Blowing against the wind: the case for shifting the current paradigm on theatre ventilation

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Operating theatre ventilation systems play a role in preventing contamination, but also regulating environmental temperature and humidity.

Deep infection after total joint replacement is a devastating complication. The incidence of recurrent infection is low, but remains a significant complication which may require several procedures at considerable expense[1].

The importance of the operating theatre ventilation system in reducing surgical site infections (SSIs) has been discussed for numerous years. There are two main ventilation systems:

- Turbulent mixed airflow – also called plenum flow.
- Laminar airflow.

The questions that arise are:

- What is the carbon footprint of these systems?
- Do we need to challenge our current paradigm that all T&O surgery is done in an ultraclean setting?
- Can we reduce the carbon footprint of ventilation systems?

Carbon footprint

Laminar flow relies on the use of ventilator systems that use fans to generate a positive air pressure in the roof of the theatre. The fans are connected to high efficiency particulate air (HEPA) filters to remove bacteria and other debris.

To attain laminar flow, there must be a continuous flow of highly filtered ultraclean air (UCA) of <10 colony-forming units per metre cubed (CFU/m^3) of bacteria. Once the contaminants are removed, the air is returned to theatre, creating up-to 300 air changes per hour.

The Medical Research Council trial confirmed the value of laminar-flow theatres in the reduction of CFUs[3]. Plenum ventilation systems rely on filtered but turbulent air currents, which are forced via positive pressure into the theatre suite. These systems create fewer air changes; between 15 and 35 times an hour.

From the point of air changes per hour, laminar flow requires more energy than plenum flow, but there is little in the literature to quantify this.

Shifting the paradigm

Many cite the study by Lidwell *et al*., using a cohort of over 8,000 patients across the UK and Sweden in a randomised control trial setting[4]. They followed up all patients undergoing a total hip and knee replacement for between 2-3 years for any evidence of peri-prosthetic joint infection (PJI). A statistically significant reduction in PJI in the laminar flow group (0.6% v 1.5%) was reported, particularly where laminar flow was used as an adjunct to other means of asepsis such as occlusive clothing and exhaust suits. However, this study has been widely criticised for lack of controls of the variables and uncontrolled use of peri-operative prophylactic antibiotics.

It has now become unclear whether laminar flow systems that reduce the overall numbers of potentially contaminating particles within the operative field, translates to a significant effect on the rates of peri-prosthetic joint infection (PJI)[5-7]. To date, there have been no studies which have shown conclusively that fewer colony-forming units relates to a lower rate of wound contamination and infection. The evidence for the use of laminar flow in reducing infection rates in lower limb arthroplasty is now questioned[8-10].

Three studies, with increasing evidential value, demonstrate the changing evidence that doubt the benefit of laminar flow in reducing surgical site infection.

1. A simple observational study utilising a new hospital with an old hospital by Van Griethuysen *et al*. demonstrated that the addition of laminar flow in a new theatre suite resulted in no significant reduction of deep PJI per se[11]. Similar protocols were followed, after the introduction of laminar flow and while the air quality was improved, this did not correlate with any demonstrable reduction in PJI.

2. A study of 63 surgical departments in Germany evaluated whether laminar flow impacts on surgical site infection for both orthopaedic and abdominal surgery[12]. Compared to normal ('turbulent') ventilation, the risk for severe SSI after hip prosthesis implantation was significantly higher using laminar airflow (1.63 < 1.06; 2.52>). This study, which controlled for many patient and hospital-based confounders, demonstrated that laminar airflow showed no benefit and was even associated with a significantly *higher* risk for severe SSI after hip prosthesis.

3. The 10-year results of the New Zealand Joint registry investigated the use of laminar flow ventilation in reducing the rate of revision for early deep infection after hip and knee replacement[13]. A large retrospective study of 83,311 TKR and THR cases the results mirror the study by Brandt *et al* [12]. The rates of revision for PJI were statistically significantly higher in laminar flow theatres (0.148%) versus conventional ventilation theatres (0.061%), with similar results in TKR (0.243% v 0.098%).

	Date	Study size (n=)	Odd ratio
Kakwani *et al* [15]	2007	435	0.05
Brandt *et al* [12]	2008	28,623	1.53
Dale *et al* [16]	2009	93,958	1.32
Pedersen *et al* [17]	2010	80,756	0.74
Breier *et al* [18]	2011	41,212	1.84
Hooper *et al* [13]	2011	51,485	2.42
Namba *et al* [19]	2012	30,491	1.10
Song *et al* [20]	2012	3,186	1.2
Total		330,146	1.29

Table 1: Published cohort studies comparing risk of deep surgical site infection after total hip arthroplasty for laminar airflow v conventional ventilation.

	Date	Study size (n=)	Odd ratio
Miner *et al* [21]	2007	8,288	1.57
Brandt *et al* [12]	2008	9,396	1.42
Breier *et al* [18]	2011	20,554	1.09
Hooper *et al* [13]	2011	36,826	1.92
Song *et al* [20]	2012	3,088	0.51
Namba *et al* [22]	2013	56,216	0.83
Total		134,368	1.29

Table 2: Published cohort studies comparing risk of deep surgical site infection after total knee arthroplasty for laminar airflow vs conventional ventilation.

In 2017, the effect of laminar flow ventilation on surgical site infection was analysed in a systematic review and meta-analysis[14], which includes both the studies from Germany and New Zealand described above. In total, 12 observational studies compared laminar airflow ventilation with turbulent ventilation in orthopaedic, abdominal and vascular surgery were included in systematic review. Eight cohort studies form the basis of the meta-analysis for hip replacements and six studies for knee replacements (see tables 1 and 2).

The outcome of this meta-analysis demonstrate that laminar airflow ventilation does not reduce the risk of deep surgical site infection after hip and knee replacements compared to plenum ventilation, which we need to note.

Figure 1: Laminar airflow ventilation in action.

> "To attain laminar flow there must be a continuous flow of highly filtered ultraclean air (UCA) of <10 colony-forming units per metre cubed (CFU/m^3) of bacteria. Once the contaminants are removed, the air is returned to theatre, creating up-to 300 air changes per hour."

Actions to reduce the carbon footprint of ventilation systems

These we can divide into short or immediate-term actions and longer-term options.

In the short term, turning the ventilation system off when not in use would seem simple, safe and cost effective and has been put forward[23,24].

In the longer term, adopting energy capture systems, for instance heat exchangers,[26] could be worthwhile and can be retrofitted to existing systems. There are also newer technologies, for example, using temperature-controlled airflow – a variant of laminar flow. This uses a cooled HEPA filtered area above the operating area which, being denser, flows downwards, but uses less energy than laminar flow[25].

Summary

We need a strategy led by the BOA that looks forward to include revaluating our 40-year-old values around the use of laminar flow and the type of surgery done in these theatres.

There are some easy 'wins' to be made with switching laminar flow systems off when not in use, as well as newer technologies that we should be evaluating and promoting. ■

References

References can be found online at www.boa.ac.uk/publications/JTO.