Neuromuscular Electrostimulation Device Reduces Preoperative Edema and Accelerates Readiness for Theater in Patients Requiring Open Reduction Internal Fixation for Acute Ankle Fracture

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Abstract: Significant edema manifests as soft tissue swelling that can delay surgery in patients with ankle fractures. Interventions that expedite swelling reduction may yield clinical and economic benefits. This case-control pilot study aimed to assess the ability to recruit ankle fracture patients to a prospective study using a neuromuscular electrostimulation (NMES) device. Device effectiveness, safety, and patient acceptability were also assessed. Prospective evaluation of 20 patients admitted for ankle fracture fixation with the application of NMES device to the skin just below the knee (intervention arm). Participants were matched for baseline demographics and injury descriptors to a historical operative cohort (control arm). The time until the swelling had settled to a level permitting surgery ("readiness for surgery") was recorded alongside patient tolerability and device acceptance. The mean time until swelling reduced to a level permitting surgery was 1.66 days (NMES) versus 3.66 days (control) ($P = 0.001$). Overall 60% of participants were ready for theater after 2 days of treatment with the NMES device compared with 27% in the control group ($P < 0.01$). Independent health economic modeling of this scenario suggests that the savings associated with this accelerated readiness for theater is £569 per patient. The NMES device is safe and well tolerated by patients with ankle fractures. It is easy to apply, can be worn continuously, and does not restrict patients to their bed space. This study suggests that it is effective in reducing ankle edema and accelerating readiness for theater and may therefore allow earlier surgery and reduced length of stay in this patient group.

Level of Evidence: Diagnostic Level 3. See Instructions for Authors for a complete description of levels of evidence.

Key Words: ankle, surgery, swelling, transcutaneous electric nerve stimulation, trauma

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Ankle fractures comprise 9% of all orthopedic fracture referrals and ~15,000 cases are surgically treated every year in the United Kingdom.[1,2] Indications for fixation include actual or potential fracture displacement with associated talar shift and loss of joint congruency.[3] Soft tissue swelling secondary to edema resultant from tissue disruption at injury can delay surgery because of concerns about potential wound breakdown.[4] Delay in fixation may increase hospital stay, result in a higher risk of generic complications of recumbency, and lower levels of patient satisfaction.[5,6]

Various strategies are in use to decrease swelling in patients with ankle fractures with no "gold standard" treatment. "Passive" methods such as leg elevation and ice therapy and "active" interventions such as arteriovenous foot pumps (AVFP) and intermittent pneumatic compression (IPC) devices have all been described.[7–11] A recent systematic review on the use of AVFP and IPC devices suggested that although there was some evidence that these devices reduce time to surgery and degree of swelling before the operative intervention, the overall strength of evidence to support their use is poor.[12]

The NMES device (Fig. 1) used in this study offers an alternative to traditionally used AVFP and IPC devices. It is applied to the skin just proximal to the patient's plaster cast overlying the common peroneal nerve (Fig. 2). Neuromuscular electrostimulation (NMES) of the nerve activates the calf and foot muscle pumps of the lower leg that return blood towards the heart mimicking the process observed when walking.[13] By activating the muscle pump, intermittent pressure is created within the veins, interstitial, and lymph system. This augments venous and lymphatic return. It has been shown to reduce edema in a range of traumatic and nontraumatic settings,[14,15] including ankle sprain[16] and has been found to be safe and effective in a systematic review,[17] with no reported adverse incidents.

The primary aim of this study was to evaluate the ability to recruit ankle fracture patients to a prospective study utilizing the NMES device within a major trauma center. Secondary aims were to: (a) assess time until swelling reduced permitting surgery for patients requiring ankle fixation when treated with NMES compared with data from matched retrospective controls and (b) assess the safety and tolerability of the NMES device in this population.

METHODS

This study was a single-center, feasibility, open-label comparison of a prospective cohort of patients treated with the NMES device against a retrospective matched control group. The prospective cohort allowed assessment of the feasibility to recruit ankle fracture patients to a study utilizing the NMES

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FIGURE 1. The geko device.

device (primary aim) in addition to assessing the safety and tolerability of the NMES device in this patient population (secondary aim). Matching to a retrospective control group allowed for preliminary assessment of the effectiveness of the NMES for the treatment of preoperative ankle edema in patients awaiting surgery for an ankle fracture (secondary aim).

Prospective Cohort

The prospective cohort included 20 consecutive consenting patients with ankle fractures requiring surgical fixation presenting to the trauma service of a major trauma center. Eligible participants were recruited between July 2016 and January 2017. Inclusion and exclusion criteria are described in Table 1. All participants consented into the study before the application of the NMES device.

Patients were approached at the point of admission to the trauma ward. Initial care in the emergency department followed standard practice (initial x-ray, fracture reduction if needed, application of plaster backslab, repeat x-ray in the cast to confirm satisfactory reduction and fracture position).

Every patient presenting with an ankle fracture that, in the opinion of the treating surgeon, required surgical fixation was assessed for inclusion in the study. Once consented the participants had their swelling assessed for suitability for theater by an experienced orthopedic surgeon (senior registrar or consultant) by splitting their backslab and the NMES device was then applied. The NMES device was worn continuously from application until theater. Standard care included inpatient admission for bed rest and elevation in the plaster backslab. No other adjunctive measures to reduce swelling (eg, cryotherapy and pneumatic foot pumps) were used for the duration of the study.

Further assessments of ankle swelling were made each morning by the treating orthopedic consultant. This was on the basis of subjective assessment of "readiness for theater" on the basis of their standard practice. This mirrors standard care across the United Kingdom as presently there are no guidelines for the assessment of a patient's suitability for theater after ankle fracture and no standardized method for assessing edema in this patient population. This continued until the patient

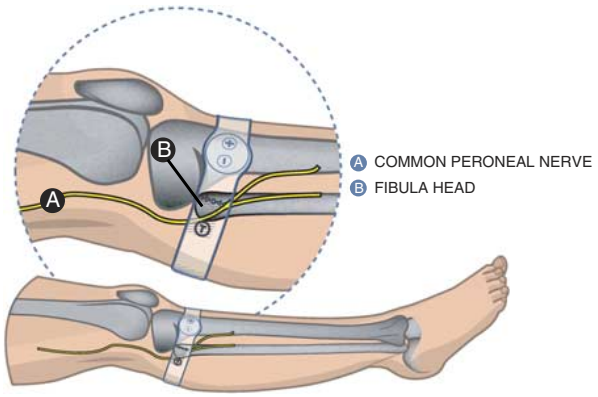

FIGURE 2. The geko device placement.

TABLE 1. Study Inclusion and Exclusion Criteria

Inclusion criteria	Aged 18-60 y old
	Clinically and radiologically diagnosed acute ankle fracture that, in the opinion of the treating surgeon, requires operative fixation
	Able to understand the patient information sheet and willing to sign the written informed consent form
	Able and willing to follow the protocol requirements
Exclusion criteria	Has a pacemaker
	Morbid obesity (BMI $>40\ kg/m^2$)
	Patients who on presentation to the hospital are known to be pregnant
	Clinically significant comorbidities that need to be treated before surgical intervention and could therefore impact upon time to theater
	History or signs of previous deep or superficial vein thrombosis/pulmonary embolism
	Varicosities, ulceration, or erosion around the area of the leg where the study device would be fitted
	Diabetic
	Already taking part in a clinical study, or has so within the last 8 wk
	Nonresponder to NMES device

BMI, body mass index; NMES, neuromuscular electrostimulation.

underwent surgical fixation. For each participant, the time from admission until their swelling was deemed to be "ready for theater" was noted. This does not always coincide with time to theater and this was separately recorded. Length of hospital stay both preoperation and after surgery was noted. Tolerability of the device was evaluated each morning using a Likert scale (1: no sensation to 5: severe discomfort). Adverse events and device removal for each patient were monitored and recorded. For each patient, the time to surgery from admission and length of hospital stay were noted.

The NMES Device

The geko is a (Conformite Europeene) CE-marked small disposable, internally powered, neuromuscular stimulation (NMES) device that is applied to the skin (Fig. 1). The device is self-adhesive and is applied to the lateral/posterior aspect of the knee. This positioning enables integral electrodes to apply a stimulus to the common peroneal nerve eliciting a twitch of the muscles activating the venous pumps of the leg (Fig. 2).

In the study cohort, the effectiveness of the NMES device was assessed by looking for discernible dorsiflexion of the foot when the impulse was generated.[18] If the T2 (27 mA) device did not generate a satisfactory contraction, then the protocol allowed an R-2 (54 mA) device to be applied. In this cohort, no R-2 devices were used as there were no nonresponders with the T-2 geko device.

Retrospective Matching

To allow comparative analysis each patient from the prospective cohort was retrospectively matched to historical control. Matching was undertaken on the basis of 5 defined criteria: age (±5 y), sex, ethnicity, fracture type (unimalleolar vs. bimalleolar/trimalleolar), dislocated at presentation to hospital (yes vs. no) and the match had to agree for all 5 criteria for it to be valid. Matches were achieved by working back from December 31, 2015 through surgically treated ankle fracture cases treated within the trust. The first valid match was chosen for each case (Fig. 3).

The case notes of all matches were reviewed to confirm they fulfilled both the matching criteria and the inclusion

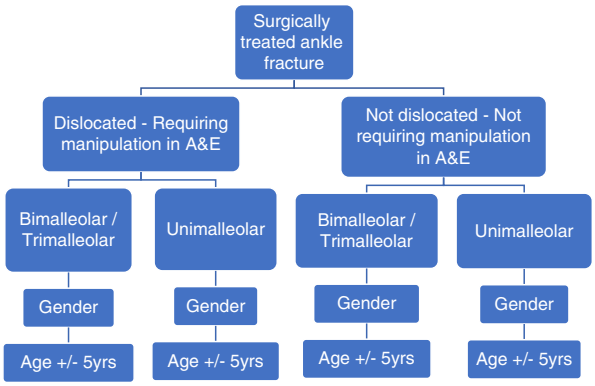

FIGURE 3. Outline of the algorithm used to match historical patients to our prospective cohort.

criteria used within the prospective element of the trial. If they did not fulfill the inclusion criteria, then the next most recent match was identified and similarly assessed. This continued until an appropriate match on the basis of the matching algorithm and fulfillment of the study inclusion criteria was identified. Having identified an appropriate match, the case notes were reviewed for information relating to "readiness for theater," time to theater, and length of stay.

Data Analysis and Statistics

A comparison of readiness for surgery and time to surgery for the study group and the matched retrospective cohort was assessed using the Wilcoxon signed-rank test. Tolerability data for each intervention were collected on discharge, measured using a Likert 1 to 5 scale. Interventions were compared with the Mann-Whitney U test. A P-value of <0.05 was considered to be significant. A formal power calculation was not used as this was a pilot feasibility study with the primary aim of assessing the ability to recruit ankle fracture patients to a prospective study utilizing the NMES device.

Health Economic Analysis

Independent health economic analysis was conducted by Mtech Access Ltd (Bicester) alongside the study to assess the potential savings associated with earlier "readiness for theater." Costs were sourced locally and the only differences between the 2 pathways where the inclusion or exclusion of the NMES device and the respective time from admission to "readiness for theater."

Ethics

The study was ethically approved by the UK Research Ethics Service ref: 16/LO/0380 and before the first participant being recruited the study registered on clinicaltrials.gov ref: NCT02841007.

Funding

This study was sponsored by Firstkind Ltd (High Wycombe, UK). The participants were not reimbursed for participation in the study.

RESULTS

Twenty eligible participants (9 female individuals) of mean age 45.4 years (range, 19 to 64) were recruited over a 6-month period, comprising 14 bimalleolar/trimalleolar and 6 single malleolus fractures. Eleven were dislocated or subluxated at presentation, undergoing manipulation in the emergency department.

TABLE 2. Demographic Details of the Matched Comparison Groups

Variable	All Participants (N = 30)	Retrospective Matched Controls (N = 15)	NMES Group (N = 15)
Mean age	48.4 (±13.0)	49.6 (±13.5)	47.3 (±12.9)
Sex			
Male	16 (53%)	8	8
Female	14 (47%)	7	7
Ethnicity			
White	30 (100%)	15	15
Dislocation			
Yes	14 (47%)	7	7
No	16 (53%)	8	8
Unimalleolar	12 (40%)	6	6
Of which dislocated	4 (33%)	2	2
Bimalleolar/ Trimalleolar	18 (60%)	9	9
Of which dislocated	10 (56%)	5	5
Readiness for theater days, mean (SEM)	2.66 (0.40)	3.66 (0.59)	1.66 (0.37)

NMES, neuromuscular electrostimulation.

Five patients were withdrawn from the study. One participant was treated without an operation after discussion among the surgical team; 4 participants were treated with external fixation by their treating surgeon before the index open reduction internal fixation procedure and details on "readiness for theater" were therefore not available. However, all 4 of the participants who underwent external fixation wore the device for a minimum of 2 days allowing safety and device tolerability data to be collected for these participants. Data matching and subsequent analysis were performed on the remaining 15 participants. The details of the comparison groups are given in Table 2.

Edema, "Readiness for Theater" and Time to Theater

The mean time until the edema had been reduced facilitating a "readiness for theater" was 1.66, with a standard error of mean (SEM) 0.37 days in the NMES group versus 3.66 (SEM 0.59) days in the control group ($P = 0.001$). Overall 60% of participants were ready for theater after 2 days of treatment by the NMES device compared with 27% in the control arm ($P < 0.01$).

Despite earlier "readiness for theater" the time to theater for both groups was similar: NMES group 3.87 days (SD, 0.6) versus control group 4.00 days (SD, 0.7), ($P = 0.89$). In the NMES group, participants waited for a combined total of 2.2 days for theater after swelling had subsided because of the lack of theater capacity which may explain this finding.

Safety and Tolerability

A 1 to 5 scale for the tolerability of the device was used, with 1 = no sensation and 5 = severe discomfort. On the first-day postadmission, 15 of 19 (79%) participants rated the device tolerability as a 2 = minimal sensations, 1 of 19 (5%) as 3 = mild discomfort, 2 of 19 (10%) as moderate discomfort, and 1 of 19 (5%) as severe discomfort. Of the 19 participants fitted with the device, only 1 participant was noncompliant with its use and stopped using it on day 3 postadmission, the remaining 95% of participants wore the device until withdrawal or of the open reduction internal fixation procedure. In the NMES group, there was 1 device deficiency (battery failure). This was replaced with a new device.

Health Economics

Independent health economic modeling of the study outcome ("readiness for theater") demonstrated that the value of reducing the readiness for theater by 2 days compared with the historical control group would save £569 per patient.

DISCUSSION

This study demonstrates that the NMES device is both safe and well tolerated in a group of patients with ankle fractures awaiting fixation. We found that it is possible to recruit ankle fracture patients into a prospective study and rates of patient-related withdrawals because of device issues was extremely low. In addition, within the limitations of the study design, the device demonstrated greater preoperative edema reduction when compared with a retrospective "standard care" control group. On average, patients were ready for theater 2 days earlier.

Ankle fractures are common injuries with a substantial number requiring fixation. Operating in the presence of edema can result in suboptimal soft tissue conditions leading to wound problems. Surgeons often delay surgery to allow edema to resolve with a resultant increase in the length of hospital stay and cost to the health care system.[19,20] In settings where ankle fractures are managed as outpatients after a 7 to 10 day delay, the device can potentially reduce that delay, with the additional benefit of reducing the risk of deep vein thrombosis,[21] and earlier return to work. The NMES device is an adjunct to allow early resolution of soft tissue edema that may consequently help to minimize delays to surgery. In this study, patients treated with NMES were ready for surgery 2 days earlier when compared with a matched historical cohort. However, the *overall* time to fixation in both groups was similar. There are a number of reasons that may explain this finding. First, the time periods in which data on the 2 groups were collected were different. The control group coincided with the early development of the local trauma network, whereas the NMES group occurred once this had been established and came during a period when referrals into the trauma service had increased without an associated expansion in a service capacity. This meant that routine trauma such as ankle fracture fixations were on average waiting longer for surgery because of the clinical prioritization of other fracture types. Delays to surgery were observed even when patients were deemed "ready" because of the competing interests of major trauma cases, hip fractures, and long bone fractures that are all associated with best practice guidelines relating to timing of surgery.[22]

NMES is not the only modality that can influence postinjury swelling. A recent systematic review of established treatment strategies included only 5 comparative studies of which only 1 showed a reduction in time to surgery with the use of either AVFP or IPC devices.[7] Overall compliance with treatment and the patient's tolerability were globally poor. Application of AVFP and IPCs can be time consuming and can require specialist equipment such as compressor pumps that are noisy and restrict patients to their bed space. Their application is frequently delayed because of availability of trained staff, equipment, and requirement for patients to be admitted into a hospital bed. In contrast, NMES can be easily applied as soon as the patients' fracture is stabilized in a backslab. It can be worn 24 hours a day, it does not restrict the patient and could therefore be used out of the hospital. In this situation, patients could be managed at home using NMES to reduce edema before readmission for "day case" surgery. This has the dual advantage of reducing inpatient bed demands and allowing the time of surgery to be planned. In the current study, the NMES device was well tolerated by almost all participants and only 1 patient developed a reaction to the device in the form of a heat rash.

This work was designed as a pilot feasibility study. It was restricted to a small group of patients to ensure compliance, tolerability, and clinical benefit before a larger study is undertaken. We were able to recruit 20 participants within the 6 months and >90% of patients approached to participate consented to their involvement. Despite the nature of the study and the number of participants recruited, the size effect observed for the "readiness to theater" outcome was so large that we were able to demonstrate a significant difference between the groups.

We accept that there are a number of limitations to this work. Inferences made from the study are limited by its design with data collected during 2 different periods of time during which service demand and capacity significantly differed. This is reflected in the difference between the patient being "ready for surgery" earlier, but frustratingly, not progressing to the operating theater at that point. The study design was primarily chosen to assess the feasibility of recruitment alongside device safety and tolerability. A prospective randomized controlled trial would have allowed a more robust comparison between the intervention and control groups while limiting the effects of confounders and bias in this pilot. Furthermore, the use of "readiness" for theater as an outcome measure is limited by its subjective nature. There is a risk of selection bias if the treating surgeon is aware that the patient is wearing an NMES device as was the case in this study.

Measurement of swelling and its perceived impact is a challenge in the acute management of ankle fractures. There is currently no "gold-standard" method to quantify edema in patients with a lower limb fracture stabilized in a plaster. Surgeons rely on subjective assessments such as skin wrinkling, decreased tension of the edematous skin, and resolution of blisters. More objective markers of edema are difficult to implement in this patient population. Circumferential ankle/calf measurement figure of 8 measurements and water displacement are difficult when the leg is supported by a plaster cast unless tape measures are placed within the cast before the application or the cast is removed.[23,24] This is difficult to achieve either because the orthopedic team only becomes aware of the patient once initial reduction and stabilization have been achieved within the emergency department or removal of the cast risks loss of fracture reduction.

This pilot study has established the safe use of the NMES device in perioperative ankle fracture management. There was an improvement in the time to be "ready for theater" because of edema resolution. Patient compliance with the device was good and it was well tolerated. Within the limitations discussed above, the NMES device can be safely used in ankle fracture patients in which soft tissue swelling does not allow immediate surgery or if this is not possible because of other factors such as theater availability. In the United States, the device costs (in the region of US$21 per pair) are covered within a Diagnostic-Related Group (DRG) payment for an ankle fracture. Should the finding of reduced time for "readiness for theater" be confirmed in a further prospective randomized controlled trial, NMES could potentially deliver significant clinical and economic benefits to the patient and their health care team.

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