THE INFLUENCE OF PROSTHESES AND PROSTHETIC FOOT ALIGNMENT ON POSTURAL BEHAVIOR IN TRANSTIBIAL AMPUTEES

Barbora Paráková, Marcela Míková, Miroslav Janura

Faculty of Physical Culture, Palacký University, Olomouc, Czech Republic

Lower limb amputation presents a kinesiological problem. The type and alignment of each prosthetic component in transtibial amputees is determinative for postural stability and bipedal locomotion to a great extent. The aim of this study was to qualify the influence of variation in prostheses and prosthetic foot alignment in transtibial amputees on postural behaviour. Postural behaviour was analyzed in a group of 13 males (age 56 ± 13 years) with five different prostheses and prosthetic foot alignment. The results of the study show that change in prostheses alignment has an influence on muscle activity and on selected posturographic parameters. As the kinesiologically most optimal we have identified the extension of the prostheses by 1 cm with regard to normal prosthesis alignment.

Keywords: Transtibial amputation, postural stability, prostheses, posturography, surface EMG.

INTRODUCTION

Lower limb amputation presents a kinesiological problem due to the alteration of postural behaviour. Transtibial amputations result in compensatory and adaptative mechanisms. Further understanding of pathokinesiological relations between postural stability and limb loss could serve the optimalization of postural behaviour in transtibial amputees in both prosthetic component alignment and prosthetic component selection.

Postural stability in transtibial amputees

Postural stability is a basic precondition of all activities in a close kinematic chain. Postural stability is dependent on the integration of feedback information about inner and outer human space, on the position of segments, on sufficient muscle tone, and on the direction and magnitude of destabilizing forces (Shumway-Cook & Woollacott, 2001). Transtibial amputation leads to postural stability impairment because of biomechanical and neurophysiologic changes. These changes result in an absence of dynamic muscle co-activation in the ankle, of mechanical support, and in the absence of afferent input from proprioreceptors and foot pressure receptors. There are also other factors which limit each prosthetics user, such as painful and uncomfortable feelings in the residual limb and secondarily developed musculoskeletal problems such as low back pain, non amputated limb pain, etc. as well as psychological problems and increased energy costs in bipedal locomotion with prosthesis (Ehde & Smith, 2004; Ries & Brewer, 2000; Seymour, 2002).

Compensatory and adaptative postural mechanisms

Compensatory and adaptative postural mechanisms which follow after lower limb amputation are determined by the length of the residual limb (a longer residual limb involves better physiological and functional abilities), by a sense of the quality of feeling, by nociceptive afferent inflow, and by both type and alignment of prosthetic components (Gauthier-Gagnon et al., 2000; Sabolich & Ortega, 1994). The centre of mass position is displaced slightly upwards, backwards and above the non amputated leg (Gauthier-Gagnon et al., 2000). Ankle strategy is replaced by less effective hip strategy on the amputated side and more strain on the non amputated leg's ankle (Aruin et al., 1997; Geurts et al., 1991; Ries & Brewer, 2000). Elimination of neural input from the distally amputated lower limb's receptors leads to an alteration of both afferent and efferent sensory pathways which results in a reorganization of the cortical projection distribution of segmental structures (Aruin et al., 1997; Latash, 1998). Afferent inflow absence is first compensated for by increased visual dependence, which decreases over time (Gauthier-Cagnon et al., 2000; Geurts, 1991; Kovounoudias et al., 2005). After a few months of common prosthetic usage, sensory adaptation in amputation consists of equalization at the sensory level. Besides changed neural and biomechanical relations after transtibial amputation, adequate pos-

38

Acta Univ. Palacki. Olomuc., Gymn. 2007, vol. 37, no. 4

tural reactions and postural stability must be achieved (Aruin et al., 1997).

The influence of prosthetic alignment on postural stability

In lower limb amputees the prostheses – its construction, choice of prosthetic components, and their alignment, participate in postural stability to a great extant. Prostheses compensate for a missing lower limb because of the functionally enlarged base of support and therefore represent a necessary component in the foot's postural stabilization during both standing and bipedal locomotion (Gauthier-Gagnon, 2000). There are wide varieties of prosthetic components, materials and production technologies with specific advantages and disadvantages, which have to provide sufficient comfort to the particular prostheses user. Individuals who have been through lower limb amputation are able to adapt to a wide variety of prosthetic component configurations, but only an optimal prosthetic alignment minimizes asymmetries during standing and gait (Fridman et al., 2003).

OBJECTIVES

The aim of this study was to measure changes in the transtibial amputee's postural behaviour by means of surface electromyography and posturography in dependence on a prosthetic foot alignment.

MATERIAL AND METHODS

SUBJECTS

The experimental group included 13 transtibially amputated males (7 right leg amputated and 6 left leg amputated). The subject's average age at the time of measurement was 56 ± 13.1 years and they had been prosthetics users on the average, for 11.5 ± 13.2 years. The average height of the probands was 1.79 ± 0.1 m and average body weight was 88.46 ± 12.3 kg. The average length of each residual limb in the group was 18.12 ± 5.6 cm. The prosthetic foot type SACH was the standard used by 3 of the probands, whereas the type Sure-Flex was used by 5 subjects, the Vari-Flex type by 1 proband and the Dynamic type by 4 subjects. There wasn't any subject in the group who used a support device for common everyday activities. Tactile, algic, discriminative and vibratory sensations were examined in all subjects.

METHODS

Prior to the measurement itself, each subject underwent a kinesiological examination and filled out a questionnaire and in this way provided both information about their personal medical history and also current information about the state of their musculoskeletal system. The measurements and examinations which took place were done in the Kinesiological laboratory at the Department of sports and exercise medicine in the University hospital in Olomouc and in the Department of biomechanics and cybernetics engineering at the Faculty of Physical Culture, Palacký University, Olomouc.

In transtibial amputated subjects postural behaviour was tested in five different alignments of the prosthesis and prosthetic foot. All tested alignments are commonly present during everyday life. We evaluated postural behaviour within the framework of normal prosthetic foot alignment (with the prosthetic foot being set up in a way that the subject was used to), within the framework of a 1 cm shorter and a 1 cm longer prosthesis than would be the case for normal alignment and within the framework of a prosthetic foot set up at 5° dorsal flexion and 5° plantar flexion as compared to normal alignment. Postural behaviour was evaluated by the posturographic Motor Control Test (MCT) using the SmartEquitets system of NeuroCom®. This test is based on platform translations at three different speeds (small, medium, and large in that order). These speeds result from the individual subject's height. The translations were always in both a backwards and a forwards direction. We evaluated weight symmetry within each subtest [%] and the latency of the reaction to translation in each subtest [ms]. Within the Motor Control Test activity of the following muscles was measured bilaterally: m. erector spinae, m. tensor fasciae latae, m. biceps femoris, and m. rectus femoris, then just on the non amputated leg, including m. gastrocnemius medialis and m. tibialis anterior. The electromyographic signal was rectified and smoothed (RMS 25 ms), signal normalization was done with respect to 20 s of rest activity, particularly for each prosthesis and prosthetic foot alignment. For the purpose of this study reactive muscle activity was evaluated (at 500 ms intervals) and muscle reaction proceeded as an answer to platform translations of different intensities. We considered muscle to be active in cases when its measured activity (MEAN) was higher than the value of its rest activity plus two standard deviations.

For the statistical analysis of the examined data the programme Statistica version 6.0 (Anova, Fischer LSD post hoc test) was used.

RESULTS

Posturographic parameters

Minimal differences in weight symmetry between the amputated and non amputated leg (parameter weight symmetry) were found (results from measured data) when the prosthesis was 1 cm shorter compared to normal alignment (Fig. 1).

In the latency of postural reactions (latency parameter) there was a statistically significant difference (in all tested situations) between the prosthetic foot in dorsal flexion and when the prosthesis was extended by 1 cm in comparison with normal alignment in large forward platform translations. Just in normal prosthesis alignment the latency gradually decreased with every tested situation independently of the direction or magnitude of the platform translation. For other tested prosthetic alignments, this trend was insignificant, because there was always an increase in latency time in the four tested situations (with changed direction of the platform translation) (Fig. 2).

Fig. 1
Weight symmetry in terms of the interdependence of prostheses and prosthetic foot alignment during the Motor Control Test
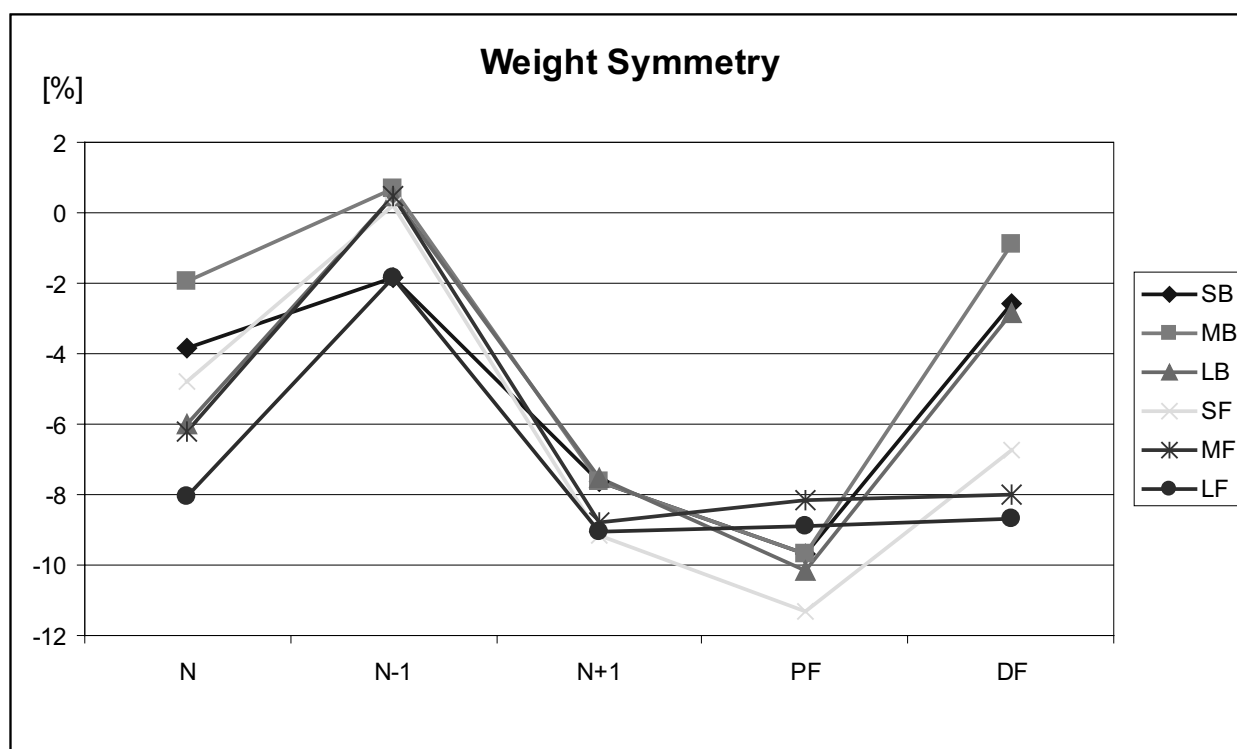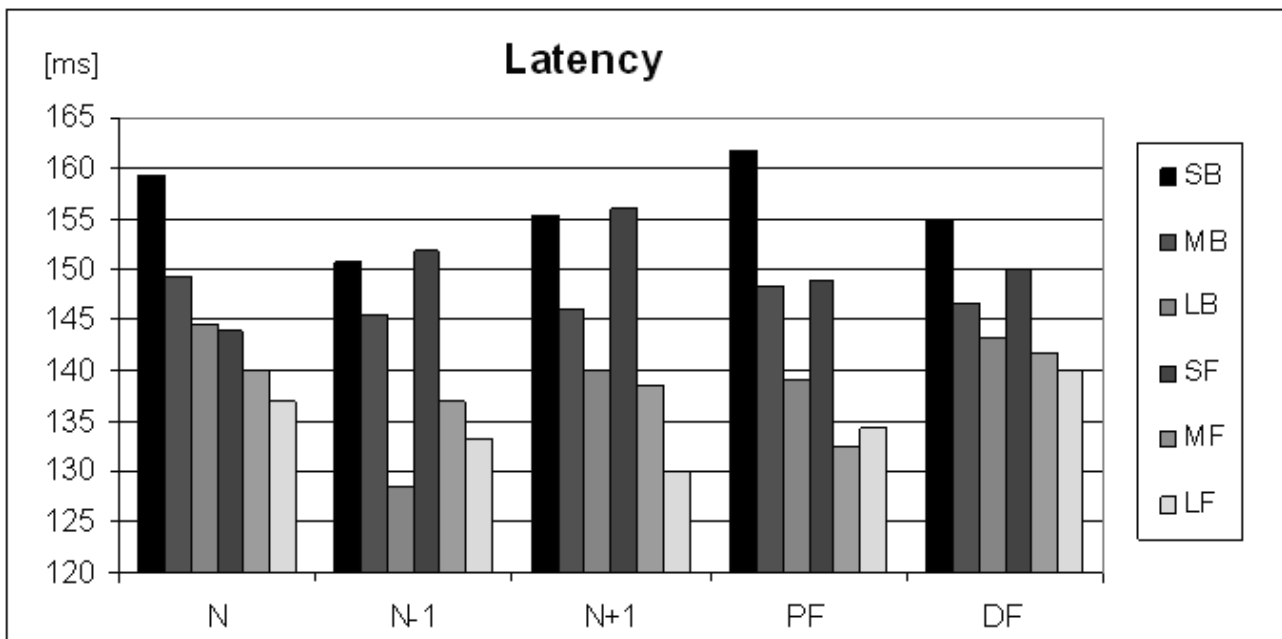

Legend
N – normal prosthesis alignment
N–1 – prosthesis 1 cm shorter
N+1 – prosthesis 1 cm longer
PF – prosthetic foot in 5° plantar flexion
DF – prosthetic foot in 5° dorsal flexion
SB – small backwards shifts
MB – medium backwards shifts
LB – large backwards shifts
SF – small forward shifts
MF – medium forward shifts
LF – large forward shifts

Note
If the measured value is on axis Y < 0, then the weight is on the non amputated lower limb. If the measured value is on axis Y > 0, then the weight is on the amputated lower limb.

Fig. 2
Latency of motor reactions on platform shifts with regard to dependence on direction and speed and on prosthetic and prosthetic foot alignment

Legend
N – normal prosthesis alignment
N–1 – prosthesis 1 cm shorter
N+1 – prosthesis 1 cm longer
PF – prosthetic foot in 5° plantar flexion
DF – prosthetic foot in 5° dorsal flexion

SB – small backwards shifts
MB – medium backwards shifts
LB – large backwards shifts
SF – small forward shifts
MF – medium forward shifts
LF – large forward shifts

Reactive activity of the muscles

In cases of the mean of the reaction activity in every tested muscle we can see changes in muscle activity, depending on its directions and the speed of these translations within the framework of the Motor Control Test. There is also an evident change in muscle activity in every tested situation depending on prosthetic alignment and foot alignment. A statistically significant difference ($p < 0.05$) in muscle reaction activity depending on the alignment of the prosthesis and the foot was found between any prosthesis which was 1 cm longer than normal alignment and also in any prosthetic foot which was in dorsal flexion. There were always small forward translations for the following tested muscles: m. biceps femoris, m. gastrocnemius medialis, and m. tibialis anterior on the non amputated lower limb and for the m. tensor fasciae latae on the amputated lower limb.

In all tested bilateral muscles, the extension of the prostheses by 1 cm led to the most symmetrical mean of the reaction activity of the muscles of the experimental group. This prosthesis alignment led also to a decrease

in the mean of the reaction activity in the m. gastrocnemius medialis and the m. tibialis anterior on non amputated leg. "Normal" prosthesis alignment didn't present the most optimal alignment for any measured muscle. Neither in the case of a decrease of muscle activity on non amputated leg in comparison with tested prosthesis alignments nor in the case of more symmetrical activity among bilaterally tested muscles.

The trend of reactive muscle activity is showed in Fig. 3 (the evaluated section is marked off with two white vertical lines) in measured muscles of the amputee's left leg in small forward translation during four alignments of the prostheses (normal alignment, prosthetic foot in dorsal flexion, prostheses 1 cm longer and 1 cm shorter than normal). The section marked with a dart demonstrates a bilateral optimalization of the reactive activity in the m. rectus femoris in a situation, when the prosthesis was extended by 1cm. From the Fig. 3 is also evident that in this alignment the bilaterally lowest activity was to be found in m. tensor fasciae latae and the lowest activity was in the m. tibialis anterior in all tested situations in the case of this amputee's image.

Fig. 3
The trend of reactive muscle activity of all tested muscles in a subject with an amputated left leg in four different prosthesis alignments in the case of a small forward shift
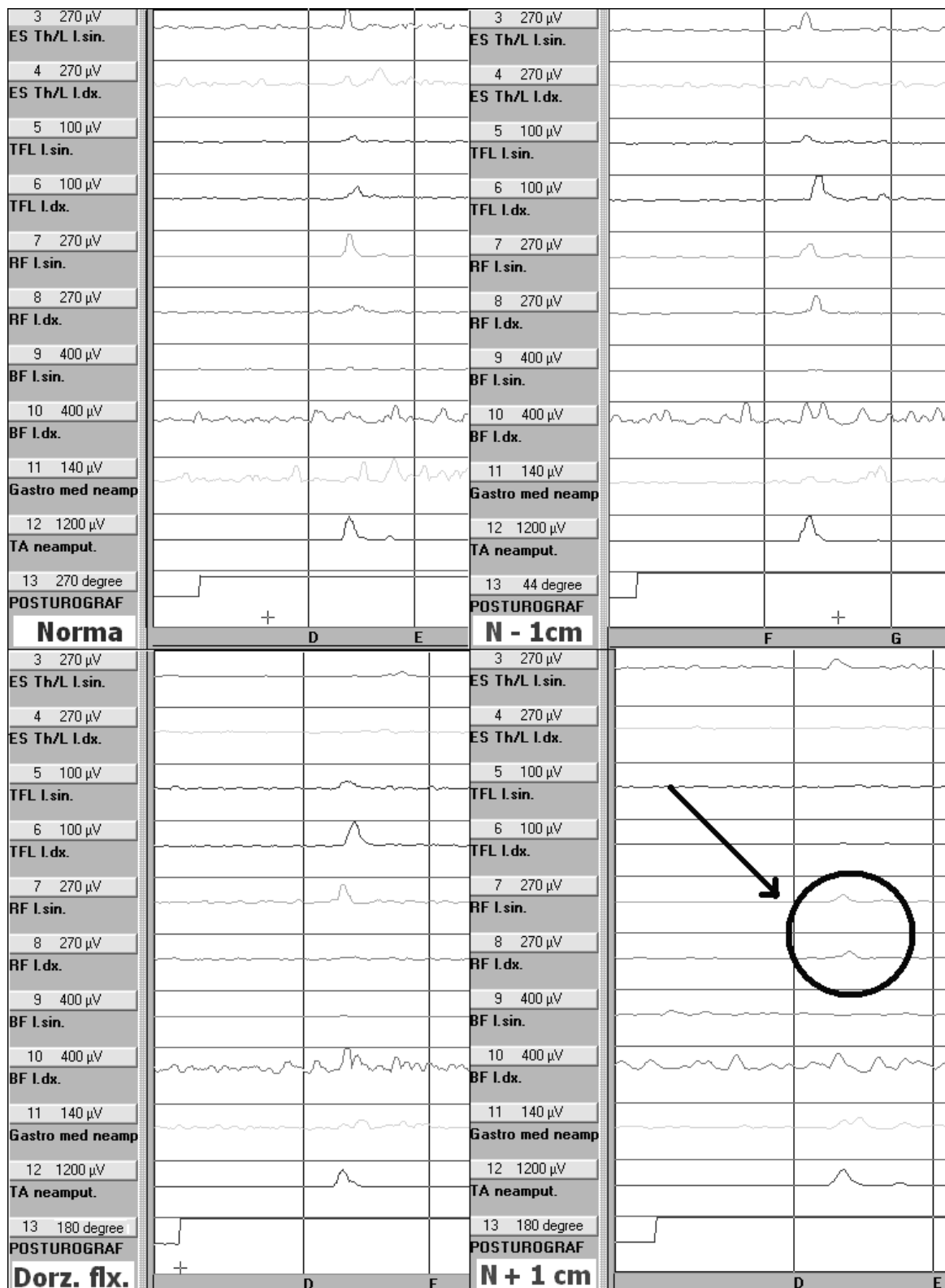
Legend
TFL – m. tensor fasciae latae
RF – m. rectus femoris

BF – m. biceps femoris
Gastro med. – m. gastrocnemius medialis
TA – m. tibialis anterior

42

Acta Univ. Palacki. Olomuc., Gymn. 2007, vol. 37, no. 4

Assessment of the measured data with a kinesiological examination and medical history data

A qualitative assessment of both the measured and examined data and each patient's personal medical history suggested the positive influence of the residual limb length on weight symmetry. On the other hand, for the latency there wasn't found any connection with those data. There is not any evident relationship between muscle activity, the examined data and the patient's personal medical history in the experimental group.

DISCUSSION

When we want to make an assessment of the measured data we have to take into account not just the variability of the experimental group (the variability is because of broad age differences, varied duration of prosthesis usage, and the cause of amputation), but also the fact, that not every human being in common circumstances (i.e. circumstances which don't require maximal effort) reacts in the same way in one tested situation – (the principle of indefinableness) (Véle, 2006; Míková, 2006). Each time each person chooses a different strategy to achieve the objective. This is a particular manifestation of "healthy movement". The tested prosthesis alignments were chosen on purpose because of the simulation of the everyday situations which can be present in transtibial amputees. This means, that the experimental group were accustomed to these small changes of prosthesis alignments by some way. There is also the relatively difficult "correlative" interpretation of several kinesiological methods – surface electromyography, kinesiological examination and the patent's personal medical history.

Postural stabilization is a complex motor skill. The only way as we can obtain valid information is to evaluate postural stabilization in its complexity (Míková, 2006). Posturography provides us with the means to test all aspects of postural stabilization. The Motor Control Test, which was used in our study, gives us information about postural stabilization during reactions to any unexpected exactly defined external stimulus. This test evaluates postural control during both involuntary movements and also during the action of unexpected external forces. Particular parameters of posturographic tests in combination with both surface electromyography and kinesiological examination enable us to obtain a comprehensive picture about postural behaviour. This combination is necessary for testing of postural stability.

Weight symmetry parameter

For all tested situations most of the body weight was on the non amputated leg in the experimental group. This matches the statement that COG displaces toward the non amputated limb (Gauthier-Gagnon, 2000). The minimum difference from all tested situations in the distribution of body weight between the amputated and non mputated leg was when the prosthesis was extended by 1 cm shorter within the dynamic conditions (Fig. 1). However we don't consider this alignment to be the most kinesiologically optimal, as the maximum symmetry in this tested situation was not actively secured by increasing reactive muscle activity on the amputated leg.

Latency parametr

The latency of postural reactions gradually decreased in normal prosthesis alignment with every tested situation independently on direction or magnitude of platform translations (Fig. 2). Thus that after every following tested situation (platform translations) income more effective answers on external stimulus. But in the tested prosthesis alignment differed from the normal one there was always a longer reaction time within the first small forward translation with regard to the previous tested translation. Therefore when the prosthesis alignment differs from common alignment of the user, the effectiveness of the answer on dynamic external stimulus is lowered.

Reactive activity of the muscles

The activity of the measured muscles in the experimental group was variable. This could be to a great extent influenced by inhomogeneity of tested subjects. The tested prosthesis alignment changes differed only "slightly" from normal one and therefore it is difficult to find relations between change in prosthesis alignment and muscle activity.

A statistically significant difference was measured in non amputated leg muscles (m. gastrocnemius medialis, m. tibialis anterior and m. biceps femoris) between 1 cm longer than normal prostheses alignment and the prosthetic foot alignment in dorsal flexion within small forward platform translations. This indicated that an unexpected change in the direction of platform translations led to an increased effort in activity of non amputated leg muscles. This took place when the prosthetic foot was in dorsal flexion, in the situation whereby the ground reaction force vector displaced forward because of dorsal flexion. On the contrary, whereby the

prosthesis was 1 cm longer than the normal prosthesis alignment, the effort was lowered on non amputated thigh muscles in first small forward translation. In this prosthesis alignment there was also an equation in reactive activity between amputated and non amputated thigh muscles and decrease in effort of reactive activity of m. gastrocnemius medialis and m. tibialis anterior (on non amputated leg).

In light of optimal and economic reactive activity of all tested muscles we consider as the most optimal prosthesis alignment extension of the prostheses by 1 cm. We presume that it is due to of better "postural certainty" in situations whereby the position of the COG replaced more above the non amputated leg. The amputees were feeling subjectively better in the situation, whereby the prosthesis was 1 cm shorter than normal alignment (personal announcement). Within the activities in a close kinematic chain is optimized muscle activity as reaction on external stimulus whereby the prosthesis is extended by 1 cm.

We suggest more investigation into impact of extension of the prostheses by 1 cm in kinesiotherapy of transtibial amputees. To complete this data of long term measurements within gait in different prostheses alignments.

Even though "normal alignment" appears to be the most optimal alignment in light of stand asymmetry minimalization (Fridman et al., 2003), in our study, normal alignment didn't present the most optimal alignment for any tested muscle in the terms of reactive muscle activity equation between either leg or in the terms of muscle activity effort reduction.

From the measured data and the personal medical history we can state that the length residual limb participates in the amputee's body weight symmetry. The longer residual limb presents a longer lever arm and then less muscle activity needed for stabilizing of destabilizing forces between the residual limb and the socket. The personal medical history of the experimental group showed, that subjects with knee pain on the non amputated leg and above average residual limb length, put more weight on the amputated leg. It is known, that lower limb pain influences the postural stabilization and functional capacity to a great extent (Menz & Lord, 2001). It is possible that the transtibial amputees are able to compensate for non amputated leg pain through amputated leg functional capacity improvement.

CONCLUSIONS

We found the extension of the prostheses by 1 cm as compared with normal alignment most optimal, as this alignment led to more symmetrical measured muscle activity. The normal prosthetic alignment presented

the most effective adaptation on external stimulus in transtibial amputees. The weight symmetry within the platform translations was the most optimal in 1 cm shorter prostheses alignment than in the normal one. Nevertheless in this alignment the "advantage" wasn't approved by more optimal gradation in the reaction muscle activity.

We suggest using the combination of surface electromyography with both posturography and kinesiological examination. It is necessary to employ a comprehensive view on the postural behaviour.

REFERENCES

Aruin, A. S., Nicholas, J. J., & Latash, M. L. (1997). Anticipatory postural adjustments during standing in below the knee amputees. *Clinical Biomechanics, 12,* 52–59.

Ehde, D. M., & Smith, D. G. (2004). Chronic pain managment. In D. G. Smith, J. W. Michael, & J. H. Bowle (Eds.), *Atlas of amputations and limb deficiencies: Surgical, prosthetic, and rehabilitation principles* (3rd ed.). Rosemond: American Academy of Orthopaedic Surgeons.

Fridman, A., Ona, I., & Isakov, E. (2003). The influence of prosthetic foot alignment on transtibial amputee gait. *Prosthetics and Orhotics International, 27,* 17–22.

Gauthier-Gagnon, Ch., Gravel, D., St. Amand, H., Murie, Ch., & Goyette, M. (2000). Changes in ground reaction forces during prosthetic training of people with transfemoral amputations: A pilot study. *Journal of Prosthetics & Orthotics,* 72–79.

Geurts, A. C. H., Wulder, T. W., Nienhuis, B., Eng, M., & Rijken, R. A. J. (1991). Dual task assessment of reorganization of postural control in persons with lower limb amputation. *Archives of Physical Medicine and Rehabilitation, 72,* 1059–1064.

Kovounoudias, A., Tremblay, C., Gravel, D., Iancu, A., & Forget, R. (2005). Bilateral changes in somatosensory sensibility after unilateral below knee amputation. *Archives of Physical Medicine and Rehabilitation, 86,* 634–640.

Latash, M. L. (1998). *Neurophysiological basis of movement.* Champaigne, IL: Human Kinetics.

Menz, B. H., & Lord, S. R. (2001). Foot pain impairs balance and functional ability in community dwelling older people. *Journal of the American Podiatric Medical Association, 91,* 222–229.

　　　　　　　　　　　　Acta Univ. Palacki. Olomuc., Gymn. 2007, vol. 37, no. 4

Míková, M. (2006). *Posturografie – význam a uplatnění ve výzkumu a v klinické praxi.* Dizertační práce, Univerzita Palackého, Fakulta tělesné kultury, Olomouc.

Murrell, P., Cornwall, M. W., & Doucet, S. K. (1991). Leg length discrepancy: Effect on the amplitude of postural sway. *Archives of Physical Medicine and Rehabilitation, 72,* 646–648.

Ries, J. D., & Brewer K. M. (2000). Transtibial prosthetic training and rehabilitation. In M. M. Lusardi & L. F. Owens (Eds.), *Orthotics and prosthetics in rehabilitation.* Woborn: Butteworth Heinemann.

Rodová, D. (2002). *Hodnocení činnosti kosterního svalstva povrchovou elektromyografií.* Dizertační práce, Univerzita Palackého, Fakulta tělesné kultury, Olomouc.

Sabolich, J. A., & Ortega, G. M. (1994). Sense of feel for lower limb amputees: A phase one study. Retrieved 1. 12. 2007 from the World Wide Web: http://www.oandp.org/jpo/library/1994_02_036.asp

Seymour, R. (2002). Transtibial components: Clinical decision making. *Prosthetics and orthotics, lower limb and spine.* Pensylvania: Lippincott Williams & Wilkins.

Shumway-Cook, A., & Woollacott, M. H. (2001). *Motor control: Theory and practical applications.* Philadelphia: Lippincott.

Véle, F. (2006). *Kineziologie, přehled klinické kineziologie a patokineziologie pro diagnostiku a terapii poruch pohybové soustavy.* Praha: Triton.

VLIV NASTAVENÍ PROTÉZY A PROTETICKÉHO CHODIDLA NA POSTURÁLNÍ CHOVÁNÍ U OSOB PO TRANSTIBIÁLNÍ AMPUTACI
(Souhrn anglického textu)

Amputace dolní končetiny představuje aktuální kineziologický problém vzhledem k alteraci posturálního chování. Biomechanické a neurofyziologické změny následující po amputaci dolní končetiny jsou důsledkem mnoha kompenzačních a adaptačních mechanismů. Volba a nastavení jednotlivých protetických komponent u jedinců po transtibiální amputaci do značné míry determinuje charakter posturální stability a bipedální lokomoce. Cílem této studie bylo posoudit vliv změny nastavení protézy a protetického chodidla na posturální chování u osob s transtibiální amputací. U souboru 13 probandů (věk 56 ± 13 let, hmotnost 88,46 ± 12,3 kg) bylo analyzováno posturální chování při pěti různých nastaveních protézy a protetického chodidla. Pro všechna nastavení jsme hodnotili symetrii rozložení tělesné hmotnosti a latenci posturálních reakcí za dynamických podmínek posturografického testu Motor Control Test (NeuroCom®) za současného snímání svalové aktivity pomocí povrchové elektromyografie (Noraxon). Z výsledků studie vyplývá, že změna nastavení protézy a protetického chodidla má vliv na svalovou aktivitu a na vybrané posturografické parametry. Za kineziologicky nejoptimálnější lze označit prodloužení protézy o 1 cm vzhledem k normálnímu nastavení, protože při tomto nastavení došlo k nejvíce symetrické aktivaci testovaných svalů. Při normálním nastavení byli transtibiálně amputovaní jedinci schopni nejefektivnější adaptability na vnější podnět, což se projevilo kontinuálním snižováním latence posturálních reakcí na rozdíl od jiných testovaných nastavení. Nejmenší asymetrie v rozložení tělesné hmotnosti při testu MCT byla při nastavení chodidla o 1 cm kratším, to se však neprojevilo na svalové aktivitě při tomto nastavení.

Klíčová slova: transtibiální amputace, postojová stabilita, protézy, posturografie, povrchová EMG.

Contact
Mgr. Barbora Paráková
barpar@atlas.cz