Department of Veterans Affairs

Journal of Rehabilitation Research
and Development Vol. 30 No. 4, 1993
Pages 388–392

Gait analysis in peripheral vascular insufficiency through-knee amputation

Michael S. Pinzur, MD
Loyola University Medical School, Maywood, IL 60153; Edward Hines Jr. VA Hospital, Hines, IL 60141

Abstract—Due to recent improvements in prosthetic limb componentry, through-the-knee (knee disarticulation) amputation has gained new interest for rehabilitation-minded amputation surgeons. Recent objective scientific studies from our gait analysis laboratory have described the walking characteristics of peripheral vascular insufficiency through-knee amputees, and have compared their function with similar patients amputated above (trans-femoral), or below (trans-tibial), the knee joint. This paper provides a summary of that available information.

Key words: *amputation (surgery), gait analysis, gait characteristics, knee disarticulation, through-knee amputation.*

INTRODUCTION

Through-knee amputation allows direct load transfer for walking, as well as the intrinsic stability of the four-bar linkage polycentric prosthetic knee system. We have objectively studied walking dynamics in patients with through-knee amputation in our gait analysis laboratory. These studies have yielded the following observations: 1) the metabolic cost of walking for peripheral vascular insufficiency through-knee amputees appears to be midway between trans-femoral and trans-tibial amputees; 2) limited capacity elderly trans-tibial amputees do not adequately use their remaining thigh musculature in walking and therefore do not retain the walking propulsion associated with trans-tibial amputee gait; 3) peripheral vascular insufficiency through-knee amputees are more stable in walking than similar trans-tibial amputees; and, 4) there appears to be no difference in walking propulsion between limited walking trans-tibial and similar through-knee amputees.

Refinement in the polycentric four-bar linkage prosthetic knee joint has revived interest in the knee disarticulation/through-knee amputation. When compared to trans-femoral (above-the-knee) amputation, knee disarticulation (through-knee amputation) has the potential benefits of: 1) durable end-weight bearing (direct load transfer); 2) retention of a long, powerful muscle-stabilized femoral lever arm for walking with a prosthesis; 3) ease of prosthetic socket suspension due to the bulbous end; 4) decreased surgical blood loss; and, 5) resistance to infection by maintaining the cartilage barrier to infection (1,2). The polycentric, four-bar linkage prosthetic knee joint has a moving instantaneous center of rotation which lies far proximal and posterior to the anatomic knee center, maintaining it posterior to the weight-bearing axis of the lower limb. This provides an extension moment at the knee (**Figure 1**), decreasing the potential for knee

Address all correspondence and requests for reprints to: Michael S. Pinzur, MD, Department of Orthopaedic Surgery, Loyola University Medical Center, 2160 South First Avenue, Maywood, IL 60153.

Dr. Pinzur is Professor of Orthopaedic Surgery, Loyola University Medical School, Maywood, IL 60153 and Director of the STAMP (Special Teams for Amputations, Mobility, Prosthetics/Orthotics) Program, at Edward Hines Jr. VA Hospital, Hines, IL 60141.

This paper was an Invited Paper presented at the Seventh World Congress of the International Society of Prosthetics and Orthotics, Chicago, IL, July 2, 1992.

This work was supported in part by local funds derived from the Rehabilitation Engineering Laboratory, Edward Hines Jr. VA Hospital, Hines, IL 60141.

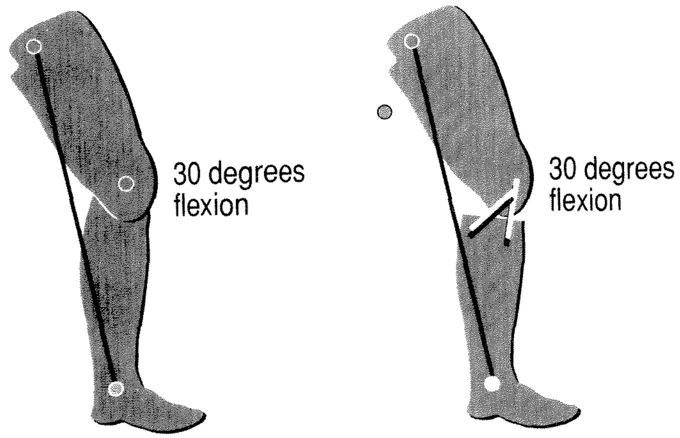

Figure 1.
When the ground reaction force (weight-bearing line) of a patient falls posterior to the knee center, the prosthetic knee will "buckle," and the subject might fall. The effective knee center of the four-bar linkage prosthetic knee is sufficiently posterior to the anatomic knee center, so as to produce an extension moment at the knee, producing intrinsic knee joint stability on weight bearing.

buckling, and decreasing the risk of the patient falling (3). Weight-bearing is accomplished by direct load transfer (i.e., end-bearing, making intimate prosthetic fit less essential than the total contact prosthetic sockets used with trans-osseous amputations), where the terminal residual limb can tolerate little, if any, weight-bearing pressure (4).

This review paper presents a compilation of data derived from previously published studies performed in the Gait Analysis Laboratory/ Rehabilitation Engineering Laboratory at the Department of Veterans Affairs hospital in Hines. This compilation of previously published data is presented to provide a somewhat "scientific" understanding of the gait adaptations utilized by the peripheral vascular insufficiency through-knee amputee. The vast majority of the patients were elderly and projected to be only limited household ambulators. Any patient with projected potential to do any walking outside of the house had trans-tibial amputation performed (4,5,6). It has also been our experience that functional rating scales in peripheral vascular insufficiency amputees are so subjective, as to not be helpful. We, therefore, have used a simple functional ambulatory rating scale, initially described by Hoffer, evaluating the ambulatory capacity of patients with myelomeningocele (7).

METHOD

Metabolic Cost of Walking

Walking velocity is directly related to amputation level in both traumatic, as well as peripheral vascular disease trans-tibial amputees. This was first reported in a classic study by Waters, et al., when they measured self-selected walking velocity and oxygen consumption in traumatic and peripheral vascular insufficiency trans-femoral, trans-tibial, and ankle disarticulation amputees (8).

We performed a similar study on five peripheral vascular insufficiency subjects at each of the unilateral trans-femoral, through-knee, trans-tibial, ankle disarticulation, and midfoot amputation levels. We also found that subjects with amputations above the knee joint walk at relatively slower speeds than those amputated below the knee joint. This decrease in both self-selected walking velocity, as well as maximum walking speed, was directly related to the number of retained functioning anatomic joints. By walking at slower speeds, and requiring more oxygen consumption per step, the metabolic cost of walking is proportionally greater with shorter residual extremities. In addition, as the residual extremity has less functional anatomic joints, the subjects lessen their potential to increase their walking speed.

As would be expected when an individual loses the propulsive drive of the knee joint, the metabolic cost of walking for knee disarticulation is greater than with trans-tibial amputation, but less than trans-femoral amputation as shown in **Figure 2** (9).

Walking Electromyography (EMG)

Normally, trans-tibial amputees increase the electrical activity of their remaining hamstring and quadriceps muscles to compensate for their absent muscle groups (10). We performed walking electromyography (EMG) on 12 similarly aged peripheral vascular insufficiency trans-tibial amputees who were either independent community walkers, or limited to household walking. All of the subjects had optimal residual limbs with adequate bone length and soft-tissue envelope (4). We found that the seven independent community ambulators were able to maintain the duration of quadriceps electrical activity, while increasing the period of hamstring muscle activity. The five household ambulators showed a marked decrease in relative muscle electri-

Journal of Rehabilitation Research and Development Vol. 30 No. 4 1993

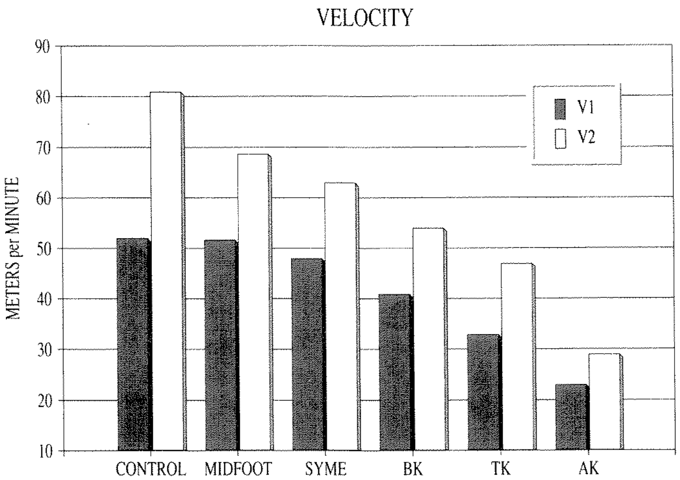

Figure 2a.
Walking velocity related to amputation level in a series of age- and sex-matched peripheral vascular disease amputees.

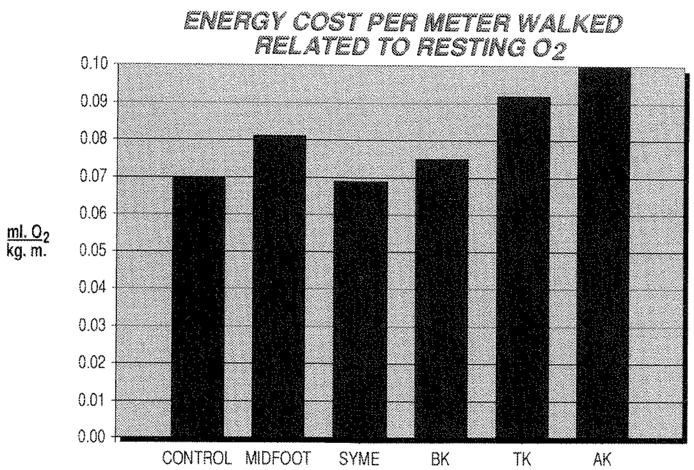

Figure 2b.
The net energy cost of walking in the same population using oxygen consumption as a measure of metabolic cost of walking.

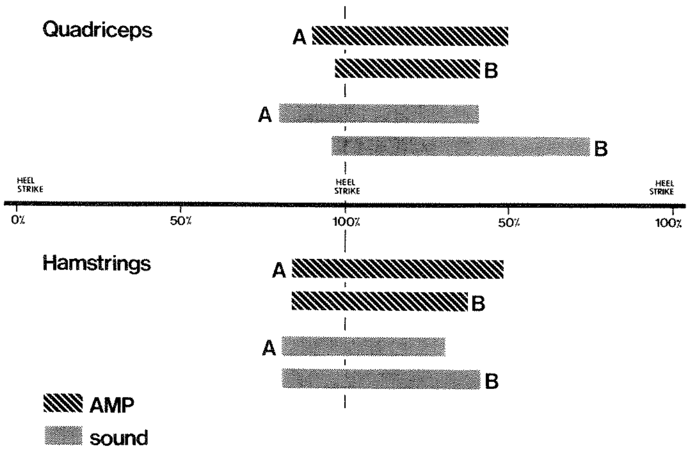

Figure 3.
Phasic myoelectric activity (Walking EMG) of the quadriceps and hamstring muscles in the amputated and sound limbs of independent community walking (*A*), and limited household walking (*B*) trans-tibial amputees. Note that the duration of EMG activity is less and the delay in quadriceps recruitment is greater in the poor (*B*) walkers as compared to the good (*A*) walkers.

cal activity in both muscle groups as compared with their contralateral remaining limbs (**Figure 3**).

These data suggest that sedentary trans-tibial amputees do not adequately use the propulsive capacity of their thigh musculature and may not reap the benefit of retention of their quadriceps-tibial lever arm (11).

Walking Propulsion

We have observed that limited capacity trans-tibial amputees do not appear to functionally outperform similar through-knee amputees. It is also well accepted that bilateral lower extremity peripheral vascular disease amputees are unlikely to become independent community walkers (5,7). In order to provide walking stability, we performed through-knee amputation in a small series of peripheral vascular insufficiency trans-tibial amputees with gangrene of the contralateral remaining limb necessitating at least trans-tibial amputation. The goal of surgery was to provide the walking stability afforded by through-knee amputation and prosthetic limb fitting with four-bar linkage prosthetic knee joint, combined with the propulsive capacity afforded by the retained quadriceps-tibial lever arm of trans-tibial amputation.

We performed gait analysis with two AMTI (Advanced Medical Technologies, Inc. Newton, MA) Biomechanics Force Platforms and a WATSMART Motion Monitoring System (Northern Digital, Waterloo, Ontario, Canada). The subjects all appeared to "lock" the four-bar linkage prosthetic knee into extension during midstance and double limb support phases of gait and to use their trans-tibial residual limb for walking propulsion. Weight-bearing occurred during 63 percent of the gait cycle on the trans-tibial limb, 54 percent on the through-knee limb, and 17 percent in double limb support. Walking propulsion, as measured by forefoot impulse, was similar in the two limbs. The first peak of vertical force, corresponding to the elevation of the center of body weight as it passes over the weight-bearing limb averaged 98 percent of body weight on the through-knee limb and only 93 percent on the trans-tibial limb. The second peak, corresponding to the kinetic energy of the falling trunk and muscle function providing linear acceleration of the center of body weight during propulsion, averaged 96 percent of body weight on the through-knee limb, and only 73 percent on the below-knee limb. Progression of the center of pressure, a qualitative measure of limb stability, was more orderly in the through-knee limbs, as seen in **Figure 4** (12). In this small group of patients, where we could directly compare trans-tibial with through-knee function in the same subjects, the individuals were clearly more stable in walking on their residual through-knee limb, with no apparent difference in walking propulsion.

RESULTS

Functional Outcome

We performed an outcome analysis on 33 consecutive peripheral vascular disease patients who underwent through-knee amputation with a goal of prosthetic limb fitting and gait training. We compared their outcome with similar trans-tibial amputees performed at our center. We used the Rancho Los Amigos functional outcome scale to measure walking independence (7). Twenty-one (64 percent) were able to rehabilitate to their preamputation walking status, and 24 (73 percent) were able to recover within one functional ambulation level (out of seven) of their pre-amputation capacity (6). This compared favorably with similar patients undergoing trans-tibial amputation under our care (5).

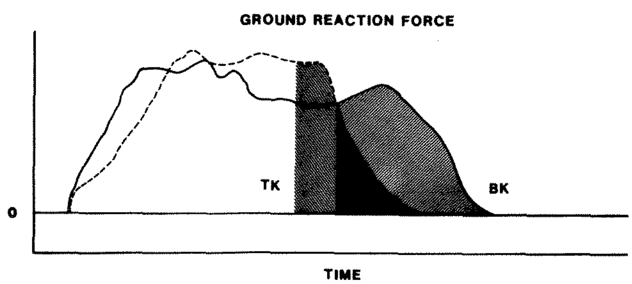

Figure 4a.
Vertical ground reaction force curves on a trans-tibial/through-knee bilateral amputee. The shaded areas represent forefoot impulse, which we have equated to walking propulsion. The area of forefoot impulse is virtually identical in both limbs (i.e., propulsion power is similar in both limbs). The bimodal vertical peaks correlate to limb loading.

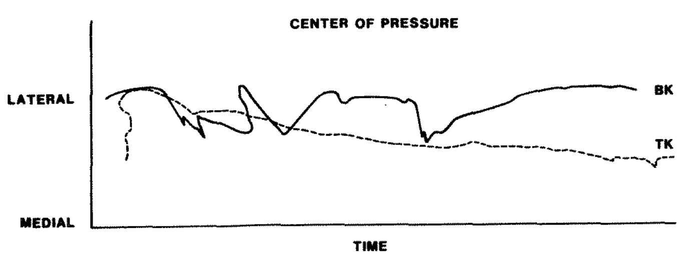

Figure 4b.
Center of pressure recordings from the same subject. Note that the through-knee limb progresses in an orderly fashion, while the trans-tibial limb recording vacillates back and forth. This vacillation corresponds to the gross shifting of the center of body mass, and the overcompensating response.

DISCUSSION

Peripheral vascular insufficiency amputees rarely achieve walking skills and prosthetic competence approaching that of younger traumatic or tumor amputees. They do not possess the energy reserve necessary to overcome the metabolic demands for walking with a prosthetic limb. The peripheral vascular disease that necessitated the amputation is present in other major organ systems, limiting cardiopulmonary and cerebral function. Many are diabetic with peripheral neuropathy which compounds their limitations.

Through-knee amputation allows direct load transfer of body weight to the prosthesis (end-weight bearing) and the intrinsic knee joint stability of the four-bar linkage prosthetic knee joint system. Results of these preliminary laboratory studies indicate that knee stability is apparently enhanced with through-knee amputation and a four-bar linkage prosthetic knee, without the loss of walking propulsion expected from absence of a functional knee joint and quadriceps mechanism.

REFERENCES

1. Burgess EM. Disarticulation of the knee. A modified technique. Arch Surg 1977:112:1250-5.
2. Rogers SP. Amputation of the knee joint. J Bone Joint Surg 1940:22:973-9.
3. Greene MP. Four bar linkage knee analysis. Orthot Prosthet 1983:37:15-24.
4. Pinzur MS. New concepts in lower-limb amputation and prosthetic management. In: Greene WB, ed. Instructional course lectures of the American Academy of Orthopaedic Surgeons. Vol. XXXIX. Park Ridge, IL: American Academy of Orthopaedic Surgeons, 1990:361-6.

5. Pinzur MS, Littooy F, Daniels J et al. Multidisciplinary preoperative assessment and late function in dysvascular amputees. Clin Orthop 1992:281:239-43.
6. Pinzur MS, Slosar PJ, Reddy NK, Osterman H. Through-knee amputation in peripheral vascular insufficiency: functional outcome. Contemp Orthop 1992:24:157-60.
7. Volpicelli LJ, Chambers RB, Wagner FWW, Jr. Ambulation levels of bilateral lower extremity amputees. J Bone Joint Surg 1983:65A:599.
8. Waters RL, Perry J, Antonelli D, Hislop H. Energy cost of walking of amputees. The influence of level of amputation. J Bone Joint Surg 1976:58A:42-6.
9. Pinzur MS, Gold J, Schwartz D, Gross N. Energy demands for walking in dysvascular amputees as related to the level of amputation. Orthopaedics 1992:15:1033-7.
10. Breakey J. Gait of unilateral below-knee amputees. Orthot Prosthet 1976:30:17-24.
11. Pinzur MS, Asselmeier M, Smith D. Dynamic electromyography in active and limited walking below-knee amputees. Orthopaedics 1991:14:535-8.
12. Pinzur MS, Smith D, Tornow D, Meade K, Patwardhan A. Gait analysis of dysvascular below-knee and contralateral through-knee bilateral amputees: a preliminary report. Orthopaedics. In press.