	2	1	16
12	Left	-3	-4	1	-2	5	5
	Right	-3	1	11	0	2	0
13	Left	0	1	2	0	0	3
	Right	0	1	2	1	0	1
14	Left	5	8	13	3	-1	10
	Right	1	4	48	0	8	45

compartment were 6.4±4.4 mmHg (p=0.0001, %95 CI 3.8-9) and 7.2±4.3 mmHg (p=0.001, %95 CI 4.7-9.7).

In the neutral position, we also found elevated pressures (for example, for the anterior compartment there was a mean elevation of 2.4 mmHg in the first phase), but these increases were not statistically significant (Student's t-test, p>0.05). In particular, four patients exhibited remarkably high increases (Fig. 2).

Finally, in the plantar-flexed position, alterations in the ICP from the relaxed position were minimal and statistically not significant (p>0.05).

Discussion

Matsen produced a model to explain the development of acute compartment syndrome.[11] This model was based on the premise that, when local blood flow is unable to meet the demands of the tissue, ischemia begins. When tissue pressure increases, the intraluminal venous pressures within the compartment increase. This reduces the magnitude of the arterio-venous pressure gradient, which in turn reduces the blood flow to the tissues of the compartment. The resulting reduction in venous drainage causes a further rise in interstitial tissue pressure with the formation of tissue edema. The lymphatic drainage is increased to protect against the rising interstitial fluid pressure, but once this reaches a peak level, further increases in the ICP cause deformation and collapse of the lymphatic vessels. Only in the late stages of a compartment syndrome is the arterial flow into the compartment seriously compromised, and the continuing flow

Table 2. Alterations in the intracompartmental pressures (mmHg) with relation to the relaxed-resting position for the deep posterior compartment (7 patients)

		Before exercise			After exercise		
Patient	Side	Plantar	Neutral	Dorsal	Plantar	Neutral	Dorsal
1	Left	1	8	13	-6	6	14
	Right	-1	2	5	8	10	12
2	Left	0	6	15	2	7	13
	Right	-1	7	6	-3	5	5
3	Left	4	-6	0	4	-5	-1
	Right	6	-4	9	5	-3	10
4	Left	0	-3	3	0	-4	5
	Right	1	-6	9	2	-4	8
5	Left	5	14	0	0	10	2
	Right	2	3	7	-3	6	8
6	Left	1	0	8	2	1	7
	Right	-1	0	2	-2	-1	3
7	Left	0	-8	9	1	-6	10
	Right	-2	-4	4	-3	-5	5

of blood into the compartment augments the swelling and edema.[1]

The pathogenesis of CECS is similar to that of ACS. Intramuscular pressure rises during contraction. Vigorous exercise may acutely raise muscle weight by 20% due to increased muscle blood volume. Pressure elevation during muscle contraction is caused by compression of the interstitial fluid.[12]

Gershuni et al.[7] investigated the effect of the ankle position on the ICP of the leg in six healthy volunteers. They inserted slit catheters in all four compartments of both legs and measured the ICP in various positions of the knee and ankle. With the knee extended, statistically significant increases were found in the anterior compartment and in the deep posterior compartment in the passive dorsiflexed position of the ankle. There were significant decreases in ICP with the ankle fully plantarflexed. Finally, in the superficial posterior and lateral compartments, significant elevation in the ICP occurred only in the passive dorsiflexed position of the ankle joint.

Dorsiflexion of the ankle produced increases in the ICP of the anterior compartment in 27 volunteers.[8] Weiner et al.[9] reported a similar study apply-

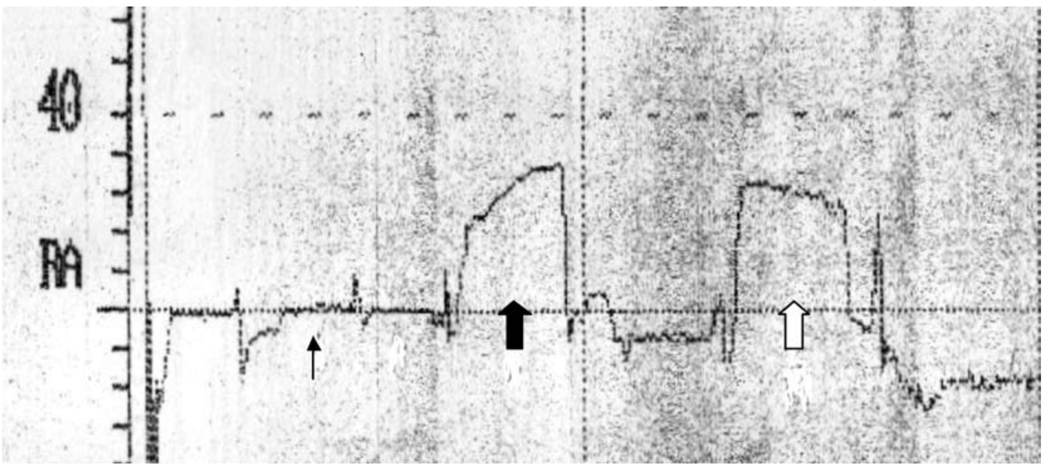

Fig 2. Anterior compartment tracings of another patient. In passive dorsiflexion (black arrow), the intracompartmental pressure (ICP) is 30 mmHg higher than the resting pressure (small arrow). Even in the neutral position (white arrow), the ICP is up to 25 mmHg higher than the resting pressure.

ing a plaster cast on the leg. Studying the ICP of seven healthy volunteers, they found that ICP was lowest in the anterior compartment when the ankle was in the relaxed-resting position, and in the deep posterior compartment when the ankle was plantarflexed.

To our knowledge, this is the first study in the English literature evaluating the influence of ankle position on the ICP of the leg in actual patients suffering from symptoms of CECS, and not just in healthy volunteers. In both the anterior and deep posterior compartments, we found statistically significant increases in the ICP in the dorsiflexed position of the ankle, with no statistically significant differences for other positions. The lowest ICP values were recorded in the relaxed-resting position.

These findings may be helpful in the management of CECS. The literature is dominated by reports of surgical management of CECS with fasciotomy, with minimal attention paid to conservative management.[13] Some authors reported moderate success rates for the management of anterior and deep posterior compartment syndromes using a variety of methods.[14,15]

Increases in ICP, in some patients, may be exercise-specific; i.e., increases only occur when a specific activity is undertaken.[16] One possible etiology for these increases could be the actual position of the ankle joint during this activity. In addition, foot orthotics may be associated with increased ICP of the leg.

The fact that a given position of the ankle produces significant increases or decreases in the ICP of the leg compartments merits further investigation for the clinical evaluation of modalities that alter the position of the ankle during training and competition (for example, application of heel raisers or avoidance of uphill running).

The findings of this study might also have implications for the prevention of ACS after leg injuries. For example, fractures of the tibia are the most common cause of ACS. Approximately 40% of all ACS occur after a fracture of the tibial shaft with an incidence ranging from 1% to 10%.[1] Patients who are at greatest risk for developing ACS are young men with a fracture of the tibial diaphysis, patients with a high-energy fracture of the proximal tibial metaphysis, young men with soft tissue injuries, bleeding diathesis, hypotension, prolonged extrication, floating knee, and burns.[17-19]

Immobilizing the ankle in a long leg plaster in some plantar flexion of the ankle produces the lowest elevations in the ICP of the leg compartments. However, immobilization of the ankle in plantar flexion may contribute to the development of equinus contracture, which has a negative effect on the long-term rehabilitation of the patient.[20]

In four of our patients, the ICPs of all compartments were markedly elevated even in the neutral position. It is possible that these patients may have an increased risk for developing ACS following immobilization in a long-leg plaster in this ankle position after a leg injury.

The answers to the above-mentioned problems could lie somewhere in the middle. Since ACS can develop from the first hour to the first few days after the injury,[21] immobilization of the leg for up to 72 hours in a long leg plaster with the ankle in some degrees of plantar flexion may be considered. After the critical time has elapsed, final immobilization of the ankle in the 90° position can be carried out. In this way, we can minimize the possibility of developing ACS.

In conclusion, the measurement of ICP is the standard in diagnosing CECS. We found statistically significant pressure elevations in the dorsiflexed ankle position. In addition, we found clinically relevant elevations in the neutral position of the ankle joint. Plantar flexion of the ankle did result in decreased pressure, but it was not statistically significant. The results of this study might have clinical implications in the conservative management of both CECS and tibial fractures.

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