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ORIGINAL CLINICAL ARTICLE

Transtibial Ertl amputation for children and adolescents: a case series and literature review

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Abstract
Purpose Despite advances in limb reconstruction, there are still a number of young patients who require trans-tibial amputation. Amputation osteoplasty is a technique first described by Ertl to enhance rehabilitation after trans-tibial amputation. The purpose of the study reported here was to evaluate the results of the original Ertl procedure in skeletally immature patients and to assess whether use of this procedure would result in a diminished incidence of bony overgrowth.
Methods The cases of four consecutive patients (five amputations) treated between January 2005 and June 2008 were reviewed. Clinical evaluation consisted of the completion of the prosthesis evaluation questionnaire (PEQ) and physical examination. Radiographic analysis was performed to evaluate bone-bridge healing, bone overgrowth, and the development of genu varum as measured by the medial proximal tibial angle (MPTA).
Results The best mean PEQ score in the question section was 91.8 (range 74–100) for 'well being' and the worst mean score was 66.6 (range 50–78) for 'residual limb health'. Examination of the residual limbs revealed no bursae, and all knees were stable with full range of movement. All bony bridges united at an average age of 1.7 (range 1–2) months. One case required stump revision for bony overgrowth, and one case developed asymptomatic mild genu varum.
Conclusions The original Ertl osteomyoplasty may serve as one of the options for treatment of trans-tibial amputation in older children.
Clinical relevance Our results suggest that the Ertl osteomyoplasty is a feasible option in this challenging patient population.

Keywords Ertl osteomyoplasty · Child amputation · Stump overgrowth

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Introduction

Despite all the advances in limb reconstruction techniques for trauma, congenital deformity, and tumors, a small group of young patients still require trans-tibial amputation [1–3]. The Ertl osteomyoplasty procedure is a technique which aims to optimize end weight bearing prosthetic use, reduce the problems of stump force mal-distribution and disuse, and, in the young patient, potentially reduce the rate of stump overgrowth requiring revision surgery if a Symes amputation is not possible [4–7]. Use of the original Ertl procedure in reducing stump overgrowth has not been described in the pediatric literature. In contrast, modifications of the Ertl procedure have shown little if any benefit in preventing stump overgrowth [8–10].

The purpose of the study reported here was twofold. The first was to evaluate the clinical and radiographic results of this procedure in skeletally immature patients. Our hypothesis was that the original Ertl procedure would result in good clinical outcomes, especially in terms of prosthetic use and overall function, at a minimum 3-year follow-up. The second was to evaluate whether the use of the original Ertl procedure would result in a diminished incidence of bony overgrowth compared to other trans-tibial amputations.

Methods

Four consecutive patients treated between January 2005 and June 2008 with five Ertl trans-tibial amputations were enrolled in the study. Medical records and radiographs were reviewed retrospectively after institutional review board approval was obtained. The Ertl procedure was performed as the initial amputation in one case (trauma) and as revision surgery in four cases due to stump overgrowth (three meningococcal infections and one trauma). All procedures were performed by the senior author (KK). Follow-up X-rays were done every 2 weeks for the first 6 weeks and monthly thereafter until the bone bridge united. Follow-up was performed at a mean of 49.2 (range 36–60) months. Table 1 summarizes the clinical details of the five cases.

Surgical technique

The operation was performed according to the original procedure described by Ertl [4]. A tourniquet was applied to the thigh. Subperiosteal exposure of the bony portions of the residual tibia and fibula were performed, with attached bony flakes. Care was taken to preserve the entire periosteum in continuity. Appropriate shortening of the tibia and fibula was performed. The canals were opened as required to ensure medullary continuity. Vessels were suture ligated individually. The nerves were then injected with local anesthetic and sharply cut back to avoid neuromas. The periosteal sleeve, including chips of attached cortical bone, was fashioned to enclose the exposed distal bone ends, allowing continuity between the medullary canals in an attempt to obtain a closed intramedullary cavity. This periosteal sleeve was filled with autologous cancellous bone graft. A careful myoplasty was performed to achieve firm coverage of the distal stump. The fascia and muscle were closed as one layer. The skin was closed with interrupted non-absorbable sutures as a separate layer in fish-mouth fashion over a drain. An above knee plaster cast was applied in extension. The cast was removed at 2 weeks post-surgery for a wound check and suture removal. The leg was then splinted until the prosthesis could be applied. The post-operative rehabilitation program and prosthetic fitting was identified as a vital role in managing these patients. Each patient was seen by the rehabilitation team consisting of an orthopedic surgeon, a physiatrist, a physiotherapist, and a prosthetist. An active protocol, which was specific for patients with a trans-tibial osteomyoplastic amputation, was adhered to. The core differences of this rehabilitation compared with that for standard transtibial amputations are (1) minimal compression of residual tissues, (2) active muscle contraction of the most distal stump muscles, and (3) progressive end weight bearing and mechanical therapy to reduce mechanical pain [11].

Clinical assessment

The clinical evaluation consisted of the completion of the prosthesis evaluation questionnaire (PEQ) and physical examination. The PEQ is a validated questionnaire consisting of 82 questions divided into seven sub-sections [12]. From the 41 questions within these seven sections, nine validated scales are created (Table 2). Each scale comprises multiple related questions with a visual analog scale

Table 1 Clinical summary of patient population

Case and side	Gender	Diagnosis leading to original amputation	Age at initial amputation (years)	Age at Ertl (years)	Number of stump overgrowths requiring surgery up until Ertl procedure	Time to union after Ertl (months)	Number of stump overgrowths requiring surgery after Ertl procedure	Follow-up (months)	Complications
1 (right)	Male	Trauma (lawn mower)	10.5	10.5	1	2[b]	0	36	Early infection
2 (left)	Male	Trauma (lawn mower)	3.6	6.9	1	1	0	44	–
3 (right)	Male	Meningococcemia	1	14.7	2	1.5	0	46	–
4 (right)[a]	Female	Meningococcemia	1	6.2	1	2	0	60	–
5 (left)[a]	Female	Meningococcemia	1	6.2	3	2	1	60	Overgrowth
Mean (range)			3.4 (1–10.5)	8.9 (6.2–14.7)	1.6 (1–3)	1.7 (1–2)	0.2 (0–1)	49.2 (36–60)	

[a] Same patient with bilateral Ertl amputations

[b] Patient united 2 months after modified Ertl performed 26 months after removal and revision of acutely infected Ertl stump

Table 2 Results of the prosthesis evaluation questionnaire (PEQ) scale

PEQ scales	Patient one	Patient two	Patient three	Patient four	Mean
1. Ambulation	97	71	97	91	89.2
2. Appearance	93	86	79	55	78.8
3. Frustration	100	71	81	100	88.5
4. Perceived response	96	78	85	100	89.5
5. Residual limb health	78	66	70	50	66.6
6. Social burden	97	63	90	96	86.7
7. Sounds	82	77	22	100	71.4
8. Utility	88	67	80	74	78.1
9. Well being	99	74	93	100	91.8

format (0–100), where 0 = maximal pain or maximal dissatisfaction and 100 = no pain or maximum satisfaction [13]. During the physical examination, the condition of the residual soft tissues, knee range of movement, and stability were recorded.

Radiographic assessment

Radiographic analysis consisted of antero-posterior and lateral views of the distal tibia to evaluate bone-bridge healing, bone overgrowth, spurs, spikes, and myositis ossificans (MO). All three authors reviewed the radiographs at the final follow-up. The medial proximal tibial angle (MPTA) was measured on the latest radiograph, using the mid portion of the tip of the distal tibia in lieu of the center of the ankle joint.

Results

Clinical assessment

The highest mean score on the PEQ scale was 91.8 (range 74–100) for the sub-section 'Well being' and the lowest mean score was 66.6 (range 50–78) for the 'Residual limb health' sub-section (Table 2). Patients scored a mean of >80 in the following sub-sections: 'Ambulation', 'Frustration', 'Perceived response', 'Social burden', and 'Well being'. All patients had minimal residual pain. Three patients experienced pain once a month. One patient experienced pain once a week, but was able to work as a manual laborer. For all patients, the pain was never sufficient to hinder prosthetic use.

Examination of the residual limbs revealed that no bursae were present and that all knees were stable with a full range of movement. The patient with bilateral amputations secondary to meningococcemia had a healing skin blister which developed after a fall while using her prostheses. At the time of the physical examination, she had not been using her prostheses for 1 week and her skin was healing well.

Radiographic assessment

All bony bridges united at an average age of 1.7 months (range 1–2). Myositis ossificans did not occur. Only one of the five cases required stump revision for bony overgrowth. One patient developed asymptomatic mild genu varum with an MPTA of 83° (Table 1; Fig. 1).

Discussion

The Ertl procedure has a number of potential advantages over a traditional trans-tibial amputation. It promotes the maintenance of tissue with better sensation, proprioception, and blood flow, potentially resulting in improved end weight bearing and less pain, with more hours of functional prosthetic use [14, 15]. Ertl [4] described a procedure that resulted in a bony synostosis between the distal weight bearing ends of the tibia and fibula through the construction of an osteoperiosteal tunnel between the distal ends of transected long bones, using local or distant cancellous bone graft to fill the periosteal tunnel. It was felt that the resulting amputation was more stable by avoiding discomfort from unstable pathologic motion of the fibula and increasing the surface area available for dissipating the mechanical load associated with weight-bearing [16]. In a review by Pinzur et al. [5], 32 patients with an Ertl procedure were compared to highly functional patients who had had standard trans-tibial amputations. Those who had had the Ertl procedure scored higher in the 'Ambulation' and 'Frustration' scales of the PEQ but lower in the 'Appearance' scale. In our study, the patients scored a high mean of 89.2 in the 'Ambulation' scale and 88.5 in the 'Frustration' scale. The 'Appearance' scale scored third lowest but with a relatively high mean score of 78.8. Based on the results of a subsequent study, Pinzur et al. [17]

Fig. 1 **a, b** One-month radiographic assessment of post-Ertl osteomyoplasty for stump overgrowth showing signs of early union (Table 1, Case 3). **c, d** At the 45-month follow-up the bone bridge has reached maturation with normal alignment and good functional outcome

suggested that some of the perceived benefit after revision surgery with an Ertl procedure was in fact due to the improved soft tissue envelope and not from the Ertl procedure itself. The Ertl osteomyoplasty involves not only bony bridge formation, but also a prescribed myoplasty which is supported by the underlying bridge. The perceived benefit may well be partly due to the myoplasty in which agonist and antagonist muscle groups are utilized to maintain appropriate tension and bulk without direct forces being applied to the bone end, as in the traditional trans-tibial amputation. One of the weaknesses of our study is that direct comparison with standard trans-tibial amputations was not performed.

Osseous overgrowth is a well-known complication of trans-tibial pediatric amputations. Such overgrowth can be periosteal, endosteal or heterotopic in origin [18]. Periosteal and endosteal overgrowth occur mainly in a cone shape at the tip of the stump with a sharp spike, by local appositional overgrowth of the bone in skeletally immature patients [19, 20]. This may lead to skin perforation, pressure ulcers, and difficulties with the prosthesis [21]. In our series, all five cases were revision surgeries for stump overgrowth following standard trans-tibial amputations. O'Neal et al. [18] found stump overgrowth in 27% of their population requiring revision surgery in a population of 132 pediatric amputees at an average age of 10 years. This increased to 42% for diaphyseal amputations requiring revision surgery for overgrowth. These authors sited age, level, anatomic location, and modes of amputation as the reason for this discrepancy. These figures are higher than those of Abraham et al. [22] who showed an incidence of 18.5% overgrowth requiring revision surgery for acquired trans-tibial amputations (compared with 4% for congenital amputations). Patients over the age of 12 years or those requiring disarticulation did not require revision surgery. Our patient with stump overgrowth at 9.7 years of age (case incidence 20%), 3.5 years after the original Ertl osteomyoplasty, compares favorably with these results. Several operative methods have been proposed to prevent stump overgrowth, including distal resection, proximal epiphyseodesis, capping of the bony stump using epiphyseal transplants or foreign materials [silicon, polyethylene or polytetrafluoroethylene (PTFE) felt pads], and prolonged skin traction [20, 23–28]. The results, however, have been variable. Tenholder et al. [20] used PTFE end caps in 17 limbs with a 29% failure rate requiring revision surgery for three infections and two painful bursae. They noted that PTFE end caps are better used in the upper limb. Other complications of prosthetic caps include fracture, loosening, and overgrowth. Although the Ertl osteomyoplasty has been used extensively in adults [29], there are only two reports in the literature that analyze the results of Ertl-type procedures in a pediatric group. Barber [8] reported on a mixed pediatric and adult population who underwent synostosis of the distal tibia and fibula without periosteal sleeve reconstruction. The lack of periosteal sleeve, a deviation from the original Ertl technique, may increase the risk of terminal overgrowth. Anticipating overgrowth of the fibula in children, Barber [8] cut the fibula shorter than the tibia. He reported good results using this procedure, especially in terms of prosthetic use. Drvaric et al. [9] found an unacceptably high rate of stump recurrence requiring revision (5/7 cases) at an average time of 36 months following a modified Ertl osteomyoplasty using a fibular oblique strut graft for the distal bone bridge technique. Their patients included three congenital constriction bands, one septic embolus, one meningococcemia, and one chronic osteomyelitis [9]. The use of an oblique strut graft is not recommended as it violates the principles inherent to a traditional Ertl procedure, namely, bony synostosis between the distal weight bearing ends of the tibia and fibula through the construction of an osteoperiosteal tunnel with increased end weight bearing potential. Our study is the first series showing that the original Ertl

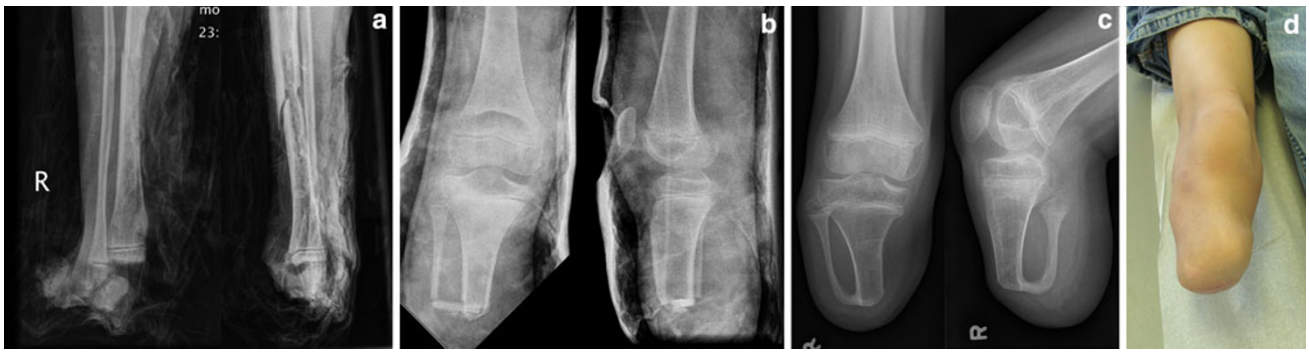

Fig. 2 **a** Radiograph following lawnmower injury and partial amputation of the leg in a 10.5-year-old male (Table 1, case 1). Subsequent deep infection developed following guillotine amputation and Ertl osteomyoplasty, performed within 24 h of injury, requiring debridement and removal of the bone bridge. **b** Immediate post-operative radiographs post-revision Ertl osteomyoplasty at 26 months after the initial injury for stump overgrowth, using iliac crest graft and attached periosteal sleeve. **c** Good bone bridge between tibia and fibula without overgrowth at the 36-month follow-up but asymptomatic genu varum (medial proximal tibial angle 83°). **d** Clinical appearance at follow-up shows healthy residual limb

procedure can be used with good effect to minimize the risks of stump overgrowth in children (1/5 cases). No notch-plasty or fibular graft was used. A periosteal tunnel filled with bone graft was reconstructed to allow the bone bridge to develop. The results obtained using this technique are promising, with only one of five cases requiring revision surgery after an average of 49.2 months of follow-up. We hypothesize that this good outcome may be a result of the bone graft within the periosteal envelope forming a larger, more rounded weight bearing area, with maintenance of intramedullary pressures, resulting in fewer episodes of bone overgrowth, requiring revision surgery.

The other potential complication of the Ertl procedure is the development of genu varum after tibio-fibular synostosis. Segal et al. [30] presented 13 cases of genu varum following a modified Ertl procedure in ten of these cases. This study raised awareness of this potential complication, but the authors did not report its overall incidence. The mean age at the time of traumatic amputation in these patients was 4.5 years, with a mean age of 14.9 years at the time of revision for tibia vara. In our series, there was one case of asymptomatic mild genu varum which has not required revision surgery (Table 1, case one). The case involved a 10.5-year-old boy who sustained a traumatic amputation and underwent an initial guillotine amputation followed by an Ertl osteomyoplasty within 24 h of his injury. This became septic and required excision of the osteomyoplasty. He was converted to a revision Ertl osteomyoplasty amputation after bony overgrowth 26 months later, using an iliac crest bone graft with medial table iliac crest periosteal sleeve attached. This went on to unite uneventfully 2 months later. Final follow-up at 36 months revealed a well-united bone bridge with no evidence of bony overgrowth but asymptomatic genu varum with an MPTA of 83° (Fig. 2a–d). Segal et al. [30] showed that age at amputation was an important factor in the subsequent development of genu varum. Nine of their eleven cases were under the age of 5 years. This may be partly the reason why the current series had a low incidence of genu varum as the mean age at surgery was 8.9 years. Contributions to growth of the proximal and distal tibia and fibula growth plates are not identical and this may contribute to the development of genu varum following distal tibia-fibula synostosis in very young patients [31]. Vigilance is required to monitor younger patients following an Ertl osteomyoplasty. Genu varum can be addressed in the setting of a distal tibia-fibular synostosis with proximal hemi-epiphysiodesis, which eliminates the need for stump revision and its potential complications.

The two major limitations of this study are the medium-term follow-up (mean 49.2 months) and the small number of patients (five cases). Despite these limitations, however, this series is unique in that it reports the outcome of the original Ertl procedure performed on children in a number comparable with that presented in recent reports (Fig. 2a–d).

In conclusion, the original Ertl osteomyoplasty, although associated with the potential risk of overgrowth and development of tibia vara, may serve as one of the options for the treatment of trans-tibial amputation in older children.

Conflict of interest None.

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