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PLANTAR PRESSURES REVEAL ADAPTIVE CHANGES FOR POSTURAL BALANCE IN AMPUTEES

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ABSTRACT. There is a high prevalence of peripheral arterial disease in the general population. A minority of this group will require lower limb amputation with important functional and social consequences. Energy costs of amputees gait severely strains the cardiovascular resources of the amputee. Such findings have led us to aim to improve the mobility and thus decrease cardiovascular output by determining the gait patterns of patients with below the knee amputations due to peripheral arterial disease. 8 patients with below the knee amputations were analyzed using a capacitive platform. They all had healed stumps, patellar tendon supporting cups and simple, articulated ankles and important co-morbidities. The inappropriate forward transmission of inertia is apparent on the ground reaction forces readings. The healthy limb has longer steps, stance, single support and pre-swing loading and a decreased load response; these modifications show inappropriate control and confidence in the prosthetic limb, as well as deficient ankle function during pre-swing and heel strike. Uncertainty of position sense can be seen even when the patient is standing and has visual balance control. We conclude that both postural and gait alterations are clearly identifiable in transtibial amputees using plantar pressure distribution analysis. These measurements can aid with rehabilitation, follow-up progression and prosthetic design.

Keywords: amputee, balance, adaptive changes, gait, plantar pressures

INTRODUCTION

There is a high prevalence of peripheral arterial disease in the general population. The burden of the disease increases with age and among diabetic. A minority of this group will require lower limb amputation with important functional and social consequences (JOHANNESSON et al., 2009). Johannesson et al performed an epidemiological study on lower limb amputations and found an incidence of initial unilateral amputation of 192/197 (female/male) per 100 thousand / year in diabetic and 22/24 for nondiabetic (JOHANNESSON et al., 2009). In the general population over 45 years of age , the incidence of vascular lower limb amputation at or proximal to the transmetatarsal level is eight times higher in diabetic than in nondiabetic individuals (JOHANNESSON et al., 2009). One in four amputees may require contralateral amputation and/or reamputation (JOHANNESSON et al., 2009).

The major amputation rate was found to be between 20 and 50 per 100 thousand / year and occurs mainly in patients presenting with an acute onset of critical leg ischemia (DORMANDY et al., 1999). Diabetics, who form 2 - 5% of the population, are 40 - 45% of amputees (DORMANDY et al., 1999). Data in the literature report primary healing of below the knee amputations between 30 to 92% and the reamputation rate from 4% to 30% (DORMANDY et al., 1999). A palpable popliteal pulse is predictive for success in 90% of cases while and bleeding during the operation has no influence on healing. Roughly half of the cases that do not heal primarily will require a higher amputation (DORMANDY et al., 1999). Two to three times as many below the knee amputees achieve full mobility in comparison to higher level with constant variations over the last two decades (DORMANDY et al., 1999). A report by Dormandy et al considers that 2 years after a successful below the knee amputation approximately 15% will have a higher amputation, 15% will have had a contralateral major amputation, and 30% will be dead (DORMANDY et al.,1999).

A recent systematic review identified biomechanical and physiological parameters most relevant for the gait analysis of lower-limb amputees (SAGAWA et al., 2011). For the orthopedic and trauma emergency team a recent corelation has gained potential interest. GUZMAN et al found that increased age and traditional atherosclerosis risk factors were associated with higher tibial artery calcification scores (GUZMAN et al., 2008). In turn, these were associated with worsening levels of limb ischemia and predicted amputation better than the ankle-brachial index (GUZMAN et al., 2008).

Many years ago, Skinner et al have shown marked differences from normal gait in both above and below the knee amputees (SKINNER et al., 1985). Forward walking velocity is significantly lower in the amputee and is lower the higher the amputation level (SKINNER et al., 1985). Traumatic above the knee amputees ambulate with velocity, cadence, stride length and gait cycle parameters two standard deviations less than normal and one standard deviation less than normal for below the knee amputees respectively (SKINNER et al., 1985). The symmetry of

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walking seen in the normal subject is not present in the lower extremity amputee (SKINNER et al., 1985). This asymmetry of motion increases the excursion of the center of mass during each cycle and thereby increases the energy cost of ambulation (SKINNER et al., 1985). Energy cost of amputee gait often places the cardiovascular above the knee amputee at his limits and strains other amputees severely (SKINNER et al., 1985).

Such findings have led us to aim to improve the mobility and thus decrease cardiovascular output by determining the gait patterns of patients with below the knee amputations due to peripheral arterial disease.

MATERIALS AND METHODS

8 patients with below the knee amputations were analyzed using a capacitive platform (Zebris). Each subject performed 5 crossings over the measuring unit at desired comfortable speed wearing socks over the foot as well as the prosthetic limb.

They all had healed stumps, patellar tendon supporting cups and simple, articulated ankles. The standard surgical technique was used for all cases (fig.1).

Fig. 1 – postoperative AP and Lateral x-ray of the stump.

For all cases the reason for amputation was peripheral arterial disease with acute limb ischemia which required emergency amputation. The mean age was 67years (SD=9.3), 7 patients were male, 6 have had type II diabetes for 8 years (SD=5.5); all patients were previous smokers for an average of 17.5 years (SD=7.5), 5 have dyslipidemia, one has compensated ethanolic cirrhosis, one has chronic obstructive pulmonary disease, 6 have ischemic heart disease under medication, one has coronary stent, all have elevated blood pressures and 2 have had minor strokes without sequelae. 4 have had claudication for a mean of 5.3 years (SD=3.7) prior to amputation and 2 have peripheral neuropathy without ulceration. 2 have had previous amputations prior to the one below the knee (2 fingers, one midtarsal). 5 have had failed emergency attempts for revascularization. 5 were right feet, all caonsidered the right foot to be functional dominant.

RESULTS

On the colored footprints in figure 2 there is an apparently normal walking. The continuous black line depicts the course of the center of pressure (body's center of mass). We can observe that this line in fluent on the left, normal side and abruptly angled under the prosthetic foot due to improper rolling of the artificial ankle articulation during stance. This inappropriate forward transmission of inertia is not apparent on the GRF graphs but is evident on the capacitive platform pressure readings (fig.2).

The healthy limb has longer steps, stance, single support and pre-swing loading and a decreased load response; these modifications show inapropriate control and confidence in the prosthetic limb, as well as deficient ankle function during pre-swing and heel strike (fig.3).

The rigid foot sole presents as longer contact lines and the medio-lateral wobble of the normal foot is probably due to imprecise proprioception caused by the prosthetic right limb (fig.4).

Higher support is placed on the unaffected left side due to inappropriate proprioception from the prosthetic limb; there is permanent movement of the left foot seen as the variable red line on the graph on the right; this uncertainty of position sense can be seen even when the patient has visual balance aid (fig.5).

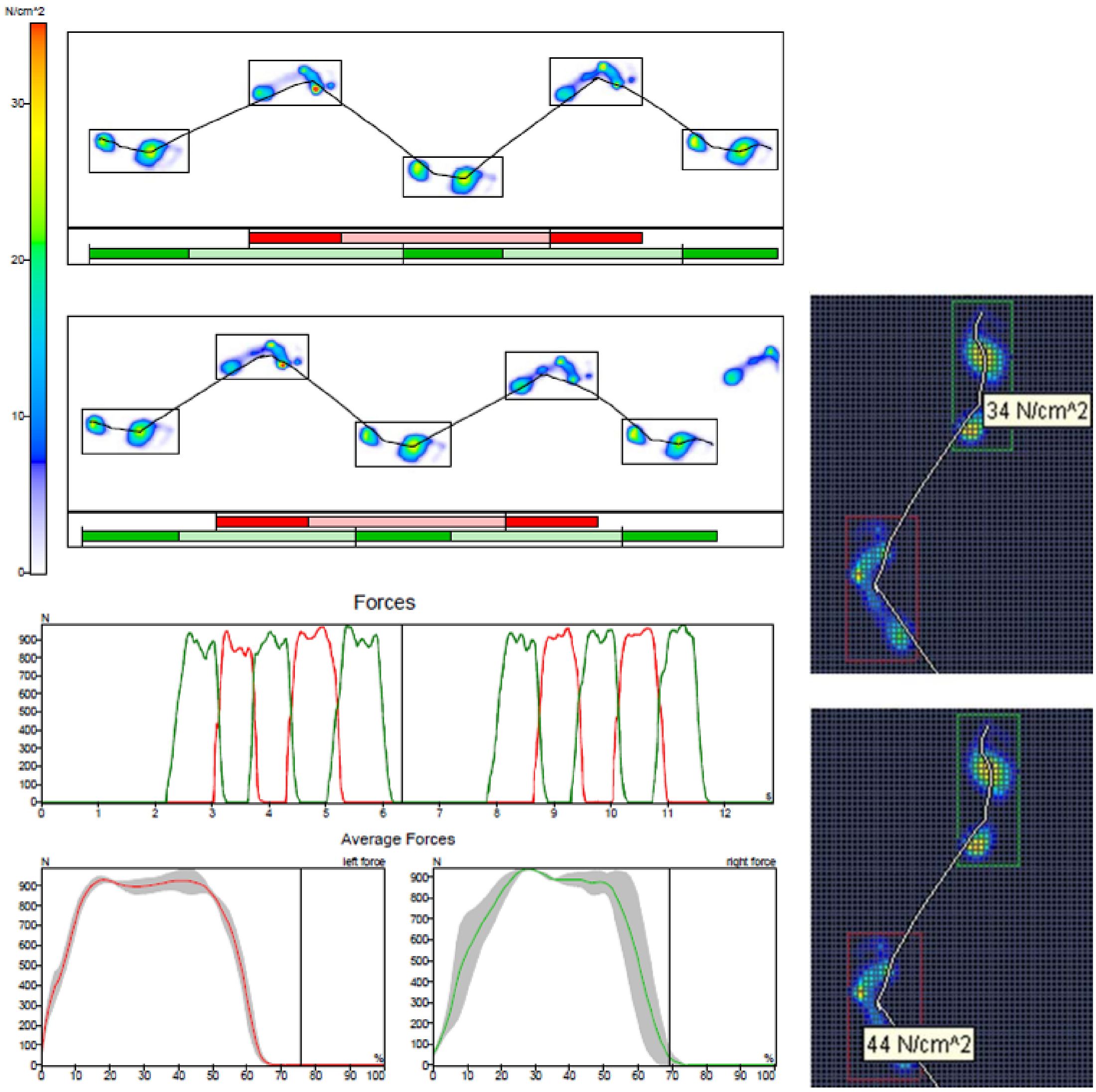

Fig.2 Ground reaction forces (GRF) determined on the capacitive platform.

Parameter Table

	left	right	
Step time, sec	0.76	0.67	
Swing time, %	24.34	30.54	
Stance time, %	75.66	69.46	
Load response, %	16.56	28.94	
Pre-swing, %	28.94	16.56	
Single support, %	30.16	23.95	
Step length, cm Normalized	44 -	40 -	

Fig. 3 shows the measured stages of the gait cycle

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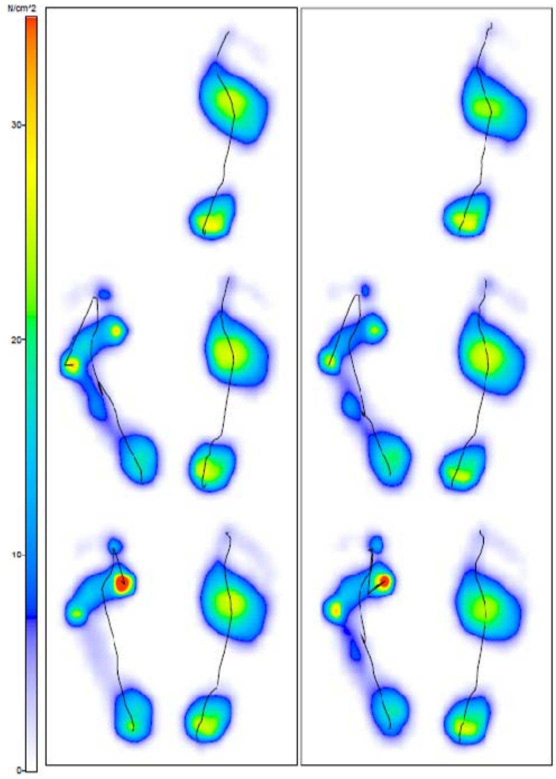
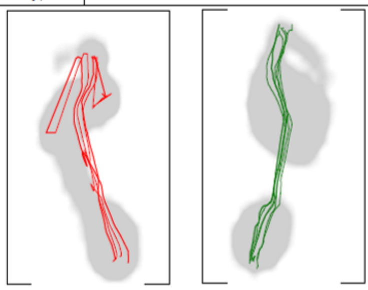


Butterfly Table

Parameter, mm	Left	Right
Gait line length, mm	209±1	240±1
Single support line, mm	93±3	106±11
Ant/post position, mm	125	
Ant/post variability, mm	2	
Lateral symmetry, mm	-5	
Lateral variability, mm	3	



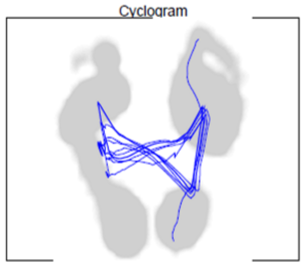


Fig. 4 presents the course of the center of pressure over each footprint in color coding; the same data are presented synthetically in the butterfly table and cyclogram.

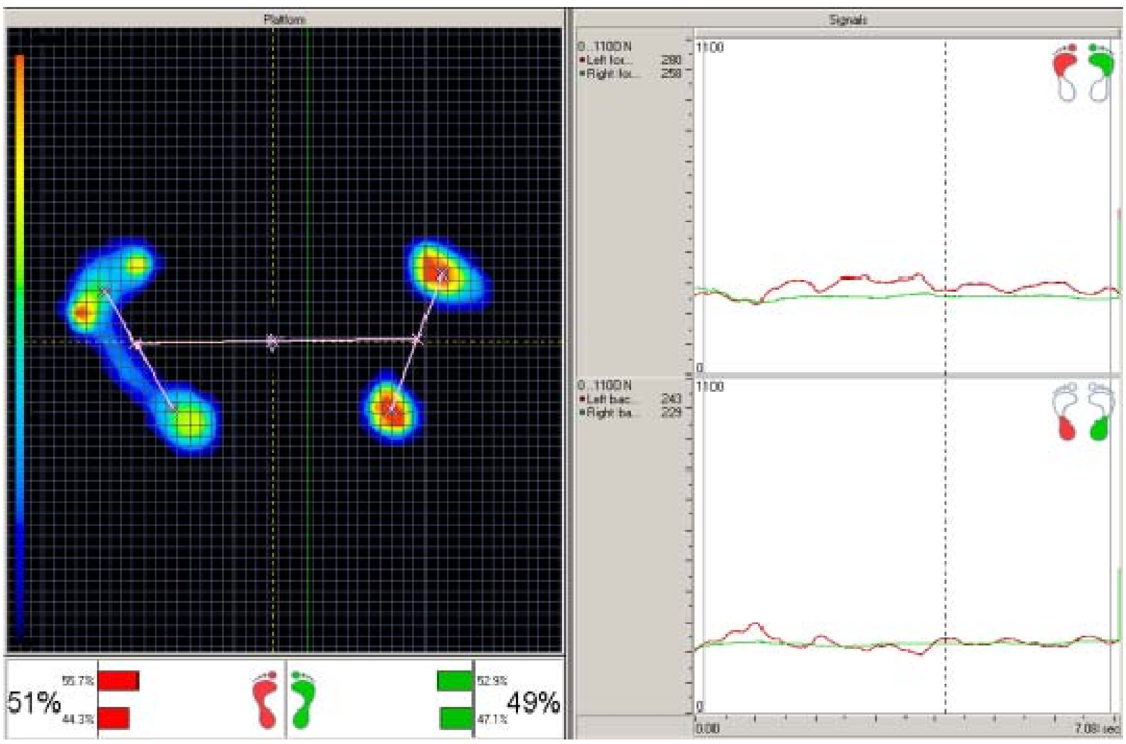


Fig. 5 Variations of the pressure distribution under the fore and rearfeet during standing.

DISCUSSION AND CONCLUSIONS

It is unclear whether an improved ankle joint prosthesis will lead to better gait and function for above the knee amputees. Hofstad et al, in a systematic review, found insufficient evidence for the overall superiority of any individual type of prosthetic ankle-foot mechanism (HOFSTAD et al., 2004). Nevertheless, this benefit has been confirmed in transtibial amputees during incline walking and high walking speed (HOFSTAD et al., 2004). On the other hand, a study by MCNEALY et al found that prosthetic ankle units improved sagittal plane motion and increased comfort and functionality by restoring a significant portion of the ankle rocker mechanism during the stance phase for bilateral transfemoral amputees (MCNEALY et al., 2008).

With regard to prosthetic weight distribution, Selles et al found that stump-socket interface forces increased after mass addition but the energy consumption increased only when mass was added distally and decreased when was added proximally (SELLES et al., 2004).

The absence of active ankle motion in transtibial amputees alters their ability to initiate and terminate gait, in addition to their ineficient rocker mechanism during stance. This increase in movement duration was attributed to the stability and movement limitations of the prosthetic limb (TOKUNO et al., 2003). On the other hand, such patients can compensate for the saggital plane impairments by increasing coronal plane mobility (TOKUNO et al., 2003).

Vrieling et al found that amputees demonstrated a decrease in peak anterior ground reaction and braking force a small or diminished posterior as well as anterior centre of pressure shift, a lower gait initiation and termination velocity and an increased mediolateral centre of pressure shift (VRIELING et al., 2008a, VRIELING et al., 2008b). The principal compensatory mechanisms were increased limb-loading and duration of propulsive force generation on the abled side, and initiation of gait preferably with the prosthetic limb, as well as longer production of braking force in the non-affected limb (VRIELING et al., 2008b). They conclude that functional limitations and adjustment strategies are the same in above and below the knee amputees (VRIELING et al., 2008a, VRIELING et al., 2008b).

Gait alterations are perpetuated even during standing. Many authors proved amputees have increased dependence on vision for maintenance of postural balance, regardless of age. However, postural sway in patients with transtibial amputations was found to be significantly greater than that in those with transfemoral amputations (FERNIE et al., 1978). To compensate for deficitary proprioception, more weight is put on the sound limb (NADOLLEK et al., 2002). There is also less anterior-posterior movement under the prosthetic limb, more apparent when the eyes are closed. On the other hand, medio-lateral motion was the same (NADOLLEK et al., 2002). Strong hip abductor muscles correlate with improved weight-bearing, gait parameters and postural control on the amputated limb (NADOLLEK et al., 2002).

Mayer et al studied adaptation strategies for balance; they found reduced postural sway while standing on the nonaffected leg appears before amputation due to pain and fatigue (MAYER et al., 2011). After rehabilitation and regular use of the prosthesis there is normal weight-bearing associated with reduced postural sway on two legs and return to the normal postural stability on one leg (MAYER et al., 2011).

HLAVACKOVA et al determined that regularity of CoP fluctuation could be considered as a marker of the amount of attention invested in the control of bipedal unperturbed posture (HLAVACKOVA et al., 2011). Their findings suggest that the limbs contribute unequally to control bipedal posture in above the knee amputees with compensatory proprioception obtained from the preserved leg (HLAVACKOVA et al., 2011).

We conclude that subtle postural and gait alterations are clearly identifiable in transtibial amputees using plantar pressure distribution analysis. These measurements can aid with rehabilitation, follow-up progression and prosthetic design.

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REFERENCES

Dormandy J, Heeck L, Vig S. Major amputations: clinical patterns and predictors. Semin Vasc Surg. Jun 1999;12(2):154-61

Fernie GR, Holliday PJ: Postural sway in amputees and normal subjects. J Bone Joint Surg Am 1978, 60:895-8.

Guzman RJ, Brinkley DM, Schumacher PM, Donahue RM, Beavers H, Qin X. Tibial artery calcification as a marker of amputation risk in patients with peripheral arterial disease. J Am Coll Cardiol. 2008 May 20;51(20):1967-74.

Hlavackova P, Franco C, Diot B, Vuillerme N. Contribution of each leg to the control of unperturbed bipedal stance in lower limb amputees: new insights using entropy. PLoS One. 2011;6(5):e19661.

Hofstad C, Linde H, Limbeek J, Postema K. Prescription of prosthetic ankle-foot mechanisms after lower limb amputation. Cochrane Database Syst Rev. 2004;(1):CD003978

Johannesson A, Larsson GU, Ramstrand N, Turkiewicz A, Wiréhn AB, Atroshi I. Incidence of lower-limb amputation in the diabetic and nondiabetic general population: a 10-year population-based cohort study of initial unilateral and contralateral amputations and reamputations. Diabetes Care. 2009 Feb;32(2):275-80.

Mayer et al.: Adaptation to altered balance conditions in unilateral amputees due to atherosclerosis: a randomized controlled study. BMC Musculoskeletal Disorders 2011 12:118.

McNealy LL, Gard SA. Effect of prosthetic ankle units on the gait of persons with bilateral transfemoral amputations. Prosthet Orthot Int. Mar 2008;32(1):111-26

Nadollek H, Brauer S, Isles R. Outcomes after trans-tibial amputation: the relationship between quiet stance ability, strength of hip abductor muscles and gait. Physiother Res Int. 2002;7(4):203-14.

Sagawa Y Jr, Turcot K, Armand S, Thevenon A, Vuillerme N, Watelain E. Biomechanics and physiological parameters during gait in lower-limb amputees: a systematic review. Gait Posture. 2011 Apr;33(4):511-26.

Selles R, Bussmann J, Van Soest AJ, Stam H. The effect of prosthetic mass properties on the gait of transtibial amputees--a mathematical model. Disabil Rehabil. Jun 17 2004;26(12):694-704

Skinner HB, Effeney DJ. Gait analysis in amputees. Am J Phys Med. 1985 Apr;64(2):82-9.

Tokuno CD, Sanderson DJ, Inglis JT, Chua R. Postural and movement adaptations by individuals with a unilateral below-knee amputation during gait initiation. Gait Posture. Dec 2003;18(3):158-69.

Vrieling AH, van Keeken HG, Schoppen T, Otten E, Halbertsma JP, Hof AL, Postema K. Gait termination in lower limb amputees. Gait Posture. 2008a;27(1):82-90.

Vrieling AH, van Keeken HG, Schoppen T, Otten E, Halbertsma JP, Hof AL, Postema K. Gait initiation in lower limb amputees. Gait Posture. 2008b;27(3):423-30.