Gait Parameter Differences Between Standard and Ertl Transtibial Amputees

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Introduction:

With the increase in traumatic amputees due to current military conflicts, there is renewed focus in the military on amputee rehabilitation and the return of amputees to full military service.[12] Much has been written recently regarding the outcomes of limb salvage and amputation for civilian traumatic injuries,[1, 6] however, with battlefield injuries, limb salvage is often not feasible.[12] When salvage is not possible, amputation is the first step in the rehabilitation process.[9] There are numerous techniques of transtibial amputation. One of the most controversial is the Ertl procedure. In 1949, Ertl published his technique of amputation osteoplasty where a periosteal flap from the tibia was secured to the fibula to provide an osseus union between the tibia and fibula. He felt this technique would improve rehabilitation after transtibial amputation.[4] Authors have argued that a bone bridge between the tibia and fibula with myoplasty creates a stable residual "organ" that aides prosthetic fitting and decreases fibular instability due to a disruption of the interosseus membrane. This technique has been modified and reported upon by numerous authors.[2,3,7,12]

To date, the literature has been sparse regarding the Ertl or modified Ertl technique. Controversy exists as to whether Ertl amputation facilitates the rehabilitation process in comparison to standard transtibial ampution.[9] Pinzur, et al. reported that Brazilian Ertl amputees have higher patient satisfaction scores when compared to highly functional American standard transtibial amputees.[10] However, in a follow up study, Pinzur found no difference when American Ertl patients where compared to American highly functional transtibial amputees.[8] Many have reported that the residual limb of Ertl amputees is more conical and helps obtain a better prosthetic fit when compared to the more "V" shaped standard transtibial residual limb.[2-4,7,10,12] This has, however, yet to be objectively examined.

It also remains unclear as to whether there are truly any quantifiable functional differences between Ertl and standard transtibial amputees. To the best of our knowledge, there are currently no published studies analyzing potential ambulation differences between Ertl and standard transtibial amputees. The purpose of this study is to determine if any significant differences in gait or motion parameters exist between between Ertl and standard transtibial amputees as well as to compare gait parameters of these groups to a cohort of healthy individuals. We report our pilot data. Our hypothesis was there were no differences between the two amputee groups, but a significant difference would be found when amputees were compared to normal ambulators.

Materials and Methods:

Following IRB approval, 16 active duty military members who had undergone transtibial amputation were identified. Study inclusion criteria included transtibial amputation and availability of an ambulation study between six and nine months from the time the patient initiated ambulation on their prosthesis without an assistive device. Exclusion criteria included lack of available ambulation studies or incomplete records and contralateral limb injury that resulted in arthrodesis of the hip, knee or ankle, contralateral above-knee or below-knee amputation or other injury that would extensively hinder ambulation. Ten patients met inclusion criteria. All subjects were male. Average age was 25.4 (range 22-28). Five of these patients had received Ertl amputations and five had undergone standard transtibial amputation. Patient variables are contained in **Table 1**. There were no differences found between amputee groups. Previously collected gait analysis data from our motion laboratory on a cohort of 20 healthy, normal ambulators was available for comparison purposes.

As part of their standard rehabilitation, amputees undergo motion analysis in the C5 gait lab. The Center for Comprehensive and Complex Casualty Care (C5) at Naval Medical Center San Diego was created to allow those injured in combat to receive state of the art integrated care for their injuries. The C5 clinic is one of three specialized rehabilitation centers in the military. Through this facility, amputees can see their physician, physical therapist and prosthetist in a single visit through integrated clinics, which streamline medical decisions and accelerate rehabilitation. Each individual in the study was analyzed in the C5 motion laboratory using a standard protocol. Thirty infrared electrodes were placed and recorded by 10 infrared cameras as the patient ambulated in the gait lab. From this, joint centers of motion were captured and a computerized model was produced (**Figure 1**). Each patient walked across four AMTI (Watertown, MA) forceplates embedded in a 12-meter walkway at a self-selected and a fast walking pace. The data was captured using Cortex software (Motion Analysis Corporation, Santa Rosa, CA). The data was processed using OrthoTrak software (Motion Analysis Corporation, Santa Rosa, CA).

Variables studied included gait velocity, cadence, stride length, step width, step length for both involved and uninvolved extremities, step symmetry (involved step length minus uninvolved step length), single limb support time for involved and uninvolved extremities, single limb stance symmetry (uninvolved single limb stance time minus involved single limb stance time).

Evaluated gait kinematics included peak vertical force generation for both involved and uninvolved extremities at heel strike (F1) mid stance (F2) and terminal stance (F3).

Statistical Review:

ANOVA statistical analysis was used to compare gait parameters between the Ertl Amputee, Standard Transtibial Amputee and Normal groups. Comparison of amputees to normal ambulators was performed using a Student's T-test. All statistical analysis was performed on SPSS software (Chicago, IL). A post hoc power analysis was performed revealing 51 members would be required in each group to reach a power of 80%.

Results:

No statistically significant differences were identified for any of the gait parameters between standard transtibial amputees and Ertl osteoplasty amputees at either fast or self selected walking speeds except for single limb stance symmetry (difference between single limb stance for uninvolved extremity vs involved) at a fast walking pace ($p<.01$) with amputees spending less time in stance on their affected extremity.

Vertical ground reaction force generation for early, middle and late single-limb stance for both involved and uninvolved extremities did not differ between the two amputation groups.

When compared to normal controls, both standard transtibial and Ertl amputees demonstrated significant differences in step length at a fast walking pace ($p<.002$). All amputees increase their affected step length or "step out" with their prosthesis as they increase their speed. Additionally, all amputees spent less time in the single-limb stance phase of ambulation on their involved extremity when compared to normal controls.

There were no significant differences between standard transtibial amputees and Ertl amputees when vertical ground reaction forces were compared between the two amputee groups. However, at a fast walking pace Ertl amputees demonstrated significantly less initial peak loading force (early loading of prosthesis) when compared to the transtibial amputee group ($p<.05$). The clinical significance of this result is unknown. When comparing all amputees as a single group to normal controls the amputees demonstrated less terminal stance peak force (late loading of prosthesis prior to toe off) when compared to normal subjects ($p<.01$). Results are in **Table 2** and graphically in **Figures 2-5**.

Discussion:

In civilian trauma, the LEAP study has provided significant evidence regarding the outcome of amputation and limb salvage.[1,6] While the LEAP study provides valuable information for civilian trauma, military trauma is often different. The seemingly endless resources of Level 1 trauma centers are not available when the orthopaedic surgeon provides emergent care in a combat setting. Limb salvage may be impossible due to the constraints of far forward military medical care so amputation is often performed as a life saving measure before the patient is evacuated to the next level of military medical care. If amputation is required in the battlefield, Ertl amputations have not routinely been performed due to increased operative time as another injured service member may required life saving surgery. When amputation or revision of the residual limb is performed in a delayed fashion, the Ertl procedure has often been performed by military orthopaedic surgeons, however, there remains significant controversy regarding the benefit of the Ertl transtibial amputation. [12]

Pinzur and Pinto, et al [10] reported on a group of 32 Ertl patients from Brazil. When these patients were given a validated outcome measure (Prosthetics Evaluation Questionnaire) at an average of 16.3 months post surgery, they reported improved functional outcomes when compared to 17 high functioning standard transtibial amputees from the United States who averaged 14.7 years post surgery. In a recent follow up study, Pinzur contradicted those results and reported no difference between Ertl amputees from the United States and the same standard transtibial amputees from his previous study. [8]

This study, although underpowered, is the first study to attempt to use motion analysis to detect gait parameter differences between Ertl and standard transtibial amputees. Our results would indicate that although small statistical differences were found with some gait variables, there is not a clinically significant difference between the two amputee groups. Additionally, when compared to normal controls, military transtibial amputees had similar gait studies to the normal ambulators. Waters reported the energy requirement for traumatic amputees to ambulate was 35-37% of max VO2.[14] Energy required to ambulate was not measured in our study, but the similarities seen between amputees groups and normal ambulators suggests our young study population was able to overcome this aerobic disadvantage. This remains a clear area for further investigation.

The main limitation of this pilot study is that it is underpowered. Additionally, although no evidence exists for different socket kinematics among transtibial amputees, proponents of Ertl amputations would state that an end bearing prosthetic socket would be required to maximize the potential advantages of an Ertl procedure. None of our amputees were fit with an end bearing socket. This may have decreased our ability to detect any differences between our amputee groups.

Conclusions:

The results of this study provide valuable information regarding ambulation similarities and differences between standard below knee amputees and Ertl osteoplasty patients. This information is currently missing from published literature. Interestingly, no significant clinical differences in gait parameters were identified between patients who had undergone a standard transtibial amputation and those who underwent Ertl amputation osteoplasty.

In conclusion, the limited differences found between transtibial and Ertl osteoplasty amputation groups in this study suggest there is no advantage to performing and Ertl procedure. The increased operative time and possible delay in rehabilitation while a solid union is obtained between the tibia and fibula for an Ertl procedure do not appear to benefit the patient. Additionally, below knee amputees in a military population can be expected to possess similar gait mechanics independent of the type of amputation technique utilized. Continued evaluation with increased study patients in each amputee group would be required to definitively prove our conclusions.

Table 1

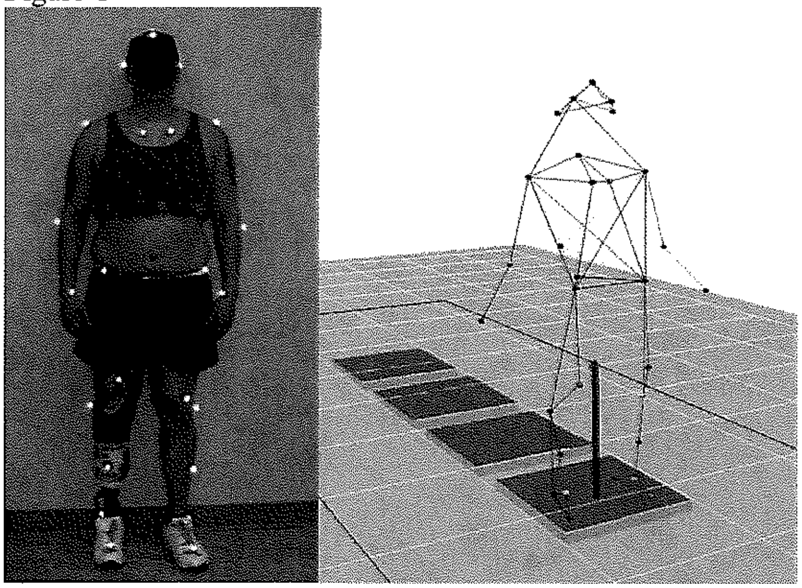
Patient Characteristics

Patient Number	Extremity Amputated	Amputation	AGE	Height (cm)	Weight (kg)	Mechanism	Other Major Injuries
1	L	Standard	27	179	107	IED	TBI, Left Femur Fx, C3-4, L4 fx, Right tib-fib fx,
2	L	Standard	24	174	93.5	RPG	Numerous ST injuries, Left forearm fx
3	L	Standard	24	174.5	74.5	IED	R Fem neck fx, Left tib plateau fx
4	R	Standard	22	179.5	79.6	IED	Retained shrapnel, left hand
5	R	Standard	23	178.5	94.5	IED	Left closed Calcaneus fx
6	R	ERTL	26	168	77.5	IED	TBI, R Femur Fx
7	R	ERTL	26	184.5	75.6	IED	Left tib-fib fx
8	R	ERTL	24	174	67.1	MVA	TBI, Liver Lac, T1 fx
9	R	ERTL	28	180	95	IED	R Femur fx, R tib-fib fx
10	L	ERTL	23	180.5	75	Fall from 3rd story	None

Table 2

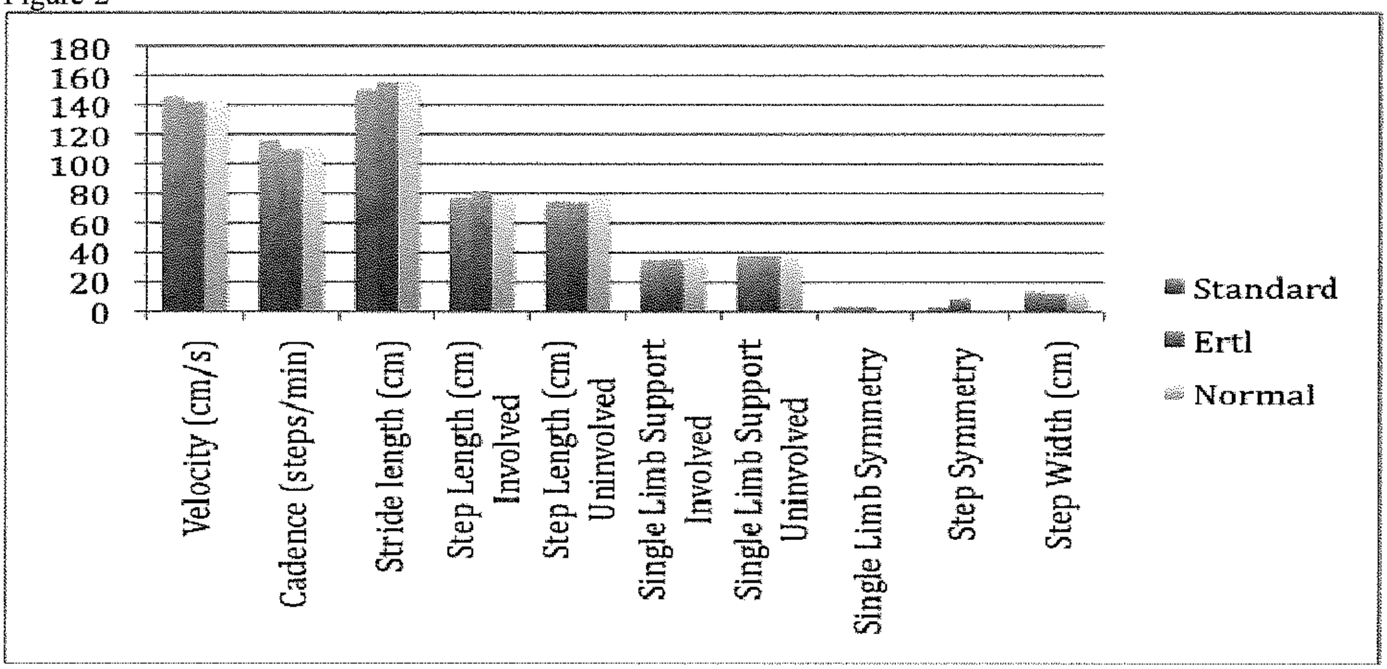
Self Selected Pace	Amputee Averages	STDEV	Normal Averages	STDEV	p value
Velocity (cm/s)	144.00	18.07	144.80	13.65	0.92
Cadence (steps/min)	112.70	9.42	111.53	6.80	0.44
Stride length (cm)	152.90	9.01	155.55	9.45	0.60
Step Width (cm)	12.43	2.16	13.03	2.05	0.40
Step Length (cm) Involved	79.10	7.08	77.54	5.16	0.29
Step Length (cm) Uninvolved	73.80	4.89	77.85	4.58	0.13
Step Symmetry (uninv-inv)	-5.30	7.76	0.00	0.00	**0.002**
Single Limb Support Involved	34.90	1.37	36.27	1.56	**0.01**
Single Limb Support Uninvolved	37.40	1.26	36.64	1.48	0.26
Single Limb Symmetry (uninv-inv)	2.50	1.90	0.00	0.00	**0.0001**
F1 Involved	1.11	0.14	1.15	0.07	0.27
F2 Involved	0.68	0.09	0.64	0.08	0.45
F3 Involved	0.96	0.06	1.12	0.06	**0.001**
F1 Uninvolved	1.22	0.10	1.15	0.08	0.07
F2 Uninvolved	0.64	0.08	0.64	0.08	0.33
F3 Uninvolved	1.08	0.08	1.12	0.07	0.290
Fast Walking Pace					
Velocity (cm/s)	190.40	23.92	207.09	26.42	0.27
Cadence (steps/min)	131.50	11.72	135.45	15.16	0.68
Stride length (cm)	173.50	9.77	183.39	12.16	0.07
Step Width (cm)	13.71	2.74	14.48	2.26	0.21
Step Length (cm) Involved	90.30	8.55	91.70	6.23	0.54
Step Length (cm) Uninvolved	83.30	4.16	91.54	6.28	**0.002**
Step Symmetry (uninv-inv)	-7.00	9.14	0.00	0.00	**0.01**
Single Limb Support Involved	38.50	5.52	38.55	1.81	0.37
Single Limb Support Uninvolved	39.50	1.96	38.85	1.66	0.51
Single Limb Symmetry (uninv-inv)	-0.40	6.00	0.00	0.00	**0.01**
F1 Involved	1.29	0.21	1.37	0.12	**0.04**
F2 Involved	0.55	0.12	0.44	0.15	0.11
F3 Involved	0.91	0.11	1.16	0.14	**0.001**
F1 Uninvolved	1.52	0.17	1.41	0.13	0.06
F2 Uninvolved	0.40	0.09	0.41	0.15	0.81
F3 Uninvolved	1.18	0.13	1.17	0.14	0.51

Figure-1



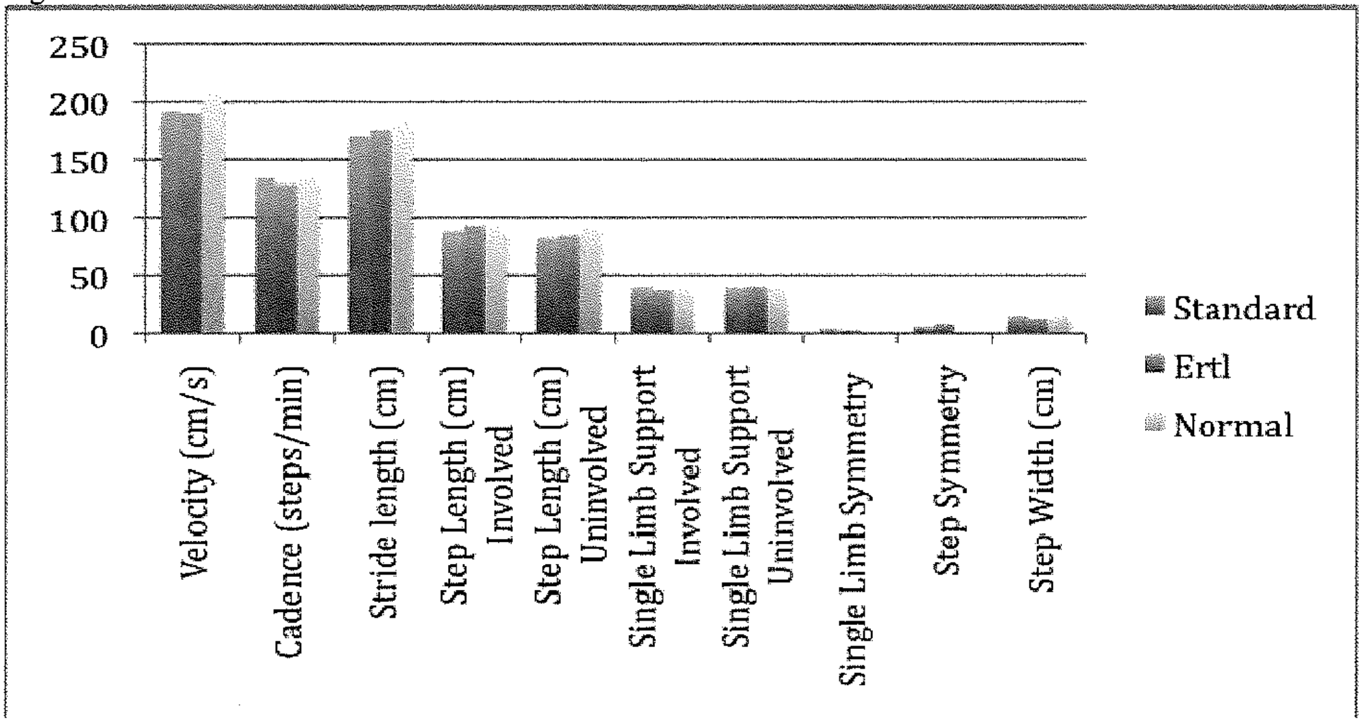
Infrared transducers Computer generated model

Figure-2



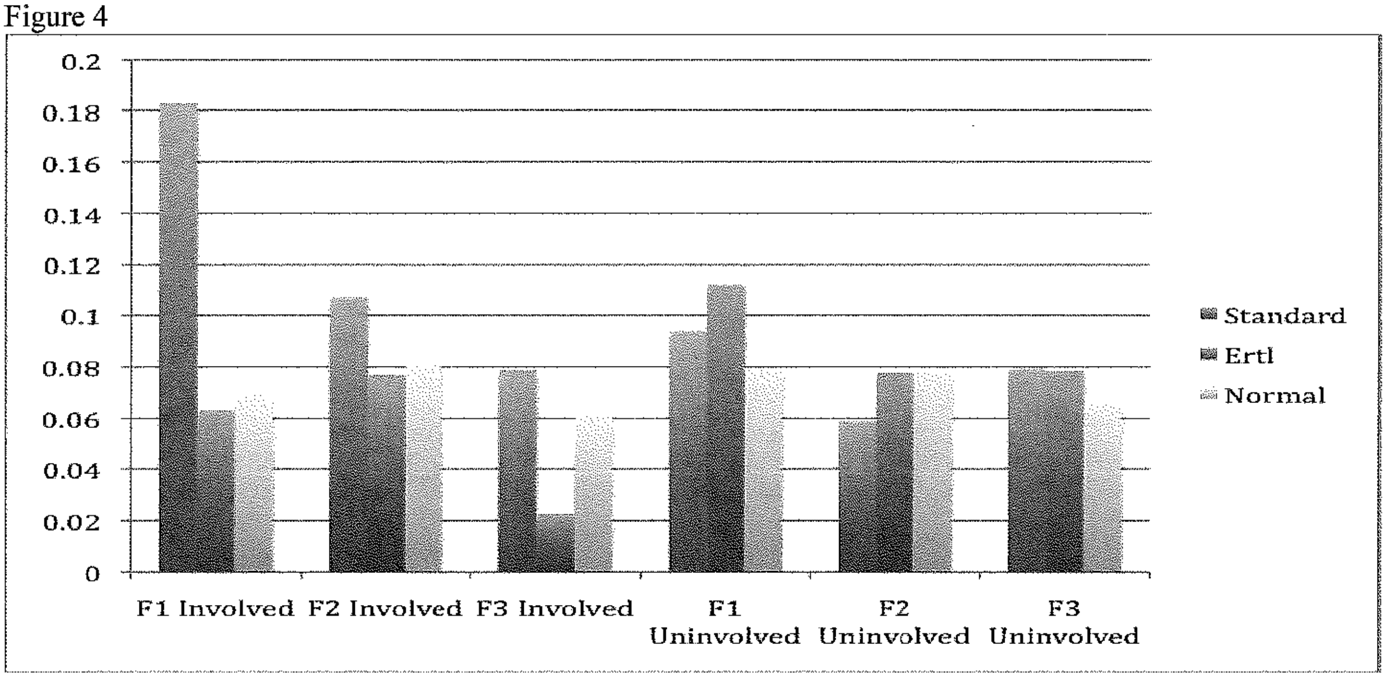
Gait Results at Self Selected Pace

Figure 3



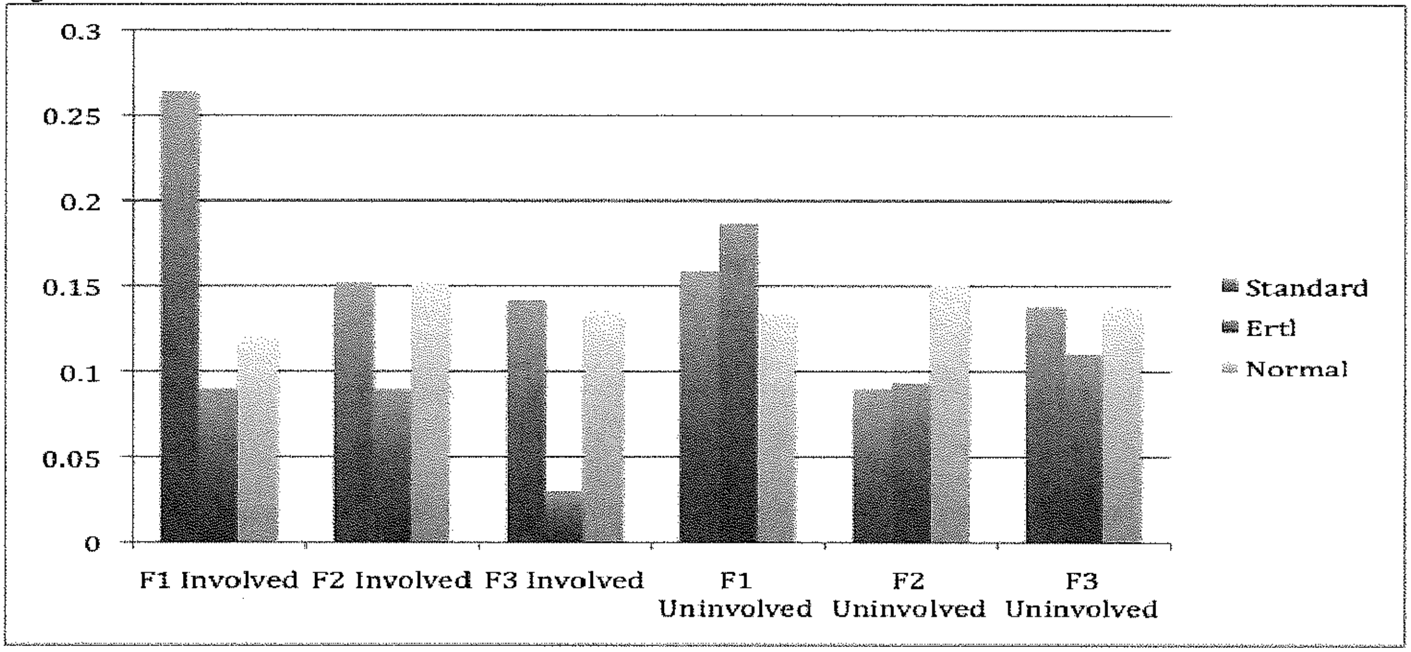
Gait Results at Fast Walking Pace

Figure 4



Ground Reaction Force Self Selected Pace

Figure 5



Ground Reaction Force Fast Walking Pace

References:

1. Bosse MJ, MacKenzie EJ, Kellam JF, et al: An Analysis of Outcomes of Reconstruction or Amputation of Leg-Threatening Injuries. N Engl J Med 2002;347:1924-1931.

2. DeCoster T, Homedan S: Amputation Osteoplasty. Iowa Orthop J 2006; 26:54-9.

3. Deffer PA, Moll J, LaNoue AM: The Ertl osteoplastic below-knee amputation. Proceedings of the American Academy of Orthopaedic Surgery. J Bone Joint Surg Am 1971; 53:1028.

4. Ertl J: Operationstechik. Dieser Abschnitt soll der Veröffentlichung der von einzelnen Chirugen geübten operativen Technik dienen.Uber Amputations-stümfe. Chirug 1949;218-224.

5. Huang, C; Jackson, J, et al. Amputation: Energy Cost of Ambulation. Arch Phys Med Rehabil 1979; 60: 18-24.

6. MacKenzie EJ, Bosse MJ, Castillo RC, et al. Functional Outcomes Following Trauma-Related Lower-Extremity Amputation. *J Bone Joint Surg* 2004;86:1636-45.

7. Pinto, M; Harris, W. Fibular Segment Bone Bridging in Transtibial Amputation. Pros Orth Int 2004; 28(3): 220-4.

8. Pinzur M, Beck J, Himes R, et al: Distal tibiofibular bone-bridging in transtibial Amputation. J Bone Joint Surg Am 2008; 90:2682-7.

9. Pinzur, M, Gottschalk, F, Pinto, M, Smith, D. Controversies in Lower-Extremity Amputation. J. Bone Joint Surg. Am., 2007; 89: 1118-27.

10. Pinzur M, Pinto M, Saltzman M: Health-related quality of life in patients with transtibial amputation reconstruction with bone bridging of the distal tibia and Fibula. Foot Ankle Int 2006; 27:907-12.

11. Skinner, H, Efeney, D. Gait Analysis of Amputees. AM J Phys Med 1985;64(2):82-9.

12. Stewart, J, Anderson, C, Unger, D. The Portsmouth Modification of the Ertl Bone-Bridge Transtibial Amputation: The Challenge of Returning Amputees Back to Active Duty Oper Tech Sports Med 13:222-6.

13. Ward, K; Meyers, M. Exercise Performance of Lower Extremity Amputees. Sport Med 1995; 20(4): 207-14.

14. Waters, R; Perry,J, et al. Energy Cost of Walking of Amputees: the influence of level of amputation. J. Bone Joint Surg. Am. 1976; 58-A: 42-6.