

## Postoperative dressing and management strategies for transtibial amputations: A critical review

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**Abstract**—Postamputation management is an important determinant of recovery from amputation. However, consensus on the most effective postoperative management strategies for individuals undergoing transtibial amputation (TTA) is lacking. Dressings can include simple soft gauze dressings, thigh-high rigid cast dressings, shorter removable rigid dressings, and prefabricated pneumatic dressings. Postoperative prosthetic attachments can be added to all but simple soft dressings. These dressings address the need to cleanly cover a fresh surgical wound, but not all postoperative dressings are designed to facilitate the strategic goals of preventing knee contractures, reducing edema, protecting from external trauma, or facilitating early weight bearing. The type of dressing and management strategy often overlap and are certainly interrelated. Current protocols and decisions are based on local practice, skill, and intuition. The current available literature is challenging, and difficulties include variations in healing potential, in comorbidity, in surgical-level selection, in techniques and skill, in experience with postoperative strategies, and with poorly defined outcome criteria. This paper reviews the published literature and compares measures of safety, efficacy, and clinical outcomes of the various techniques. Analysis of 10 controlled studies supported only 4 of the 14 claims cited in uncontrolled, descriptive studies.

**Key words:** air splint, immediate postoperative prosthesis, pneumatic postoperative prosthesis, soft dressings, transtibial amputation.

The literature supports that rigid plaster cast dressings result in significantly accelerated rehabilitation times and significantly less edema compared to soft gauze dressings, and prefabricated pneumatic prostheses were found to have significantly fewer postsurgical complications and required fewer higher-level revisions compared to soft gauze dressings. No studies directly compared pneumatic prostheses with rigid dressings, and no reports compared all types of dressings within one study. In conclusion, the literature and evidence to date is primarily anecdotal and insufficient to support many of the claims. Future randomized trials on TTA dressing and management strategies are clearly needed to collect the evidence needed to best guide clinicians with the decision.

**Abbreviations:** TTA = transtibial amputation; IPOP = immediate postoperative prosthesis; STAMP = Special Teams for Amputations, Mobility, Prosthetics/Orthotics; VAMC = Veterans Affairs medical center.

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## INTRODUCTION

Patients with transtibial amputations (TTAs) frequently experience problems with pain, edema, knee contractures, wound healing, additional surgery, limited return to function, limited satisfaction, and high rehabilitation costs [1–3]. In the United States, TTAs represent approximately 35,000 out of the 134,000 lower-limb amputations performed every year, with cost estimates ranging from \$27,000 to \$50,000 per TTA episode [1,4–6]. Indications for TTA include diabetes mellitus, peripheral vascular disease, gangrene, ischemic pain, trauma, tumor, infections, nonhealing ulcers, and osteomyelitis [6–8]. Two-thirds of all lower-limb amputations occur in people with diabetes [4,8–10]. Because the incidence of diabetes is increasing with the aging U.S. population, the prevalence of TTAs also will rise and impact the health care system through increased use and health care costs. Assessments of surgical techniques and effective rehabilitation procedures often have ignored the role and type of postsurgical dressings and management strategies [2,11]. Recognizing where and when in the healing process that noteworthy improvements can be made is imperative. This paper reviews the published literature on postoperative dressings and management strategies for TTA.

Currently, no consensus exists on the most effective postoperative management strategy for individuals who undergo TTA. Typical postoperative dressings and management strategies include the use of—

- Soft gauze dressings with an elastic wrap [12–14].
- Thigh-level rigid plaster dressings without an immediate prosthesis.
- Thigh-level rigid plaster dressings with an immediate postoperative prosthetic (IPOP) [15–17].
- Shorter removable rigid plaster dressings [18–19].
- Prefabricated pneumatic postoperative prosthesis [20–23].

Current clinical practice often is a mixture of these five major technique methods or their variations. While all the dressings address the need to cleanly cover a fresh surgical wound, not all postoperative dressings are designed to facilitate the strategic goals of preventing knee contractures, reducing edema, protecting from external trauma, or facilitating early weight bearing. The dressing and management strategy clearly overlap and are certainly interrelated. The ultimate goals of a postamputation dressing and management strategy is to improve wound

healing, control pain, allow early prosthetic fitting, and enable a rapid return to function.

While safety and efficacy of these five strategies are debated, definitive evidence to support the benefit of any single technique is lacking. There have been numerous descriptive case series reports on the different types of management strategies but relatively few randomized comparative studies. Also, the outcomes definition to measure success or failure of a specific type of dressing or management strategy has not been standardized in the literature, making comparisons between studies difficult. Therefore, this review (1) presents the historic development of the different types of TTA management strategies, (2) identifies the limitations of the published literature, (3) reviews the claims made in descriptive studies, and (4) presents data from evidence-based controlled studies.

## METHODS

We extensively searched several electronic databases, locating both controlled and uncontrolled studies of TTA dressing management techniques. The sources that we searched to obtain data for this review were PubMed (from 1960 to March 2002), Index Medica using MEDLINE (from 1960 to March 2002), reference lists from articles, reviews and book chapters, and personal communication with content experts. The terms used in the search were TTA, below-knee amputation, rigid plaster dressings, soft gauze dressings, air limb, air splint, pneumatic prosthesis, diabetic complications, pain, and cited author cross-references. Studies were included if the amputation was transtibial, data was provided on clinical outcomes, and the results were stratified by the type of dressing. Controlled studies were required to have a control or comparison group, provide information on how study groups were defined, and provide data on both groups.

## HISTORIC DEVELOPMENT

TTA management practice has evolved significantly over the ages. Postoperative soft gauze bandages were used most commonly until World War I (WWI), when troops were fitted with plaster casts affixed with wooden or metal tips. Wilson reported the benefits of early weight bearing in the recovery process for these WWI patients

who were fitted with plaster casts with a prosthetic tip [24]. The use of a weight-bearing cast lost favor between the world wars but was reintroduced later in France and Poland. When 21,000 soldiers returned from WWII with amputations, the Veterans Administration (now known as the Department of Veterans Affairs [VA]) increased its focus on rehabilitation research. The VA Health Care System, Office of Research and Development, established the Rehabilitation Research and Development (R&D) Service to improve the quality of life for the impaired and disabled veterans. A thigh-level rigid plaster cast with a prosthesis attached immediately in the operating room was introduced by Berlemont in France in 1958 and reported in 1961 [25]. Weiss in Poland reported on his similar accomplishments in 1966 [26]. In 1964, Burgess et al. and Zettl et al. brought this technique to the United States and established the Prosthesis Research Study [15,27]. The use of a pneumatic postoperative prosthesis was introduced in Australia by Little in 1970 to allow for easy removal and residual-limb inspection [28]. Then, in 1977, Wu et al. developed a shorter version of a plaster cast system that did not encompass the thigh, called the “removable rigid dressing technique” [18].

Even with the availability of these techniques, consensus on which one should be used in specific clinical circumstances was not reached. The lack of agreement spurred increased interest and established several major research programs. From 1985 to 1991, the VA operated the STAMP (Special Teams for Amputations, Mobility, Prosthetics/Orthotics) Program. In 1992, the VA established PACT (Preservation Amputation Care and Treatment), a program that mandated a multidisciplinary team for every VA medical center (VAMC) to track each of its amputees [9]. Under the VA Rehabilitation R&D Service, the Center for Limb Loss Prevention and Prosthetic Engineering was established in Seattle during 1997 to study amputation prevention and engineer-improved lower-limb prostheses and to measure functional outcomes.

Despite extensive training and efforts by the VAMCs, surgeons have not uniformly adopted any particular dressing techniques. Improvements in amputation surgical technique and surgical decision making (e.g., use of a long posterior skin flap and TTA levels, rather than transfemoral levels) have resulted in fewer complications and better rehabilitation, but the optimal type of postsurgical dressing management still is being debated [29–31]. Although various postoperative techniques have been

used for decades, a definitive answer still has not been found as to which dressings or management strategies are most efficacious.

Current practice patterns vary widely. When intensive rehabilitation programs are located on-site or are closely coordinated with the acute surgical service, providers tend to use rigid, rather than soft, dressings. A survey in 1993 by Pinzur et al. of 299 patients who had TTAs at six VA hospitals with STAMP programs found that wound management was accomplished with rigid plaster dressings 75.3 percent of the time, pneumatic air dressings 14.0 percent, and soft dressings 10.7 percent [23]. A more recent and comprehensive survey in 2001 of 101 surgeons at 92 VA hospitals performing greater than 30 lower-limb amputations a year indicated a reversal of that trend, with 67 percent of patients receiving soft gauze dressings, 14 percent with conventional rigid dressings (with no prosthetic attachment), 5 percent with IPOP, and 14 percent with removable rigid dressings [32]. Neither the number of amputations performed by the surgeon nor academic affiliation or hospital bed size resulted in significant differences in the type of dressing management chosen. Orthopedic surgeons were more likely than vascular or general surgeons to apply rigid dressings. The differences between these two surveys may be due to the differences in the number of hospitals or the number of subjects and the types of VA hospitals included in the two surveys, or the differences could represent a decrease in the frequency of use of rigid dressings as time progressed by the VA system. The later survey, covering over 3,000 subjects in 92 hospitals, and a smaller proportion of these hospitals had specialized STAMP teams.

## RESULTS OF LITERATURE REVIEW

### Methodologic Issues

#### *Lack of Defined End Points*

Comparisons of published study results for TTAs from descriptive studies (**Table 1**) or from controlled studies (**Tables 2 and 3**) are limited by the lack of a standardized definition for end points that measure the success or failure of a specific dressing management strategy [12–14,16–18,20,21,30,33–48]. “Healing or rehabilitation success” as an end point has been measured with the use of numerous indicators, including 1° and 2° healing rates, time to healing or rehabilitation, associated mortality rates, and determination whether higher-level revision was required.

**Table 1.**

Postoperative outcomes of different types of TTA dressing and management strategies from descriptive studies.

Type of Dressing	Study Design	Number of TTA Patients	Reported Claims	Reference
Soft Gauze	Case series	17	Tourniquet effect	Isherwood et al. [13]
Rigid Cast No IPOP	Case review	100	Less swelling, prevents knee contracture protective of trauma	Golbranson et al. [33]
Rigid Cast No IPOP	Case series	186	Time to final prosthesis 7 weeks less swelling, 76% rehabilitated, 4.5% mortality	Cummings [34]
IPOP	Case series	134	64% rehabilitated, 5% mortality	Sarmiento et al. [35]
IPOP	Case series	20	90% 1° healing, time to permanent prosthesis 27 days, 0% mortality, 10% higher-level revisions	Moore et al. [36]
IPOP	Case series	10	60% 1° healing, 20% mortality	Warren & Moseley [37]
IPOP	Case series	37	60.5% 1° healing, 30% no postoperative narcotics for pain, 10.8% higher level revisions, 8% mortality	Condon & Jordan [38]
IPOP	Case control survey*	161	Rehabilitated 78% if ischemic, 98% nonischemic, 12% mortality if ischemic, 0% if nonischemic	Kihn et al. [39]
IPOP	Case series	11	91% 1° healing, time to permanent prosthesis 32 days, 0% mortality, 82% use of permanent prosthesis	Kraeger [40]
IPOP	Case survey	170	76% rehabilitated, 8% mortality	Jones & Burniston [41]
IPOP	Case survey	17	76% rehabilitated, 12% mortality	Weinstein et al. [16]
IPOP	Case control*	59	86% rehabilitated, time to rehabilitation 15 days, 5% mortality	Folsom et al. [42]
Air Splint	Case series	11	Time to rehabilitation 6–8 weeks, no knee contractures	Kerstein [43]
Air Splint	Case histories	3	100% rehabilitated, 0% mortality	Bonner & Green [21]
Air Limb	Case series	38	86% rehabilitated, 0% mortality	Pinzur et al. [44]

IPOP = immediate postoperative prosthesis

TTA = transtibial amputation

\*No data on controls provided.

Adding to the confusion, authors use different criteria to define these indicators, and in addition, over time, the definitions of these criteria have changed. Rehabilitation success has been measured by rates of 1° healing (uncomplicated) and 2° healing (complicated because of infection, blisters, ulcers, or other postoperative problems) [16,17,30,38,40,42,46–48]. Kihn et al., using yet another measurement of rehabilitation success, considered patients a success if he or she was “walking and ready for discharge within 30 days” [39]. Rehabilitation success also has been defined by “the use of a prosthesis for at least 50 percent of the time [12,37,40,45,46,48].

Another outcome measure that has been used is the “time to healing or rehabilitation.” Mooney et al. and Wu et al. defined healing time as the interval between amputation and ordering a temporary prosthesis [12,18], whereas others defined it as the time to a permanent prosthesis [17,34,40]. Baker et al. and Kraeger defined “rehabilitation

time” as the time between the operation and the beginning of gait training [30,40], whereas others defined it as the interval between amputation and final ambulatory discharge with a prosthesis [16–18,20,37,42]. It should be noted that healing of a residual limb is a continuous process and does not have a clear and decisive point of “being healed.” Many TTAs do not heal in perfect primary fashion, and small areas of the wound commonly require secondary healing and a period of minor open-wound care. Determining healing time will always be prone to subjective interpretation of epithelialization completion, the small open areas, individual bias, timing of the return clinic visits, and research savvy of the prosthetic and rehabilitation team. Thus, researchers need to define clearly how “time to healing” has been determined for their studies. Time to healing may always be difficult to standardize and to measure and, in reality, cannot be determined accurately from a simple retrospective review of a clinical chart.

**Table 2.**

Postoperative outcomes associated with wound healing in different types of TTA dressing and management strategies from controlled or comparative studies.

Outcomes	Number in Study	Soft Dressings	Thigh-Level Rigid Cast	Thigh-Level Rigid with IPOP	Short Removable Rigid Cast	Prefabricated Pneumatic IPOP	Reference
Time to Wound Healing (days)*	49	109.5	—	—	46.2	—	Wu et al. [18]
1° Wound Healing†	27	11 (78%)	13 (100%)	—	—	—	Nicholas & DeMuth [45]
	100	—	43 (53%)	40 (85%)	—	—	Moore et al. [17]
	51	14 (58.3%)	18 (66.7%)	—	—	—	Baker et al. [30]
	48	35 (89.5%)	—	4 (44%)	—	—	Cohen et al. [46]
	70	19 (56%)	23 (68%)	—	—	—	Barber et al. [47]
2° Wound Healing‡	100	—	12 (23%)	2 (4%)	—	—	Moore et al. [17]
	51	6 (25%)	5 (18.5%)	—	—	—	Baker et al. [30]
	70	8 (23%)	8 (23%)	—	—	—	Barber et al. [47]
Postoperative Pain§	27	48.4 m.e.	41.6 m.e.	—	—	—	Nicholas & DeMuth [45]
	52	3.47 mg/d	—	3.9 mg/d	—	—	Kane & Pollak [48]
Postoperative Complications¶	100	—	7 (14%)	1 (2%)	—	—	Moore et al. [17]
	52	3 (17%)	—	7 (21%)	—	—	Kane & Pollak [48]
	42	15 (65.2%)	—	—	—	3 (15.8%)**	Schon et al. [20]
Higher-Level Revision Required	100	—	13 (24%)	5 (11%)	—	—	Moore et al. [17]
	182	17 (22%)	3 (6%)	7 (12%)	—	—	Mooney et al. [12]
	48	1 (2.7%)	—	3 (33%)	—	—	Cohen et al. [46]
	42	10 (43.5%)	—	—	—	0 (0%)**	Schon et al. [20]
		4 (16.7%)	4 (14.8%)	—	—	—	Baker et al. [30]
		8 (44%)	—	9 (26%)	—	—	Kane & Pollak [48]
Volume Decrease	16	31.2 ± 49	—	—	70.1 ± 21.3**	—	Mueller [14]

\*Interval between amputation and ordering prosthesis; statistical significance not addressed by authors.

†1° healing = uncomplicated residual-limb healing

‡2° healing = delay in healing

§Measured by either number morphine equivalents (m.e.)/wk or mg/d.

¶Post-op complications include residual-limb infections, bruising, burns, ulcers, and necrosis.

\*\* $p < 0.05$

“Failure of TTA” is another common end point and has been defined by some authors as requiring higher revisions or repeated surgeries [12,17,20,30,38,39,46] and by other authors as a higher rate of mortality in the 30 days after the amputation [12,16,34,37,38,40,46–48]. Mortality end points are problematic without controlling for age and comorbid conditions. Results obtained from various authors using different criteria leave no consistent definitions for success or failure end points, making efficacy of the various postoperative dressing strategies more difficult to determine.

While the postoperative strategy for TTA is an important factor in rehabilitation, the effect of different postoperative interventions may well be masked by the larger impact of other factors. These factors include level selection, skill and surgical technique, and the extent of the patients’ comorbidities. Amputation level selection has a quite a large influence on healing and prosthetic use. The primary goal is to balance the likelihood of the rehabilitation success against the risk of a subsequent revision to a higher amputation level for wound failure. The amputation level decision is made after consideration

**Table 3.**

Postoperative outcomes associated with rehabilitation in different types of TTA dressing and management strategies from controlled or comparative studies.

Outcomes	Number in Study	Soft Dressings	Thigh-Level Rigid Cast	Thigh-Level Rigid with IPOP	Short Removable Rigid Cast	Prefabricated Pneumatic IPOP	Reference
Use of Prosthesis	27	12 (85.7%)	10 (76.9%)	—	—	—	Nicholas & DeMuth [45]
	52	4 (22%)	—	19 (56%)	—	—	Kane & Pollak [48]
	182	45 (59%)	34 (65%)	40 (74%)	—	—	Mooney et al. [12]
	48	31 (79.8%)	—	8 (83%)	—	—	Cohen et al. [46]
Time to Initial Rehabilitation (days)	51	35.5	29.6*	—	—	—	Baker et al. [30]
Weeks to Permanent Prosthesis or Final Ambulation	49	27.0	—	—	14.6	—	Wu et al. [18]
	100	—	17.8	4.6	—	—	Moore et al. [17]
	182	40.0	32.0	34.0	—	—	Mooney et al. [12]
	42	13.6	—	—	—	20.4	Schon et al. [20]
Number of Falls	42	11 ± 0.18	—	—	—	34 ± 0.42	Schon et al. [20]
Length of Stay (days)	27	34.0	35.0	—	—	—	Nicholas & DeMuth [45]
	52	25.0	—	34.0	—	—	Kane & Pollak [48]
	51	22.3	22.6	—	—	—	Baker et al. [30]
Rehabilitation Failure	52	5 (28%)	—	4 (12%)	—	—	Kane & Pollak [48]
	51	4 (17%)	4 (15%)	—	—	—	Baker et al. [30]
	48	1 (2.7%)	—	7 (78%) <sup>†</sup>	—	—	Cohen et al. [46]
	70	7 (20%)	3 (8.6%)	—	—	—	Barber et al. [47]
Mortality (%)	182	8.0	5.0	6.0	—	—	Mooney et al. [12]
	100	—	8.0	0.0	—	—	Moore et al. [17]
	48	2.7	—	0.0	—	—	Cohen et al. [46]
	52	11.0	—	12.0	—	—	Kane & Pollak [48]
	70	5.7	8.6	—	—	—	Barber et al. [47]

\* $p < 0.05$

<sup>†</sup>Four of the seven caused by blistering secondary to incorrect technique (hot plaster).

of physiologic factors (tissue necrosis, transcutaneous oxygen tension, circulatory status), comorbidity (diabetes, peripheral vascular disease, other infections, age), the surgeon's skill and experience, and the patient's nutritional status [49,50].

Controlling these variables is indeed very difficult, and most published studies do not achieve good control of these other important variables when attempting to compare postoperative strategies.

#### *Lack of Standard Criteria for Selection of a Particular Management Strategy*

Clinical criteria for choosing the type of postoperative dressing are lacking. Some authors suggest that rigid dressings with IPOP be chosen only if a potential exists for subsequent ambulation [16,39]. Cummings pointed out that because rigid dressings allow for quicker healing, less pain, and shorter hospitalizations, they should be the

preferred choice even for those who will not walk afterward [34]. Some authors have suggested that IPOP not be used for patients with vascular disease [48] or if the wound needs to be left open because of infection [16]. The state of current practice is that the surgeon chooses dressing type frequently based on prior experience and training and not on scientific criteria.

#### *Limitations of Controlled Trials*

While an initial literature review found 12 possible controlled trials, a closer examination of the studies determined two studies did not meet our defined criteria. These two studies stated in the abstract and methods sections that controls were included in the study, but no data on the control population were provided in the paper [39,42]. Thus, only 10 studies directly compare one type of post-TTA dressing with another strategy and provide data on the results. The findings from controlled studies

by the type of outcome variable and type of amputation dressing strategy used are presented in **Table 2** for variables associated with wound healing and in **Table 3** for variables associated with rehabilitation. Only four studies used random allocation of dressing management methods [12,14,30,47]. Four other studies retrospectively selected controls [17,18,20,46]. In one study, the surgeon determined the dressing type [45] and the final paper did not describe the dressing selection process [48]. Comparing the results of these 10 studies poses numerous challenges, because of a lack of standardized outcome definitions, study protocols, and follow-up times. The study population characteristics were different, groups were not compared on known prognostic factors, and not all studies compared the four major postoperative management strategies. Most studies compared one type of rigid cast dressing with simple soft gauze dressings. Finally, no study contained a blinded assessment of outcomes.

### Specific Dressing and Management Strategies Issues

#### *Soft Dressings*

Traditionally, soft dressings are used on the residual limb and a prosthesis is fitted only after healing and maturation of the residual limb [26,27]. The soft dressing strategy usually consists of a nonadherent dressing over the suture line, sterile 4 × 4 pieces of gauze, absorbent fluffed gauze applied anteriorly and distally, and gauze roll over-wrap. Typically, but not always, an elastic bandage is used to secure the soft gauze and control edema [12,30]. Weight bearing and gait training are delayed for many weeks until healing is achieved. Physical therapy commonly starts soon after surgery and includes range of motion, muscle strength training, and personal self-care. However, protocols are not standardized.

Advantages of the soft gauze dressing claimed in descriptive studies (**Table 1**) include ease of application, low cost, and accessibility to the wound. Disadvantages of soft dressings, based on descriptions from case series or other reports and descriptive studies, include—

1. Application of the elastic wrap can generate high local or proximal pressures that impair skin survival and healing.
2. A tendency for the gauze wrappings to loosen and fall off.
3. An increased likelihood of knee flexion contracture.
4. Prolonged bedrest or limited mobilization may be required for pain control, which could increase hos-

pital stays and heighten the risk of pulmonary complications, strokes, and pneumonia.

5. Higher health care costs because of extended hospital stays [7,16,46,51].

Data from controlled trials (**Table 2**) found that for soft dressing strategies, frequency of uncomplicated healing rates, postoperative pain, eventual use of a prosthesis (**Table 3**), and mortality were not significantly different when compared with other types of dressings [12,30,45–48]. Data documenting the health and financial impact of complications and disadvantages are not well presented.

Management of the postoperative amputee with simple soft dressings is commonly viewed as the least expensive and time-consuming strategy. However, when a cost-benefit analysis is considered, the initial savings in cost must be balanced with complications that many believe are potentially preventable. For example, because of the short mechanical lever that remains after TTA, knee flexion contractures do occur. The patient who develops a severe contracture often cannot be fitted with a prosthesis. When soft dressings are used, knee contractures might be minimized with prompt physical therapy and the use of a knee immobilizer. The effectiveness of these strategies is not well documented in the current literature. Years of experience have also shown that attention to correct wrapping technique is vitally important to prevent the complications of residual-limb pressure damage, overaggressive proximal compression, and tissue strangulation [12]. The incidence of complications related to wrapping and elastic bandages is not well documented.

#### *Thigh-Level Rigid Dressings with No Immediate Prosthesis*

Thigh-level rigid dressings usually begin with an inner soft gauze dressing, a postoperative residual-limb sock, varied amount of soft cast padding, polyurethane or felt pads on the tibial flare regions, and a reticulated foam end pad. These materials are carefully applied, and then a plaster cast is rolled and molded in the final step [15,41]. The rigid cast dressing is changed on a variety of protocols, ranging from every 5 days to every 21 days. No consistent physical therapy protocols exists for exercises and weight bearing in the cast or for range of motion of the knee during cast changes. While the simple thigh-level rigid dressing does splint the knee in extension and protects the residual limb inside the cast, weight bearing and gait training are delayed for several weeks until the wound is healed and a prosthesis can be fitted [33].

Data from descriptive studies (**Table 1**) claim that rigid plaster dressings reduce edema, pain, and healing times; increase tolerance to weight bearing; and enable early ambulation [33,34]. Descriptive studies also report that rigid casts are more difficult to apply, require a skilled surgical or prosthetic team and, thus, cost more than soft dressings [34]. Conclusions about the purported advantages were drawn from descriptive studies with no comparison groups, so one cannot determine whether reductions in healing time, pain, and edema were due to the type of dressing or other characteristics of the patients studied. Golbranson et al.'s descriptive paper discussed the lesions learned with 112 rigid dressings for 100 individual amputees; some patients were treated with rigid dressings alone, and some were treated with rigid dressings with prosthetic attachment and weight bearing. This paper does detail the benefits of a simple rigid dressing in preventing knee contractures, controlling edema, and protecting the residual limb from external trauma [33].

Data from controlled studies comparing thigh-level rigid dressings to soft gauze dressings (**Table 3**) found significantly shorter rehabilitation times, when measured as time to initial gait training [30]. Mooney et al. (**Table 2**) found only 6 percent of thigh-level rigid cast procedures required higher-level revisions compared to 22 percent of soft gauze dressings, but due to the small sample sizes, insufficient power existed to document statistical significance [12]. Other outcomes that were not statistically significantly different for thigh-level rigid dressings compared to other types include frequency of uncomplicated healing, postsurgical pain, eventual use of a prosthesis, time to final rehabilitation, length of hospitalization, or failure rate [12,30,45,47].

#### *Thigh-Level Rigid Dressings with an IPOP*

The difference between the IPOP method and other rigid dressings is that a connector, pylon, and foot are immediately attached to the cast in the operating room [15,17,25,52]. The addition of the pylon and foot converts a rigid dressing cast to a postoperative prosthesis. Early weight bearing can begin once the cast is dry (12 hours), and thus gait training can begin more rapidly than when a rigid dressing with no immediate prosthesis is used.

Benefits of the IPOP, in descriptive studies (**Table 1**), include a low percentage of significant limb complications, few surgical revisions, and a short time period to custom prosthesis fitting [36,38,40,42]. Kihn et al. and others also described that patients were emotionally less troubled post-

operatively because the presence of a prosthetic foot aided in self-imaging [38,39,53]. Several descriptive studies also claimed that the IPOP method resulted in less pain, reduced edema, and reduced rehabilitation times from 9 days to 7 weeks [16,38,40]. Rehabilitation failure with an IPOP has ranged from 9 to 36 percent [16,37,39,41]. Disadvantages include reduced access for wound inspection, tissue necrosis because of incorrect wrapping of the gauze bandage, possible mechanical tissue trauma inside the cast, and the requirement of a skilled prosthesis team [17,46,54]. However, once again, these claims were from descriptive studies with no comparison groups.

Experts also have failed to agree on the impact of weight bearing on early wound healing. Opinions vary from the beneficial aspects of controlling edema and stimulation of circulation to the detrimental aspects of excessive loading damaging fragile new tissue and harming the healing response [15–17,36–42]. Unfortunately, there are no standard protocols for the amount, time, and advancement of weight bearing. The published studies use many different weight-bearing protocols, and often, an individual study will discuss modifications in the study group.

Apparently, the patient populations differ greatly among the published descriptive IPOP studies. These studies did not measure or control for comorbid conditions, and the mortality range varied widely from 0 to 20 percent. Moore et al. reported a 0 percent mortality in his study of 20 patients, Jones and Burniston reported 8 percent in their study of 170 patients, and Warren and Moseley cited a 20 percent mortality in their study of 10 patients [36,37,41].

Evidence from comparative trials do not support the claims cited in the descriptive studies using IPOP. No statistically significant differences were found in any of the variables listed in **Table 2** when the IPOP procedures were compared with any other type of dressing or management strategy. Several reviews of TTA caution that the IPOP dressing procedure can lead to severe problems and that rigid cast methods require extensively trained professionals. One editorial stated, "Unskilled application could lead to disaster" [55]. The only evidence comes from one study, which, upon closer examination, does not support its flamboyant title [46]. Cohen et al. found that patients who were managed with IPOP had a lower rate (44 percent) of 1° wound healing when compared to patients managed with soft dressings (89 percent) [46]. However, in this study of 97 patients, only 9 were TTA-managed with IPOP, and 4 of these 9 patients were burned when the plaster casts were mixed with water that was too hot.

Cohen et al. concluded that a deleterious effect of rigid dressing was tissue damage caused by the procedure. Interestingly, most studies using rigid plaster casts with IPOPOP have not reported adverse reactions.

For patients with vascular disease, some studies have cautioned against the use of IPOPOP too early in the healing process, possibly because residual-limb trauma could be caused by early ambulation, resulting in failure at the transtibial level [54]. No controlled studies actually have supported this warning with detailed evidence.

### *Short Removable Rigid Dressings*

Wu et al. blended available techniques to create a removable rigid dressing that was shorter than the typical thigh-level dressings and combined a rigid dressing with a polyvinyl-chloride (PVC) pipe to form a pylon unit and attach a prosthetic foot [19,56]. Their technique provided a transition between molding the residual limb and using preparatory prostheses. This technique resulted in a lighter-weight interim prosthesis that took less than 2 hours to fabricate and enabled patients to move about easier. No descriptive studies have provided outcome data using the short removable rigid dressing. Dr. Wu et al.'s 1979 paper highlights some of the difficulties in reaching evidence-based conclusions from the current literature [18]. This paper reports a large reduction in the time to healing from 109.5 days for a soft dressing protocol down to 46.2 days for the removable rigid protocol. In review, however, the exact time to wound healing is difficult to analyze because the time to ordering the temporary prosthesis was used as the primary determinant of healing time. Time to ordering the prosthesis is subject to other influences and variables besides wound healing. Also, more detailed statistical information, such as standard deviations and *p* values, were not published.

Of the two controlled trials with short removable rigid dressings, one did find a significant advantage of this technique over soft gauze dressings. Mueller found that the removable rigid cast resulted in significantly less edema (**Table 2**) compared to soft gauze dressings [14].

### *Prefabricated Pneumatic Prostheses*

Prefabricated pneumatic prostheses are similar to previous IPOPOP methods but use either air cells that line the socket or an air-bag system to surround the residual limb. The pneumatic portion is applied over standard gauze dressings and can be inflated to between 20 mmHg and 40 mmHg to apply external compression to the resid-

ual limb. The pneumatic support can be thigh-high or only below the knee. For the shorter systems, an attachment can be added to splint the knee in extension to prevent knee flexion contractures [20,43,57].

Earlier versions were made with the use of a rigid cast with pneumatic air bladders, but contemporary models usually comprise a single plastic prosthetic unit that fits over one or more pneumatic air bags. This postoperative strategy was developed to improve the rigid cast with IPOPOP while maintaining its advantages (including the ability to splint the knee, protect the end of the limb from trauma, and allow earlier weight bearing).

Three design waves are highlighted by the work of Little in 1970 in Australia [28], by the description of the Jobst Softstem prosthesis by Pinzur et al. in 1989 [44], and finally by the AirLimb system by Schon et al. in 2002 [20]. Since each of these three designs has different features, concluding which type is more advantageous for particular patient characteristics is difficult. All the design developments are reported to be superior to the rigid cast with IPOPOP: they are lighter weight, have more controlled compression of the limb to minimize edema, have a removable prosthesis to allow wound inspection, and can be used as a provisional prosthesis while the residual limb matures. Because these systems are prefabricated, they might reduce the need for highly trained staff that may be necessary for other techniques [52,54,57].

Schon et al. found that significantly fewer patients managed with a prefabricated pneumatic IPOPOP had postoperative complications (16 percent) when compared to patients managed with soft gauze dressings (65 percent) [20]. Not surprisingly, the same study found that patients with a pneumatic IPOPOP required no higher-level revisions, while 44 percent of the patients with soft dressings required higher-level revisions [20].

## DISCUSSION

Examination of the results of the controlled studies shows very few statistically significant differences in clinical outcomes by dressing type. Baker et al. found that patients managed with a thigh-level rigid cast had a significantly shorter rehabilitation time compared to patients managed with soft dressings [30]. Mueller found a statistically significant reduction in limb volume in patients managed with a short removable rigid cast when

compared to those patients managed with only soft gauze dressings [14]. Schon et al. found that the prefabricated pneumatic prosthesis had significantly fewer postoperative complications and fewer required higher revisions [20]. These controlled studies all have large variations in healing ability, surgical technique, and functional levels of the patients. This variation makes it difficult to reach statistically significant conclusions other than the few just described.

Most of the claims reported in descriptive studies were not statistically proven by the evidence and data of controlled trials. Despite the commonly held belief that pain is reduced in patients with rigid dressings (reported frequently in descriptive studies), the controlled trials did not support the conclusion. Two studies compared the amount of postoperative pain by measuring the quantity of pain medication taken, but neither found any significant difference in pain reported by patients managed with rigid casts (with or without IPOP) when compared to patients with soft dressings [45,48]. These data contradict anecdotal evidence that rigid dressings result in less pain [38]. The lack of a statistical difference in these two studies may have been due to a lack of power resulting from a small sample size (27 and 52 patients, respectively), or the method used to quantify pain may not have been sufficiently sensitive [45,48]. Future studies should use more sensitive pain questionnaires instead of relying solely on the amount of pain medication taken [3,58–61].

Two of the three studies that reviewed postoperative complications (residual-limb infections, bruising, burns, wound breakdown, necrosis, or ulceration) did find lower rates in patients managed with rigid casts with IPOP when compared to patients with either soft dressings or rigid casts without IPOP [17,20]. One study found a higher percentage of complications in rigid casts with IPOP [48]. However, only one of these studies found a statistically significant difference [20]. A similar situation emerged when we considered studies that analyzed required higher-level revisions. Three of the four studies reported fewer revisions were needed for patients with an IPOP [12,17,46], but in only one study was the difference statistically significant [20].

The published literature on pneumatic postoperative devices is generally quite supportive, but it tends not to discuss some of the potential disadvantages. These potential disadvantages might include expense, bulkiness, possible difficulty with donning and doffing, and controlling weight bearing.

When variables relating to rehabilitation were considered, only a shorter time to the initial period of gait training was found to be significantly less for patients managed with rigid casts when compared to patients with soft dressings [30]. Achieving final rehabilitation (as measured by either the use of a prosthesis, time to ambulation, or fitting of the final prosthesis) was not influenced by the type of dressing management. Other variables previously assumed to be advantages of rigid cast dressings, including fewer falls, shorter hospitalizations, reduced mortality, or less prosthetic failures [12,17,20,30,45–48], did not show a significant difference in these small comparative studies.

The current literature primarily is descriptive and does not provide sufficient evidence to support clinical decisions of (1) when to fit a cast with a prosthetic and (2) when to begin weight bearing, especially in patients with peripheral vascular disease. The literature examines the use of IPOP in patients with peripheral vascular disease and most suggest caution and frequent monitoring, but this has not prevented the use of IPOP in this population [17]. A surgeon's experience with a specific procedure is invaluable but has not been adequately documented in the literature.

Since the 1960s, the national leaders in amputation surgery and rehabilitation have been strong proponents and educators in the thigh-level IPOP system. Despite educational classes, training workshops, and courses, this system has not been universally adopted. In medical care centers where specific training programs or research has been established, the IPOP system has been perceived as beneficial. Many centers continue to use this system enthusiastically. Unfortunately, the scientific support for all the benefits of IPOP is lacking to date.

None of these studies provided data on total health care use or health care costs related to the postoperative rehabilitation period. If the main effect of rigid dressings (with attached prosthesis) is to decrease the time until full rehabilitation is reached and patient discharge, the cost savings could be substantial.

Further controlled, randomized studies are needed to directly compare different types of post-TTA management strategies. This will not be easy. Future studies will need to consistently define their outcome measures, detail rates, and the impact of complications; use a more sensitive measure of postoperative pain; and quantify any savings of health care use and rehabilitation costs. As highlighted earlier, postoperative dressing and management strategies

are not the only determinant of outcome, and other variables might have a greater impact on outcome. Future studies need to more accurately document and control for variables such as amputation-level selection, surgical skill and technique, healing potential, comorbidity, nutrition, immune status, and functional ability.

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Included in the on-line version only is an abstract painting by Lynne V. McFarland, PhD, entitled "View from a Prosthesis Engineer's Bench," depicting prosthesis and dressings parts from the different types of post-amputation dressing strategies. Its inspiration came from a series of abstracts, spotlighting the contribution of engineers to the applied research of rehabilitation.

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