Factors associated with delays in revascularization in patients with chronic limb-threatening ischaemia: population-based cohort study

P. Birmpili [1,2,*], A. Johal [1], Q. Li[1,3], S. Waton[1], I. Chetter[2,4], J. R. Boyle[5] and D. Cromwell[1,3]

[1]Clinical Effectiveness Unit, Royal College of Surgeons of England, London, UK
[2]Hull York Medical School, Hull, UK
[3]Department of Health Services Research and Policy, London School of Hygiene and Tropical Medicine, London, UK
[4]Academic Vascular Surgical Unit, Hull University Teaching Hospitals NHS Trust, Hull, UK
[5]Cambridge Vascular Unit, Cambridge University Hospitals NHS Foundation Trust, Cambridge, UK

*Correspondence to: Clinical Effectiveness Unit, Royal College of Surgeons of England, 35–43 Lincoln's Inn Fields, Holborn, London WC2A 3PE, UK (e-mail: Panagiota.Birmpili@nhs.net)
Presented to the Annual Scientific Meeting of the Vascular Society of Great Britain and Ireland, 24-27th November 2020

Abstract

Background: Prompt revascularization in patients with chronic limb-threatening ischaemia (CLTI) is important, and recent guidance has suggested that patients should undergo revascularization within 5 days of an emergency admission to hospital. The aim of this cohort study was to identify factors associated with the ability of UK vascular services to meet this standard of care.

Methods: Data on all patients admitted non-electively with CLTI who underwent open or endovascular revascularization between 2016 and 2019 were extracted from the National Vascular Registry. The primary outcome was interval between admission and procedure, analysed as a binary variable (5 days or less, over 5 days). Multivariable Poisson regression was used to examine the relationship between time to revascularization and patient and admission characteristics.

Results: The study analysed information on 11 398 patients (5973 open, 5425 endovascular), 50.6 per of whom underwent revascularization within 5 days. The median interval between admission and intervention was 5 (i.q.r. 2–9) days. Patient factors associated with increased risk of delayed revascularization were older age, greater burden of co-morbidity, non-smoking status, presentation with infection and tissue loss, and a Fontaine score of IV. Patients admitted later in the week were less likely undergo revascularization within 5 days than those admitted on Sundays and Mondays ($P < 0.001$). Delays were slightly worse among patients having open compared with endovascular procedures ($P = 0.005$) and in hospitals with lower procedure volumes ($P < 0.001$).

Conclusion: Several factors were associated with delays in time to revascularization for patients with CLTI in the UK, most notably the weekday of admission, which reflects how services are organized. The results support arguments for vascular units providing revascularization to have the resources for a 7-day service.

Introduction

Chronic limb-threatening ischaemia (CLTI) is the most severe form of peripheral artery disease, affecting 500–1000 patients per million population per year in the UK[1]. It is characterized by rest pain and tissue loss and, if not revascularized promptly, can lead to major lower limb amputation[2]. Revascularization options include open surgical procedures (such as lower limb bypass), endovascular procedures (such as angioplasties and stents), or a combination of these two approaches (hybrid procedures).

The 2018 *Vascular Surgery Getting it Right First Time (GIRFT) National Specialty Report*[3] highlighted considerable regional variation in the time to revascularization for patients with CLTI across the UK, and recommended the provision of scheduled operations at weekends, in an attempt to increase the early availability of revascularization surgery and reduce excessive waits for urgent procedures. The report also recommended the development of a Lower Limb Ischaemia Quality Improvement Framework by the Vascular Society of Great Britain and Ireland (VSGBI), with specific timelines from referral to treatment. The VSGBI published *A Best Practice Clinical Care Pathway for Peripheral Arterial Disease* in 2019 and recommended that patients with CLTI admitted as an emergency receive revascularization within 5 days of admission, whereas non-admitted stable patients undergo intervention within 14 days from referral[4]. This was the first document to specify a recommended target time for revascularization in the UK and thereby generate a definition of what constitutes a delay.

The relationship between the timing of lower limb revascularization and patient outcomes has not been studied extensively,

Lay summary

Chronic limb-threatening ischaemia (CLTI) is a severe form of peripheral artery disease that reduces blood flow to the legs and can lead to amputation. Between 2016 and 2019, only 50.6 per cent of patients admitted to UK vascular units urgently with CLTI underwent revascularization within 5 days from admission. Several factors were associated with delays in time to revascularization, most notably the weekday of admission, which reflects how services are organized. The results support arguments for vascular units providing revascularization to have resources for a 7-day service.

particularly compared with the impact of delay before carotid endarterectomy or hip fracture surgery[5,6], but it has been suggested that earlier intervention leads to improved outcomes. Shorter time to revascularization increases the probability of healing for ischaemic diabetic foot ulcers[7], and limb salvage rates in diabetic patients with CLTI[8]. However, the short time frame is challenging to achieve and factors associated with delays have not been studied in detail.

The aim of this study was to identify patient and pathway factors that affect the timing of revascularization for patients presenting non-electively with CLTI, in order to inform the reconfiguration efforts of National Health Service (NHS) vascular services and improve the quality of care for patients with CLTI.

Methods

The study was based on a prospective, population-based cohort of vascular procedures collected by the National Vascular Registry (NVR). The NVR is a national clinical audit, commissioned by the Healthcare Quality Improvement Partnership (HQIP), and collects demographic and clinical information on five major vascular procedures undertaken within NHS hospitals in the UK. Approximately 90 per cent of open and 40 per cent of endovascular lower limb revascularization procedures performed in NHS hospitals are captured in the NVR[9]. The study involved secondary analysis of existing pseudoanonymized data and was therefore exempt from UK National Ethics Committee approval. The NVR has approval for processing healthcare information under Section 251 (reference number: CAG 5-07(f)/2013) for adult patients undergoing vascular surgery in NHS hospitals.

Study population

The study cohort comprised adult patients who presented non-electively with CLTI, and who underwent either open or endovascular lower limb revascularization between January 2016 and December 2019. Open revascularization procedures consisted of lower limb bypasses and endarterectomies with or without an endovascular component, and endovascular procedures included balloon angioplasties with or without a stent. Patients were identified as having CLTI if the admission Fontaine score was documented as III (rest pain) or IV (ulceration or gangrene), and the presenting problem was chronic limb ischaemia, neuropathy, tissue loss or uncontrolled infection; acute limb ischaemia, aneurysms, and trauma were excluded. For patients having elective treatment, the median interval from admission to intervention was 0 (i.q.r. 0–1) days, which suggested that these patients followed an outpatient pathway, and so they were not included in the study.

For patients who underwent multiple revascularization attempts during one inpatient episode, only the first revascularization procedure during that admission was included. Patient records were excluded if data were missing on key variables (age, sex, co-morbidities, smoking status, presenting problem, Fontaine score), patients were treated as a day case (no preoperative or postoperative hospital stay), or the interval between admission and intervention exceeded 100 days as this indicated that the patient was unfit for surgery on admission. Data from non-arterial centres and hospitals that did not perform at least one procedure of each type every year of the study period were also excluded.

Patient characteristics

The NVR data set contains demographic (patient age, sex, co-morbidities, smoking status) and clinical (presenting problem, Fontaine score, date of admission, date and type of procedure, hospital of treatment) information. Data on co-morbidities include the presence of diabetes, chronic lung disease, ischaemic heart disease, chronic heart failure, chronic renal disease, stroke, and cancer. Diabetes was included in the model as a distinct co-morbidity as there can be different care pathways for such patients. The other co-morbidities were grouped into a variable that indicated whether patients had none or one, two, or three or more co-morbidities. A variable for centre volume of procedures was defined according to the mean number of revascularization procedures (open and endovascular) per year conducted at each hospital; the hospitals were stratified into three categories (high, medium, and low volume), with an approximately equal number of procedures in each[10] (*Table S1*). The volume of endovascular procedures at each hospital was estimated using activity recorded in the Hospital Episode Statistics database rather than the NVR owing to low case ascertainment[9].

Outcomes

The primary outcome was the proportion of patients who underwent revascularization within 5 days from admission, the time frame set by the VSGBI recommendation in 2019. Time to intervention was defined as the number of calendar days from admission to the first revascularization procedure performed during that admission. The secondary outcome was the waiting time from admission to procedure in days.

Statistical analysis

The study was based on a complete-case analysis. Summary statistics were used to describe the demographic and clinical characteristics of patients. Age was categorized into four groups (less than 60, 60–69, 70–79, at least 80 years). Categorical variables were expressed as frequencies and proportions. The pattern of

variation of patient factors across the days of admission was explored by calculating the Mahalanobis distance[11] for each patient and plotting the resulting distribution for each day. The distance is a measure of how different a specific patient is from the typical patient in the cohort.

Univariable and multivariable Poisson regression with robust standard errors was used to estimate the crude and adjusted effects of patient and admission characteristics on the primary outcome[12]. Logistic regression was not used, because odds ratios overestimate the risk ratio for common outcomes[12]. The multivariable Poisson model estimated incidence rate ratios (IRRs) for the primary outcome, controlling for patient age, sex, presence of diabetes, co-morbidity burden, smoking status, Fontaine score, presenting problem, weekday of admission, procedure type, and hospital volume. The statistical significance of interaction terms between day of the week and the variables Fontaine score and type of procedure was evaluated using the Bayesian information criterion. The Kruskal–Wallis test was used to examine the association between co-variables and the continuous outcome interval from admission to intervention.

Several sensitivity analyses were performed. The first repeated the analysis with a 7-day admission-to-intervention time frame as the outcome. The second restricted the analysis to high-volume hospitals with more than 80 per cent case ascertainment[9] and 100 or more endovascular procedures per year recorded in the NVR. All statistical tests were two-sided and $P < 0.050$ was considered statistically significant. All analyses were done using Stata® version 15.1 (StataCorp, College Station, Texas, USA). Results are presented in accordance with the RECORD extension of the STROBE statement for observational studies[13].

Results

A total of 13 149 non-elective revascularization procedures performed for CLTI between 2016 and 2019 were extracted from the NVR. Of these, 136 day cases, 828 patients treated in non-arterial centres and hospitals with missing years of procedures, 476 subsequent procedures in the same admission, 301 patients with missing data, and 10 with an admission-to-intervention interval of more than 100 days were excluded. This left 11 398 patients for analysis, among whom there were similar proportions of open (5973, 52.4 per cent) and endovascular (5425, 47.6 per cent) procedures. Some 1026 of the open surgical procedures (17.2 per cent) had an adjunct endovascular element. The open procedures were performed in 75 NHS hospitals, and endovascular procedures were recorded in 50 of these; the remaining 25 did not submit data on endovascular procedures to the NVR.

The median age on admission was 72 (i.q.r. 64–80) years and 7836 patients (68.7 per cent) were men (*Table 1*). Overall, 6283 patients (55.1 per cent) had diabetes. Tissue loss was the most common reason for presentation (5451, 47.8 per cent) and 9124 patients (80.0 per cent) had a Fontaine score of IV on admission. The greatest number of admissions occurred on Monday (2092, 18.4 per cent) and the lowest on Sunday (667, 5.9 per cent).

Table 1 Characteristics of 11 398 patients undergoing revascularization for chronic limb-threatening ischaemia between January 2016 and December 2019 in UK National Health Service hospitals

	Overall ($n = 11\,398$)	Open procedure ($n = 5973$)	Endovascular procedure ($n = 5425$)
Age (years)			
< 60	1701 (14.9)	925 (15.5)	776 (14.3)
60–69	3057 (26.8)	1741 (29.1)	1316 (24.3)
70–79	3753 (32.9)	2068 (34.6)	1685 (31.1)
≥ 80	2887 (25.3)	1239 (20.7)	1648 (30.4)
Men	7836 (68.7)	4190 (70.1)	3646 (67.2)
No. of patients with diabetes	6283 (55.1)	2717 (45.5)	3566 (65.7)
No. of other co-morbidities			
0–1	8127 (71.3)	4353 (72.9)	3774 (69.6)
2	2343 (20.6)	1196 (20.0)	1147 (21.1)
≥ 3	928 (8.1)	424 (7.1)	504 (9.3)
Smoking status			
Current smoker	3648 (32.0)	2424 (40.6)	1224 (22.6)
Ex-smoker	5842 (51.3)	2957 (49.5)	2885 (53.2)
Never smoked	1908 (16.7)	592 (9.9)	1316 (24.3)
Fontaine score			
III	2274 (20.0)	1507 (25.2)	767 (14.1)
IV	9124 (80.0)	4466 (74.8)	4658 (85.9)
Presenting problem			
Chronic ischaemia	5188 (45.5)	2867 (48.0)	2321 (42.8)
Tissue loss	5451 (47.8)	2791 (46.7)	2660 (49.0)
Uncontrolled infection	759 (6.7)	315 (5.3)	444 (8.2)
Day of admission			
Sunday	667 (5.9)	366 (6.1)	301 (5.5)
Monday	2092 (18.4)	1061 (17.8)	1031 (19.0)
Tuesday	2067 (18.1)	1108 (18.6)	959 (17.7)
Wednesday	1980 (17.4)	1033 (17.3)	947 (17.5)
Thursday	1979 (17.4)	1016 (17.0)	963 (17.8)
Friday	1894 (16.6)	993 (16.6)	901 (16.6)
Saturday	719 (6.3)	396 (6.6)	323 (6.0)
Hospital volume			
Low	3585 (31.5)	1807 (30.3)	1778 (32.8)
Medium	3882 (34.1)	2102 (35.2)	1780 (32.8)
High	3931 (34.5)	2064 (34.6)	1867 (34.4)

Values in parentheses are percentages.

Patient factors associated with delay to revascularization

The median delay from admission to intervention was 5 (i.q.r. 2–9) days, and 10 055 patients (88.2 per cent) underwent revascularization within the first 2 weeks of inpatient stay. However, only 5771 patients (50.6 per cent) with CLTI had revascularization within 5 days from admission.

In the multivariable model, patient characteristics associated with a longer interval between admission and intervention included: older age, a larger number of co-morbidities other than diabetes (at least 3 *versus* 0–1), non-smoking status *versus* current smokers, Fontaine score IV versus III, and tissue loss and uncontrolled infection as presenting problem *versus* chronic ischaemia (*Fig. 1*). The same factors were significantly associated with delays in revascularization in univariable analysis (*Table 2*). The proportion of patients who had revascularization within 5 days did not differ significantly by whether or not they had diabetes ($P = 0.474$).

The increased IRRs for patient characteristics were reflected in longer waiting times. The median delay from admission to intervention was 5 (2–9) days for patients with up to one co-morbidity apart from diabetes, and increased to 6 (3–11) days for those with two and 7 (3–12) days for patients with three or more co-morbidities ($P < 0.001$). Similarly, it was 5 (2–9) days among patients aged less than 70 years, 6 (2–9) days for those aged 70–79 years, and 6 (3–10) days for patients at least 80 years old. The median time to revascularization was 4 (2–7) days for patients with a Fontaine score of III, increasing to 6 (3–10) days for those with Fontaine IV disease ($P < 0.001$). The model was not improved by the addition of interaction terms between day of the week and patient characteristics (Fontaine score, type of procedure).

Admission factors associated with delay to revascularization

The day of admission had a significant impact on the proportion of patients who had revascularization within 5 days. Some 61.6 per cent of patients admitted on Sunday and 59.8 per cent on Monday had a more timely intervention, but for patients admitted later in the week, the proportion dropped to 46.1–50.8 per cent, being lowest on Wednesday. The pattern of patient characteristics, as summarized by the Mahalanobis distance, across various days of the week did not suggest any substantial change in case mix over the week (*Fig. S1*). Adjusting for patient and admission characteristics, the IRR for waiting more than 5 days for revascularization, using Sunday as baseline, was highest on Tuesday (IRR 1.39, 95 per cent c.i. 1.25 to 1.54) and Wednesday (IRR 1.40, 1.26 to 1.55), but was still high for Thursday (IRR 1.35, 1.21 to 1.49), Friday (IRR 1.31, 1.18 to 1.46) and Saturday (IRR 1.27; 1.13 to 1.43) (*Table 2*).

Most patients admitted on Sunday had revascularization during the same week, whereas a significant proportion of patients admitted later in the week were treated during the following week (*Fig. 2*). Only 358 procedures (3.1 per cent) were performed at the weekend. The cumulative percentage of patients undergoing revascularization exhibited a bimodal pattern that indicated the effect of day of admission was least prominent at 7 and 14

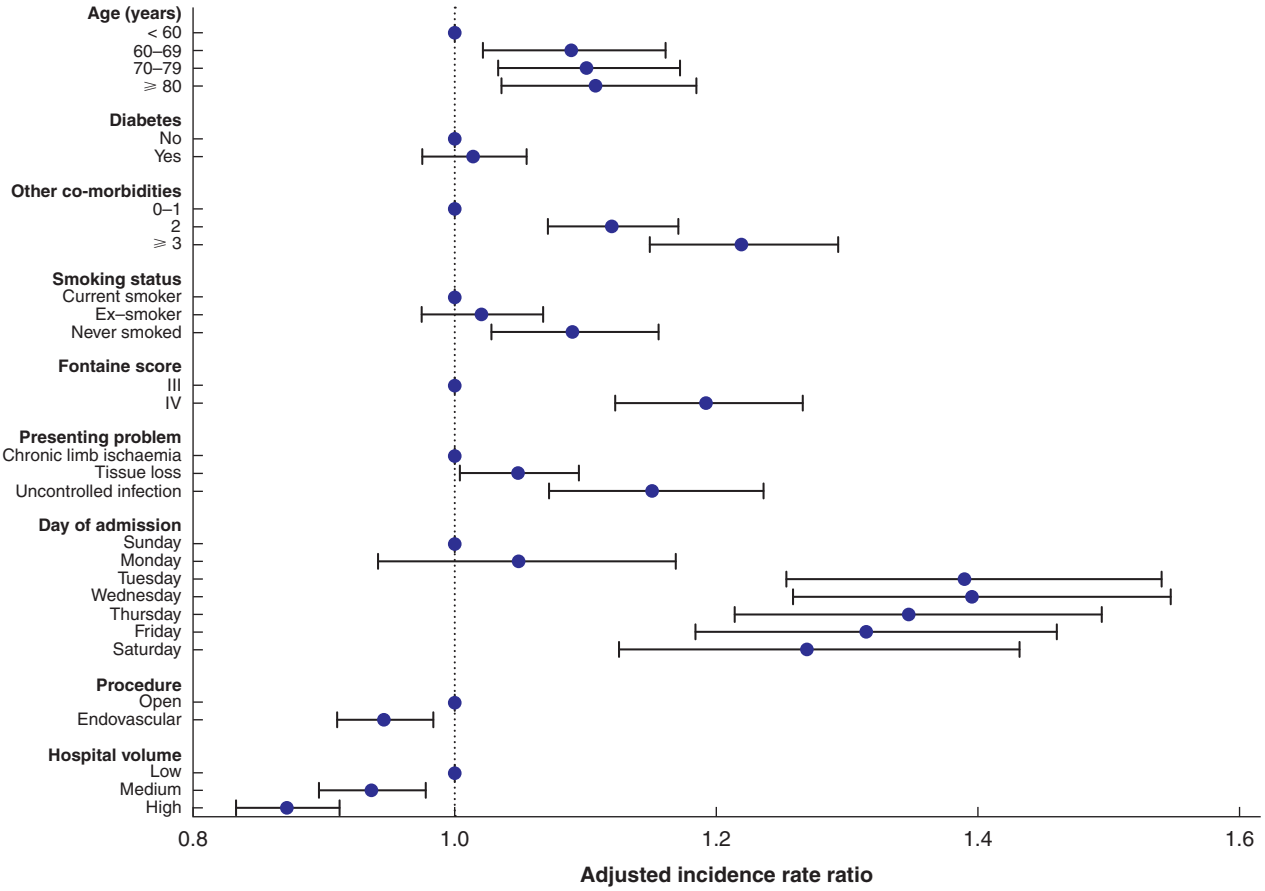

Fig. 1 Adjusted incidence rate ratios for waiting longer than 5 days from admission to revascularization for various patient and admission factors

Data points show adjusted incidence rate ratios and bars show 95 per cent confidence intervals.

Table 2 Factors associated with waiting more than 5 days for revascularization

	No. of patients waiting > 5 days	Univariable analysis		Multivariable analysis	
		IRR*	P	Adjusted IRR*	P
Age (years)			< 0.001		0.016
< 60	754 (44.3)	1.00 (reference)		1.00 (reference)	
60–69	1501 (49.1)	1.11 (1.04, 1.18)		1.09 (1.02, 1.16)	
70–79	1889 (50.3)	1.14 (1.07, 1.21)		1.10 (1.03, 1.17)	
≥ 80	1483 (51.4)	1.16 (1.09, 1.24)		1.11 (1.04, 1.19)	
Sex			0.138		0.049
M	3832 (48.9)	1.00 (reference)		1.00 (reference)	
F	1795 (50.4)	1.03 (0.99, 1.07)		1.04 (0.99, 1.08)	
Diabetes	3169 (50.4)	1.05 (1.01, 1.09)	0.012	1.01 (0.98, 1.06)	0.474
Other co-morbidities			< 0.001		< 0.001
0–1	3837 (47.2)	1.00 (reference)		1.00 (reference)	
2	1248 (53.3)	1.13 (1.08, 1.18)		1.12 (1.07, 1.17)	
≥ 3	542 (58.4)	1.24 (1.17, 1.31		1.22 (1.15, 1.29)	
Smoking status			< 0.001		0.010
Current smoker	1710 (46.9)	1.00 (reference)		1.00 (reference)	
Ex-smoker	2899 (49.6)	1.06 (1.01, 1.11)		1.02 (0.97, 1.07)	
Never smoked	1018 (53.4)	1.14 (1.08, 1.20		1.09 (1.03, 1.16)	
Fontaine score			< 0.001		< 0.001
III	935 (41.1)	1.00 (reference)		1.00 (reference)	
IV	4692 (51.4)	1.25 (1.19, 1.32)		1.19 (1.12, 1.27)	
Presenting problem			< 0.001		< 0.001
Chronic ischaemia	2374 (45.8)	1.00 (reference)		1.00 (reference)	
Tissue loss	2830 (51.9)	1.13 (1.09, 1.18)		1.05 (1.01, 1.10)	
Uncontrolled infection	423 (55.7)	1.22 (1.14, 1.31)		1.15 (1.07, 1.24)	
Day of admission			< 0.001		< 0.001
Sunday	256 (38.4)	1.00 (reference)		1.00 (reference)	
Monday	841 (40.2)	1.05 (0.94, 1.17)		1.05 (0.94, 1.17)	
Tuesday	1107 (53.6)	1.40 (1.26, 1.55)		1.39 (1.25, 1.54)	
Wednesday	1068 (53.9)	1.41 (1.27, 1.56)		1.40 (1.26, 1.55)	
Thursday	1037 (52.4)	1.37 (1.23, 1.52)		1.35 (1.21, 1.49)	
Friday	964 (50.9)	1.33 (1.19, 1.47)		1.31 (1.18, 1.46)	
Saturday	354 (49.2)	1.28 (1.14, 1.45)		1.27 (1.13, 1.43)	
Procedure			0.758		0.005
Bypass	2957 (49.5)	1.00 (reference)		1.00 (reference)	
Angioplasty	2670 (49.2)	0.99 (0.96, 1.03)		0.95 (0.91, 0.98	
Hospital volume			< 0.001		< 0.001
Low	1910 (53.3)	1.00 (reference)		1.00 (reference)	
Medium	1913 (49.3)	0.92 (0.88, 0.97)		0.94 (0.90, 0.98)	
High	1804 (45.9)	0.86 (0.82, 0.90)		0.87 (0.83, 0.91)	

Values in parentheses are percentages unless indicated otherwise; *values in parentheses are 95 per cent confidence intervals. Univariable and multivariable incidence rate ratios (IRRs) were estimated using Poisson regression.

days after admission (*Fig. 3*). Sensitivity analysis using a 7-day admission-to-intervention time frame revealed that delays were still significantly affected by patient factors, but less so by day of admission (*Table S2*).

Procedure volume of the hospital where the intervention was performed was also associated with delay to revascularization; medium-volume (IRR 0.94, 0.90 to 0.98) and high-volume (IRR 0.87, 0.83 to 0.91) hospitals were associated with a reduced risk of delay compared with low-volume centres. The median interval between admission and intervention was 6 (i.q.r. 3–11) days for low-volume and 5 (2–8) days for high-volume hospitals.

There was a slightly reduced risk of delay for patients having endovascular revascularization procedures (IRR 0.95, 0.91 to 0.98; $P = 0.005$). A sensitivity analysis of 5559 procedures undertaken in hospitals with more than 80 per cent case ascertainment for endovascular procedures produced similar results (*Tables S3* and *S4*).

Discussion

This study showed that only 50.6 per cent of patients with CLTI admitted to NHS arterial centres non-electively between 2016 and 2019 underwent revascularization within 5 days from admission. The comparatively low proportion of patients meeting the target set by the VSGBI for non-elective procedures is likely to reflect its recent introduction, but it also reveals the magnitude of the task ahead.

The timing of revascularization was associated with a number of patient characteristics, such as age, co-morbidity burden, smoking status, Fontaine score, and presenting problem. Whether or not a patient had diabetes was not associated with the time to revascularization. There was a small effect associated with hospital volume, with a slightly higher proportion of patients being treated within 5 days of admission at hospitals with larger volumes. The results suggest that the type of procedure had a small impact on delay. There was also a strong association with the day of admission. The worst performance was observed midweek; Tuesday and Wednesday were the days of admission with the lowest proportion of patients meeting the 5-day revascularization target.

The finding that older age and multiple co-morbidities were associated with an increased risk of waiting for a procedure longer than 5 days is similar to findings from other studies[14,15]. These delays may be attributed to the fact that patients with co-

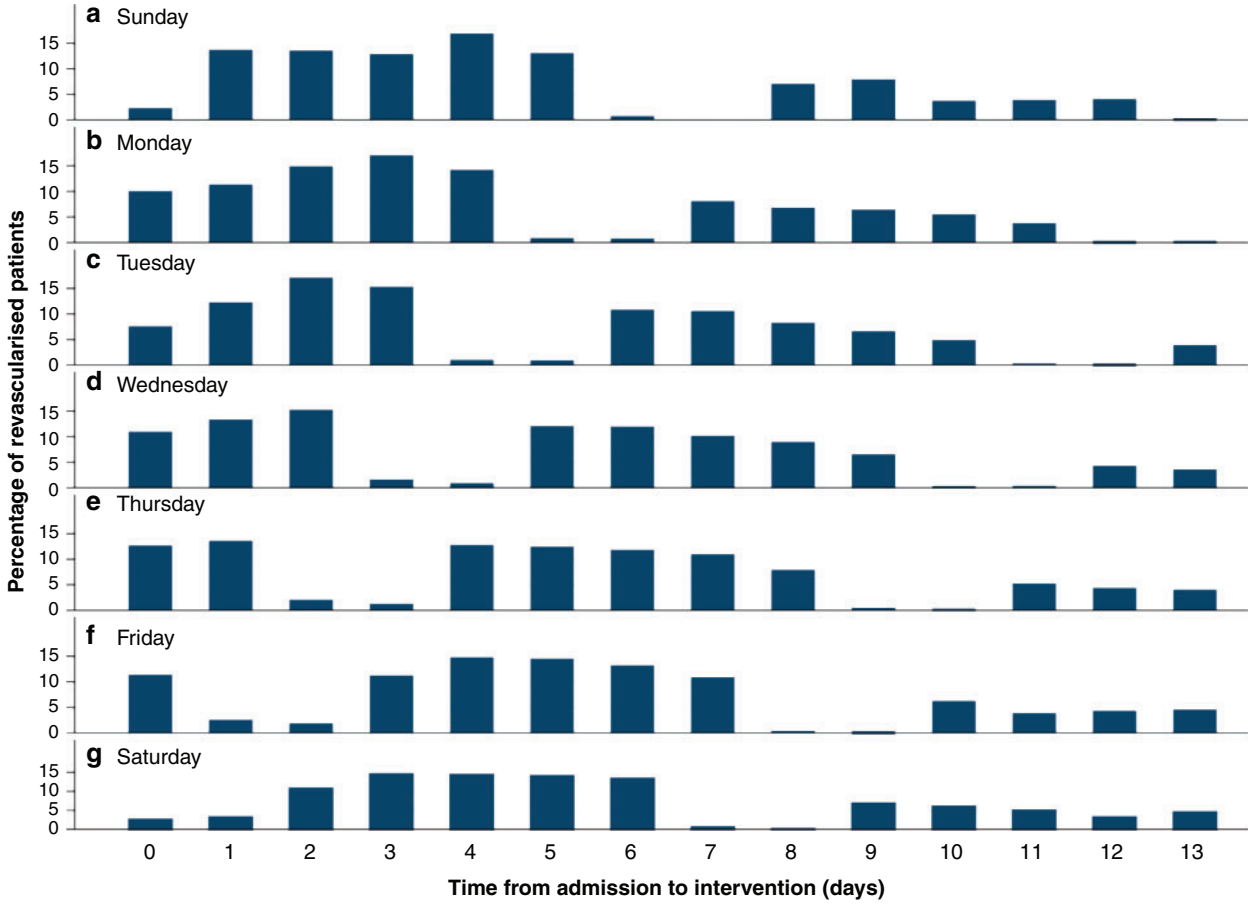

Fig. 2 Percentage of patients undergoing revascularization on specific days of preoperative inpatient stay, by day of admission
a Sunday, b Monday, c Tuesday, d Wednesday, e Thursday, f Friday, and g Saturday. Population admitted on each day used as denominator.

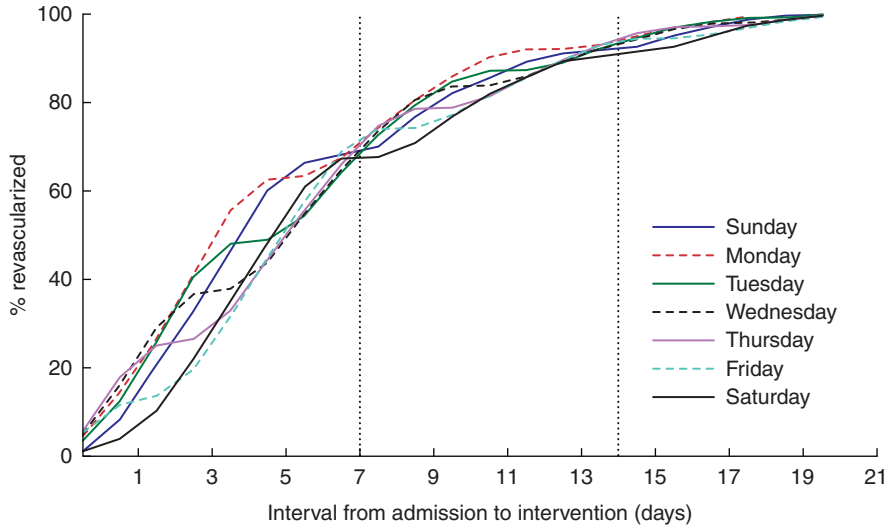

Fig. 3 Cumulative percentage of patients undergoing revascularization as duration of preoperative stay increased, by day of admission, for patients who underwent revascularization within 21 days

morbidities require medical stabilization and cardiorespiratory investigations (ECGs, echocardiograms, pulmonary function tests) after admission to assess fitness for surgery. The waiting times for these tests vary between vascular units and they are often not available out of hours, prolonging the delay to the procedure. Clinical input from medical specialties may also be required to optimize these patients, and can further delay treatment.

Patients with more severe disease, indicated by higher Fontaine score and presentation with tissue loss, also experienced longer delays to revascularization. This finding is

counterintuitive as such patients are at higher risk of limb loss, but it is possible that they have multilevel disease and require more complex decision-making about the treatment options. The delays for patients presenting with uncontrolled infection may be due to antibiotic courses or other procedures undertaken to control the source of infection before revascularization.

A slightly higher proportion of patients who had endovascular than open revascularization procedures were treated within the recommended 5-day standard. This may be because endovascular procedures are less invasive than bypass surgery and are usually performed under local anaesthetic, so patients require fewer preoperative investigations. However, case ascertainment for endovascular procedures in the NVR was substantially lower than for open surgical procedures[9], and this observation needs to be treated with caution. In the sensitivity analysis of hospitals with high case ascertainment for endovascular procedures, the difference in delays to revascularization between procedure types became non-significant.

An association between increased hospital volume and better patient outcomes, such as mortality and complication rates, has been demonstrated in studies of vascular surgery[16–18]. The present study also suggests that there may be a relationship between delay to intervention and low hospital volume. This finding may reflect that larger vascular units are better able to manage patient flow, but is hard to interpret this result owing to a lack of information on other unit-level factors, such as number of surgeons, theatre list availability, and population coverage.

The relationship between day of admission and time to revascularization is an important observation. There have been mixed results about the importance of day of admission from studies exploring its effect on process indicators, such as time to intervention, and on patient outcomes[19,20]. Studies have reported that patients admitted to hospital at the weekend with stroke[21], acute myocardial infarction[22], upper gastrointestinal bleeding[23], gallstone pancreatitis[24], and spinal metastases[25] wait longer for invasive procedures than those admitted during the week. In the USA, Orandi and colleagues[26] found that patients admitted non-electively at the weekend with critical and acute limb ischaemia had a longer wait to revascularization, lower likelihood of revascularization, and higher odds of complications and major amputation than those admitted on weekdays, but the effect of individual days of the week was not examined.

Variation in performance across the week has been observed in other settings. A study[27] of hip fracture surgery found that patients admitted from Thursday to Saturday experienced the longest delays. Complex patterns of temporal variation were also demonstrated in a study[28] of patients with acute stroke, for whom process outcomes, such as time to thrombolysis, varied both by admission day and time, indicating that the impact of the timing of admission is more intricate than the weekend effect implies.

The NVR data set does not contain variables that would allow exploration of the reasons behind the temporal variations in care. Although some variation might reflect differences in disease severity[29,30], the distinct pattern of surgery illustrated in *Fig. 2* suggests that the variation in observed delays is more likely to be the effect of organizational factors, such as the limited availability of hospital resources and other care processes[14], especially during the weekend when there are typically lower staffing levels, reduced availability of diagnostic tests, and limited access to operating or interventional theatres. Another reason for the delays could be the prioritization of patients with other vascular conditions, such as carotid disease and aneurysms, as a result of incentives created by existing waiting time standards and previous quality improvement initiatives, such as the publication of surgeon-level outcomes for these procedures[31,32].

Nonetheless, although variation in activity during the week is undesirable, a greater concern is that only 50.6 per cent of the patients with CLTI in this study underwent revascularization within 5 days. It is unrealistic to expect all patients to be treated within this time frame. Although rapid revascularization is important for patients with tissue loss, some individuals benefit from medical optimization. One approach might be to agree a national standard based on the top performing vascular units as identified in the recent NVR 2020 Annual Report[9]. An alternative could be to revise the recommendation from 5 to 7 days. However, such a change ideally requires information about how time to revascularization affects limb salvage.

The adoption of 7-day urgent vascular services, with operating slots on the weekend as a way to expand capacity, was recommended in the 2018 GIRFT Vascular Surgery report[3]. This model has improved waiting times in orthopaedic surgery[33]. Recent studies[34–36] have demonstrated the safety of aortic and lower limb procedures performed at the weekend, even though there is significant heterogeneity of outcomes in the literature[37–39]. There may be lessons to learn from the centralization of acute stroke services in London, which alleviated the effect of the day and time of admission on brain imaging and thrombolysis[40]. A strong relationship with the radiology department has been considered as one of the reasons for the success of this initiative[41]. Increased access to imaging resources would also facilitate the quick progress of the patient with CLTI through the diagnostic pathway, whereas redistribution of imaging as well as cardiorespiratory test slots to correlate with the variation in demand may alleviate this disparity in waiting times.

The development of 7-day services would come at significant cost to the NHS[42], which could be partially offset by the reduction in duration of hospital stay and complication rates thanks to early revascularization. Prioritization of patients with CLTI and reallocation of existing resources may be more attainable, but their effectiveness should be evaluated. The study findings also suggest that further guidance on the 5-day recommendation and the role of medical optimization is required. Without this advice, a range of local standards will probably develop.

The main strength of this study is its population-based design and large size, which increases the generalizability of the findings. The detailed clinical information in the NVR also allowed adjustment for relevant confounding factors.

This study has several limitations. First, although the NVR has a high case ascertainment for lower limb bypass (90 per cent), it only captures around 40 per cent of all lower limb endovascular procedures[9]. The similarity of patient characteristics from hospitals with low and high case ascertainment (*Table S3*) and the results of sensitivity analysis (*Table S4*) suggest that the estimated times to surgery for endovascular procedures are robust and have not unduly biased the estimated level of overall compliance. Similarly, there was no suggestion that data on endovascular procedures were more likely to be submitted on particular days of admission, which could have led to bias in the estimates for each day of the week. Second, the NVR data set does not record previous hospital admissions or outpatient reviews. Consequently, although the study was limited to non-elective admissions, some of the patients may have had scheduled urgent procedures, which would artificially increase the proportion of patients whose intervention

was within the 5-day recommendation. The time of admission was not available. It was therefore not possible to assess the effect of in-hours *versus* out-of-hours presentation. It is hypothesized that, because the time frame for revascularization is days rather than hours, the time of presentation should not substantially affect the interval to intervention.

Between 2016 and 2019, only 50.6 per cent of patients admitted non-electively to UK vascular units with CLTI received revascularization within 5 days. Few data exist to inform how these data compare with those from other countries in Europe or elsewhere. Given that the VSGBI best practice guidance for these patients was only published in 2019, it might be argued that it is unreasonable to expect many NHS hospitals to be meeting this standard. However, the recommendation reflects a consensus about expected standards of care in the UK, and the report on vascular services published by GIRFT in 2018 had already highlighted the issue of excessive delays. The adoption of a 5-day target has provided an explicit standard against which services can benchmark their performance and will hopefully motivate improvement. That the interval from admission to revascularization was also associated with the day of admission is another concern, and requires further investigation to identify solutions that remove this source of variation. One option might be for vascular units providing lower limb revascularization to deliver a 7-day service.

Acknowledgements

The authors acknowledge the support of the vascular specialists and hospital staff who have participated in the NVR and devoted considerable time to data collection.

This study was undertaken as part of the work of the NVR. No preregistration exists for the analyses reported in this article. The NVR was established to provide information on the performance of NHS vascular units and support local quality improvement in England, Wales, Scotland, and Northern Ireland. It was commissioned by the HQIP as part of the National Clinical Audit and Patient Outcomes Programme, and is funded by NHS England and the Welsh Government. This publication is based on data collected by, or on behalf of, the HQIP, which has no responsibility or liability for the accuracy, currency, reliability, and/or correctness of the material. The authors had complete access to the study data that support this publication. The funding bodies had no role in the study design, data collection and analysis, decision to publish, or preparation of the manuscript. The data governance arrangements for the study do not allow the authors to redistribute NVR data to other parties. Researchers interested in using NVR data can apply for access through HQIP's Data Access Request facility (https://www.hqip.org.uk).

Funding

P.B. is supported by a Royal College of Surgeons of England/Circulation Foundation Joint Clinical Research Fellowship grant. The funding bodies had no involvement in the study design, data collection and analysis, preparation of the manuscript or decision to publish.

Disclosure. The authors declare no conflict of interest.

Supplementary material

Supplementary material is available at *BJS* online.

References

1. Peach G, Griffin M, Jones KG, Thompson MM, Hinchliffe RJ. Diagnosis and management of peripheral arterial disease. *BMJ* 2012;**345**:e5208
2. Nickinson ATO, Bridgwood B, Houghton JSM, Nduwayo S, Pepper C, Payne T *et al.* A systematic review investigating the identification, causes, and outcomes of delays in the management of chronic limb-threatening ischemia and diabetic foot ulceration. *J Vasc Surg* 2020;**71**:669–681
3. Horrocks M. *Vascular Surgery GIRFT Programme National Specialty Report*. 2018. https://www.gettingitrightfirsttime.co.uk/girft-reports/ (accessed 1 December 2020).
4. Vascular Society of Great Britain and Ireland. *A Best Practice Clinical Care Pathway for Peripheral Arterial Disease*. 2019. https://www.vsqip.org.uk/resources/quality-improvement/quality-improvement-lower-limb-ischaemia/ (accessed 1 December 2020).
5. Loftus IM, Paraskevas KI, Johal A, Waton S, Heikkila K, Naylor AR *et al.* Editor's choice—delays to surgery and procedural risks following carotid endarterectomy in the UK national vascular registry. *Eur J Vasc Endovasc Surg* 2016;**52**:438–443
6. Moja L, Piatti A, Pecoraro V, Ricci C, Virgili G, Salanti G *et al.* Timing matters in hip fracture surgery: patients operated within 48 hours have better outcomes. A meta-analysis and meta-regression of over 190,000 patients. *PLoS One* 2012;**7**:e46175
7. Elgzyri T, Larsson J, Nyberg P, Thörne J, Eriksson KF, Apelqvist J. Early revascularization after admittance to a diabetic foot center affects the healing probability of ischemic foot ulcer in patients with diabetes. *Eur J Vasc Endovasc Surg* 2014;**48**:440–446
8. Noronen K, Saarinen E, Albäck A, Venermo M. Analysis of the elective treatment process for critical limb ischaemia with tissue loss: diabetic patients require rapid revascularisation. *Eur J Vasc Endovasc Surg* 2017;**53**:206–213
9. Waton S, Johal A, Birmpili P, Li Q, Cromwell D, Pherwani A *et al.* *National Vascular Registry: 2020 Annual Report*. London: Royal College of Surgeons of England, 2020
10. Kuhrij LS, Meershoek AJA, Karthaus EG, Vahl AC, Hamming JF, Nederkoorn PJ *et al.* Factors associated with hospital dependent delay to carotid endarterectomy in the Dutch audit for carotid interventions. *Eur J Vasc Endovasc Surg* 2019;**58**:495–501
11. Armitage P, Matthews JNS, Berry G (eds). Statistical methods in epidemiology. In: *Statistical Methods in Medical Research* (4th edn). Oxford: Blackwell Publishing company, 2002, 648–716
12. Zou G. A modified poisson regression approach to prospective studies with binary data. *Am J Epidemiol* 2004;**159**:702–706
13. Benchimol EI, Smeeth L, Guttmann A, Harron K, Moher D, Petersen I *et al.* The REporting of studies Conducted using Observational Routinely-collected health Data (RECORD) statement. *PLoS Med* 2015;**12**:e1001885
14. Sheehan KJ, Sobolev B, Villán Villán YF, Guy P. Patient and system factors of time to surgery after hip fracture: a scoping review. *BMJ Open* 2017;**7**:e016939
15. Ryan DJ, Yoshihara H, Yoneoka D, Egol KA, Zuckerman JD. Delay in hip fracture surgery: an analysis of patient-specific and hospital-specific risk factors. *J Orthop Trauma* 2015;**29**:343–348
16. Trenner M, Kuehnl A, Salvermoser M, Reutersberg B, Geisbuesch S, Schmid V *et al.* Editor's choice—high annual hospital volume is associated with decreased in hospital mortality and

complication rates following treatment of abdominal aortic aneurysms: secondary data analysis of the Nationwide German DRG statistics from 2005 to 2013. *Eur J Vasc Endovasc Surg* 2018; **55**:185–194
17. Poorthuis MHF, Brand EC, Halliday A, Bulbulia R, Bots ML, de Borst GJ. High operator and hospital volume are associated with a decreased risk of death and stroke after carotid revascularization: a systematic review and meta-analysis. *Ann Surg* 2019;**269**:631–641
18. Goka EA, Phillips P, Poku E, Essat M, Woods HB, Walters SJ *et al.* The relationship between hospital or surgeon volume and outcomes in lower limb vascular surgery in the United Kingdom and Europe. *Ann Vasc Surg* 2017;**45**:271–286
19. Chen YF, Armoiry X, Higenbottam C, Cowley N, Basra R, Watson SI *et al.* Magnitude and modifiers of the weekend effect in hospital admissions: a systematic review and meta-analysis. *BMJ Open* 2019;**9**:e025764
20. Arulkumaran N, Harrison DA, Brett SJ. Association between day and time of admission to critical care and acute hospital outcome for unplanned admissions to adult general critical care units: cohort study exploring the 'weekend effect'. *Br J Anaesth* 2017;**118**:112–122
21. Palmer WL, Bottle A, Davie C, Vincent CA, Aylin P. Dying for the weekend: a retrospective cohort study on the association between day of hospital presentation and the quality and safety of stroke care. *Arch Neurol* 2012;**69**:1296–1302
22. Sorita A, Ahmed A, Starr SR, Thompson KM, Reed DA, Prokop L *et al.* Off-hour presentation and outcomes in patients with acute myocardial infarction: systematic review and meta-analysis. *BMJ* 2014;**348**:f7393
23. Jairath V, Kahan BC, Logan RF, Hearnshaw SA, Travis SP, Murphy MF *et al.* Mortality from acute upper gastrointestinal bleeding in the United kingdom: does it display a 'weekend effect'? *Am J Gastroenterol* 2011;**106**:1621–1628
24. Jehan F, Khan M, Kulvatunyou N, Hamidi M, Gries L, Zeeshan M *et al.* Day of hospital admission and effect on outcomes: the weekend effect in acute gallstone pancreatitis. *J Surg Res* 2019; **233**:192–198
25. Dasenbrock HH, Pradilla G, Witham TF, Gokaslan ZL, Bydon A. The impact of weekend hospital admission on the timing of intervention and outcomes after surgery for spinal metastases. *Neurosurgery* 2012;**70**:586–593
26. Orandi BJ, Selvarajah S, Orion KC, Lum YW, Perler BA, Abularrage CJ. Outcomes of nonelective weekend admissions for lower extremity ischemia. *J Vasc Surg* 2014;**60**:1572–1579
27. Ricci WM, Brandt A, McAndrew C, Gardner MJ. Factors affecting delay to surgery and length of stay for patients with hip fracture. *J Orthop Trauma* 2015;**29**:e109–e114
28. Bray BD, Cloud GC, James MA, Hemingway H, Paley L, Stewart K *et al.* Weekly variation in health-care quality by day and time of admission: a nationwide, registry-based, prospective cohort study of acute stroke care. *Lancet* 2016;**388**:170–177
29. Sun J, Girling AJ, Aldridge C, Evison F, Beet C, Boyal A *et al.* Sicker patients account for the weekend mortality effect among adult emergency admissions to a large hospital trust. *BMJ Qual Saf* 2019;**28**:223–230
30. Walker AS, Mason A, Quan TP, Fawcett NJ, Watkinson P, Llewelyn M *et al.* Mortality risks associated with emergency admissions during weekends and public holidays: an analysis of electronic health records. *Lancet* 2017;**390**:62–72
31. Potgieter R, Hindley H, Mitchell D, McCleary J. *Delivering a National Quality Improvement Programme for Patients with Abdominal Aortic Aneurysms*. London: Vascular Society of Great Britain and Ireland, 2012
32. National Guideline Centre (UK). *Stroke and Transient Ischaemic Attack in Over 16s: Diagnosis And Initial Management (NICE Guideline 128)* London: National Institute for Health and Care Excellence, 2019
33. Taylor M, Hopman W, Yach J. Length of stay, wait time to surgery and 30-day mortality for patients with hip fractures after the opening of a dedicated orthopedic weekend trauma room. *Can J Surg* 2016;**59**:337–341
34. Ambler GK, Mariam NBG, Sadat U, Coughlin PA, Loftus IM, Boyle JR. Weekend effect in non-elective abdominal aortic aneurysm repair. *BJS Open* 2017;**1**:158–164
35. O'Donnell TFX, Li C, Swerdlow NJ, Liang P, Pothof AB, Patel VI *et al.* The weekend effect in AAA repair. *Ann Surg* 2019;**269**: 1170–1175
36. Galyfos G, Sigala F, Bazigos G, Filis K. Weekend effect among patients undergoing elective vascular surgery. *J Vasc Surg* 2019; **70**:2038–2045
37. Gillies MA, Lone NI, Pearse RM, Haddow C, Smyth L, Parks RW *et al.* Effect of day of the week on short- and long-term mortality after emergency general surgery. *Br J Surg* 2017;**104**:936–945
38. McCallum IJ, McLean RC, Dixon S, O'Loughlin P. Retrospective analysis of 30-day mortality for emergency general surgery admissions evaluating the weekend effect. *Br J Surg* 2016;**103**: 1557–1565
39. Hoehn RS, Go DE, Dhar VK, Kim Y, Hanseman DJ, Wima K *et al.* Understanding the 'weekend effect' for emergency general surgery. *J Gastrointest Surg* 2018;**22**:321–328
40. Melnychuk M, Morris S, Black G, Ramsay AIG, Eng J, Rudd A *et al.* Variation in quality of acute stroke care by day and time of admission: prospective cohort study of weekday and weekend centralised hyperacute stroke unit care and non-centralised services. *BMJ Open* 2019;**9**:e025366
41. Black GB, Ramsay AIG, Baim-Lance A, Eng J, Melnychuk M, Xanthopoulou P *et al.* What does it take to provide clinical interventions with temporal consistency? A qualitative study of London hyperacute stroke units. *BMJ Open* 2019;**9**:e025367
42. Meacock R, Doran T, Sutton M. What are the costs and benefits of providing comprehensive seven-day services for emergency hospital admissions? *Health Econ* 2015;**24**:907–912