Videofluoroscopic evaluation of prosthetic fit and residual limbs following transtibial amputation

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Abstract—The clinical examination of residual limb complications is usually subjective and may lead to inappropriate, expensive adjustments or replacement of the prosthesis. Plain films and xeroradiography only provide static images of the residual limb and socket. The purpose of this pilot study was to develop a videofluoroscopic technique to evaluate dynamic residual limb-socket relationships during gait. Sixteen videofluoroscopic studies were performed in subjects with transtibial amputation. Anteroposterior (A-P) and lateral views were obtained. The wide view field was better than the coned view. The optimal settings were found to be in the 80 to 110 kV range during manual setting (mean values: 86.3 kV in A-P view, and 88.9 kV in lateral view). The following information was obtained: A-P residual limb motion, piston action, rolling of soft tissues, and dynamic relationships of various pressure-sensitive and pressure-tolerant parts of the residual limb with the inner socket. We consider videofluoroscopy to be a potentially valuable diagnostic procedure for evaluating difficult prosthetic fitting problems and residual limb complications, and providing a better understanding of the residual limb-socket interface during different phases of the gait cycle.

Key words: prosthetics, residual limb, transtibial amputation, videofluoroscopy.

INTRODUCTION

Amputation of a limb is a significant problem despite advances in the medical and surgical management of some of the underlying etiologies, such as atherosclerotic disease of the lower limbs. The prevalence of amputation in the United States is approximately 1 million (1), and another 43,000 new major amputations are performed yearly (2).

Most amputations are performed on the lower limb and occur as a result of complications of diseases; primarily peripheral vascular occlusive disease and diabetes. The person is not only challenged by having to learn to use the artificial limb, but also by the attendant complications that may arise from poor prosthetic fit, including recurrent residual limb breakdown predisposing the subject to pain, osteomyelitis, and sepsis. Moreover, abnormal gait with the use of a prosthesis can be unsafe, cosmetically unacceptable, and increase the energy cost of ambulation. Gait deviation with a prosthesis can increase the energy cost of ambulation, risk for falls, and may predispose to the development of osteoarthritis.

Currently, the evaluation of prosthetic fitting and residual limb complications is largely based on the complaints of the subject, and limited objective criteria provided by the examination of the residual limb, prosthesis, and gait pattern. Numerous clinical methods have been used to evaluate socket fit. These include the use of skin pencils, lipstick, chalk, gum, detection of...
redness of the skin, gaps between residual limb and socket, pressure in the residual limb, and instability (3). Simple observation of gait characteristics by a trained observer is clinically useful; however, there are new procedures for gait analysis including kinetic and kinematic analysis, electromyographic activity, and energy consumption (4–8). Observational gait analysis asks the clinician to concentrate first on one leg in one projection and then the other projection. An obvious limitation is the difficulty in observing multiple events concurrently (9). Although kinetic information may not be easily translated into effective rehabilitation practice, kinematic analysis may be used to compare existing gait patterns (10). Current radiographic procedures (plain X-ray and xeroradiography) have only been able to provide static analysis of the residual limb-socket relationships. This is inadequate in light of the importance of understanding the inherent dynamic interaction between the residual limb and socket (11–13). Numerous procedures have been used for gait analysis as reviewed by Harris, but no radiographic procedure to date has been utilized to evaluate dynamic residual limb-socket relationships during the different phases of the gait cycle (14). Dynamic studies have the potential to generate critical data on bone or soft tissue movement and different prosthetic components. Fluoroscopy is a dynamic study that has been used to functionally evaluate swallowing and musculoskeletal disorders (15–17).

The purpose of this pilot study was to develop a new videofluoroscopic technique to evaluate dynamic residual limb and socket relationships. Specifically, we sought:

1. to determine the optimum kilovoltage and milliamperage settings providing the best resolution of prosthetic components and amputation residual limbs;
2. to determine whether manual exposure control setting provides better images compared to automatic exposure;
3. to identify components of the residual limb or socket requiring radiographic markers; and
4. to describe residual limb-socket relationships during the gait cycle under fluoroscopy.

METHODS

Subjects

Individuals included in this study were subjects with transtibial amputation who were seen in our prosthetic clinic; all were independent community ambulators, and none used assistive devices. To be included, subjects had to wear a patellar tendon bearing (PTB) socket, be able to ambulate with use of the prosthesis on a treadmill, and be physically able to complete the examination. All subjects had a socket insert: the Pelite liner was the most frequently used, but three subjects wore Kemblo inserts. Seven used cuff suspension, three used rubber sleeve, one used suprapatellar/suprapocondylar suspension, and one used a thigh corset/fork strap. Socks worn were of wool. Those subjects who developed symptoms, such as severe residual limb pain, chest pain, dyspnea, or lightheadedness, were excluded. Twelve males, aged 39 to 81, fulfilled the criteria to complete our study; 11 were unilateral and 1 was bilateral. Most of their amputations were due to vascular disease, the main diagnoses being arteriosclerosis sometimes associated to diabetes melilitus; three were amputated because of trauma. A total of 16 studies each for anteroposterior (A-P) and lateral views were performed. A written informed consent was obtained, and the study was carried out with the approval of the Human Subjects Committee at Stanford University Medical Center.

Videofluoroscopy Equipment

Figure 1 illustrates the videofluoroscopic imaging setup. A Siemens Siregraph fluoroscopy machine
(Siemens Medical Systems, Inc., Burlingame, CA) was utilized. It had an exposure rate of 3.5 rads/min without the use of a grid in automatic exposure control and 1.6 rads/min at 70 kV manual control. Guidelines for minimizing exposure were followed (18). Manual and automatic exposure control modes were used in order to compare their resolution. Under manual control, three different settings were used: 50, 80, and 110 kV. In 12 residual limbs, the optimum kilovoltage and the associated milliamperage settings were recorded and compared. A Sony Model VO5800 videorecorder (also from Siemens Medical Systems) was connected to a TV monitor with a VG-R2 connector. Results were recorded using a 3/4-in Ampex 187 KCA-60 VHS professional videocassette.

Procedures

Three residual limbs were studied statically in A-P and lateral views in order to identify anatomical and prosthetic components. Coned and wide view fields were compared. The same residual limbs were evaluated dynamically by asking the subject to simulate ambulation by walking in place on a platform. These preliminary studies were performed initially to identify residual limb and prosthetic components that were analyzed in the dynamic study. Leaded rubber markers were utilized to tag some prosthetic components that could not be readily identified.

Twelve residual limbs with transtibial amputation were dynamically studied while subjects ambulated on a 9880 Vitamaster Motorized Treadmill (Roadmaster Corporation, Tyler, TX). This treadmill was mounted on a wooden platform with steps and lockable casters to raise it to a height that allowed the observation of the knee and the distal residual limb in all subjects. The handrails of the treadmill were modified to allow adequate viewing of the residual limb and prosthesis. Subjects were asked to come with comfortable clothing and given a trial run without fluoroscopy to get acquainted with the use of the treadmill. They were then asked to walk at their usual and most comfortable walking speed with the control set at that level. In some subjects, leaded rubber markers were placed over discrete prosthetic areas within the socket for identification. Subjects were positioned on the treadmill within the view field in such a way that the amputated leg was closest to the fluoroscopy table (X-ray source). A-P and lateral views were obtained under fluoroscopy. These were accomplished by positioning the treadmill relative to the fluoroscopy unit.

Videotape Analysis

At completion of the study, the videotapes were reviewed independently by two investigators (C.B., J.C.). Since the videorecorder had the capacity for frame-by-frame and slow-motion analysis, we were easily able to locate a particular frame for review and return to the same point at any time as desired. An attempt was made to identify relevant parts of the residual limb, including the patellar tendon, tibial plateau, hamstring tendons, fibular head, and tibial crest. Similarly, the following prosthetic parts and associated components were studied: patellar tendon bar, popliteal bulge, hamstring channels, fibular head relief, tibial shelves, residual limb socks, insert, shank, and socket (see Figures 2 and 3). Data gathered from review of 16 videofluoroscopic studies in A-P and lateral views by both investigators were tabulated. The percentage agreement of visualizing a particular residual limb or prosthetic component out of a total of 16 residual limbs was then determined.

Statistical Methods

A chi-square test was used to determine the concordance in the visualization of components between observers. A continuity correction was applied, and an exact test when considered appropriate (19,20). Test results are presented in Table 1.
Table 1. Videotape analysis of residual limb and prosthetic components.

<table>
<thead>
<tr>
<th></th>
<th>Anteroposterior view</th>
<th>Lateral view</th>
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<tr>
<td><strong>RESIDUAL LIMB</strong></td>
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<tr>
<td>Patellar tendon</td>
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<td>16</td>
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<tr>
<td>Hamstring tendons</td>
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<td>16</td>
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<tr>
<td>Fibular head</td>
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<tr>
<td>Soft tissue edge</td>
<td>13</td>
<td>2</td>
</tr>
<tr>
<td>Tibial crest</td>
<td>1</td>
<td>15</td>
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<tr>
<td>Tibial flares</td>
<td>15</td>
<td>1</td>
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<tr>
<td><strong>PROSTHESIS</strong></td>
<td></td>
<td></td>
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<tr>
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<td>10</td>
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<tr>
<td>Insert</td>
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<td>2</td>
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<tr>
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<tr>
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<tr>
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<tr>
<td>Socket</td>
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+ = agreement by both researchers in visualization of residual limb and prosthetic components; − = agreement by both researchers in nonvisualization of residual limb and prosthetic components; +/- = disagreement; NS = no significant difference between both researchers in visualization (p=0.05) Numbers indicate number of cases studied. An X²-test with continuity correction was used when considered appropriate.

**RESULTS**

**Overview**

The initial three subjects studied under static conditions without the treadmill showed that, compared to the coned projection, the wide projection provided a better view field for visualizing the amputation residual limb and prosthesis. Percentage of agreement between observers for the residual limb parts visualized in the A-P and lateral views was 98 percent with a range of 94 to 100 percent. For the prosthetic components, average agreement was 97 percent with a range of 87 to 100 percent. Interater ability in components visualization is reported in Table 1. The visualization was performed separately by each researcher. There were no statistically significant differences. One subject had a short residual limb with adequate visualization of the distal limb segment and socket with insert at 80 kV (manual control). Generally, fewer than 50 gait cycles were required to complete each study. The average recording time was 40 s. It took an average of 20 min for each observer to review a study in A-P and lateral views.

![Figure 3](image_url)  
**Figure 3.** Diagram of lateral view. Residual limb-socket components and dynamic movements that were analyzed are labeled.
Videofluoroscopy Settings

The manual exposure control provided better resolution than automatic exposure control in the vast majority of our subjects. These were found to be generally in the 80 to 110 kV range (mean values: 86.3 kV in A-P view, 88.9 kV in lateral view). The 50 kV setting offered good resolution in only one subject. The results of kilovoltage settings plotted against milliamperage settings are presented in Figure 4.

Components in Anteroposterior View

Table 1 indicates the percentage breakdown of residual limb and prosthetic components identified by videofluoroscopy. In the A-P view, the fibular head and tibial flares were identified. Only the residual limb edge was appreciated when studying the soft tissue elements. The insert and tibial shelves were demonstrated in most subjects. Socks were occasionally seen. Folding of the socks was noted with piston action. The patellar tendon bar and fibular head relief of the socket were visualized in fewer than 50 percent of the studies. These parts will require leaded rubber markers.

Components in Lateral View

In the lateral view, the tibial crest and patellar tendon were appreciated in most subjects. In addition, the popliteal bulge and patellar tendon bar were seen. It was not possible to appreciate the hamstring channels or the socks. In this projection, leaded rubber markers may be needed to identify the hamstring tendon channel, residual limb socks, and insert.

Additional Findings

Impacting of the tibia against the anterior wall during stance phase was seen in three subjects who clinically expressed moderate complaints when walking. Lateral thrust was appreciated in three. One of them complained of distal residual limb pain; redness was noted in the lateral aspect of the residual limb. Other findings included: soft tissue rolling, loss of congruency between the fibular head and socket relief, and rolling of socks and/or soft tissues. The shank could be viewed easily in A-P and lateral projections when it came into the visual field. Additional prosthetic components visualized included the distal end pad, prosthetic hardware, popliteal bulge, tibial shelves, strap buckles, and elastic sleeve (Figures 5 and 6).

Case Reports

Two dynamic studies are described to illustrate the use of this radiographic procedure:

Case 1

RS, a 67-year-old male with left transtibial amputation came to our clinic with complaints of pain in the residual limb during ambulation. He had used a PTB socket with cuff suspension, Kemblo insert (with foam rubber and leather) for the past 3 years. He was a previous user of the Kemblo liner due to its excellent durability. Examination of the residual limb revealed redness in the lateral aspect extending from 3 cm below the fibular head to the distal end. The insert had worn out near the patellar tendon bar and corresponding tibial
Videofluoroscopy revealed lateral motion of the residual limb during stance phase. Recordings also indicated significant piston action after review of both swing and stance phase. Leaded rubber markers indicated loss of congruency between the fibular shelf and its relief (Figure 5a). Significant air gaps were noted during the gait cycle at the distal end of the socket. Manual exposure provided better images.

Case 2

JH, a 66-year-old male with left transtibial amputation came to our clinic with complaints of persistent distal pain in the residual limb. No bony or soft tissue pathology was noted on static plain films. He had some redness noted in the distal residual limb. Prosthetic checkout was essentially normal including gait pattern. Videofluoroscopy revealed adequate residual limb-socket relationships between pressure-sensitive areas of the residual limb and the socket. However, the subject had rolling of soft tissues during stance phase (Figure 6d).

DISCUSSION

Methodological Considerations

Videofluoroscopy is used for evaluating other conditions like swallowing and musculoskeletal disorders (15-17). Although it gives a slightly reduced resolution compared to cinefluorography, most clinicians and researchers choose to use videofluoroscopy due to significantly reduced radiation exposure. In general, at 25 rads or less, ordinary laboratory and clinical methods will show no indications of injury. A single test for our study delivers a radiation dose of only about 1.9 rads, which is of no clinical significance (18). This is a minimal amount of radiation exposure in light of the potential benefits from the study as previously discussed. Other advantages of videofluoroscopy include immediate playback after recording, a technique less expensive than motion picture film recording. An electric treadmill, videorecording system, and TV monitor are not expensive, and they can be easily connected to a hospital fluoroscopy unit. This system also allows real-voice recording of both subject and examiner.

Technical Difficulties

One limitation of this technique was the overlap of the residual limb with the full limb in the lateral view. This made it difficult to view the residual limb-socket relationships between pressure-sensitive areas of the residual limb and the socket. However, the subject had rolling of soft tissues during stance phase (Figure 6d).

Figure 5.
Videoframes of residual limbs (A-P view). a: Loss of congruency between fibular head and fibular head relief due to pistoning. The proximal leaded rubber marker in the lateral wall is the fibular head relief of the socket, indicating that the residual limb has sunk down into the socket. b and c: Piston action also indicated by difference in location of patellar tendon bar marker relative to the knee joint during swing phase and stance phase, respectively. d: Abnormal separation between tibia and fibula indicates interruption of interosseous membrane following surgery.

Figure 6.
Videoframes of residual limbs (lateral view). a: Hyperextension of the knee joint was demonstrated in this study. b: Patellar tendon bar (indicated by the leaded rubber marker). The ideal location is midpoint between inferior pole of patella and tibial tubercle. c: Tibia is superficial with minimal soft tissue protection (arrow) making it prone to residual limb breakdown. Radiolucent outline indicates insert. d: Arrow indicating rolling of soft tissues.
interface for a brief period during mid-swing, although this is not likely a time of distress. It was also necessary to reposition the subject and imaging unit due to the limited view field in the lateral view. This allowed us to view and record the entire gait cycle. It is also conceivable to connect the platform supporting the treadmill to the videofluoroscopic unit and remotely control subject position during the test.

Other soft tissue structures (i.e., hamstring tendons and patellar tendon) were sometimes difficult to visualize. This may be due to a poor signal-to-noise ratio and an increased level of scattered radiation resulting in a low quality of the image. We feel that the use of leaded markers would enhance the accuracy of identifying certain anatomic and prosthetic components.

Clinical Relevance

A goal of rehabilitation for the person with a transtibial amputation is to provide a safe, pain-free, energy efficient, and cosmetically acceptable use of the prosthesis. Achieving this goal is largely dependent on proper prosthetic fit, accommodating anatomical characteristics of the residual limb, and achieving satisfactory dynamic residual limb-socket relationships during the gait cycle.

Kinematic analysis comparing nonimpaired individuals with subjects with transtibial amputation can help the clinician to modify the movement pattern of the prosthetic limb to one closer to normal gait (21). However, as the displacements described are minimal and studied parts are hidden from the usual view, there are limitations attached to attempts at clinical measurement. Nevertheless, such measurement is necessary if comprehensive investigation of the mechanics associated with the correct fitting of the prosthesis is to be undertaken. X-rays and xerograms can provide important information about bony elements, blood vessel calcification, and soft tissues as well as prosthetic fit (6). However, they do not provide information about the dynamic relationships between the residual limb and socket. The study of residual limb-socket interface requires an imaging technique that allows the identification of functional landmarks in three dimensions that can be followed by measurements of residual limb motion. Videofluoroscopy may overcome these difficulties by making it possible for the observer to visualize the A-P, lateral, and axial movements of the residual limb relative to the socket. This preliminary study suggests that videofluoroscopy has the potential for offering information of clinical value that is not currently available.

There have not been, to our knowledge, previous videofluoroscopic investigations of residual limb-socket relationships in subjects with transtibial amputation. Therefore, there are no standards with which the findings in our subjects can be compared.

Future Studies

At this time, this procedure is still a research tool and possibilities of clinical application are not yet evident. Data from videofluoroscopy can be incorporated in the basic science field of amputation biomechanics. Research along these lines may also generate new radiographic criteria for diagnosing various causes of residual limb pathology, poor prosthetic fit, and gait deviations in persons with amputation. Normative data derived from future studies can provide a basis for improving the design of new sockets as well as the evaluation of newer prosthetic devices in terms of fitting and subject comfort. Videofluoroscopy also has the potential to be a diagnostic procedure for assessing the effectiveness of prosthetic readjustment or modification in the management of fitting problems. Long-term follow-up of subjects fitted with their prostheses with the assistance of videofluoroscopy can also be investigated in future studies. It could be a useful tool supplementing other methods utilized for gait analysis (22).

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REFERENCES


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