

# Investigating Lower Limb Hemodynamics during Flap Training Regimens and Patient-led Isometric Contraction Protocols

Luke Geoghegan, MBBS, BSc\*†  
Richard M. Kwasnicki, MRCS,  
PhD‡  
John M. D. Henton, FRCS, MSc§  
Shehan Hettiaratchy, FRCS, DM\*  
Abhilash Jain, FRCS, PhD\*†

**Summary:** The evidence for lower limb flap (LLF) training regimens is equivocal. The commonest cause of LLF failure is venous congestion. The aim of this study was to investigate whether venous congestion could be reduced by patient-led isometric calf contractions during flap training. A prospective clinical study was conducted using photospectroscopy and laser Doppler (Oxygen to See) to assess healthy limbs and LLF characteristics during flap training and isometric calf contractions. Tissue oxygen saturation, venous congestion, and blood flow were measured at rest, as well as during and after limb dangling and calf contraction exercises. In the acute postoperative period following LLF surgery, dependency markedly reduced superficial flow ( $-55.20\% \pm 19.17\%$ ), with a concurrent increase in venous congestion ( $33.80\% \pm 28.80\%$ ); supine isometric contractions improved superficial flow and reduced venous congestion from postoperative day 5. Contractions cause a significant increase in blood flow in the outpatient cohort ( $+84.40\% \pm 7.86\%$ ,  $P = 0.009$ ), with a mean time since discharge of 14 weeks. Our data suggest patient-led isometric calf exercises are well tolerated and may reduce venous congestion in the acute phase. Progressive changes toward normal physiological function were demonstrated in the outpatient rehabilitation period. Incorporating calf exercises into LLF rehabilitation may allow longer periods of leg dependency, quicker recovery from surgery, and ultimately improve outcomes. (*Plast Reconstr Surg Glob Open* 2020;8:e2731; doi: [10.1097/GOX.0000000000002731](https://doi.org/10.1097/GOX.0000000000002731); Published online 24 March 2020.)

## INTRODUCTION

Flap training regimens optimize perfusion following lower extremity reconstruction; however, postoperative

algorithms are informed by anecdotal evidence, with a lack of consensus guidelines.<sup>1</sup>

From the \*Department of Plastic and Reconstructive Surgery, St. Mary's Hospital, Imperial College Healthcare NHS Trust, London, United Kingdom; †Nuffield Department of Orthopaedics, Rheumatology and Musculoskeletal Science (NDORMS), University of Oxford, Oxford, United Kingdom; ‡Department of Surgery and Cancer, Imperial College London, London, United Kingdom; and §Department of Plastic and Reconstructive Surgery, Royal Victoria Infirmary, Newcastle upon Tyne, United Kingdom.

A recent systematic review demonstrated that early postoperative dependency aids flap healing, despite concurrent flap edema and venous congestion.<sup>2</sup> External compression has proved beneficial for reducing edema and facilitating venous return, which permits early mobilization.<sup>3</sup> However, compression limits the use of noninvasive flap monitoring and reduces flap perfusion below capillary closing pressures.<sup>4</sup>

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Contraction of skeletal muscle facilitates central return without compromising cutaneous flow. Calf exercises have been previously validated in reducing venous thromboembolism.<sup>5</sup>

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The aim of this study was to investigate the feasibility of patient-led calf exercises as novel adjuncts to flap training regimens. This study aimed to investigate microcirculatory

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changes following lower extremity reconstruction compared with a cohort of healthy volunteers.

**METHODS**

A prospective single-centre study was conducted, and ethical approval was granted by the Bromley Research Ethics Committee (17/LO/0433).

Patients presenting to our institution between March and May 2017 who required lower extremity reconstruction with fasciocutaneous flaps (free or local) were eligible for participation. Those with or preexisting comorbidities or injuries affecting the peripheral circulation were excluded.

Hemodynamic measurements of arterial flow, tissue oxygen saturation, and relative hemoglobin (a marker of venous congestion) were taken using the Oxygen to See (LEA Medizintechnik, Giessen, Germany) wired non-invasive sensor platform, which measures at superficial (2mm) and deep (8mm) tissue levels. All measures were standardized as previously described,<sup>6</sup> with the LT-2 probe placed at the center of the flap angled superiorly in reconstruction patients and on the midpoint of the lateral head of the gastrocnemius muscle belly in healthy volunteers.

Patients were instructed to perform 30 isometric calf contractions during a 1-minute study period. A standard in-person tutorial was provided; exercises were performed without resistance while the ankle was held at 90 degrees. Study conditions of dependency and contraction were defined; the following protocols were implemented:

1. Supine isometric contraction
2. Limb dependency
3. Limb dependency and then supine isometric contraction.

Analysis was performed with patients acting as their own controls, and percentage change from resting baseline was calculated. Distribution was assessed using the Shapiro–Wilk test. Normally distributed paired data were analyzed using a paired *t* test, and nonparametric data were analyzed using the Wilcoxon test. Significance was set at *P* ≤ 0.05. GraphPad Prism, version 8.0 (GraphPad Software, San Diego, Calif.) was used for statistical analysis.

**RESULTS**

**Acute Patient Cohort**

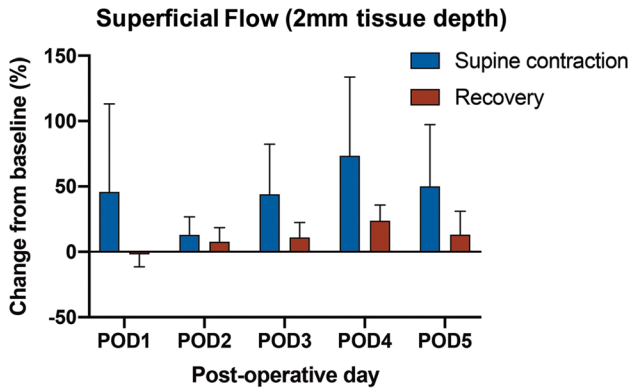
Seven patients were prospectively recruited, and 2 patients were excluded due to language barriers and postoperative confusion. All patients were men with an average age of 43 years (range: 27–61 years) (Table 1).

Supine isometric contractions demonstrated a sustained improvement in hemodynamic parameters, which peaked on postoperative day (POD) 4 (Fig. 1). Dependency was initiated on POD3 for 2min/h. On POD3, superficial flow reduced (−55% ± 19%) and relative hemoglobin (rHb) increased (+34% ± 29%), peaking at POD4 (+82% ± 78%) (see Table 1, Supplemental Digital Content 1, which displays individual data from the acute flap cohort, <http://links.lww.com/PRSGO/B348>). Supine contractions following dependency increased superficial flow and reduced rHb from POD5 (Fig. 2).

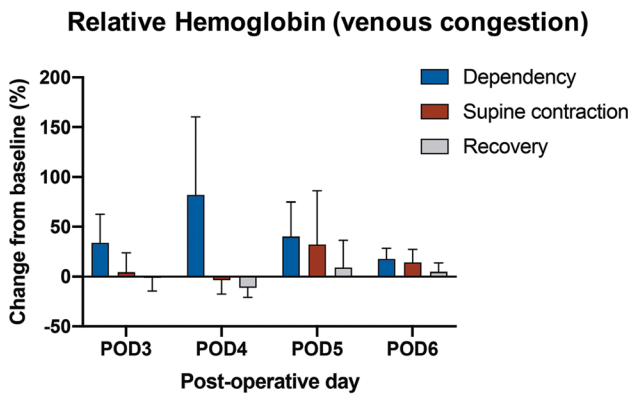
**Table 1. Demographic and Injury-specific Data for Patients Prospectively Recruited to the Acute Flap Cohort**

Patient	Age	Gender	Injury	Mechanism	Soft Tissue Reconstruction	Fracture Fixation	Smoker	Significant Comorbidities	No. Venous Anastomoses	Arterial Anastomosis	Flap Location
1	27	M	IIIc	RTA (moped versus car)	ALT	External fixation IM nail	No	Nil	1	End to end	Distal tibia and lateral malleolus
2	34	M	IIIb	RTA (pedestrian versus car)	ALT	IM nail	No	Nil	2	End to side	Distal anteromedial tibia
3	34	M	IIIa	RTA (moped versus car)	Local perforator flap ALT	IM nail	No	Nil	—	—	Middle third of the tibia
4	61	M	IIIb	RTA	ALT	External fixation ORIF	No	HTN, T2DM	2	End to side	Distal anteromedial tibia
5	59	M	IIIb	Fall from standing	RFF	ORIF	No	Nil	2	End to side	Distal anteromedial tibia

IIIb, Gustilo-Anderson grade IIIb fracture; IIIc, Gustilo-Anderson grade IIIc fracture; ALT, anterolateral thigh free flap; HTN, hypertension; IM nail, intramedullary nail; M, male; ORIF, open reduction internal fixation; RFF, radial forearm flap; RTA, road traffic accident; T2DM, type II diabetes mellitus.



**Fig. 1.** Progressive changes in superficial flow exhibited with isometric supine contractions in the acute flap cohort throughout the first postoperative week. Isometric contractions demonstrated a sustained and progressive effect on lower extremity blood flow relative to measurements taken at rest, peaking on POD4.



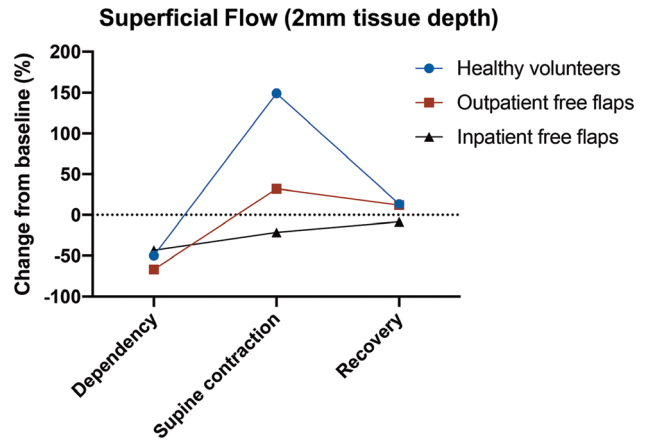
**Fig. 2.** Progressive changes in relative hemoglobin exhibited with dependency and subsequent isometric supine contractions in the acute flap cohort during the first 4 days of flap training. Venous congestion is mostly marked on the second day of flap training (POD4) with supine contractions reducing venous congestion in the first 2 postoperative days relative to resting measurements. The degree of venous congestion during dependency reduced across the subsequent 2 days of flap training (POD5 and POD6), where isometric contractions appear to have a lesser effect.

### Outpatient Cohort

Five outpatients were recruited at a mean of 14 weeks (range: 8–22 weeks) following soft tissue reconstruction. Supine isometric contractions significantly increased superficial flow (+84% ± 8%,  $P = 0.009$ ) and reduced rHb (−4% ± 3%, not significant). Dependency significantly reduced superficial flow (−60% ± 17%,  $P = 0.03$ ) and increased rHb (+22% ± 19%, not significant). Supine isometric contractions following dependency significantly reduced rHb ( $P = 0.01$ ). Our comparative analysis demonstrated a trend toward that of healthy volunteers (Fig. 3).

### Healthy Volunteers

Eighteen healthy volunteers were recruited (16 men, 2 women), with an average age of 22 years (range: 19–28 years). Supine isometric contractions significantly increased superficial flow (+261% ± 130%,  $P < 0.0001$ )



**Fig. 3.** Comparative changes in superficial flow among healthy volunteer, acute inpatient and outpatient rehabilitation cohorts during dependency, and subsequent isometric contraction. A progressive change toward flow hemodynamic exhibited in the healthy cohort is demonstrated across the acute inpatient and outpatient cohorts suggesting a healing effect.

and reduced rHb (−17% ± 20%,  $P = 0.01$ ) relative to resting baseline measurements.

Dependency significantly increased rHb (+29% ± 24%,  $P < 0.0001$ ) and decreased superficial flow (−71% ± 14%,  $P < 0.0001$ ) and tissue oxygen saturation (−22% ± 26%,  $P = 0.002$ ) relative to resting baseline measurements.

Isometric contractions after dependency significantly increased superficial flow (+195% ± 137%,  $P = 0.002$ ), decreased rHb (−36% ± 25%,  $P < 0.0001$ ), and increased tissue oxygen saturation (+12% ± 24%,  $P = 0.006$ ) relative to measurements taken during dependency.

## DISCUSSION

This study demonstrates that patient-led isometric calf exercises are well tolerated and produce a measurable change in hemodynamic parameters tending toward healthy volunteers. The observed effects were transient, variable, and normalized to resting measurements within 1 hour of exercise termination.

We demonstrate that repeated contractions can offset the increase in venous congestion brought about by dependency through supporting venous and lymphatic return. This increases blood flow through inosculation and angiogenesis secondary to ischemic conditioning and production of local metabolites.<sup>7</sup> The cumulative effect of exercises may expedite flap maturation and permit earlier tolerance of venous congestion.<sup>8</sup>

External compression has been shown to permit earlier ambulation without adverse effects in a small randomized controlled trial, although no difference in length of stay was noted, likely due to lack of power.<sup>9</sup> The present study suggests that isometric calf exercises facilitate venous return without limitation of noninvasive flap monitoring and the need for additional equipment.

Our results must be considered in view of the study limitations. Motion artifact is an intrinsic limitation of laser Doppler; however, the use of a high-pass filter significantly

reduces motion artifact.<sup>10</sup> The small cohort size and heterogeneity are inherent problems in the patient cohort. The large deviation in study measurements may, in part, be explained by factors such as the injury mechanism, flap location with respect to local superficial and deep veins, probe location, and the modality of skeletal fixation.

This study provides insight into hemodynamic changes in flow and venous stasis occurring during isometric contraction and limb dependency. The comparative difference in intervention effect between healthy volunteers and patients following limb reconstruction has been demonstrated.

There is a paucity of high-quality evidence informing postoperative management algorithms. The optimal length and duration of flap training as well as the role for adjuncts such as wrapping and exercises must be determined through adequately powered pragmatic trials, where the impact of such interventions on functional patient-reported outcome measures and length of hospital stay can be determined.

**Luke Geoghegan, MBBS, BSc**

Department of Plastic and Reconstructive Surgery  
St. Mary's Hospital  
Imperial College Healthcare NHS Trust  
Praed Street, W2 1NY, London, UK  
E-mail: Lg1813@ic.ac.uk

#### REFERENCES

1. O'Neill JK, Greenwood AJ, Khan U. A survey of U.K. units and a suggested protocol for free flap reconstruction of the lower limb: follow-up and management in the first postoperative week. *J Reconstr Microsurg*. 2010;26:601–606.
2. McGhee JT, Cooper L, Orkar K, et al. Systematic review: early versus late dangling after free flap reconstruction of the lower limb. *J Plast Reconstr Aesthet Surg*. 2017;70:1017–1027.
3. Stranks GJ, MacKenzie NA, Grover ML, et al. The A-V impulse system reduces deep-vein thrombosis and swelling after hemiarthroplasty for hip fracture. *J Bone Joint Surg Br*. 1992;74:775–778.
4. Miyamoto S, Kayano S, Fujiki M, et al. Early mobilization after free-flap transfer to the lower extremities: preferential use of flow-through anastomosis. *Plast Reconstr Surg Glob Open*. 2014;2:e127.
5. Hitos K, Cannon M, Cannon S, et al. Effect of leg exercises on popliteal venous blood flow during prolonged immobility of seated subjects: implications for prevention of travel-related deep vein thrombosis. *J Thromb Haemost*. 2007;5:1890–1895.
6. Henton JM, Simmons JM, Hettiaratchy S, et al. Perfusion dynamics in lower limb reconstruction: investigating postoperative recovery and training using combined white light photospectroscopy and laser Doppler (O2C®). *J Plast Reconstr Aesthet Surg*. 2015;68:1286–1292.
7. Sarelius I, Pohl U. Control of muscle blood flow during exercise: local factors and integrative mechanisms. *Acta Physiol (Oxf)*. 2010;199:349–365.
8. Tsur H, Daniller A, Strauch B. Neovascularization of skin flaps: route and timing. *Plast Reconstr Surg*. 1980;66:85–90.
9. Jokuszies A, Neubert N, Herold C, et al. Early start of the dangling procedure in lower extremity free flap reconstruction does not affect the clinical outcome. *J Reconstr Microsurg*. 2013;29:27–32.
10. Rajan V, Varghese B, van Leeuwen TG, et al. Review of methodological developments in laser Doppler flowmetry. *Lasers Med Sci*. 2009;24:269–283.