Laminar flow reduces cases of surgical site infections in vascular patients

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ABSTRACT
INTRODUCTION Numerous strategies are employed routinely in an effort to lower rates of surgical site infections (SSIs). A laminar flow theatre environment is generally used during orthopaedic surgery to reduce rates of SSIs. Its role in vascular surgery, especially when arterial bypass grafts are used, is unknown.

METHODS A retrospective review of a prospectively maintained database was undertaken for all vascular procedures performed by a single consultant over a one-year period. Cases were performed, via random allocation, in either a laminar or non-laminar flow theatre environment. Demographic data, operative data and evidence of postoperative SSIs were noted. A separate subgroup analysis was undertaken for patients requiring an arterial bypass graft. Univariate and multivariate logistical regression was undertaken to identify significant factors associated with SSIs.

RESULTS Overall, 170 procedures were analysed. Presence of a groin incision, insertion of an arterial graft and a non-laminar flow theatre were shown to be predictive of SSIs in this cohort. In the subgroup receiving arterial grafts, only a non-laminar flow theatre environment was shown to be predictive of an SSI.

CONCLUSIONS This study suggests that laminar flow may reduce incidences of SSI, especially in the subgroup of patients receiving arterial grafts.

KEYWORDS
Vascular surgical procedures – Surgical wound infection – Laminar air-flow areas – Postoperative complications

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Infection is a major potential complication of bypass grafting in vascular surgery. The incidence of vascular graft infections ranges from 1% to 10% of cases.1–4 However, a more commonly accepted infection rate is considered to be 2–3%.5 The sequelae of graft infections can be catastrophic. Aortic graft infections carry a mortality of 45–70%2 and graft infection in general leads to prolonged in-hospital stay, reoperation and, occasionally, limb amputation. Even non-graft related surgical wound infections result in significant morbidity. Length of in-hospital stay was increased by an average of 12.2 days following wound infections at an average cost of £5,515 for superficial wound infections and £5,547 for deep infections.5

A number of factors are associated with an increased risk of graft infection. These include groin incision,1–4 postoperative wound complication,1 diabetes mellitus,10 emergency surgery,1 prolonged hospital stay,1 smoking,1 advanced age (over 65 years)1 and early reoperation.1 The clinical presentation of graft infections is varied, with infrainguinal bypass graft infections presenting postoperatively after a mean of four months and aortic graft infections presenting after a mean of three years.1

Numerous strategies have been developed to reduce these infections, including antibiotic prophylaxis, meticulous aseptic technique and, more recently, antibiotic/antimicrobial containing graft materials.1–9 Laminar flow, a system that creates a homogenous flow of air in the operating room with very little turbulence, is used widely in orthopaedic procedures, especially during the insertion of prosthetic graft materials, to minimise contamination of the surgical field with airborne microbes.10 Surprisingly, the uptake of laminar flow in other surgical fields is limited. In spite of the similarity of operative principles during the insertion of prosthetic material in both orthopaedic and vascular surgery, and the potentially catastrophic risks of infection, there have been no studies looking at laminar flow specifically in vascular surgery.

We noted an apparent difference in a single team’s postoperative infection rates in patients undergoing surgery in non-laminar theatre environments compared with those
who had undergone surgery in laminar flow theatres despite similar operating team and surgical practice. This appeared to be particularly in cases requiring arterial bypass surgery. We therefore undertook a review of the incidence of postoperative infections in patients who had vascular surgery in either laminar or non-laminar flow theatres and performed multiple logistic regression to identify factors influencing the rate of infection.

**Methods**

A one-year retrospective analysis was carried out on a prospectively collected database of consecutive patients undergoing open vascular procedures (venous and arterial) performed by a single vascular surgeon. Endovascular or other minimally invasive vascular procedures were not included. Patients undergoing vascular procedures requiring arterial bypass using grafts were further analysed. Procedures were performed in both laminar flow and conventional theatre environments with allocation randomly assigned via the waiting list to one of three weekly scheduled lists (two half-day lists in a non-laminar flow theatre, one half-day list in a laminar flow theatre).

All procedures were performed by the same consultant surgeon, assisted by the same theatre staff and performed using similar surgical techniques. Skin preparation was identical, consisting of skin clipping immediately prior to skin preparation, which was with a chlorhexidine-alcohol solution. In the case of arterial bypass, conduit materials included autologous vein (used preferentially for infraimguinal bypasses), woven dacron or polytetrafluoroethylene. Prosthetic graft materials did not contain antimicrobial or antibiotic agents. Patients undergoing vascular procedures routinely received preoperative antibiotic prophylaxis at the time of induction (typically co-amoxiclav or a cephalosporin and metronidazole, depending on allergies).

Data collected included age, sex, procedure performed, operative time, use of a groin incision, predisposing factors for infection including diabetes mellitus and other comorbidities (defined as per international standards), current smoking status, graft type and evidence of postoperative surgical site infection (SSI). SSIs were identified, as supervised by one consultant microbiologist, by a review of the medical records for clear evidence of wound infection (Table 1) and graded as superficial (involving skin or subcutaneous tissue) or deep (involving muscle, fascia or graft material) according to Centers for Disease Control and Prevention criteria. Initial statistical analysis to compare patient groups between the two theatres used a two-tailed Student’s t-test for continuous variables (after confirmation of normality with a Kolmogorov–Smirnov test) and a two-tailed chi-square or Fisher’s exact test for categorical variables as appropriate. Univariate analysis was undertaken to examine potential variables affecting infection rates. A stepwise (backward:LR method) multivariate logistical regression analysis was undertaken subsequently to identify significant factors affecting rates of SSIs. A similar regression analysis was carried out for the subgroup of patients requiring arterial bypass.

**Results**

A total of 170 vascular operations were performed during the study period (114 in a non-laminar flow theatre, 56 in laminar flow), of which SSIs occurred in 25 patients (15.5%; 14 superficial infections, 9 deep infections). Details of patient data, operative data, significant co-morbidities and evidence of SSIs are given in Table 2. Patients in laminar flow theatres were more likely to have an arterial bypass procedure requiring a graft insertion and were generally (but not statistically significantly) older. Despite these data, SSIs tended to occur at a lower rate in the laminar flow theatre environment (7% vs 17%, p=0.1).

Infection rates appeared to be higher in patients undergoing arterial bypass using grafts and this subgroup was therefore analysed separately. Overall, 81 patients required an arterial graft as part of their operative procedure, 69 of which involved insertion of prosthetic graft material. The operations performed are detailed in Table 3. Patients in this subgroup were matched equally between theatres regarding baseline characteristics, operative details and co-morbidities.

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**Table 1 Criteria for surgical site infection**

| Criteria for surgical site infection |
|-------------------------------------|
| - cellulitis                        |
| - erythema                          |
| - wound breakdown                  |
| - purulent discharge                |
| - + /- microbiological evidence     |
| - + /- pyrexia                      |
| - + /- increased inflammatory markers or white cell count |

This table provides a list of criteria for surgical site infections, including cellulitis, erythema, wound breakdown, purulent discharge, a positive microbiological evidence, pyrexia, and increased inflammatory markers or white cell count. These factors are used to determine the presence of a surgical site infection.
LAMINAR FLOW REDUCES CASES OF SURGICAL SITE INFECTIONS IN VASCULAR PATIENTS

Table 2  Patient data from laminar and non-laminar flow theatres

|                          | Non-laminar flow | Laminar flow | P-value |
|--------------------------|------------------|--------------|---------|
| Total                    | 114              | 56           |         |
| Sex (M:F)                | 76:38            | 33:23        | 0.323*  |
| Mean age (range)         | 64.8 (19–87)     | 69.1 (19–90) | 0.06†   |
| Mean operative time (range) in minutes | 85.1 (20–350) | 95.5 (20–225) | 0.263‡ |
| ‘Re-do’ procedures       | 8 (7%)           | 4 (7%)       | 1.0†    |
| Arterial procedures      | 92 (81%)         | 51 (91%)     | 0.102*
| Arterial grafts used     | 46 (40%)         | 35 (63%)     | 0.007*  |
| Groin incision           | 50 (44%)         | 22 (39%)     | 0.539*  |
| Antibiotic prophylaxis given | 93 (82%) | 50 (89%)     | 0.283*  |
| Diabetes mellitus        | 15 (13%)         | 4 (7%)       | 0.306†  |
| Ischaemic heart disease  | 36 (32%)         | 13 (23%)     | 0.258*  |
| Chronic obstructive pulmonary disease | 18 (16%) | 9 (16%)      | 0.962*  |
| Surgical site infections | 19 (17%)         | 4 (7%)       | 0.1†    |

*chi-square test; †Fisher’s exact test; ‡Student’s t-test

Table 3  Operations performed involving arterial bypass using grafts

| Surgical procedure                                              | Laminar flow theatre | Non-laminar flow theatre | Total |
|------------------------------------------------------------------|----------------------|--------------------------|-------|
| AAA repair (open) / aortic procedures                          | 23                   | 22                       | 45    |
| Infrainguinal bypass                                           | 11                   | 17 (of which 6 vein grafts were used) | 28 |
| Axillofemoral / axilloaxillary bypass                           | 0                    | 5                        | 5     |
| Other procedures                                               | 1                    | 2                        | 3     |
| Total                                                          | 35                   | 46                       | 81    |

AAA = abdominal aortic aneurysm

Table 4  Details of patients undergoing graft insertion

|                          | Non-laminar flow | Laminar flow | P-value |
|--------------------------|------------------|--------------|---------|
| Total patients           | 46               | 35           |         |
| Sex (M:F)                | 36:10            | 25:10        | 0.48*   |
| Mean age (range)         | 67.4 (19–87)     | 70.7 (37–83) | 0.213†  |
| Mean operative time (range) in minutes | 126.4 (30–350) | 120.0 (25–225) | 0.588*  |
| ‘Re-do’ procedures       | 4 (9%)           | 2 (6%)       | 0.694†  |
| Venous conduit used      | 6 (13%)          | 6 (17%)      | 0.8424* |
| Groin incision           | 22 (48%)         | 16 (46%)     | 0.778*  |
| Antibiotic prophylaxis given | 44 (96%) | 35 (100%)    | 1.0*    |
| Arterial graft infection (requiring graft removal)             | 9 (8%)           | 0 (0%)       | 0.0086* |
| Diabetes mellitus       | 7 (15%)          | 4 (11%)      | 0.749*  |
| Ischaemic heart disease | 21 (46%)         | 10 (29%)     | 0.117*  |
| Chronic obstructive pulmonary disease                           | 11 (24%)         | 8 (23%)      | 0.912*  |
| Surgical site infections | 15 (33%)        | 4 (11%)      | 0.034*  |

*chi-square test; †Fisher's exact test; ‡Student’s t-test
As shown in Table 6, the use of a non-laminar flow theatre was the only independent predictor for wound infections, significant at both univariate and multivariate analysis (Hosmer–Lemeshow test, p=0.747).

Discussion
Laminar flow ventilation was first pioneered by Charnley in the 1960s to prevent ‘bacteriological contamination in the air of the operating theatre’. In his series of 455 patients undergoing hip arthroplasties, there was an infection rate of 9.5% in non-laminar flow theatres compared with 1.1% in laminar flow theatres. More recent studies have continued to show the importance of laminar flow in lowering postoperative SSIs. However, other studies suggest that laminar flow makes little difference to rates of SSIs or that it may even increase rates of infection. Despite this, theatres are generally all laminar flow as standard in newly built hospi-

Table 5  Univariate and multivariate analysis for factors associated with an increased risk of developing a surgical site infection among all vascular cases

|                      | SSI | No SSI | Univariate analysis p-value | Multivariate analysis p-value | Odds ratio (95% CI) |
|----------------------|-----|--------|-----------------------------|-----------------------------|-------------------|
| Total                | 23  | 147    |                             |                             |                   |
| Sex (M:F)            | 21:2| 88:59  | 0.008                       | –                           |                   |
| Mean age (range)     | 67.7 (50–83) | 66.0 (19–90) | 0.787                     | –                           |                   |
| Mean operative time (range) in minutes | 116.9 (35–230) | 84.4 (20–350) | 0.011                     | –                           |                   |
| ‘Re-do’ procedures   | 3 (13%) | 9 (6%) | 0.512                       | –                           |                   |
| Arterial procedures  | 20 (87%) | 123 (84%) | 0.49                       | –                           |                   |
| Arterial grafts used | 19 (83%) | 62 (42%) | 0.001                      | 0.002                      | 6.945 (2.092–23.056) |
| Groin incision       | 16 (70%) | 56 (38%) | 0.004                      | 0.013                      | 3.809 (1.319–10.994) |
| Antibiotic prophylaxis given | 21 (91%) | 122 (83%) | 0.139                       | –                           |                   |
| Diabetes             | 4 (17%) | 15 (10%) | 0.282                       | –                           |                   |
| Ischaemic heart disease | 10 (43%) | 39 (27%) | 0.320                       | –                           |                   |
| Chronic obstructive pulmonary disease | 4 (17%) | 23 (16%) | 0.72                       | –                           |                   |
| Cases in non-laminar flow theatre | 19 (83%) | 95 (65%) | 0.108                      | 0.026                      | 4.016 (1.178–13.689) |

SSI = surgical site infection; CI = confidence interval

Table 6  Univariate and multivariate analysis for factors associated with an increased risk of developing a surgical site infection in cases receiving arterial grafts

|                      | SSI | No SSI | Univariate analysis p-value | Multivariate analysis p-value | Odds ratio (95% CI) |
|----------------------|-----|--------|-----------------------------|-----------------------------|-------------------|
| Total                | 19  | 62     |                             |                             |                   |
| Sex (M:F)            | 17:2| 44:18  | 0.162                       | –                           |                   |
| Mean age (range)     | 68.6 (50–83) | 68.9 (19–87) | 0.676                     | –                           |                   |
| Mean operative time (range) in minutes | 124.7 (35–230) | 123.2 (23–350) | 0.913                     | –                           |                   |
| ‘Re-do’ procedures   | 3 (16%) | 3 (5%) | 0.318                       | –                           |                   |
| Groin incision       | 12 (63%) | 26 (42%) | 0.119                       | –                           |                   |
| Antibiotic prophylaxis given | 18 (95%) | 61 (98%) | 0.592                       | –                           |                   |
| Diabetes             | 4 (21%) | 7 (11%) | 0.217                       | –                           |                   |
| Ischaemic heart disease | 9 (47%) | 22 (35%) | 0.735                       | –                           |                   |
| Chronic obstructive pulmonary disease | 3 (16%) | 16 (26%) | 0.527                       | –                           |                   |
| Cases in non-laminar flow theatre | 15 (79%) | 31 (50%) | 0.04                      | 0.047                      | 3.474 (1.016–11.883) |

SSI = surgical site infection; CI = confidence interval
tals. Surprisingly, there have been no previous studies investigating the effect of laminar flow on SSI rates in vascular surgery.

In our series of 170 patients, 25 developed an SSI, 19 of which occurred in cases where arterial grafts were required. In this cohort, a greater proportion of cases came from the non-laminar flow theatre environment (33% vs 11%, \( p=0.054 \)). Multiple logistic regression identified three factors associated with an increased risk of SSIs: the use of arterial grafts, a groin incision and the use of a non-laminar flow theatre. Insertion of arterial grafts and groin incisions have been shown previously to increase the risk of SSIs in vascular surgery.\(^{2,22}\) Subsequent multiple logistic regression in patients receiving arterial grafts demonstrated that operating in a non-laminar flow environment remained the only significant risk factor for SSIs in this cohort.

Due to the retrospective nature of our study, it was not possible to include other variables associated with increased SSI rates, such as renal disease, increased body mass index, emergency surgery and a high ASA (American Society of Anesthesiologists) grade.\(^{23}\) Regardless, these data suggest laminar flow may be important in preventing SSIs in patients undergoing vascular surgery, especially in those receiving arterial grafts.

A perhaps surprisingly small number of SSIs (\( n=4 \)) were recorded in patients undergoing vascular procedures without insertion of arterial grafts. Evidence of SSIs was collected in hospital and during subsequent hospital visits. Although certainly, there was a greater true rate of infection, which was treated in the community setting. However, the assumption that these cases represent the more severe spectrum of SSIs implies these data are valid for reducing significant infections. We suggest this makes the results more important rather than less so.

A note of caution is required regarding the analysis of these data. The case mix is heterogeneous and not equally matched between the two theatre environments. For example, all five auxiliary bypass procedures were undertaken in a non-laminar flow theatre although a greater percentage of arterial bypass procedures was performed in a laminar flow theatre. Administration rates of antibiotic prophylaxis were not identical between the two groups. Furthermore, retrospective SSI data collection lacks the sensitivity of prospective data collection. Given this, definitive data from a prospective randomised study of homogenous patients undergoing similar procedures with equivalent antibiotic prophylaxis in these two theatre environments are warranted before definitive conclusions can be drawn.

Conclusions

The data from our study suggest that laminar flow may play an important role in reducing the incidences of SSIs in vascular surgery. This appears to be particularly so with operations involving arterial bypass using grafts.

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Bosanquet Jones Gill Jarvis Lewis

LAMINAR FLOW REDUCES CASES OF SURGICAL SITE INFECTIONS IN VASCULAR PATIENTS

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19

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