Original Article

Oxygen consumption testing and self-reported outcomes following limb salvage with tibiocalcaneal or tibio-talo-calcaneal fusion

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Abstract

Context: Little is known about the energy expenditure following limb salvage with tibiocalcaneal (TC) or tibio-talo-calcaneal (TTC) fusions and optimization of leg lengths. Studies have quantified the energy expenditures of amputees and tibiotalar fusion patients by measuring oxygen (O_2) consumption, but a similar study has yet to be performed on TC or TTC fusion patients. Since limb salvage with TC or TTC fusion is often considered an alternative treatment to a below the knee amputation (BKA), it will be useful to understand the relative energy expenditures of the two treatment groups.

Aims: To assess the energy expenditure and self-reported outcomes of patients who have undergone limb salvage with TC or TTC fusions, and to compare the O_2 consumption of TC and TTC fusion patients to those reported in the literature for patients who underwent BKAs.

Subjects and Methods: We gathered data on 12 TC and TTC fusion patients' O_2 consumptions at rest, their self-selected usual daily walking speed (UDWS), 80% of UDWS, 120% of UDWS, and a fixed speed of 2 miles/h (mph). Short form-36 (SF-36) and visual analog scores were also obtained.

Statistical Analysis: We calculated the averages and standard deviations of the O_2 consumption levels for our cohort of TC and TTC fusion patients.

Results: The TTC and TC patients overall averaged 10.4 mL O_2/min/kg at an average UDWS of 1.9 mph. This O_2 consumption rate was 22% higher than normal. The outcome SF-36 scores were 57 and 45 for the mental and physical components, respectively. The visual analog scale was 1.1.

Conclusion: Patients after TC and TTC fusions have minimal pain. SF-36 mental component scores were better than those of normal population, and physical component scores were minimally lower than the normal population. While O_2 consumptions was 22% above normal population, it was less than what has been reported in the literature for BKA patients.

Key Words: Ankle fusion, below knee amputation, metabolic efficiency, oxygen consumption, tibiocalcaneal fusion, tibiotalar fusion, tibio-talo-calcaneal fusion

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Introduction

Tibiocalcaneal (TC) or tibio-talo-calcaneal (TTC) fusions are often used as limb salvage measures. TC and TTC fusions are effective procedures to treat end-stage arthritis, ankle infection, failed total ankle replacements, providing the patient with a stable and plantigrade foot [Figure 1].[1] Typically, fusion procedures are accompanied by future surgical interventions to address the resulting limb length discrepancy (LLD) or use of a shoe lift to optimize limb length. TC and TTC fusions can be achieved using multiple fixation techniques such as circular external fixation, plates, screws, and intramedullary nails. TC and TTC fusions can also be used to correct severe ankle and hindfoot malalignments.[2] The wide range of approaches and the ability to correct large deformities, treat infection, and reconstruct damaged ankle and hindfoot joints while relieving pain makes fusion procedures an extremely versatile option for limb salvage patients. However, fusion patients are still at large risk for infection and nonunion, and studies such as Kugan *et al.*[1] have reported rates as high as 40% for subsequent surgeries to address nonunion and infection, as well as 22% of

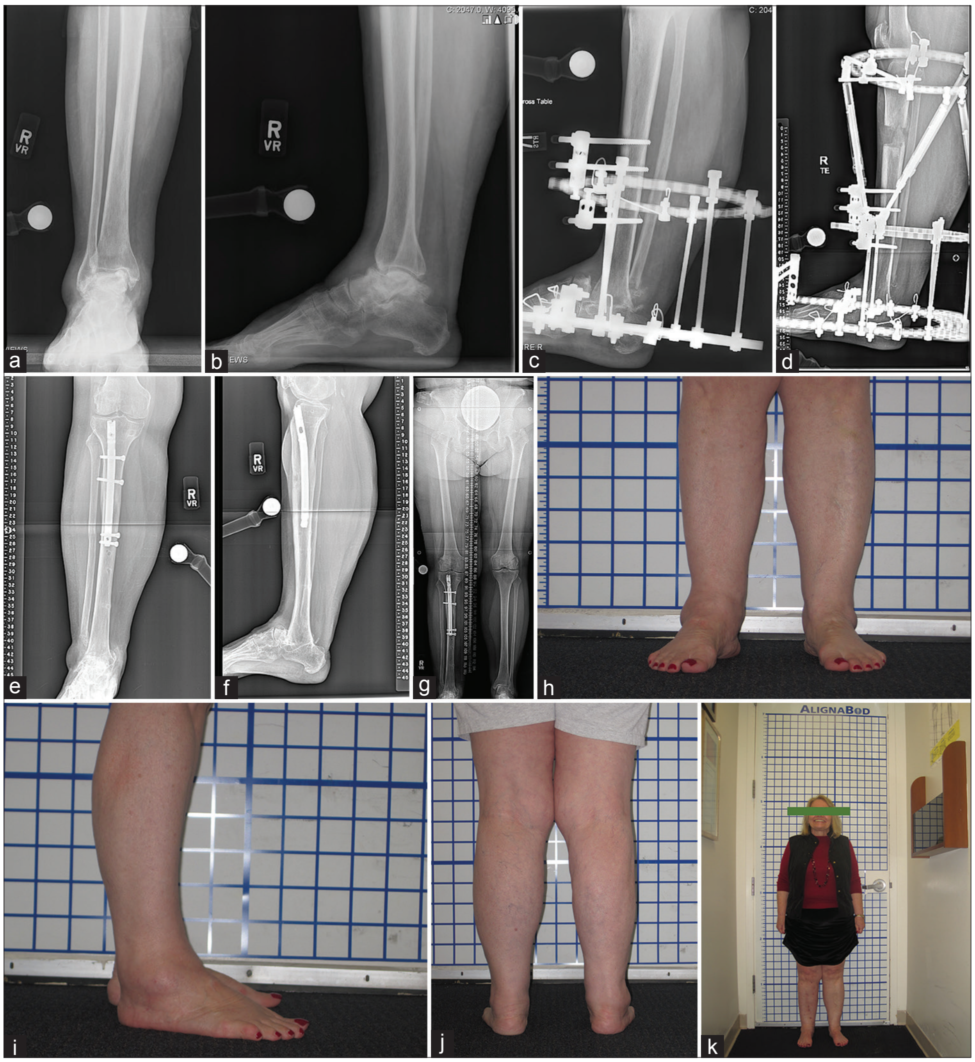

Figure 1: A 65-year-old female with extensive osteonecrosis of the talus. (a) AP X-ray of the right ankle. (b) Lateral X-ray of the right ankle. (c) Lateral X-ray showing a tibiocalcaneal fusion using circular external fixation after excision of the talus, 1 month after surgery. (d) Lateral X-ray following staged tibial lengthening and displaying the final distraction gap. The proximal ring was placed using LATN technique. (e) Anterior-posterior X-ray showing healed tibiocalcaneal fusion and lengthening site, with an intramedullary nail present as part of the LATN technique, 11 months after surgery. (f) Lateral X-ray. (g) Standing bipedal X-ray showing optimized leg lengths 11 months after tibiocalcaneal fusion and LATN. (h) Front view of the patient's ankles and legs, 2 years after tibiocalcaneal fusion and optimization of leg lengths. (i) Side view of the patient's ankles and legs, (j) Clinical photograph Rear view of the patient's ankles and legs. (k) Overall view of the patient's legs

fusion patients undergoing amputations. Even with a successful fusion, Kugan *et al.*[1] reported that 18% of patients had persistent pain. This along with gait abnormalities after TC or TTC fusion and limb salvage has led many clinicians to favor below the knee amputation (BKA).

Metabolic data for BKAs have been studied to analyze the energy consumption of BKA patients. Colborne *et al.*,[3] Herbert *et al.*,[4] and Waters *et al.*[5] studied how differences in the level of amputation, type of prosthetic, and residual limb length were shown to impact the energy consumption and overall metabolic activity of patients. There have also been studies quantifying the oxygen (O_2) consumption of tibiotalar (TT) fusion patients; however, there are no data available on how efficiently TC and TTC fusion patients consume energy. Because of this, we cannot effectively compare the metabolic outcomes of our patients who undergo a limb salvage procedure to those who undergo a BKA.

In this study, we measure the relative energy expenditures of patients who have undergone limb salvage with TC or TTC fusions. By comparing our data on the O_2 consumption of TC and TTC fusion patients to the O_2 consumption levels of posttraumatic BKA patients sourced from published literature, we hope to add a new metric to the discussion of limb salvage versus amputation. The data of this study will aid patients and surgeons in their decision-making processes between electing for limb salvage TC or TTC fusions or opting to undergo a BKA.

Subjects and Methods

Subjects

Twelve patients who were at least 1 year following limb salvage with TC or TTC fusions and optimization of leg lengths were included in the study. The average age was 55.4 years (range: 33–66), and there were 9 women and 3 men [Table 1]. Patients were treated with TC or TTC fusion for limb salvage using circular external fixation. LLD was addressed with either a shoe lift or tibia lengthening[6] [Table 1]. Shoe lifts were used based on patient comfort and ranged from complete correction of the deformity to 1 cm of shortening. LLD after tibia lengthening also ranged from 0 to 1 cm of shortening and was also based on patient comfort. There was no correlation between LLD and O_2 consumption data. The demographics including age, sex, etiology, and comorbidities are outlined [Table 1].

Methods

O_2 consumption testing was conducted using a metabolic measurement system (ParvoMedics TrueOne® 2400, Parvo, UT). Patients then selected their usual daily walking speed (UDWS) measured in miles per hour (mph). Four walking trials of 3–8 min durations were conducted. During each walking trial, patients walked until they attained a steady state heart rate (±5 heart beats/min) and O_2 consumption (±150 ml/min) for 3 consecutive min. Trials were conducted in a randomized order with gradual adjustment of speed between trials to serve as adjustment time. The four trial speeds were 80%, 100%, and 120% of their UDWS, and 2 mph. Steady state O_2 consumption (ml/min/kg) in each condition was compared to predicted values based on the American College for Sports Medicine metabolic equation for walking. Deviations from predicted values were reported for each condition. Patient self-reported short form-36 (SF-36) outcome scores were also collected and compared to normal population. Visual analog scores (VASs) were obtained after traversing stairs and scaled at 1–10. The VAS is a self-reported response scale used in questionnaires to measures patients' perception of their pain. It asks patients to draw a line between two points based on their current levels of pain and is used to measure subjective or intangible differences among patients' pain levels.

Literature comparison

Studies in the literature were gathered from numerous peer-reviewed journal articles. We selected nine articles

Table 1: TC/TTC fusion patient demographics

Patient#	Age	Sex	Fusion Type	Etiology	Method of Optimization of Limb Lengths	Co-Morbidities
1	61	M	TTC	PT	Tibia Lengthening	None
2	54	M	TTC	PT	Shoe Lift	None
3	66	F	TC	PT	Tibia Lengthening	None
4	52	F	TTC	PT	Shoe Lift	None
5	42	F	TC	Congenital, failed TAR	Tibia Lengthening	None
6	55	F	TC	PT	Tibia Lengthening	None
7	52	F	TTC	PT	Shoe Lift	None
8	60	F	TTC	Distal Tibia Osteosarcoma	Tibia Lengthening	None
9	65	F	TC	Talus Osteonecrosis	Tibia Lengthening	None
10	61	F	TTC	CMT	Shoe Lift	None
11	64	M	TTC	PT	Shoe Lift	Neuropathy
12	33	F	TTC	PT	Tibia Lengthening	None

Co-morbidities: Diabetes, Inflammatory Arthritis, Neuropathy, Smoking PT: Post-traumatic TAR: Total ankle replacement TC: Tibio-calcaneal fusion TTC: Tibio-talo-calacneal fusion CMT: Charcot Marie Tooth Disease containing data on the O_2 consumption of amputees and compared each of those articles' data to our own data gathered on fusion patients' O_2 consumption. We also gathered data on O_2 consumption after simple TT ankle fusions, and we relied predominantly on Vanderpool *et al.*[7] and Waters *et al.*[8] because these studies provided the best comparison. For the BKA group, we focused on Waters *et al.*,[5] Molen,[9] Torburn *et al.*,[10] and Nielsen *et al.*,[11] due to their similar age ranges to our cohort of fusion patients. We selected these articles from online search databases using the search terms "amputations + O_2 consumption," as well as "ankle fusion + O_2 consumption."

Results

At the UDWS of 1.9 ± 0.4 mph, the O_2 consumption was 10.6 ± 1.9 ml/kg/min and this was 23.8% ±12.9% higher than normal. At 80% of UDWS of 1.5 ± 0.3 mph, the O_2 consumption was 9.3 ± 1.6 ml/kg/min and this was 24% ±13.5% higher than normal. At 120% of UDWS of 2.3 ± 0.5 mph, the O_2 consumption was 11.2 (±1.7) ml/kg/min and this was 22.5 (±13.6) % higher than normal. At a standardized 2 mph speed, O_2 consumption was 10.6 (±1.3) ml/kg/min, and this was 19.9 (±13.9) % higher than normal [Figures 2, 3 and Table 2]. The fusion patients' SF-36 mental component score was 57 (±4), their physical component score was 45 (±13), and their VAS was 1.1 (±1.6). There was no correlation between LLD and O_2 consumption data.

Discussion

Our patients who underwent TC or TTC fusions had minimal pain as illustrated by their low VAS of 1.1 (±1.6). Their self-reported mental component SF-36 score of 57 (±4) was above the normal average of 53 (±10). In addition, their physical component scores of 45 (±12) were only slightly below the normal average of 51 (±10).

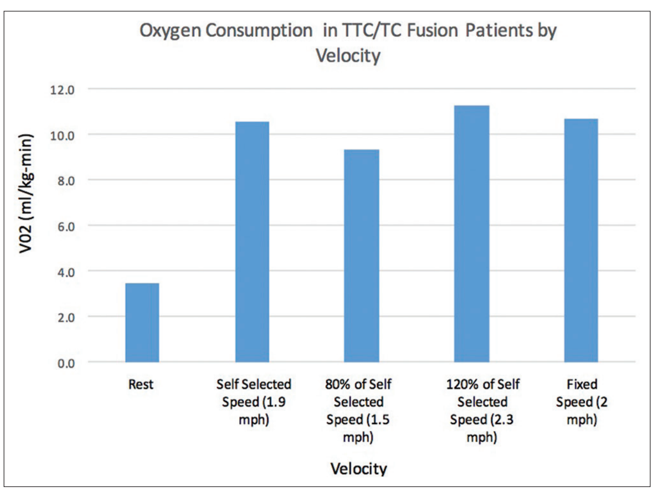

Figure 2: Average volume of oxygen consumed in fusion patients by velocity. This graph summarizes the results of our oxygen consumption trials on tibiocalcaneal and tibio-talo-calcaneal fusion patients. The average oxygen consumption across the 12 patients is displayed for each velocity

After our analysis of the O_2 consumption of complex ankle fusion patients, we compared their O_2 levels to the O_2 consumption levels of BKA [Table 3] and TT fusion [Table 4] patients in the literature. We selected six papers on BKA patients to serve as references and discussed select data from these papers to create an effective comparison to our TTC or TC fusion patients. As mentioned above, some of the data from these papers were excluded due to differences in patient age and methods. Colborne *et al.*[3] served as an effective starting point for our comparison to BKAs and their overall fitness, as it analyzed the velocity and stride lengths of amputees. However, this study was not an effective comparison due to its focus on pediatric congenital amputees as opposed to older, traumatic amputees. Herbert *et al.*[4] also served as a background source, as it analyzed O_2 consumption levels in amputees, however, like Colborne *et al.*,[3] it focused on pediatric congenital amputees.

Our most relevant comparisons were from papers that focused on O_2 consumption in traumatic BKAs [Table 3].

Table 2: Summary of the O_2 consumption results at each speed during the trial of our TC and TTC fusion patients presented with the percent above normal O_2 consumption, and the standard deviation

Speed miles/hour	Oxygen consumption ml/kg/min	Percentage above normal
UDWS 1.9±0.4	10.5±1.7	22.9±12.4
80% UDWS 1.5±0.3	9.3±1.5	24±13.5
120% UDWS 2.3±0.5	11.2±1.6	21.9±13.2
Standard speed 2	10.7±1.1	19.8±12.7
Average	10.4 ml/kg/min	22% above normal

TC: Tibio-calcaneal, TTC: Tibio-talo-calcaneal, O_2: Oxygen, UDWS: Usual daily walking speed

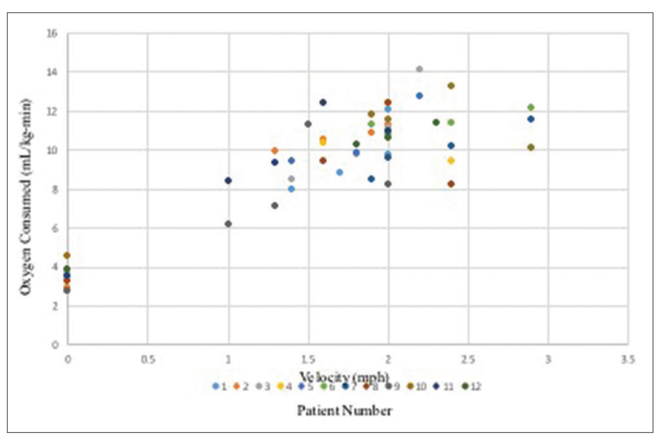

Figure 3: Volume of oxygen consumed by velocity by patient. This graph presents an additional summary of our oxygen consumption data, by showing each patient's oxygen consumption level at different speeds

Table 3: Summary of TC/TTC fusion and BKA O_2 consumption

Study	Age	Etiology	Walking speed (mph)	O_2 consumption (mL/kg*min)	Percent above normal
current	55 (33-66)	traumatic	1.9	10.4	22
Waters[5] ('76)	29	Traumatic	2.6	15.5	
Nielson[10] ('88)	26	Traumatic	2.5	~ 15	
Torburn[9] ('95)	50	Traumatic	3.07	17.72	
Herbert[4] ('94)	13 (6-18)	Congenital	2.6	Not reported	15

Table 4: Summary of TC/TTC fusion and TT fusion O_2 consumption

Study	Age	etiology	Walking speed (mph)	O_2 consumption (mL/kg*min)	Percent above normal
current	55 (33-66)	Traumatic	1.9	10.4	22
Waters[7] ('88)	37 (23-70)	Arthritic	2.5	12.0	
Vanderpool,[6] Simulated ('08)	(22-40)	n/a	2.79	16.0	

Each of the following papers used similar methods to collect their O_2 consumption data. Waters *et al.*[5] analyzed the O_2 consumption of BKAs at two speeds: The patients unrestrained walking speed and their maximum possible speed. The study's cohort included 14 traumatic BKAs with an average age of 29, which is much younger than our cohort but more comparable than the above pediatric studies. Waters *et al.* reported that at an average speed of 2.65 mph, the traumatic amputees averaged 22.4 ml/kg/min (±4.3) of O_2 consumed. Nielsen *et al.*[11] analyzed the O_2 consumption of BKAs at many speeds: At the patient's self-selected velocity, as well as at 1, 1.5, 2, 2.5, 3, 3.5, and 4 mph. The 14 patients averaged 26.7 years of age. Nielsen *et al.*'s results highlight that BKAs using two different prostheses have elevated O_2 consumption levels at each velocity compared to the nonamputee cohort. Molen[9] conducted a much larger study, observing the O_2 consumption among 35 traumatic BKAs, averaging 36 years of age. Molen and his team focused on developing a regression model for O_2 consumption and reported that their amputee patients were able to exceed expectations and consumed comparable O_2 levels to normal patients. Finally, Torburn *et al.*[10] analyzed the energy expenditures of 9 traumatic BKAs whose average age was 50 years of age at their self-selected walking speeds. Torburn *et al.*'s study was designed to compare the efficiency of different prosthesis types, and her data can be used as a large-scale control for O_2 consumption in traumatic BKAs. The results in the Torburn *et al.* study were an average O_2 consumption levels of 17.72 ml of O_2 per/kg/min at an average velocity of 82.3 m/min or 3.07 mph [Table 3].

Overall, these six papers provide a summary of the relevant studies on below the knee amputees ability to walk, and how efficiently they consume O_2 and expend energy. Most importantly, Nielsen *et al.* and Torburn *et al.* display the O_2 consumption of traumatic amputees across many different speeds, as well as their self-selected walking speed. In addition, Molen provides information on how to model expected O_2 consumption data based on the BKAs personal information.

Overall, the O_2 consumption was lower in the current study compared to the studies on BKA patients although the walking speed was also lower in the current study.

For our analysis of TT fusion patients' O_2 consumption, we selected six papers as references and focused mainly on two of them. We selected four papers that discussed how TT fusions affect different aspects of the patient's general lower limb health. Coester *et al.*[12] analyzed how TT fusions affect the onset of arthritis in the talonavicular and calcaneocuboid joints, as well as in the knee. Kaufman *et al.*[13] briefly discussed how a simulated ankle fusion in a knee ankle foot orthotic (KAFO) affected O_2 consumption. However, this study was geared more toward analyzing the stability of the knee in a KAFO as opposed to quantifying an increase in O2 consumption. Finally, Piriou *et al.*[14] and Valderrabano *et al.*[15] set out to compare ankle replacements to TT fusions. Piriou *et al.*[14] compared the gaits of patients undergoing both procedures, while Valderrabano *et al.*[15] compared the patients' range of motion in the foot following both procedures.

We focused mainly on Waters *et al.*[8] and Vanderpool *et al.*'s[7] work, as their studies honed in on the O_2 consumption levels of TT fusion patients [Table 4]. Waters *et al.*[8] study focused on the effects of different fusion procedures on patients' O2 consumption and included a group of ten posttraumatic TT fusion patients, with an average age of 37 years old. These patients consumed 12.0 mL/min/kg of O_2 while walking at an average speed of 2.5 mph. Vanderpool *et al.*[7] took a different approach, comparing the effect of a simulated TT fusion on O_2 consumption. He analyzed six patients ranging from 22 to 40 years old, and their O_2 consumption levels while wearing an ankle brace compared to those of patients walking unrestricted. Vanderpool *et al*. found that the simulated fusion patients walked at 2.79 mph and consumed 16.0 mL/min/kg of O_2. These two studies serve as an effective comparison to our own cohort, allowing us to compare the O_2 consumption levels of patients under different fusion procedures or conditions [Table 4]. Surprisingly, the O_2 consumption was higher in the TT fusions than in the current study.

Limitations

Despite our ability to quantify and analyze the O_2 consumption of TC and TTC fusion patients, we faced numerous limitations over the course of our research. We had difficulty gathering a large cohort, and thus our sample size was limited to twelve patients. In addition, we did not have our own control group of BKA and TT fusion patients to analyze, which forced us to rely on literature review for data on these patients' O_2 consumption levels. Because of this, we paid close attention to selecting studies that most closely matched our patient group, to account for differences in age and cause of amputation patients relative to our fusion patients. This also prevented us from performing an exact comparison of O_2 consumption levels across different velocities, as we were forced to rely on whichever speeds were reported in those studies. In addition, the lack of recent papers discussing O_2 consumption in amputees forced us to use studies over 20 years old, which fail to account for the advances in surgical technique, postoperative care, and prosthetics.

We did not have VAS or SF-36 data before surgery, and we were not able to do a statistical comparison of our postoperative SF-36 scores to those of the normal population.

Conclusion

Following limb salvage TC or TTC fusion and limb length optimization surgery, the patients' overall energy expenditure as measured by O_2 consumption was 10 ml/kg/min which was 22% above normal. Our patients had minimal pain, and their mental component SF-36 scores were above the normal average, and their physical component scores were only slightly below the normal average. Our patients' O_2 consumption levels compare favorably to levels reported in patients following BKAs. Because of this, we are inclined to believe that undergoing a limb salvage procedure, such as a TTC or TC fusion, has a favorable effect on metabolic efficiency compared to those who undergo a BKA.

Our clinical experience treating patients with TC and TTC fusion limb salvage along with optimization of leg lengths has been very positive, and our patients have been happy to have been able to save their limb. This study supports that this limb salvage undertaking was not at the cost of poor function, excessive energy expenditure, or pain. In the future, the addition of a control group of BKA patients and the use of a more extensive lower extremity outcome score would allow us to make more conclusive statements on patient satisfaction and function.

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Conflicts of interest

There are no conflicts of interest.

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