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KNEE-JOINT ORTHOSES AND THEIR INFLUENCE ON A PLANTAR PRESSURE DISTRIBUTION DURING WALK – PILOT STUDY

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SUMMARY

Knee-joint orthoses (KO) are widely used by doctors as well as ordinary people. Manufacturers and researchers alike study the influence of KO on an area of knee-joint, but omit the spreading of this influence to more distant parts of a body. This work's objective is a verification of changes of human walk in relation to usage of three different types of KO by the means of observing plantar pressure distribution changes during healthy individuals' walk. The experimental set consisted of 5 healthy volunteers, 3 men and 2 women, 22–32 years old. These people had their plantar pressure distribution measured using tensometric platform by comparison of pressure sum under foot regions during foot-platform contact without KO and subsequently using three types of KO. Plantar pressure distribution displays a variation related to specific KO types. However, individual probands have displayed individual degree of variation and there have been no common behaviour observed among them. The results also correspond to individual findings on probands' motion apparatus, measured during preceding clinical examination. The results of intraindividually applied statistical method implicate that using a functional KO increased a pressure under middle forefoot, using a proprioceptive KO increased a pressure under lateral forefoot and decreased it under medial heel region and finally using a girdle decreased a pressure under both regions. The acquired results varied greatly in a reflection of every examined subject's individuality during such a complex motion a human walk is. Using three types of KO caused changes in plantar pressure distribution on a platform, mainly under medial and lateral forefoot and heel regions.

Key words: plantar pressure distribution, knee-joint orthosis, walk, tensometric platform

INTRODUCTION

Orthotic devices (and especially KOs) widely used by doctors as well as ordinary people. Present technological development positively affects knee-joint orthotics and the number of KO users has been continually increasing during last 20 years. This trend correlates not only to a change in lifestyle but also to improvements in technology and wide offer of not only individually, but mainly serially made KOs (Tvrdíková, Chalupová, 2000). Orthoses are prothetic devices meant to substitute lost or weakened function (Hadraba, 2006). A knee-joint is one of the most frequent areas of injury. Various and broad possibilities of treatment include using KOs. The main objective of using these orthoses is a support, improved position or immobilisation of a knee (Chew et al., 2007). The meaning of use of orthoses is as complete as possible recovery of affected joint's original function with a goal of easing common locomotive movements and protecting a joint (Tvrdíková, Chalupová, 2000).

PROBLEM

Manufacturers and researchers alike study the influence of KOs on an area of knee-joint and their effect from the perspective of therapy or prevention of injuries or dysfunctions in this area. Only a minor number of studies focus on the influence of KOs on body equilibrium change during stand or walk or its influence on some dynamic parameters, e.g. course of centre of pressure (COP). When applying KO it is necessary to know the influence of KOs on a change of plantar pressure distribution, dynamics of stress and interaction forces and their possible suggestibility by CNS motion control. Mentioned aspects have great influence on conditions in structural joints, axis organ and path of long functional chains, going from foot area through leg and dorsum to arms and cranial-cerebral connection (Véle, 2006). Increased stress of specific regions of foot during standing can also result in nociceptive excitation[1] and consequently induced pain in given region through the whole step cycle.

Previous studies imply that plantar stress of the foot is affected by foot structure and function (Morag, Cavanagh, 1999), heel position (Waldecker, 2004), internal (foot arch shape, direction of body axis compared to gravity, projection of COP centre to supporting position, position of a femur head in a hip joint acetabulum and position and configuration of axis organ) and external (inclination of supporting foot, its profile and friction properties of a pad and a shoe) factors (Véle, 2006). A momentum and reactive forces, muscle activity (Neužilová, 1999) or body weight do also project to plantar pressure distribution – the highest increase of stress among obese people have been found under a flattened medial foot area and metatarsal heads (Hills et al., 2001). Another factor that affects maximal plantar stress is a passive eversion range. Its wider range affects pressure reduction under the medial foot area. A plantarum can probably be in higher pronation during standing this way thus shifting foot stress medially (Morag, Cavanagh, 1999). The highest plantar stress among healthy individuals takes place under the medial part of a forefoot (Kanatli et al., 2008). Amount of pressure under heel area is a result of structure and function of calcaneus action. Pressure values in this region depend on foot arch height and supporting tissue structures rigidity. A thickness of soft tissues (Morag, Cavanagh, 1999) is of great importance in this area. Pressure value in forefoot is a result of structural and functional factors of a thumb, especially mobility of the first MP joint. Among other factors affecting pressure under

[1] Nociceptive has a meaning of harmful, damaging, hurting here. Nociception is an indication of harmful (painful) stimulations (Lewit, 2003).

a thumb is a quantity of soft tissues under sesamoid bones of the first metatarsus, longer hallux and an angle between proximal and distal thumb section (Morag, Cavanagh, 1999). The other factor with effect on plantar pressure distribution is walking speed – the lower it is the higher is the share of stress under the second and third metatarsus. Rapid walk results in higher stress under a head of the first metatarsus (Jacob, 2001), (Zhu et al., 1991). The change of pressures in time on forefoot and foot fingers correlates with changes of muscle activity of m. gastrocnemius (Kernozek et al., 1996), tibialis anterior (Kavounoudias et al., 2001) or hip joint extensors and knee joint flexors (Nurse, Nigg, 2001).

Some of the previous papers were dealing with an influence of artificial stimulations (tap – O'Sullivan et al. (2008), Jaklová (2001), ice – Nurse et al. (2001), prophylactic orthosis – Kaminski and Perrin (1996), knee girdle – Chuang et al. (2007) or varied joint position – Vařeka (2004)) of a leg on stand and walk characteristics. Some authors are dealing with 3D shape analysis of a foot in their papers (Jelen et al., 2005), our work focuses on studying orthoses usage and influence on plantar pressure distribution among healthy individuals in 2D.

OBJECTIVES

The main objective of this paper is an experimental verification of possible walk change in relation to usage of three KO types by the means of observing plantar pressure distribution changes during a foot-pad contact utilizing a tensometric platform.

HYPOTHESES

There is a significant difference between observed plantar pressure distribution during walk using KO I, II, III (see below) and not using it. While using KO we presume its influence on complex motion response of lower limb including changes in pressure distribution on a plantarum. The change in pressure distribution also relies on individual characteristics of probands detected by previous clinical examination – see below.

METHODS

Measuring device

We used a modular measuring system Footscan® made by RSscan International, Olen, Belgium to detect interaction dynamics of a foot during contact with a platform. The system consists of detection platform, connection interface and control-analytic software. Footscan® software allows to evaluate dynamical footprint, area of contact planes (cm^2), time course of contact of individual regions (ms), parameters of their stressing (N, N/cm^2), mutual position of region parts, expression of width and length of a plantarum. The software also provides data export in ASCII format (stress courses as a time function) (User Manual Footscan® 7.x gait interface, 2008). We used a sampling frequency 125 Hz.

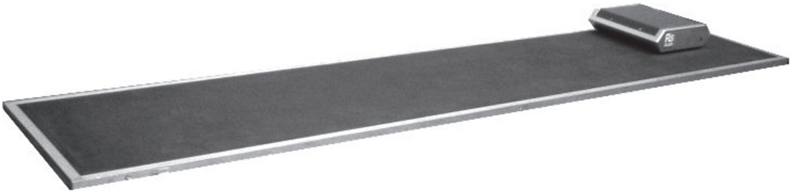


Figure 1. Sensor platform Footscan (User Manual Footscan® 7.x gait interface, 2008)

Technical parameters:	
Platform dimensions:	2 × 0.5 m
Detectable range:	0.27–127 N/cm^2 (2.7–1270 kPa)
Max. detection frequency of 3D box	500 Hz
Number of modules:	4
Number of sensor rows in one module:	64 × 64
Number of sensors in one module:	4096
Sensor dimensions:	5 × 5 mm
Resolution:	4 sensors/cm^2
Max. value of one pixel:	255 AD

Table 1. Results of anamnestic data and clinical examination of probands

Subject	M.Z.	L.CH.	R.S.	Z.K.	D.B.
Sex	female	male	male	female	female
Age	24	32	27	25	23
Height (cm)	166	179	180	168	178
Weight (kg	60	83	81	70	72
BMI	21.77	25.9	25	24.8	22.72
Foot lenght (cm)	25	28	27.5	24.5	26.5
Occupation	student	shop assistant	student	student	student
Sport	dance	football	rock-climbing	spinning	cycling
Transversal arch downcast	yes	yes	yes	no	no
Axial arch downcast	no	softly	no	no	no
Heels position	neutral, sym.	valg. bilat.	neutral, sym.	neutral, sym.	var. bilat.
Knee joint position	neutral, sym.	neutral, sym.	neutral, sym.	neutral, sym.	neutral, sym.
Hip position	neutral, sym.	neutral, sym.	neutral, sym.	neutral, sym.	neutral, sym.
Pelvis position	neutral	left lower	neutral	neutral	neutral

Experimental set

5 healthy people volunteered for the experiment – 3 women and 2 men, 22–32 years old. There must not had been any inborn, evolutional or other structural joints defect, no actual injury and no lower limbs surgery in probands' anamnesis. We also precluded all vestibular, optical and other neurological defects. The individuals only had to fulfil one specific condition – to fit in the experimental orthoses. Before we started the actual experiment, all probands were questioned for their anamnesis, clinically examined with emphasis on feet arches, positions of heels, knee and hip joints and pelves.

Orthoses used

We selected three types of KOs for the experiment. All of them were L-sized and intended for left leg.

I. Functional orthosis
The ARTROCARE® PRO, ORMED, Germany has been chosen as a representative sample of functional orthoses. It is being used for post-surgery therapy after a ligament plasty (LCA or LCP) and for a long-term functional support needed in case of medial-lateral, anterior-posterior or combined ligament instability. The KO consists of carbon-acrylate heat shapeable frame, gel condylar cushions, LCA tape for securing against anterior shift of tibia and fastening belts. According to its manufacturer the KO should provide anatomically precise knee joint motion thanks to its polycentric four-motion (Four Motion®) suspension apparatus (Products catalog Ormed, 2009), (Ortopädie-Technik, 2003). We consider it the most restrictive for lateral knee joint motion with most mechanical influence.

II. Proprioceptive orthosis
The PLAYMAKER® ECO, DONJOY, Austria has been chosen as a representative sample of proprioceptive orthoses. It is being used for minor instabilities of a knee joint and meniscal lesions. It is also often suggested as a protection for lightly injured joints or in a latter phase of post-operation rehabilitation. According to its manufacturer should its strong proprioceptive effect speed up the convalescence and restricts an edema creation (Ortopädie-Technik, 2003). The KO contributes to our experiment with a change of plantar pressure distribution caused by its proprioceptive and mechanical action on knee joint surroundings.

III. Knee girdle
For the purpose of comparison we used a common elastic girdle with a light proprioceptive effect on a knee joint without stronger mechanical influence. That is why we expect the smallest change of plantar pressure distribution during using this girdle.

Data gathering and analysis – experiment I

We performed the first measuring in order to use it in a pre-experiment. After being instructed about measurement process and after couple of test rounds had every tested subject to walk across the 8m long strip 10 times in a rhythm of metronome in such a way that his fourth step

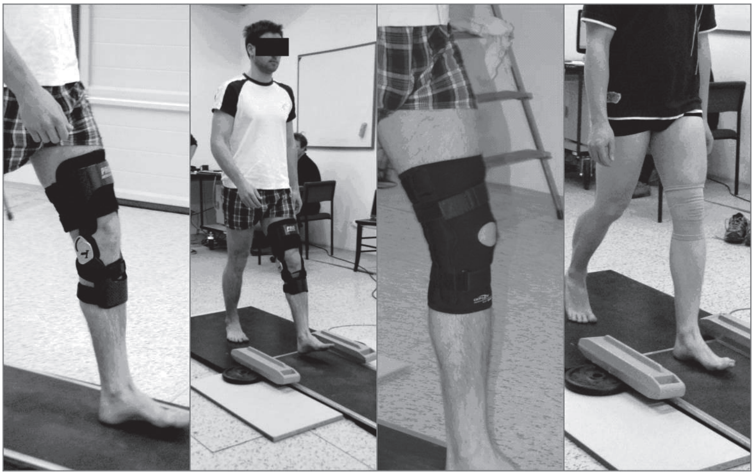
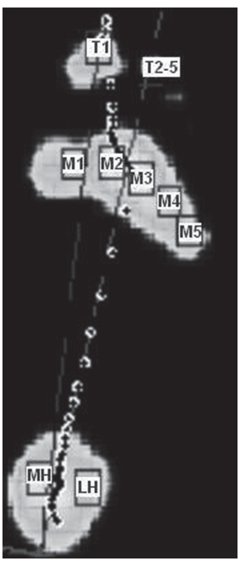


Figure 2. Display of laboratory experiment – different orthosis types

was performed by the left foot and placed in the detection area of a Footscan platform. From these measurements we picked 5 shots based on aspect walk classification (we excluded shots taken during a non-standard situation like a distraction of a proband, invalid step length,



MFF – *medial forefoot* – (M1 + T1)
IFF – *intermedial forefoot* – (M2 + M3 + T2-5)
LFF – *lateral forefoot* – (M4 + M5)
MF – *midfoot* – (MF)
LHF – *lateral hindfoot* – (LH)
MHF – *medial hindfoot* – (MH)

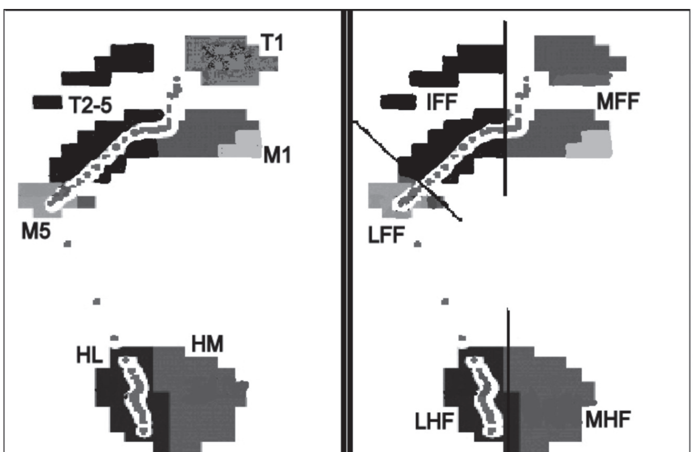


Figure 3. In the left part are regions specified by the Footscan system, in the middle is a real zone composition based on the Footscan system, in the right part are the merged zones used in this experiment

balance loss) and similar course of foot-platform contact according to Footscan. Subsequently the same test was performed using a functional orthosis, then a proprioceptive orthosis and in the end with a knee girdle. We gathered a sum of 20 data files from each of the probands, 5 for every state with or without different orthoses.

Based on its propriety for hypothesis evaluation the sole was divided into 6 regions of interest (ROI):

The data were evaluated using simple statistical tests in MS-Excel software. Individual pressure sums under each region were averaged for each proband. Values of state without and with each orthosis were compared for each ROI.

We also performed a statistical test of Analysis of dispersion (ANOVA).

RESULTS I

The results evaluating the changes of plantar distribution in dependence on usage of three KO types turned out to be very individual. The subjects with previously clinically discovered excessive foot pronation showed increased plantar stress in lateral foot regions. One of the reasons of some inconsistency of the probands' results may also be low number of performed measurements.

Average pressure change under individual regions for all 5 probands can be described as the biggest advancement using the proprioceptive orthosis. The most important stress differences in the medial region were discovered here, namely in pressure increase under lateral and medial part of the forefoot and unstressing the medium part of the forefoot compared to orthosis-free state. This unstressing, to some less extent, happened with this orthosis under both heel parts as well. Functional orthosis less affected the overall stress under individual regions, usually the stress increased under lateral part and decreased everywhere else. Only under the medial part of the foot the stress remained unchanged in

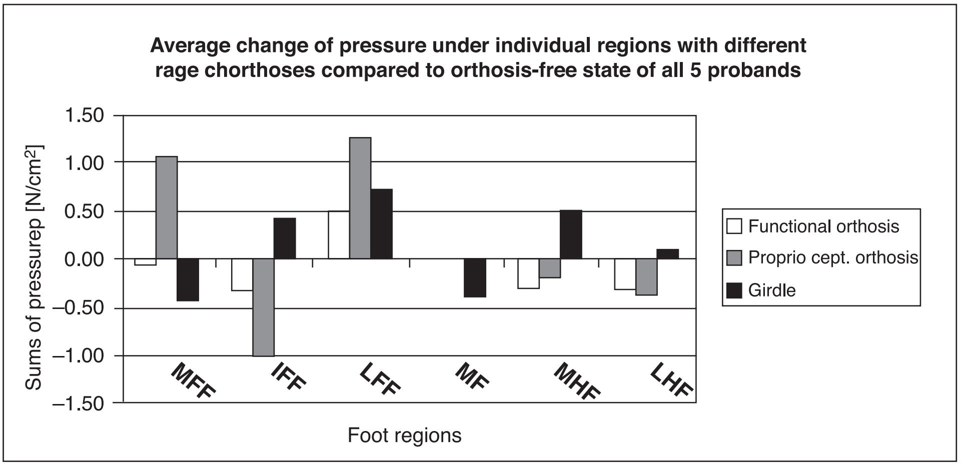


Figure 4. Average change of pressure under individual regions with different orthoses compared to orthosis-free state for all 5 probands

the average. Using a girdle affected the stress by increasing it under the lateral and medium parts of the forefoot and both heel parts. Under medial forefoot and medial foot the stress remained unchanged.

Statistical data analysis

To find out which of the stress differences under the regions were significant we used an analysis of dispersion method (ANOVA). However the differences were statistically insignificant if based on this method for all probands and regions, probably because of too few data samples. We discovered that for given variability expressed by a standard deviation σ a number of measurements needed for a level of significance $\alpha = 0.05$ is 49 [26].

Data gathering and analysis – experiment II.

The objective of the second experiment was verification of declared hypotheses by performing intraindividual study with according number of detected data sets. Only one proband was included in this experiment, which fulfilled the same conditions and was instructed like the first set of probands. The same experiment was performed under the same conditions, when 60 rounds were measured with each orthosis and without one.

Table 2. Results of anamnestic data and clinical examination of proband

Subject	M.P.		
Sex	male	Transversal arch downcast	yes
Age	33	Axial arch downcast	yes
Height (cm)	185	Heels position	L valg., R. var.
Weight (kg	85	Knee joint position	neutral, sym.
BMI	24,84	Hip position	neutral, sym.
Foot lenght (cm)	29	Pelvis position	neutral
Occupation	sitting		
Sport	rock-climbing		

RESULTS II

In the second experiment the functional orthosis caused a slight decrease of pressure under medial forefoot and heel compared to state without it. Under all other regions the pressure increased, most extensively in the medium forefoot.

A moderate increase of pressure under medial forefoot and medium foot and a strong increase under lateral forefoot occurred with a proprioceptive orthosis. Under medium forefoot and medial heel the pressure decreased slightly, under lateral heel remained unchanged.

With a girdle the pressure increased under the medial forefoot and slightly under lateral forefoot, all other regions showed a decrease, especially under both heel regions.

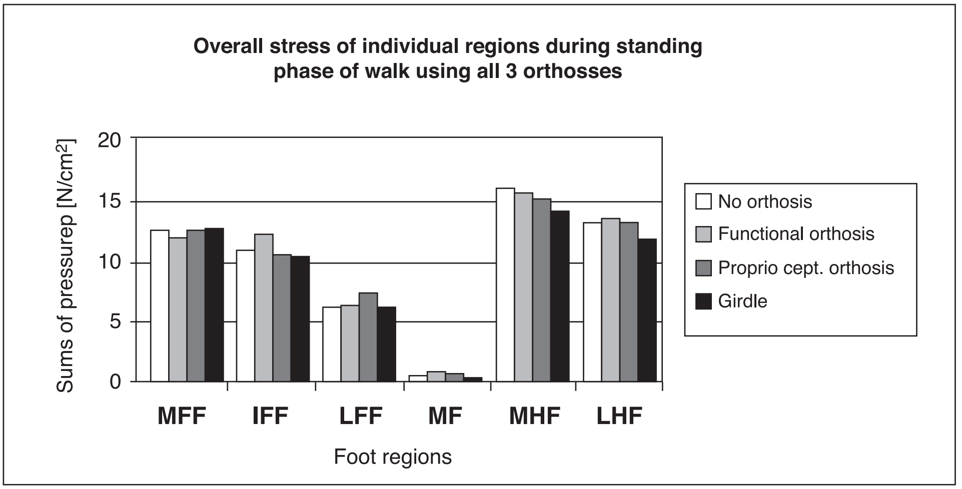


Figure 5. Overall stress of individual regions during standing phase of walk using all 3 orthoses

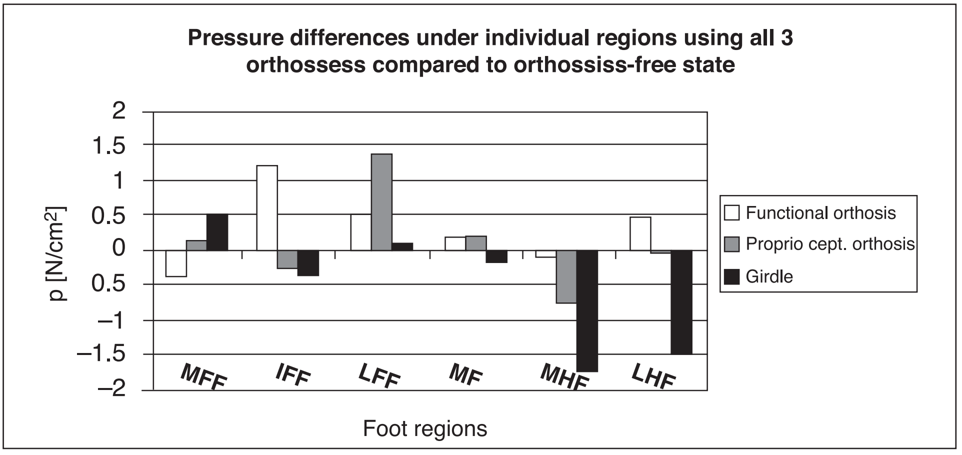


Figure 6. Pressure differences under individual regions using all 3 orthoses compared to orthosis-free state

The results of examined proband's plantar stress changes may be affected by the initial foot position which has to be considered during output processing. The initial clinical examination proved a valgus position of the left heel and related pronation in subtalar joint of examined left foot. That can be an explanation for increased stress under medial regions – MFF and MHF without an orthosis. This stress is consequently decreased with the application of orthoses. On the contrary there is a significant tendency of lateral regions (LFF, MF) to increase with a use of orthoses.

The acquired results successfully verify the first hypothesis whereas it is possible to make a presumption about something like "plantar distribution optimization" by an action of KOs on excessively proned leg based on these.

Statistical data analysis

To find a statistical significancy of intraindividual stress differences under individual regions we used dispersion analysis once again, followed by Turkey's method of mutual comparison.

As the results of the applied analysis show, there is a significant pressure difference under regions IFF – middle forefoot, LFF – lateral forefoot, MHF – medial heel and LHF – lateral heel.

Table 3. Results of a dispersion analysis followed by Turkey's method of mutual comparison for individual foot regions (in grey). 0 – no orthosis, F – functional orthosis, P – propriocept. orthosis, N – girdle

MFF		**Difference YES-NO**	**More pressure**
Anova		NO	
Tukey	0-F	x	x
	0-P	x	x
	0-N	x	x
IFF			
Anova		YES	
Tukey	0-F	YES	F
	0-P	NO	x
	0-N	NO	x
LFF			
Anova		YES	
Tukey	0-F	NO	x
	0-P	YES	P
	0-N	NO	x
MF			
Anova		NO	
Tukey	0-F	x	x
	0-P	x	x
	0-N	x	x
MHF			
Anova		YES	
Tukey	0-F	NO	x
	0-P	YES	0
	0-N	YES	0
LHF			
Anova		YES	
Tukey	0-F	NO	x
	0-P	NO	x
	0-N	YES	0

These results have been specified using a Turkey's method of mutual comparison, which verified that use of a functional orthosis increased the pressure under middle forefoot, a proprioceptive orthosis increased it under lateral forefoot and decreased it under medial heel and a girdle decreased the pressure under both heel regions (Pánková, 2009).

DISCUSSION

There has been a couple of plantar pressure distribution change trends recorded in gathered results, which appeared during usage of examined orthoses. The probands with clinically proven varus heels and feet supination had the pressure under medial regions increased. The results of plantar stress changes of the second experiment proband might have been affected by initial foot position which needs to be taken into consideration when processing the outputs. The initial clinical examination proved valgus left heel and related pronation of subtalar joint of examined left foot. That could explain the increase in stress under medial regions – MFF and MHF without an orthosis. This stress is decreased with an application of orthoses. On the contrary there is a significant tendency to increase a lateral regions stress (LFF, MF) with a use of orthoses. This phenomenon could mean an increase of activity of muscles which ensure foot supination while using proprioceptive orthosis. We are talking especially about loops of long calf muscles which act as a foot arch supporting strap during stress and m. flexor hallucis longus, which acts against medial tilting of kalkaneus (against heel bone pronation) (Véle, 2006). To explain other results with a higher level of statistical significancy like pressure decrease under both part of the heel while using a girdle or pressure increase under middle forefoot while using functional orthosis we would need to perform a deeper analysis utilizing further helper methods. From the obtained results we can presume an existence of "plantar distribution optimization" by an action of KOs on an excessively proned leg. Should this fact be proven by more extensive studies with a statistically significant set of probands, it could contribute to a solution of some locomotive problems of a population.

A strip used as a walking platform for probands was long enough to allow probands to make at least three steps before stepping on a measuring platform and 3–4 more steps after leaving it. It is likely that a steady-state gait comes from the third step further. There are at least three steps needed before actual data measuring (Young et al, 1992) and at least 5 records of the walk (Cavanagh, Ulbrecht, 1994) for studying of the walk. In this experiment the probands were supposed to place their left foot in the first quarter of the measuring platform by the fourth step. The platform provides enough room for placing the step; anyhow the effort and concentration can affect its fluent and natural course. Proband did not have to overcome any height difference, because floor and platform levels were equal but he had to step over a visually apparent join. This could have subconscious influence on the next step performance.

Among other important factors affecting the result of measuring contact forces and pressures there is a walking speed. There are multiple opinions on its moderation during experiments. Although Barnett (1997) suggests to use a natural walk without speed modification during studies of contact forces and pressures in his work, we used approximately constant forward speed of every proband's every step guaranteed by a metronome similarly to some previous studies (Zhu et al., 1991). It is however important to take into consideration that such a modified walk may not be considered natural and it can be difficult to use for testing elderly people or people with coordination issues for a complicated adaptation of the patient on the indicated rhythm. None of the probands had a problem to adapt the rhythm in this experiment though.

Another area with possibly harmful influence on results precision is a technical background of the project. Most of the measurements were performed on a Footscan platform including its software. The first area of our interest was examining pressure changes in selected regions. The Footscan software allows us to divide a footprint into 10 regions. This parting is done by the system itself with a possibility for a user to alter the region's size. However it is not possible to precisely and explicitly border these regions. That is why we worked with a system offered regions, generated from algorithms specified by a manufacturer. At least we divided a sole into greater parts by uniting smaller regions in order to minimize mistakes from region displacement.

The results could be further specified by utilizing more specialized equipment like electromyography for muscular activity monitoring or 3D kinematic analysis for precise recording of body segments movement.

Influence of various orthoses on foot stress during walk has been detected in relatively short time after their mounting. Also it was the first time for the probands to wear such a device. It is possible that after some longer time of using the orthoses the stress parameters would change because of organism adaptation on such new impulses. As Jaklová (1999) states in relation to a functional tape application, there is an influence of exteroceptive skin afference in the beginning of tape use, which may be substituted by a deep proprioception from the orthosed segment area due to some adaptation and decreased tension. On the taped motion apparatus level is therefore created a new situation by the elastic tape application and hence the conditions are changed for information input from given motion segment. The organism adapts to such afference change and is forced to react on the situation. We presume a similar effect during use of KOs being a specific change of afferent input.

CONCLUSION

With the application of tested orthoses the plantar pressure distribution changed. The average pressure change under individual foot regions of all 5 subjects can be described as the biggest with a use of proprioceptive orthosis. There were the most significant stress differences in middle foot parts displaying here, namely increase of pressure under lateral and medial forefoot and easing of middle forefoot compared to state without the orthosis. Using a functional orthosis usually caused a stress increase under lateral regions and its decrease everywhere else. Use of a girdle increased the pressure under middle and lateral forefoot and both heel parts. Under the medial forefoot and middle foot the pressure increased. It became evident that the results from the first experiment, when each proband was tested only 5 times for each orthosis type or no orthosis at all, were statistically inconclusive and its outputs greatly varied. It is necessary to perform at least 50–60 measurements for each examined state (see experiment II). With this condition fulfilled there has been detected a significant intraindividual change of plantar distribution related to use of individual orthoses. The examined subject displayed following statistically significant changes in comparison to orthosis-free state: with a functional orthosis a pressure increase under middle forefoot, with a proprioceptive orthosis a pressure increase under lateral forefoot and pressure decrease under medial heel, with a girdle a pressure decrease under both heel parts. It is necessary to take every examined subject's individuality into consideration when evaluating the walk characteristics and the evaluated outputs always compare to findings from a comprehensive clinical examination.

The results of this study are used in the learning process at the Faculty of Physical Education and Sport.

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ORTÉZY KOLENNÍHO KLOUBU A JEJICH VLIV NA DISTRIBUCI PLANTÁRNÍHO TLAKU BĚHEM CHŮZE – PILOTNÍ STUDIE

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SOUHRN

Ortézy kolenního kloubu jsou lékaři i laiky hojně užívanou metodou. Výrobci i řešitelé studií týkajících se kolenních ortéz ve většině případů zkoumají jejich vlivy na oblast kolenního kloubu, ovšem nezabývají se šířením jejich vlivu do vzdálenějších regionů těla. Cílem této práce je ověření změn chůze v závislosti na použití tří různých typů kolenních ortéz pomocí sledování změn plantární distribuce tlaku při chůzi u zdravých jedinců. Výzkumný soubor byl tvořen 5 zdravými dobrovolníky, 3 muži a 2 ženami ve věku 22–32 let, u kterých byla pomocí tenzometrické plošiny měřena plantární distribuce tlaku pomocí porovnání celkové sumy tlaku během kontaktu nohy s podložkou pod jednotlivými regiony nohy ve stavu bez ortézy a následně s použitím tří typů kolenních ortéz. Plantární distribuce tlaku vykazuje změnu v závislosti na použití různých typů ortéz. U jednotlivých probandů je však tato tendence individuální a nebyla nalezena stejná tendence mezi jednotlivými subjekty. Výsledky korespondují také s individuálními nálezy na pohybovém aparátu probandů, zjištěnými předchozím klinickým vyšetřením. Z výsledků intraindividuálně použité statistické metody vyplývá, že při použití funkční ortézy se tlak zvýšil pro region střední části přednoží, s použitím proprioceptivní ortézy se tlak zvýšil pro region laterální části přednoží a snížil pod regionem mediální části paty a při použití návleku se tlak snížil pod oběma regiony paty. V získaných výsledcích se projevila značná variabilita, odrážející individualitu každého sledovaného subjektu při tak komplexním pohybu, jako je lidská chůze. S použitím tří druhů ortéz se plantární distribuce tlaku během kontaktu s podložkou změnila, nejvýznamněji pod regiony střední a laterální části přednoží a paty.

Výsledky této studie jsou využívány v pedagogickém procesu na FTVS UK Praha

Klíčová slova: distribuce plantárního tlaku, kolenní ortéza, chůze, tenzometrická plošina

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