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ORIGINAL ARTICLE

Plantar pressure distribution patterns during gait in patients with liver cirrhosis

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Purpose: Peripheral neuropathies, changes in body composition, presence of ascites which means pathologic fluid accumulation in peritoneal cavity, leg edema and lower extremity muscle mass loss are possible factors that may alter plantar pressure distribution in patients with liver cirrhosis. Our aim was to determine the changes in plantar loading characteristics during walking in patients with cirrhosis using dynamic pedobarographic measurements and to compare the results with a healthy control group.

Methods: Twenty-one patients with liver cirrhosis (10 females and 11 males, median age 38 years) and 21 healthy controls (11 females and 10 males, median age 36 years) were included in the study. Barefoot plantar pressure distribution during gait was measured on 10 regions as follows: Hindfoot, midfoot, 1st, 2nd, 3rd, 4th and 5th metatarsal heads, big toe, second toe and toes 3, 4, 5 using an EMED-M® pressure plate. The data of peak pressure (Newton/cm^2) and Force-Time-Area Integral (Ns/cm^2) were used for the analysis.

Results: Peak pressure on the left first metatarsal head and the second toe were significantly lower in patient group (p=0.025 and p=0.020, respectively). Force-Time-Area Integral on midfoot was significantly higher in patient group on both left and right foot (p=0.007 and p=0.017, respectively).

Conclusion: Force-Time-Area Integral, which provides more sensitive information about risk of tissue damage, was higher on midfoot of both feet in patients with cirrhosis suggesting that feet of the patients need special attention in daily clinical practice.

Keywords: Gait, Liver cirrhosis, Plantar pressures.

Karaciğer sirozu olan hastalarda yürüyüş sırasındaki plantar basınç dağılımı paternleri

Amaç: Periferal nöropatiler, vücut kompozisyonundaki değişiklikler, peritoneal boşluk içinde patolojik sıvı birikimi anlamına gelen asit varlığı, bacak ödemi ve alt ekstremite kas kaybı, karaciğer sirozu olan hastalarda plantar basınç dağılımını etkileyebilecek muhtemel faktörlerdir. Çalışmanın amacı, karaciğer sirozu olan hastalarda dinamik pedobarografik ölçümleri kullanarak, yürüyüş sırasındaki plantar yüklenme özelliklerindeki değişiklikleri belirlemek ve sağlıklı kontrol grubu ile karşılaştırmaktı.

Yöntem: Çalışmaya karaciğer sirozu olan 21 hasta (10 kadın, 11 erkek, ortanca yaş 38 yıl) ve 21 sağlıklı kontrol (11 kadın, 10 erkek, ortanca yaş 36 yıl) alındı. Yürüyüş sırasındaki çıplak ayak plantar basınç dağılımı EMED-M® basınç platformu kullanılarak 10 bölgeden ölçüldü: arka ayak, orta ayak, 1, 2, 3, 4 ve 5. metatarsal baş, baş parmak, ikinci parmak ve 3, 4, 5. parmaklar. Zirve basınç (Newton/cm^2) ve Kuvvet-Zaman-Alan İntegrali (Ns/cm^2) verileri analiz için kullanıldı.

Bulgular: Sol birinci metatarsal baş ve ikinci parmak zirve basınçları hasta grubunda anlamlı olarak yüksekti (sırasıyla p=0.025 ve p=0.020). Hasta grubunda hem sol hem sağ orta ayak üzerinde Kuvvet-Zaman-Alan İntegrali anlamlı olarak daha yüksekti (p=0.007 ve p=0.017, sırasıyla).

Tartışma: Doku hasarına ilişkin duyarlı bilgi sağlayan Kuvvet-Zaman-Alan İntegrali'nin siroz hastalarının her iki orta ayağında anlamlı olarak yüksek olması, siroz hastalarının ayaklarına günlük klinik pratikte önem gösterilmelidir.

Anahtar kelimeler: Yürüyüş, Karaciğer sirozu, Plantar basınçlar.

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Karaciğer sirozu olan hastalarda yürüyüş sırasındaki plantar basınç dağılımı paternleri.

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The foot, terminal link of kinematic chain in locomotion, is exposed to high static and dynamic forces of load during very simple activities of daily living such as standing and walking.[1] During standing, ground reaction force, the force between the ground and the body, is equal to the body weight and nearly 50% of this weight is distributed to plantar surface of each foot.[2] As a result, moderate peak plantar pressures, which is higher at the heel than the forefoot, occur.[3] These pressures may occlude the capillary blood flow despite being moderate.[4] Especially during dynamic activities such as walking or running, plantar surface of foot is exposed to much higher stresses than static activities such as standing. Therefore, it is important to measure distribution of plantar pressures in order to detect changes to prevent tissue deformation in compromised areas.

In recent years pedobarographic analyses have been used to show distribution of plantar pressures for both diagnosis and measurement of efficiency of therapeutic interventions. Pedobarography is a method that measures the pressure between foot and the floor during loading,[5] and it allows to determine plantar pressure distribution in patients at higher risk of injury. Within this context, there are many studies presenting the abnormal plantar pressures in patients with musculoskeletal and metabolic diseases mainly leading to motor and sensory neuropathies, muscle imbalance, foot deformities, limited joint mobility, and higher body weight. Although liver cirrhosis presents important risk factors for abnormal plantar loading including peripheral neuropathy, muscle strength loss, and severe leg edema,[6,7] no pedobarographic data has been shown in the literature. Moreover ascites, means the abnormal fluid accumulation in abdominal cavity, may further affect the plantar pressure distribution by increasing body mass and altering the center of gravity.

Therefore, the aim of the present study was to determine the changes in plantar loading characteristics during walking in patients with liver cirrhosis using the dynamic pedobarographic measurements and to compare the findings to a healthy control group.

METHODS

Twenty-one patients with liver cirrhosis (10 females and 11 males, median age 38 years) were recruited from the Department of Gastroenterology, Medical Faculty of Dokuz Eylul University. Patients were diagnosed with cirrhosis by clinical, analytical and ultrasonographic findings or by liver biopsy. Exclusion criteria were as follows: being ≥ 65 years old, having severe neurological disease, history of severe lower extremity injury, alcoholic liver cirrhosis, diabetes mellitus, active alcohol consumption (in last three months), and severe co-morbidities (e.g., cardiac, pulmonary, renal, psychiatric). Twenty-one healthy controls (11 females and 10 males, median age 36 years) without any chronic diseases and previous lower extremity injury were included in the study.

All participants were evaluated by the same physiotherapist at Gait Analysis Laboratory, School of Physical Therapy and Rehabilitation, Dokuz Eylul University, Izmir, Turkey.

The study protocol conformed to the ethical guidelines of the 1975 Declaration of Helsinki and was approved by the research ethics committee of Dokuz Eylul University (2012/08-06). All patients and healthy controls gave written consent to be included in the study after receiving appropriate verbal and written information.

Initial Assessment

Demographic characteristics, cirrhosis etiology, time from the diagnosis, history of hepatic encephalopathy, medications, and shoe size of the patients were recorded. Child-Pughand Model for End-Stage Liver Disease (MELD) scores indicating the severity of disease were also recorded. Child-Pugh is a scoring system measuring the severity of chronic liver disease which is composed of five categories including total bilirubin, serum albumin, international normalized ratio for prothrombin time (INR), presence of ascites and presence of hepatic encephalopathy. The patient is classified as Class A (5-6 points), Class B (7-9 points) or Class C (10-15 points). The MELD is also a scoring system indicating the severity of chronic liver disease to predict survival using the patient's values of serum

bilirubin, serum creatinine and INR. An increasing MELD score is associated with increased risk of severity of hepatic dysfunction and mortality.

Dynamic Plantar Pressure Measurement

Before the dynamic assessment of plantar pressure distribution during gait, subjects were asked to walk at their usual speed for a few minutes in a 30-meter-long corridor. Then, the barefoot plantar pressure distribution was measured by using an EMED-M® pressure plate with 3792 sensor cells at 50-60 Hz in the 38×24 cm sensor area (Novel GmbH, Munich, Germany). The data obtained from an average of the three steps on each foot were recorded for the analysis. The dynamic plantar pressure of footprints obtained from each subject were divided into 10 regions as follows: Hindfoot, midfoot, first, second, third, fourth, and fifth metatarsal heads, big toe, second toe and toes 3, 4, and 5. Total object scores were also recorded. The data of peak pressure (PP, Newton/cm^2) and Force-Time-Area Integral (FTAI, Ns/cm^2) as division of force-time integral (Newton s) by Contact Area (cm^2) in order to obtain for a more accurate mean cumulative load time per square centimeter as described in a previous study were used for statistical analysis.[8]

Statistical analysis

Statistical analyses were performed using the SPSS software version 15.0 (SPSS Inc., Chicago, IL, USA). All continuous variables were evaluated for normality using Shapiro-Wilk test. According to this test, the most of the variables were not normally distributed. Therefore, non-parametric tests were used for this study. Medians and interquartile ranges (25th-75th percentile, IQR) were used for the descriptive analyses. Demographics and pedobarographic measurements were compared using Mann Whitney U Test between the patient and the control groups. The significance level was set at 0.05.

RESULTS

There was no significant difference between the demographic characteristics of the patient and the control groups (Table 1). The etiologies of cirrhosis included viral hepatitis, cryptogenic liver cirrhosis, autoimmune hepatitis, Wilson disease, Budd-Chiari Syndrome, primary sclerosing cholangitis, and overlap syndrome (Table 1).

According to Child-Pugh classification seven patients were Child A (33.3%), nine patients were Child B (42.9 %) and five patients were Child C (23.8%). Median MELD score was 15 (9-16). Median time from the diagnosis was 5 (2-11) years. 5 patients had the history of hepatic encephalopathy (23.8%).

The PP on left first metatarsal head and second toe were significantly lower in the patient group (p=0.025 and p=0.020, respectively) (Table 2). The FTAI on midfoot was significantly higher in patient group on both left and right foot as compared with the controls (p=0.007 and p=0.017, respectively) (Table 3).

DISCUSSION

The results of the current study showed a decrease in peak pressures on the left first metatarsal head and the second toe which are the part of the "*forefoot*" and an increase in FTAI on "*midfoot*" of both feet in patients with liver cirrhosis during gait.

Most of the current literature focused on postural control and it has been revealed that postural stability is deteriorated in patients with liver cirrhosis correlated with the severity of disease resulting in an increase in fall risk.[9,10] Moreover, patients may present balance and gait impairments as early signs of "chronic Parkinsonism associated with cirrhosis".[11] Similarly, Soriano et al. found longer test durations in Timed Up & Go Test which was a dynamic balance assessment for cirrhotics categorized as "*fallers*" with cognitive dysfunction in comparison to "*non-fallers*".[12]

The foot should be considered important in this kind of scientific research since it is the most distal segment of lower extremity kinetic chain representing a relatively small base of support on which the body maintains postural stability. Minor alterations in biomechanics of the foot may affect postural control strategies.[13] To detect foot pathologies and evaluate foot functions, measurements of plantar foot pressure have been widely used in recent years.[14] Although posturographic and fall-related studies were conducted in patients with

Table 1. Demographic characteristics of the groups and classification of the patients according to their etiologies of liver cirrhosis.

	Patient Group (N=21) Median (IQR)	Control Group (N=21) Median (IQR)	p
Age (years)	38 (34.50-44.50)	36 (34-43)	0.553
Body mass index (kg/m^2)	24.38 (21.46-27.14)	24.93 (22.78-27.34)	0.687
Shoe size	40 (38-42)	41 (38-43)	0.657
	n (%)	n (%)	
Gender (male/female)	11/10 (52/48)	10/11 (48/52)	0.758
Etiologies of liver cirrhosis			
Viral Hepatitis	9 (42.9)		
Cryptogenic Liver Chirrhosis	4 (19.0)		
Autoimmune Hepatitis	2 (9.5)		
Wilson Disease	2 (9.5)		
Budd-Chiari Syndrome	2 (9.5)		
Primary Sclerosing Cholangitis	1 (4.8)		
Overlap Syndrome	1 (4.8)		

IQR: Interquartile range.

Table 2. Comparison of peak pressures between the patient and the control groups.

Peak pressures (N/cm^2)	Patient group Median (IQR)	Control group Median (IQR)	p
Left foot			
Hindfoot	30.0 (22.6-36.8)	33.8 (28.60-38.05)	0.105
Midfoot	14.3 (12.4-17.6)	13.7 (11.40-15.50)	0.113
1st metatarsal head	21.3 (18.8-24.2)	26.7 (20.10-38.35)	0.025*
2nd metatarsal head	31.5 (26.2-43.2)	37.0 (33-43.65)	0.116
3rd metatarsal head	35.8 (28.6-44.5)	35.0 (29-39.95)	0.860
4th metatarsal head	26.0 (20.3-32.7)	24.50 (19.75-33.15)	0.980
5th metatarsal head	16.0 (11.0-27.1)	13.30 (11.65-24.80)	0.715
Big toe	30.5 (24.7-48-4)	45 (27.40-60.30)	0.159
Second toe	13.3 (9.3-18.7)	19.50 (16.80-28.60)	0.020*
Toes 3, 4, and 5	11.7 (5.3-16.8)	12.70 (8.35-19.10)	0.385
Total	49.0 (38.8-76.6)	61.50 (45.45-67.85)	0.314
Right foot			
Hindfoot	29.5 (22.5-34.6)	29.20 (26.55-36.35)	0.687
Midfoot	14.8 (11.3-17.6)	13 (11.35-13.60)	0.131
1st metatarsal head	19.3 (15.8-28.1)	25.40 (20.20-31.60)	0.076
2nd metatarsal head	33.5 (26.9-38.9)	35 (30.15-43.50)	0.237
3rd metatarsal head	32.8 (27.4-38.4)	32.80 (27.90-38.90)	0.697
4th metatarsal head	23.3 (19.6-32.4)	23 (21.25-32.25)	0.725
5th metatarsal head	17.5 (10.9-30.2)	13.60 (11.40-20.60)	0.624
Big toe	36.5 (23.4-46.9)	43.20 (30.45-57.60)	0.148
Second toe	18.5 (12.7-25.6)	19.80 (16.50-22.95)	0.669
Toes 3, 4, and 5	14.3 (7.6-19.4)	11.20 (805-13.50)	0.285
Total	48.8 (40.8-58.4)	55.50 (46.45-67.05)	0.152

*p<0.05. IQR: Interquartile range.

Table 3. Comparison of Force-Time-Area Integral (Ns/cm)^2 between the patient and the control groups.

Force-Time-Area Integral (Ns/cm)^2	Patient group Median (IQR)	Control group Median (IQR)	p
Left foot			
Hindfoot	4.31 (3.39-5.19)	4.06 (3.71-4.90)	0.870
Midfoot	2.06 (1.62-2.89)	1.68 (0.89-1.94)	0.007*
1st metatarsal head	3.23 (2.87-4.03)	3.85 (2.64-4.68)	0.660
2nd metatarsal head	5.34 (4.72-6.77)	4.67 (4.39-6.98)	0.633
3rd metatarsal head	5.90 (5.11-7.33)	5.65 (4.18-6.77)	0.099
4th metatarsal head	4.86 (3.86-6.03)	4.28 (2.93-5.38)	0.094
5th metatarsal head	2.85 (2.07-4.68)	2.81 (1.73-3.34)	0.346
Big toe	2.86 (2.18-4.53)	3.29 (2.32-4.18)	0.990
Second toe	1.54 (1.03-2.09)	1.75 (1.18-2.36)	0.291
Toes 3, 4, and 5	1 (0.58-1.92)	0.97 (0.67-1.46)	0.870
Total	3.58 (3.31-4.30)	3.54 (3.01-4.23)	0.320
Right foot			
Hindfoot	4.15 (3.51-4.81)	4.06 (3.71-4.90)	0.155
Midfoot	2.02 (1.50-2.99)	1.68 (0.89-1.94)	0.017*
1st metatarsal head	3.17 (2.80-4.98)	3.85 (2.64-4.68)	0.660
2nd metatarsal head	5.70 (4.78-6.39)	4.67 (4.39-6.98)	0.950
3rd metatarsal head	5.83 (5.22-6.62)	5.65 (4.18-6.77)	0.105
4th metatarsal head	4.71 (4.01-6.23)	4.28 (2.93-5.38)	0.072
5th metatarsal head	2.60 (1.91-4.54)	2.81 (1.73-3.34)	0.606
Big toe	3.25 (2.19-4.67)	3.29 (2.32-4.18)	0.811
Second toe	1.86 (1.42-3.45)	1.75 (1.18-2.36)	0.385
Toes 3, 4, and 5	1.28 (0.88-1.98)	0.97 (0.67-1.46)	0.072
Total	3.55 (3.29-4.21)	3.54 (3.01-4.23)	0.064

*p<0.05. IQR: Interquartile range.

liver cirrhosis no data has been reported regarding the plantar pressure distribution in this patient population. In this respect, our study is the first to be designed in order to compare the plantar pressure distribution during gait between patients with liver cirrhosis and healthy controls.

Plantar pressure distribution may alter due to peripheral neuropathy, muscle imbalance, joint deformities, and increased body weight. Peripheral neuropathy is common in patients with liver cirrhosis.[6] Histopathological studies have reported segmental demyelination even in patients without clinical evidence of neuropathy.[15] Kharbanda et al reported nerve conduction abnormalities in 73% of patients with liver cirrhosis which was subclinical or mild, detected only on electrophysiological testing.[6] Patients mainly present distal sensory loss, paresthesia, absent ankle jerks and rarely motor weakness. Studies on patients with non-alcohol related cirrhosis suggested that neuropathy is caused by the liver disease itself rather than a concomitant finding.[16]

Lower extremity muscle mass loss is also a risk factor for cirrhotics that may alter plantar pressure distribution. Loss of skeletal muscle mass is a common complication in cirrhosis called as "*hepatic cachexia*".[7] Decrease in lower extremity muscle strength has been reported as an independent factor for fall risk in patients with cirrhosis in previous studies.[12,17]

Patients with cirrhosis frequently have significant changes in their body composition, characterized by increased extracellular fluids represented as ascites and edema and decrease in muscle and adipose tissue.[7] Specifically, leg edema is common in patients before and after liver failure leading to limitations in leg

movement and pain in severe cases.[18] Sola et al reported a 56% incidence of leg edema in their cirrhosis group of 523 patients which was one of the major factors for impaired health-related quality of life.[19] Ascites may also affect plantar pressure distribution by increasing body weight and altering the center of gravity due to abdominal fluid accumulation.

Surprisingly, we could not find any differences between the total peak plantar pressures of our cirrhosis population and healthy individuals. As a matter of fact, it was noticeable that peak pressure values of all separated regions had downward tendency in comparison to healthy group. Merely, peak pressures on the left first metatarsal head and the second toe, the parts of the "*forefoot*", were found to be decreased significantly. This finding suggested that patient group preferred to walk with higher peak pressures on their lateral foot side than healthy individuals.

In addition to peak pressure we calculated FTAI which was described by Melai et al in order to obtain a measure of the cumulative load on the corresponding area.[8] The division of force time integral by the contact area provided a more accurate mean cumulative load per square centimeter. This data gives more sensitive information about the risk of tissue damage. We found an increase in FTAI on midfoot in our patients with cirrhosis on both the left and the right foot compared to healthy controls. As a conclusion, subjects with cirrhosis participated in the present study were at higher risk to injure their skin on midfoot region of their both left and right feet.

Our findings may bring new initiatives in research field related with this patient group. Further knowledge on possible foot influence would lead to challenges in health management approaches of people with cirrhosis. In addition to postural control assessments, plantar pressure distribution should also be evaluated in cirrhotics especially in patients with higher fall risk. Muscle strengthening, sensory education and balance exercises should be a part of the multidisciplinary approaches before and after liver transplantation in this special patient population.

Study limitations

As our limitations, we could not report any data related to peripheral neuropathy, lower extremity muscle strength or body composition of our study population. However, our aim was to investigate the plantar pressure distribution during gait in our cirrhosis patients and compare the results to an age and sex matched healthy controls.

Conclusion

This is the first study, which provides the pedobarographic data during gait in patients with liver cirrhosis. Sensitive parameters related to risk of tissue damage was found to be significantly higher on midfoot of both feet in cirrhotics in comparison to healthy controls. This suggests the possible foot influence in patients with liver cirrhosis which may further deteriorate health related quality of life in addition to the leg edema, sensory impairments and muscle mass loss. Further study is needed to investigate the factors that may alter plantar pressures and their clinical consequences in larger patient samples in order to explain the detailed biomechanical changes that lead to postural abnormalities and increased fall risk.

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