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Hemodynamic Performance of NMES in the Early Post Operative Period Following Orthopaedic Surgery

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***Abstract*—Patients post total hip arthroplasty (THA) remain at high risk of developing Deep Vein Thrombosis (DVT) during the recovery period following surgery. The use of calf muscle neuromuscular electrical stimulation (NMES) during the hospitalized recovery period on this patient group may be effective at preventing DVT. However, the haemodynamic effectiveness and comfort characteristics of NMES in post-THA patients immediately following surgery has yet to be demonstrated.**

The popliteal veins of 5 patients, who had undergone unilateral total hip replacement surgery on the day previous to the study, were measured using Doppler ultrasound during a 4 hour calf-muscle NMES session. The effect of calf muscle NMES on peak venous velocity and volume flow were compared to resting values. Comfort was assessed using a 100 mm non-hatched visual analogue scale taken before application of NMES, once NMES was initiated and before NMES was withdrawn.

Results of the study showed that NMES produces a beneficial hemodynamic response in patients in the early post-operative period following orthopaedic surgery. This patient group found extended periods of calf-muscle NMES tolerable.

I. Introduction

VENOUS thromboembolism (VTE) is the compound term used to describe the formation of deep vein thrombosis (DVT) followed by its frequent sequela, pulmonary embolism (PE). A DVT is an abnormal blood clot that develops in a deep vein. A dislodged clot can result in damage to the venous valvular system or migrate to the lungs causing a pulmonary embolism. DVT remains a serious concern among hospitalised patients due to its propensity to develop into a fatal PE with death occurring in approximately 6% of DVT cases and 12% of PE cases [1]. In addition to increasing mortality, DVT also prolongs hospitalization and increases health-care costs [2].

Venous stasis is one of the leading causes of DVT. It is defined as the slowing down or stopping of blood flow in the veins and typically arises as a result of long periods of immobility [3]. Venous stasis can be prevented by improving venous circulation. Neuromuscular Electrical Stimulation (NMES) is the application of an electrical stimulus to motor points in the body using electrodes placed on the surface of the skin to elicit a muscular contraction. Contracting the calf muscles increases lower limb blood flow in order to meet the metabolic demands of exercising skeletal muscles [4]. Calf muscle activation compresses the intramuscular and surrounding veins which raises venous blood pressure and forces blood back toward the heart. The increase in lower limb blood flow resulting from activation of the calf muscle pump prevents the pooling and stagnation of blood in the lower limb and hence, prevents venous stasis. NMES could be used in situations of low mobility to artificially activate the calf muscle pump, thereby preventing the stagnation of blood and hence DVT.

Patients post total hip arthroplasty (THA) remain at high risk of developing DVT during the recovery period following surgery despite the availability of effective pharmacological and mechanical prophylactic methods [5]. The restricted hip range of motion and the necessity for bed rest contribute to lack of skeletal muscle pump activity, resulting in reduced venous return of blood from the lower extremities [6]. The use of NMES during the hospitalized recovery period on this patient group may be effective at preventing DVT by artificially activating the calf muscle pump. Previous studies have demonstrated that NMES is effective at increasing popliteal vein blood flow in healthy participants subjected to bed rest and in patients who have previously undergone both hip and knee replacement surgery [7, 8]. Furthermore, it has been shown that NMES does not cause hypersensitivity in patients with metal implants [8]. However, the hemodynamic effectiveness and comfort characteristics of NMES in post-THA patients immediately following surgery has yet to be demonstrated.

II. Objectives

The hypothesis of this study is that the application of NMES to the calf muscles of patients in the immediate hospitalised recovery period following THA will significantly increase venous return. The main objectives are:

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TABLE 1
RESTING AND STIMULATED BLOOD FLOW MEASUREMENTS

#	Start			End			% Delta	Stimulus Intensity (V)	
	Resting	Stimulated	% Difference	Resting	Stimulated	% Difference	NMES Start-End	Operated Leg	Non-operated Leg
				Peak Velocity (cm/s)					
2	-	-	-	19.3±0.4	28.1±10.9	45.09	-	62	55.8
3	-	-	-	12.7±0.4	18.2±3.6	43.14	-	27.9	27.9
4	14.1±0.8	26.9±5.3	91.69	22.4±0.4	26.5±1.5	17.92	-2.00	62	62
5	6.8±0.3	12.9±1.3	90.01	4.2±0.1	7.5±1.1	78.47	-42.35	37.2	37.2
				Volume Flow (ml/min)					
2	-	-	-	104.5±21.1	97.7±5.9	-6.48	-	-	-
3	-	-	-	99.9±7.3	207.5±14.9	107.7	-	-	-
4	73.1±5.4	133.6±15.4	82.8	59.4±5.3	180.4±21.9	203.9	35.07	-	-
5	7.4±3	11.3±1.8	52.6	2.7±0.3	6.5±31.2	135.7	-42.16	-	-

Values for resting and stimulated peak velocity and volume flow are expressed as mean±standard deviation.

1) Determine how well post-THA patients can tolerate an extended NMES session.
2) Determine if applying NMES to patients immediately post-THA increases venous outflow from the lower limb over resting conditions.

III. METHODS

A. Recruitment

Patients who had undergone THA at the Mid Western Regional Orthopaedic Hospital, Croom, Co. Limerick, Ireland on the previous day were recruited for this study. Each patient gave their written informed consent to take part and the study was approved by the Ethics Research Committee at the Mid Western Regional Hospital, Limerick.

B. Equipment Setup

Two surface electrodes measuring 5cm x 5cm PALS (UltraStim, Axelgaard Manufacturing Co., Ltd., CA, USA) were placed over the motor points of the soleus muscles of both legs of consenting patients. NMES was applied using a custom-built, two-channel stimulator (Duo-STIM, Bioelectronics Research Cluster, NUI Galway). The stimulator was programmed to apply a biphasic square-wave of pulse width of 350μs, an inter-pulse interval of 100μs and a frequency of 36 Hz. A comfortable calf muscle contraction was produced using a contraction time of 1s, a ramp up time of 500ms and ramp down time of 500ms which resulted in a slight plantar flexion. A series of test pulses were applied initially at a very low intensity to ensure correct electrode placement and to establish that the patient was comfortable with the sensation of electrical stimulation. The stimulus intensity was then gradually increased until a noticeable contraction was observed for both legs, as indicated by a visible tightening of the soleus muscle or a slight plantar flexion. Once the patient was comfortable with the chosen set of stimulation parameters, the Duo-STIM was set to run for 4 hours. Stimulation parameters were set so that stimulation was applied alternatively to each leg every 30 seconds. Both legs were stimulated despite the patient having only a single operated limb. This is because both legs are susceptible to DVT during unilateral THA [9].

Lower limb hemodynamic performance and patient comfort were the primary outcome measures of the study. Duplex Doppler ultrasound was used to monitor the patients' lower limb hemodynamics using a 4–8MHz linear transducer (LOGIQ e; GE Medical Systems). Hemodynamics were measured on the operated limb from the popliteal vein by placing the probe in the popliteal fossa. The Doppler sample gate size was matched to the diameter of the popliteal vein. Measurements of peak venous velocity (cm/s) and popliteal vein diameter were recorded. The Doppler machine's own software was used to calculate volume flow (ml/min). Each measurement was taken three times for rigour and the mean of the three measurements was used for analysis. At least one minute of rest was allowed between successive Doppler measurements. Doppler measurements were taken initially at rest, before the application of NMES. Doppler measurements were taken once again when the NMES session had commenced and finally, just before the end of the NMES session.

At each of 3 time points (before application of NMES, after application of NMES had begun and at the end of the protocol), comfort was assessed by asking patients to mark their level of comfort using a 100 mm, non-hatched visual-analogue-scale (VAS). A VAS of 30 mm or less was categorised as mild pain, between 31 and 69 mm as moderate pain and scores of 70 mm or greater as severe pain. The minimum clinically significant difference (MCSD) in VAS was set as an increase in scores between test stages of 12 mm [18].

IV. STATISTICAL ANALYSIS

Differences between resting and stimulated peak venous velocity measurements and between resting and stimulated

TABLE 2
VAS SCORES AFTER NMES WAS STARTED AND JUST BEFORE NMES WAS FINISHED

Patient	VAS scores Baseline	Pain category	VAS scores Start	Pain category	Difference Baseline – Start	VAS scores End	Pain category	Difference Start-End
1	3	Mild	20	Mild	17 >MCSD	23	Mild	3
2	4	Mild	4	Mild	0	4	Mild	0
3	12	Mild	7	Mild	-5	10	Mild	3
4	3	Mild	2	Mild	-1	40	Moderate	38 >MCSD
5	70	Severe	74	Severe	4	66	Severe	8

venous volume flow were analysed using a paired-samples t-test. VAS scores were analysed by a repeated-measures analysis of variance (ANOVA). A p-value of <0.05 was considered statistically significant in all cases.

V. RESULTS

Five patients took part in this study (1 male, 4 female). The operated limb of each patient had a considerably reduced range of motion and therefore acquiring consistent blood flow measurements from the popliteal vein was challenging. Blood flow measurements were successfully recorded in 4 out of the 5 patients. Measurements of peak venous velocity, volume flow and the percentage difference between resting and stimulated blood flow are summarized in Table 1. At the end of the treatment session, stimulated peak venous velocities were significantly higher than resting ($p<0.05$). However, stimulated venous volume flow was not significantly different from resting ($p=0.19$). Three of the patients experienced an increase in venous volume flow however, one patient's flow decreased slightly by 6.5%.

Each patient's individual VAS scores are summarized in Table 2 and Fig. 1. The repeated measures ANOVA revealed no differences between the baseline, start and end VAS scores ($p=0.359$). Baseline VAS categorical scores, before the application NMES, indicated mild pain in 4 patients and severe pain in one. When NMES session was started, categorical scores remained unchanged in all patients. At the end of the NMES session, VAS categorical scores remained unchanged in 4 patients, with one patient indicating an increase from mild to moderate pain. This patient's increased VAS score was greater than the MCSD with a reported increase in 38mm. This patient started the session with a very high intensity which was maintained throughout the study. By the end of the study the patient reported that the intensity was no longer comfortable and had caused the calf muscles to fatigue. The patient who indicated severe pain before the application of NMES reported that the surgical site was the source of pain, yet the patient was happy to take part in the study. NMES did not significantly influence this patients VAS score. The same patient reported severe stiffness of the ankle on the operated limb before starting the NMES protocol which was significantly improved by the end of the protocol.

VI. DISCUSSION

This study showed that applying NMES to the calf muscles for an extended period of time on patients in the early post-operative period following THA increased popliteal venous blood flow. All participants easily tolerated the 4-hour NMES duration. VAS scores were in line with previous observations on healthy participants and on patients with metallic hip implants.

In as early as 1964, Doran et al. [10] demonstrated an improvement in venous return when electrical muscle stimulation was applied to the calf muscles of patients compared to when no stimulation was used. Since Doran's study, dramatic improvements in lower limb venous blood flow have been demonstrated in healthy patients with calf NMES resulting in peak velocities of 43-120 cm/s in the popliteal vein [7, 11-14]. More recent contributions to the area of NMES for blood flow assist included the investigation of the ideal pulse repetition rate on ejected blood volume from the lower limb [11] and the benefits of targeting the peroneal nerve with surface stimulation rather than targeting the motor points of the muscle directly [12].

In our study, we observed a popliteal peak velocity of ~20 cm/s in the operated limb in response to calf muscle NMES. This was lower than that of these previous healthy studies but was in line with patients with chronic venous

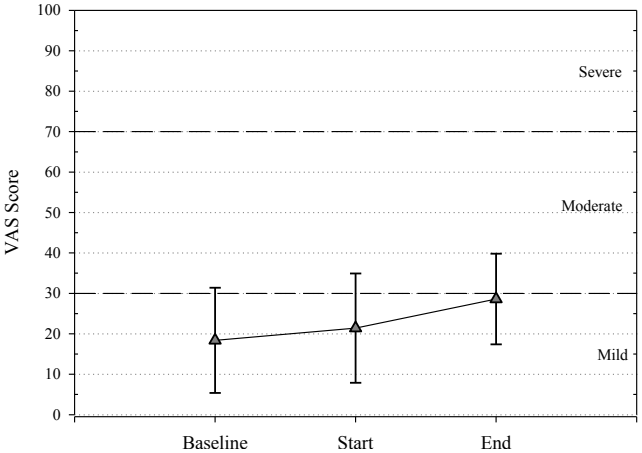

Fig. 1. VAS scores at three time points: before the application of NMES (baseline), once the NMES session had started (start) and just before the NMES session completed (end). VAS categorical scores remained unchanged throughout the 4 hour period of the study. Error bars indicate SEM.

insufficiency [15]. This could have been caused by the difficulty in accurately placing the NMES electrode over the motor points of the muscle in the operated limb which may have reduced the strength of the NMES induced calf muscle contraction.

Implementing this study in a post-operative hospital environment identified a number of practical challenges that have implications for applying NMES for the duration of the hospitalised recovery period following THA. On the first post-operative day, electrode placement is very difficult as patients have a significantly reduced range of motion on the operated leg. In previous studies, electrodes were placed with the patient in a standing or prone position which allows for the easy identification of the required muscle landmarks. While patients who are one day post-THA can be brought into a standing position, it is a significant ordeal for the patient, it can only be adopted for a very short period of time and requires the assistant of several health care professionals. Therefore, placing the NMES electrodes at this point would be impractical. Furthermore, the patients cannot adopt a prone position, nor can they perform a plantar flexion in order to help identify muscle landmarks. Therefore, placing the electrodes could only be done with the patient lying in a semi-supine position. The procedure required two people, one to carefully hold the leg in a slightly elevated position and the other person to place the electrodes. As an incorrect electrode placement can lead to an unsatisfactory treatment outcome sand can lead to an unpleasant sensory perception from the stimulus, we recommend that sufficient time and care be taken when placing the electrodes and ensure that a smooth calf muscle contraction is observed before starting the NMES treatment protocol.

The reduced range of motion also increased the difficulty of acquiring accurate Doppler blood flow measurements from the popliteal vein. In order to image the popliteal vein, the Doppler probe is placed in the popliteal fossa. When a patient is in a semi-supine position, access to the popliteal fossa is established by bending the knee at an ankle of approximately 20° while leaving the ankle in contact with the bed. This allows clearance for the Doppler probe to be positioned at the correct angle to image the popliteal vein. This position was difficult for the post-THA patient to adopt on their own and required the assistance of the investigator to hold the leg in the correct position.

In addition to the difficulty in placing the electrodes, the electrode-to-electrode lead connector was very short and had to be placed underneath the antiembolism stocking. The pressure exerted by the stocking on the connector resulted in the connector being pressed against the already swollen leg. Patients complained that this was uncomfortable and a red mark was visible on the skin one the electrodes were removed. This situation did not arise in previous studies as NMES was never applied underneath antiembolism stockings. To prevent this occurring in future NMES studies on post-THA patients, electrodes with longer lead connectors should be used so that they are not placed under the stocking.

VII. Conclusion

The results of this study show a beneficial hemodynamic response to NMES in patients in the early post-operative period following orthopaedic surgery which has implications for DVT prevention and reduction of edema. These patients find the application of calf muscle NMES tolerable. The use of NMES on postoperative orthopaedic patients may be considered as a DVT prevention method; however, further study of this is required with a larger sample size to ensure statistical power. Furthermore, the practicality of applying NMES during this recovery period needs further investigation and the associated reduction in DVT has yet to be evaluated.

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