Transtibial Amputee Gait: Kinematics and Temporal-Spatial Analysis

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Abstract—**Transtibial amputees gait patterns are widely studied. Usually, kinematic and temporal-spatial parameters data are used to investigate their gait pattern. The Gait Profile Score (GPS) and the Movement analysis Profile (MAP) are new tolls that summarize kinematics data in one single number. The aim of this study was to use GPS, Movement analysis Profile (MAP) and temporal-spatial parameters to quantify gait deviations of a homogeneous group of transtibial amputees, using the same prosthetic components and that were rehabilitated in a specific center. Besides, it was observed the correlation between GPS scores and temporal-spatial parameters. Five unilateral traumatic transtibial amputees participated on this study. All the participants used KBM (Kondylen Bettung Münster) prosthetic fitting and solid ankle cushion heel (SACH) foot. Kinematic and temporal-spatial data were assessed through 3D gait analysis. All analyzed variables presented deviations compared with normal expected values. Prosthetic limb GPS score was larger than intact limb GPS score as well as step length with the prosthetic leg was longer than with the intact one. Time of single support with the intact limb was longer than that with the prosthetic limb. The largest gait variable scores (GVS) were in the hip flexion/extension for the prosthetic limb, knee flexion/extension for the intact limb, and hip rotation for both. The strongest correlation occurred between overall GPS and prosthetic step length, overall GPS and time of single support with the prosthetic limb, prosthetic limb GPS and prosthetic step length, and between prosthetic limb GPS and time of single support with the prosthetic limb. The GPS, MAP and temporal-spatial parameters were useful in quantifying gait deviation on transtibial amputees. GPS scores were increased and temporal-spatial parameters values were lower than that found in health subjects.**

Keywords—**Gait Profile Score, transtibial amputees, kinematics, temporal-spatial parameters, gait deviation.**

I. INTRODUCTION

Many studies used 3D gait analysis (3DGA) to investigate transtibial amputees' ambulation [1-3]. They described some kinematic and temporal-spatial deviations often found on this population, such as decreased self-selected walking velocity longest step length shorter single support duration with the prosthetic limb, increased hip and knee flexion during swing phase, low range of motion of the prosthetic ankle [1, 2, 4]. Some of them compared types of prosthetic feet and sockets [3, 5]; others did not considered prosthetic components on their analysis [1, 6]. All of them tried to find some deviation pattern for this group. Findings present consistent results that make it possible to understand the strategies developed by these patients during walking [7]. Methodological inconsistence of the studies and diversity of gait parameters used to describe their ambulation make it difficult to distinguish gait patterns usually adopted for transtibial amputees [4, 7].

New tolls that can be used to analyze transtibial amputees gait are the Movement Analysis Profile (MAP) and the Gait Profile Score (GPS)[6, 8]. GPS is a gait summary measure that is obtained by the calculation of the root mean square (RMS) difference between subject's kinematic data and data from a person with no gait pathology [9]. GPS summarizes gait kinematic data to a single number, measured in degrees. It helps clinicians to understand quickly the magnitude of kinematic problems. First the RMS of nine kinematic variables (pelvic tilt, pelvic obliquity, pelvic rotation, hip flexion/extension, hip abduction/adduction, hip rotation, knee flexion/extension, ankle dorsi/plantar flexion and foot progression) are calculated for left and right sides. Each value is called Gait Variable Score (GVS) for one specific kinematic variable. The GVS for these nine kinematic variables for the right and left legs are combined to form a bar chart, called MAP [10]. It can be used to highlight where patients have specific gait problems. Left and right GPS scores are the RMS average of the nine GVS for the right and left sides. An overall GPS score is obtained by the RMS average of all GVS. An increased value of GVS and GPS, compared to people without gait pathology, indicates more gait deviation [9, 10].

One group of researchers studied the use of the MAP and GPS with lower limb amputees [6, 8]. On the first study they tested the ability of these tolls to detect asymmetries and differentiate between two levels of amputation [8]. On the other one they assessed the suitability of gait summary measures for use with this population [6]. Both studies concluded that MAP and GPS can be applied to quantify and identify gait deviations among lower limb amputees [6, 8]. The authors included in their sample transtibial and transfemoral amputees with vascular and trauma etiology of amputation. Besides, they did not controlled prosthetic components and rehabilitation process.

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The aim of this study was to use GPS, MAP and temporal-spatial parameters to quantify gait deviations of a homogeneous group of transtibial amputees, which used the same prosthetic components and which were rehabilitated in a specific center.

II. MATERIALS AND METHODS

A. Subjects

Five unilateral traumatic transtibial amputees (four men and one woman) participated on this study. They were recruited from a group of patients that were rehabilitated at Ana Carolina Moura Xavier Hospital Rehabilitation Center (CHR), Curitiba, Brazil, to ensure that all of them received the same treatment in both preprosthetic and post-prosthetic stages. Then, they provided their informed consent. All the participants used KBM (Kondylen Bettung Münster) prosthetic fitting and solid ankle cushion heel (SACH) foot. Exclusion criteria were amputation in upper limbs or another lower limb, less than three months consistent prosthesis use, use of ambulation aids, other cause of amputation and muscular, neurological or/and circulatory diseases that affect gait pattern.

B. Procedure

3DGA was captured in the Gait Laboratory at CHR. Before capturing gait data, patients' anthropometric data, range of motion and muscular strength were measured. Individuals wore a pair of shorts and a vest and reflexive markers (20-mm diameter) were placed on anatomical and prosthetic corresponding landmarkers according to the Helen Hayes marker set. Kinematic data was captured by 6 cameras Hawks (Motion Analysis Corporation, Santa Rosa, CA) at 60 Hz. First, subjects were placed in the center of the walkway and a static trial was collected. Then, medium markers from the knees and the ankles were removed. Patients walked across a 10-m walk-way at their self-selected speed. At least 10 trials for each subject were collected.

C. Data Analysis

Trials collected for each subject were edited with the software Cortex 1.1.4.368 (Motion Analysis Corporation, Santa Rosa, CA) and the one which represented better patient's gait pattern was chosen to the analysis. Ortrotrak 6.5.1 software (Motion Analysis Corporation, Santa Rosa, CA) was used to calculate kinematics data and the six most representative trials were used to calculate GPS (Gait Profile Score), which were calculated according to the authors [9]. All correlations were performed with SPSS version 20.0 and the level of significance set at $p < 0.05$.

III. RESULTS

The sample consisted of one woman and four men, with mean age of 46.2 (± 6.94) years. All of them lost the limb because of a trauma, four due to motor vehicle accidents and one due to an accident during sporting practice. The average time since amputation was 8.6 (± 8.2) years.

The Table 1 and Table 2 show the results of GPS, GVS and the temporal-spatial parameters of prosthetic and intact limbs.

Table 1 Average and Standard Deviation (SD) for GPS scores and Temporal-spatial parameters

Amputees characteristics	Average ± SD
Overall GPS	9,59 ± 1,38
Prosthetic limb GPS	9,32 ± 2,05
Intact limb GPS	9,02 ±1,00
Velocity (cm/s)	89,66 ± 16,16
Cadence (steps/min)	91,55 ± 8,25
Step Width (cm)	16,43 ± 3,03
Prosthetic limb step length (cm)	61,04 ± 9,19
Intact limb step length (cm)	55,8 ± 6,7
Prosthetic limb Single Support (% cycle)	31,24 ± 2,13
Intact limb Single Support (% cycle)	37,8 ± 1,55

Table 2 Average and Standard Deviation of GVS scores for the nine kinematic variables

	Prosthetic limb	Intact limb
Pelvic Tilt	6.72 ± 4.01	6.72 ± 4.01
Hip flexion/extension	10.26 ± 4.80	9.57 ± 4.36
Knee flexion/extension	8.24 ± 3.64	10.54 ± 2.44
Ankle dors/plant flexion	9.31 ± 1.12	8.61 ± 1.91
Pelvic obliquity	4.47 ± 2.66	4.47 ± 2.66
Hip abduction/adduction	6.5 ± 3.15	5.97± 2.99
Pelvic rotation	8.97 ± 2.21	8.97 ± 2.21
Hip rotation	14.54 ± 3.88	10.26 ± 6.43
Foot progression	8.46 ± 2.92	9.45 ± 2.86

Table 3 shows how many normal GVS scores each subject got, its velocity and step length for the prosthetic and intact limbs. Individual D got 7 normal GVS scores and had better values for velocity (114.90 cm/s) and step length (74.10 and 67.27 cm/s) than the others.

Table 3 Number of normal GVS scores, velocity and step length for the five subjects

Subject	Numbers of normal GVS	Velocity (cm/s)	Step Length (cm)	
			Prosthetic limb	Intact limb
A	2	79.20	65.50	52.60
B	1	72.60	49.74	49.91
C	2	89.21	58.08	55.01
D	7	114.90	74.10	67.27
E	0	92.40	57.79	54.22

Correlation coefficients (Spearman's rho) between GPS scores and temporal-spatial parameters and their statistical significance (*p*-value) are summarized in Table 4. Overall GPS was moderately correlated (r = -0.50) with velocity and single support for the intact limb. Moreover, GPS correlations with step length and single support for the prosthetic limb were strong (r = -0.70). GPS score with the prosthetic limb was strongly correlated (r = -0.70) with step length and single support for the prosthetic side and moderately correlated (r = 0.50) with single support for the intact leg. Correlations didn't show significance for the sample size of this present study.

Table 4 Spearman's correlation (rho) and statistical significance (*p* -value) between GPS scores and temporal-spatial parameters

		Spearman's rho	*p-value*
Overall GPS	Velocity	-0.50	0.196
	Step length Pro	-0.70	0.094
	Step Length Int	-0.30	0.312
	Single support Pro	-0.70	0.094
	Single support Int	0.50	0.196
Prosthetic limb GPS	Step length Pro	-0.70	0.094
	Step Length Int	-0.30	0.312
	Single support Pro	-0.70	0.094
	Single support Int	0.50	0.196
Intact limb GPS	Step length Pro	-0.30	0.312
	Step Length Int	0.00	0.500
	Single support Pro	-0.30	0.312
	Single support Int	-0.20	0.374

IV. DISCUSSION

Kinematic and temporal-spatial parameters data are usually used to describe and quantify transtibial amputees' deviations [4]. These were some of the first variables used to describe the ambulation of this population [5, 7]. These data are used to determine gait deviations, to analyze the effectiveness of rehabilitation programs, to detect prosthetic alignment problems and to help to define the end of the rehabilitation process.

Participants presented temporal-spatial parameters deviations compatible with previous studies [7]. They presented walking speed average of 89.66 (16.16) cm/s, while able-bodied individuals walk at 124.63 cm/s. Besides, their mean step lengths (61.04 and 55.8 cm) were short compared with the 65.20 cm expected for individuals with no gait pathology. So, markedly, subjects' functional ability was poorer than that of healthy individuals.

Similar to previous findings, subjects gait were asymmetrical [11, 12]. Step length with amputated limb was greater (61.04 cm) than that with the intact limb (55.8 cm) and single support with intact leg (37.8% of the gait cycle) was longer than with the prosthetic leg (31.24 %). In amputees, the difference of stance duration contributes to asymmetry as well as deficiencies associated with prostheses fitting and components [4]. Due to these factors, transtibial amputees fell less confident to load over prosthetic limb and, also, tend to increase the base of support. In this study individuals presented a step width of 16.43 cm (± 3.03), while in able-bodied subjects the base of support measures about 12 cm.

Two studies used GPS to quantify gait deviations in transtibial amputees [6, 8]. However, their sample consisted of traumatic and vascular transtibial amputees, which present poorer gait prognosis compared with traumatic amputees, and have a variety of other pathologies that can influence negatively the power of the study's findings. In addition, they did not control prosthetic components. Different types of feet and prosthetic fitting influence differently some gait parameters [3-5].

On the present study the sample size consisted of only traumatic transtibial amputees, using KBM socket and SACH foot. Besides that, all participants were rehabilitated in the same center, following the same preprosthetic and post-prosthetic protocol. All of these inclusion criteria had the objective of minimize mistakes in the gait analyzes, due to variation in the sample.

Overall, prosthetic and intact limbs GPS scores (9.59°, 9.32° and 9.02°, respectively) were higher than the expected for individuals with no gait pathology (5.6°, 5.3° and 5.3°) [9]. Previous studies obtained similar results [6, 8]. On both studies, prosthetic limb GPS was higher than that with the intact one. The first study found a GPS score of 12.3° for the amputated leg and 11.4° for the opposite leg [8]. On the one, GPS scores were 7.1° for prosthetic limb and 6.3° for the intact limb [6].

This asymmetry reflects the influence of the natural ankle function absence on the gait pattern in transtibial amputees. That fact became worst with the use of SACH foot, which present less range of motion compared with others feet. In addition, this kind of foot prolongs the time which the amputated leg maintain a heel-only contact, which increases asymmetry and results in a period of instability with this limb [4].

On the study of Kark et al [8], pelvic tilt, hip flexion/extension and knee flexion/extension were the kinematic variables that obtained the highest scores, what represent that they presented larger deviations from normal. Our study obtained similar results, differentiating from that just in the hip rotation variable, which had the major GVS score (14.54° on the prosthetic limb). Problems with prosthetic alignment and the difficulty to position knee and ankle landmarkers can cause this deviation. An increased internal or external rotation of the prosthetic foot can influence the final hip rotation angle. Furthermore, the positions of knee and ankle landmarkers are used to calculate the rotation center of these joints, which are used to calculate hip's joint center.

On the present study, subject D had more GVS with normal values (7) and, at the same time, presented the best functional ability, represented by a velocity of 114.9 cm/s and values of 74.10 and 67.27 cm for step length. However, the opposite pattern was not observed. This indicates that these findings could suggest a strong relationship between the GPS and amputees' functional ability but, they should be more explored at the next phase of the research.

Overall GPS was moderately correlated with self-selected velocity (r = -0.50), but this correlation did not show significance. Another study found a better correlation between these two variables (r = -0.70) [6], which could be attributed to a larger sample size of it. The strongest correlation occurred between overall GPS and prosthetic step length, overall GPS and time of single support with the prosthetic limb, prosthetic limb GPS and prosthetic step length, and between prosthetic limb GPS and time of single support with the prosthetic limb (r = -0.70).

The poor statistical significance of this relationship may be due to sample size of this study. The increase of sample size can increase the significance of these correlations.

V. Conclusion

The GPS, MAP and temporal-spatial parameters were useful in quantifying gait deviation on transtibial amputees. GPS scores were increased and temporal-spatial parameters values were lower than that found in able-bodied subjects. The poor correlation observed between GPS and temporal-spatial parameters may be due to small sample.

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