Objectives: To compare the effect of three different styles of neck support on the head position and subsequently on the cervical vertebrae (C1-7) during everyday activities.

Methods: Ten healthy volunteers were assigned to receive one of the three neck supports: a) a standard pillow, b) a custom-made foam cervical collar, or c) a soft neck support. The participants performed a set of everyday activities while wearing each neck support and their trunk, head, and neck positions were recorded using a combination of optical motion capture and radiography.

Results: The analysis of the results showed that the custom-made foam cervical collar significantly reduced the range of motion in the cervical spine compared to the standard pillow and the soft neck support. The soft neck support provided the least restraint on the cervical spine.

Conclusions: The custom-made foam cervical collar was found to be the most effective in limiting cervical motion during everyday activities, potentially reducing the risk of cervical spine injury.
benefits can be expected by reducing it to 1 CFU/m³, given that very low levels of clinically relevant coagulase-negative staphylococci can initiate a device-related infection. A landmark study found a strong linear relationship between the level of bacterial air contamination and the prevalence of deep SSI.

The most common ventilation systems in use today are turbulent, displacement, and laminar airflow (LAF) systems. Whereas turbulent and displacement ventilation systems differ primarily in the methods used to supply clean air, both are incapable of opposing heat emissions from people and lamps. Both types of systems are sensitive to movement, leading to the formation of local eddies.

The most important source of airborne contamination is related to the dispersal of particles from persons present in the OR and their movements. Clothing OR staff in scrubs with lower air permeability compared with conventional scrubs can reduce the dispersal of microorganisms by the OR staff, thereby significantly reducing the airborne contamination. An experimental study has indicated that the protective ability of tightly woven clothing systems can be expected by reducing it to 1 CFU/m³, given that microorganisms by the OR staff, thereby significantly reducing the airborne contamination.

The study was performed at a Swedish university hospital that was sampled at a 7-month period from April to November 2010, with the exception of the holiday month of July.

**Air sampling method**

A Sartorius MD-8 air scanner (Sartorius Mechatronics, Göttingen, Germany) was used to collect airborne microorganisms. Air was sampled at a flow rate of 3 m³/hour (0.83 L/second) in 20-minute periods continuously during the operations. The instrument was placed outside the sterile zone, and a sterilized flexible hose was extended to reach the wound area, with a filter holder attached to the end. The filter holder with a gelatin filter (3 μm pore size; 80 mm diameter) was placed 20-40 cm from the wound. The filters were placed vertically (n = 60), slightly upward (n = 23), slightly downward (n = 17), or horizontally (n = 3). In those cases in which the OR nurse had problems attaching the filter holder close to the wound (n = 13), the holder was placed on the Mayo stand. Data on filter placement was absent in 4 cases. The filter was changed every 20 minutes by the scrub nurse or the assistant and given to the researcher, who immediately placed it on a nonselective Colombia agar base plate with 5% horse blood. Agar plates were incubated at 30°C for 4 days, after which the total aerobic bacterial count was measured. Microbiological results are expressed as CFU/m³. A total of 116 samples were analyzed; 4 samples were accidentally contaminated and thus excluded from the analysis. Filters and plates were handled using strict aseptic technique. To evaluate the technique, filters that had not been used for air sampling were placed on agar plates and incubated in the same way as the used filters; no bacterial growth was detected.

**Observational method**

Data was collected using a pretested, structured observation form. The following variables were included: date and time, OR, room temperature, type of surgery and fixation method. The period from incision time to wound closure was divided into 20-minute intervals corresponding to the ongoing air sampling. During 119 intervals (each interval corresponding to 20 minutes of air sampling), traffic flow was measured, as well as the reasons for door openings, and the current step in the surgical procedure was recorded. The number of people present in the OR, patient and researcher excluded, was recorded.

**Data analysis**

Primary analyses showed that CFU/m³ could not be considered a variable with a normal distribution. For this reason, the linear relationship between CFU/m³ per 20-minute interval and traffic flow per 20-minute interval was investigated using Spearman’s rho. To investigate the strength and direction of the linear relationship between the total traffic flow per operation and the total CFU per operation, partial correlations were conducted, enabling the removal of duration of surgery as a potentially confounding variable and thereby giving a more accurate description of the relationship between the variables. Investigations of correlations between normally distributed variables (ie, traffic flow, duration of surgery, and number of people present) were performed using Pearson’s product-moment correlation coefficient. Significance was defined as P < .05. All tests were 2-tailed. In relation to hierarchical multiple regression analysis, preliminary analyses were conducted to ensure no important violations of the assumptions of normality, linearity, and multicollinearity.
One-way between-group analysis of variance with post hoc tests found no significant difference in mean CFU counts among the 3 ORs. However, applying the same test on sampling device positioning indicated that these variations can lead to differences in mean CFU/m³ values. The mean difference between vertically placed filters and filters placed on the Mayo stand was significant ($P = .01$) (Table 1). In 2 operations involving tibia fractures fixed with an intramedullary nail, the sampling filters had been placed vertically on the opposite leg. During surgery, the injured leg was flexed at 90 degrees, thereby partially or completely blocking the sampling filters with the sterile drape during most of the operation. For this reason, further analysis of air quality in the vicinity of the wound area, samples obtained on the Mayo stand and during the 2 operations for tibia fracture were excluded, leaving 92 samples for analysis. Four operational phase were defined: 1, incision phase; 2, dissection phase; 3, implantation phase; and 4, wound closure phase. Content analysis was used on observational data.

### Ethics

The study was approved by the University of Gothenburg’s Ethics Committee (157-10). Written and oral information was provided in line with the 4 principal requirements of the Helsinki Declaration (autonomy, beneficence, nonmalfeasance, and justice). Accordingly, informed consent was obtained from all of the OR teams before observations and sampling.

### RESULTS

Air sampling was performed during 30 orthopedic operations in a total of 120 air sampling intervals. The distributions of surgical procedures were 73 plates and screws (60.8%), 26 intramedullary nails (21.7%), and 21 hemiarthroplasties (17.5%). The variations in CFU/m³ values were found between operations rather than during operations ($P = .001$). In 52 of 91 samples, the CFU/m³ values exceeded the recommended level of $<10$ CFU/m³. In 14 of 24 operations, the mean values exceeded 10 CFU/m³; in 5 of these operations, the mean values exceeded 25 CFU/m³. The highest mean values were 37.5 and 44.3 CFU/m³. Qualitative analysis revealed high activity levels (ie, movements within the OR as well as traffic flow) during these operations, along with other potentially negative variables, such as hair hanging outside the surgical hood, the presence of a sneezing person, and more than 5 people present in the OR. In 5 operations, mean values were $<5$ CFU/m³, with the lowest values being 1.6 and 2.3 CFU/m³, and notes written during these operations reveal that there was no traffic flow and low activity. Basic results on air quality, expressed as CFU/m³, and related variables are provided in Table 2.

#### Traffic flow

The relationships between the total traffic flow rate per operation and the total CFU/m³ sampled per operation and between traffic flow rate per 20-minute interval corresponding to 20 minutes of air sampling were investigated. A positive correlation was found between CFU/m³ and traffic flow rates when measured in 20-minute intervals ($r = 0.309; P = .003$). The data show a strong, positive correlation between the total CFU/m³ per operation and total traffic flow rate per operation ($r = 0.74; P = .001; n = 24$ operations). Because duration of surgery correlates to the total CFU and traffic flow rates, duration of surgery was controlled for in the analysis.

A total of 529 door openings were recorded. Reasons for OR entries and exits were grouped into categories, as shown in Table 3. No reason could be identified in relation to 93 entries and exits. To exemplify, this could mean that a staff member would enter the OR, take a look around, and then walk out.

Traffic flow rates in relation to the previously mentioned 4 phases of the operation were analyzed by one-way analysis of variance with post hoc tests showing no significant difference in mean traffic flow rate per 20-minute intervals. In addition, no significant differences in mean CFU/m³ values were found among the different phases. No correlation was detected between the number of people present and traffic flow rates in the OR.

#### Number of people and the effect on air quality

A minor correlation was found between CFU/m³ and the number of people present in the OR ($r = 0.22; P = .04; n = 82$).

#### Duration of surgery and type of surgical procedure

No correlation was found between CFU/m³ rates measured in 20-minute intervals and duration of surgery measured in minutes. A positive correlation was found between the total CFU/m³ per operation and duration of surgery ($r = 0.62; P = .01; n = 23$). No correlation was found between traffic flow rate per 20-minute interval and duration of surgery, but a strong correlation was noted between total traffic flow rate per operation and duration of surgery ($r = 0.79; P = .01; n = 23$). Differences in mean CFU values in relation to type of surgical procedure are presented in Table 4.

#### Predictors of CFU

Hierarchical multiple regression was used to assess the ability of traffic flow and number of people present in the OR to predict CFU/m³ levels after controlling for duration of surgery. Duration of surgery was entered in step 1, explaining 36% ($R^2 = 0.359$) of variance with post hoc tests showing no significant difference in mean traffic flow rate per 20-minute intervals. In addition, no significant differences in mean CFU/m³ values were found among the different phases. No correlation was detected between the number of people present and traffic flow rates in the OR.

### Table 1

<table>
<thead>
<tr>
<th>Position</th>
<th>n (missing)</th>
<th>Mean (SD)</th>
<th>95% CI for mean</th>
<th>Median (range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical</td>
<td>60 (17)</td>
<td>15.8 (13.9)</td>
<td>12.2-19.4</td>
<td>13 (0-55)</td>
</tr>
<tr>
<td>Downward</td>
<td>17 (2)</td>
<td>15.2 (10.2)</td>
<td>10.0-20.5</td>
<td>9.0-20.5</td>
</tr>
<tr>
<td>Slightly upward</td>
<td>23 (3)</td>
<td>13.0 (13.4)</td>
<td>7.1-18.8</td>
<td>5.4-10.0</td>
</tr>
<tr>
<td>Horizontally</td>
<td>3 (9)</td>
<td>8.6 (3.7)</td>
<td>-0.74-18.0</td>
<td>8.0-20.5</td>
</tr>
<tr>
<td>Mayo stand</td>
<td>13 (11)</td>
<td>6.6 (4.4)</td>
<td>3.9-9.4</td>
<td>6.0-9.0</td>
</tr>
<tr>
<td>Total</td>
<td>116 (6)</td>
<td>13.9 (12.6)</td>
<td>11.6-16.3</td>
<td>6.0-20.0</td>
</tr>
</tbody>
</table>

*Number of air samples.

### Table 2

<table>
<thead>
<tr>
<th>Variables</th>
<th>n (missing)</th>
<th>Mean (SD)</th>
<th>95% CI for mean</th>
<th>Median (range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFU/m³</td>
<td>96 (1)</td>
<td>15.9 (13.4)</td>
<td>12.1-18.7</td>
<td>9.0-17.0</td>
</tr>
<tr>
<td>Total CFU/m³ per operation</td>
<td>24</td>
<td>60.4 (55.9)</td>
<td>36.8-84.5</td>
<td>33.5 (7-187)</td>
</tr>
<tr>
<td>Number of people</td>
<td>111 (9)</td>
<td>5.4 (1.5)</td>
<td>5.2-5.6</td>
<td>4.9-5.6</td>
</tr>
<tr>
<td>Traffic flow rate</td>
<td>119 (1)</td>
<td>4.3 (2.9)</td>
<td>3.8-4.8</td>
<td>3.9-4.4</td>
</tr>
<tr>
<td>Traffic flow rate per operation</td>
<td>30</td>
<td>17.4 (13.5)</td>
<td>12.4-22.4</td>
<td>14.0 (6-71)</td>
</tr>
<tr>
<td>Duration of surgery, minutes</td>
<td>29 (1)</td>
<td>83.5 (39.7)</td>
<td>68.4-98.5</td>
<td>60 (20-200)</td>
</tr>
</tbody>
</table>

*Number of operations.

1Measured in 20-minute intervals.

2From incision time to end of closure in minutes.

---

Table 1: CFU/m³ values and sampling positions

Table 2: Air quality and related variables

---

Reducing risk factors in the surgical environment clearly would be beneficial for this group of patients.36 Adding smoking habits and old age (the latter of which is common in patients with osteoporotic hip fracture), a picture of a highly vulnerable group of patients emerges. trauma carry an extra burden of preoperative soft tissue and skeletal damage, and have minimal opportunities to be optimized in the OR, because it is highly dependent on other variables and can be reduced to almost nondetectable levels under optimal conditions. In addition, merely counting exits and entries while failing to analyze the reasons behind traffic flow behavior could lead to misdirected interventions.37

Directing the focus of change at an organizational level, including enhanced knowledge, logistics, and perioperative planning, would give the OR staff the necessary tools to minimize door openings in the OR. This would not only minimize traffic flow, but also likely reduce the duration of wound exposure. Lynch et al38 reported a mean rate of 40 door openings per hour for orthopedic total joint surgery, and Young et al39 reported a mean rate of 19.2 per hour for cardiac surgery, compared with the rate of 12.9/hour in the present study. The traffic flow patterns reported in these 3 studies must be considered in light of the high correlation between door opening rate and elevated CFU levels, representing a major patient safety problem.

The large variation in CFU values among operations in the present study is in line with previous reports.12,30,31 This supports the perception that CFU/m3 level should not be discussed as an independent variable with a presumed normal distribution in the OR, because it is highly dependent on other variables and can be reduced to almost nondetectable levels under optimal conditions. The importance of the duration of surgery in relation to CFU/m3 levels measured at 20-minute intervals was of minor importance. However, the duration of surgery is of clinical relevance, given that the total CFU level increases with increasing duration of surgery, thereby exposing the wound to an increased total number of CFUs and increasing the risk of SSI.10,40 In addition, longer duration of surgery was associated with higher total OR traffic flow rates. In this sample, only very small variations in relation to the number of people present in the OR were observed; as a result, the effect of the number of people present in the OR on CFU level could not be investigated thoroughly. The differences in CFU levels related to type of surgery, with fixation with plates and screws associated with the highest levels, can be explained by the fact that these procedures were associated with 50% more door openings. The fact that in almost half of cases, at least one of the air inlet supply devices was partially blocked by medical equipment might suggest that the staff has poor knowledge of how the ventilation system works and how to deal with the reality of underdimensioned operating rooms. To investigate the consequences of blockage of air inlets, it would be necessary to control for how close the medical

of the variance in total CFU/m3 per operation. After entering traffic flow and number of people present, the total variance explained by the model as a whole was 68% [R²(3,16) = 14.32; P < .001]. The 2 control measurements, traffic flow and number of people, explained an additional 34% (adjusted R² = 0.336) of the variance in CFU/m3 when controlling for duration of surgery (R² change = 0.34; F change (2,16) = 9.91; P = .002). In the final model, only traffic flow was statistically significant (standardized β = 0.95; P = .001).

### DISCUSSION

In orthopedic surgery, large-scale efforts and research activities have focused on infection control, mainly in relation to elective primary joint replacement surgery. The findings of the present study show that the recommended limit of >10 CFU/m3 was exceeded in 57% of the samples analyzed. Patients with orthopedic trauma carry an extra burden of preoperative soft tissue and skeletal damage, and have minimal opportunities to be optimized in relation to comorbidities that are known to be major risk factors in this group of patients.36 Adding smoking habits and old age (the latter of which is common in patients with osteoporotic hip fracture), a picture of a highly vulnerable group of patients emerges. Reducing risk factors in the surgical environment clearly would be beneficial for this group of patients. One of the most important findings of the present study is the highly negative impact of traffic flow in the OR on bacterial contamination of the air close to the wound; that is, a high rate of door openings was associated with high rates of CFU/m3 values. This correlation is weaker when analyzing CFU/m3 per 20-minute interval compared with the total CFU/m3 per operation, which may be related to the unorganized manner in which bacterial dispersion reaches the wound area after an OR entry or exit because of turbulent air flow patterns as well as movement of people in the OR. Analysis of the factors affecting traffic flow found that only 7% of the door openings were related to the need for expert consultation. Supply issues represented the largest category (26%); improving preoperative planning and communication between the surgeon and OR nurse in charge could possibly reduce these door openings. Staff breaks accounted for 20% of door openings; surgical team members entering or leaving the OR when the wound was open, for 14%. Reductions in all of these large categories of traffic flow are possible. Door openings for logistic reasons could all be avoided by telephone communication. Door openings related to social visits and for no detectable reasons together accounted for 27% of the traffic flow, possibly reflecting an OR culture that accepts door openings for no special reason. Although it is reasonable to think that an individual who enters an OR always has a good reason for doing so, in those cases we could find no link to the ongoing procedure. Blaming individuals for lack of discipline is not be a fruitful way to address this problem, given that the cause probably extends the individual level. In addition, merely counting exits and entries while failing to analyze the reasons behind traffic flow behavior could lead to misdirected interventions.37

### Table 3

<table>
<thead>
<tr>
<th>Necessary door openings*</th>
<th>n</th>
<th>Semi-necessary door openings</th>
<th>n</th>
<th>Unnecessary door openings</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expert consultations (eg, help needed from senior surgeons, expert nurses, or anesthesiologists)</td>
<td>40</td>
<td>Surgical team members entering after incision or leaving before closure</td>
<td>76</td>
<td>Logistic reasons planning next or other operation</td>
<td>30</td>
</tr>
<tr>
<td>Instruments or other material needed</td>
<td>137</td>
<td>Lunch and coffee breaks</td>
<td>108</td>
<td>Social visits</td>
<td>45</td>
</tr>
<tr>
<td>Total</td>
<td>177</td>
<td>184</td>
<td>93</td>
<td>30</td>
<td></td>
</tr>
</tbody>
</table>

*The need assessed in relation to patient safety and ongoing procedure.

### Table 4

| Relationships among CFU, surgical procedures, and traffic flow, analysis of variance |
|---------------------------------|----|----|----|----|
| | n | Mean | SD | 95% CI | P value |
| Mean CFU/m3 value in relation to surgical procedure* | .001 |
| Plates and screws | 69 | 18.7 | 13.3 | 15.5-21.9 |
| Hemiarthroplasty | 11 | 4.73 | 9.87 | 1.1-18.6 |
| Intramedullary nails | 11 | 4.73 | 9.87 | 1.1-18.6 |
| Mean traffic flow rates in relation to surgical procedure* | .004 |
| Plates and screws | 69 | 4.5 | 2.7 | 3.8-5.1 |
| Hemiarthroplasty | 11 | 2.3 | 1.4 | 1.3-3.3 |
| Intramedullary nails | 11 | 2.2 | 2.3 | 0.6-3.77 |

*Number of air samplings corresponding to type of surgical procedure.

*Number of surgical procedures corresponding to traffic flow rate per 20-minute interval.
equipment was placed in relation to the inlet device and also for how large an area of the inlet supply was blocked. These data were not registered in the present study, precluding analysis of the possible impact on air contamination rates. Given that our regression model explains 34% of the variance of total CFU/m³ per operation, future research should aim at developing a clinically relevant predictive model for estimating bacterial contamination under different environmental and behavioral conditions, taking into account clothing systems and activity levels in the OR.

**Methodological considerations**

Conducting representative air sampling in the OR in live conditions proved highly challenging, and many methodological and technical issues had to be addressed both before and during the present study. The choices of sampling velocity, time, and culture media were based on recommendations from infection control practitioners performing surveillance sampling on a regular basis. Studies have reported that the viability of microorganisms might be affected by prolonged sampling times and high airflow rates.\(^\text{41,42}\)

Evaluation of the Sartorius air sampler demonstrated no reduction in the viability of cocci after drawing 2.6 m³ for 20 minutes, but negative effects for *Escherichia coli*.\(^\text{43}\) Various cocci were the main relevant species found in the OR,\(^\text{24}\) and these bacteria also are the leading cause of infections related to implanted medical devices.\(^\text{44}\)

Based on this, we believed that the sampling time was an acceptable compromise between the purpose of the study and the need to avoid being overly intrusive during the procedures. However, we consider the wide variety of sampling positions in this study a limitation, which might have led to underestimation of CFU values. The literature typically reports on the distance from the wound to the sampling device (striving to be as close as possible), sampling velocity, and time; unfortunately, methodological issues are rarely studied or discussed. Further studies addressing the positioning of sampling filters, the angle between filters and air flow, sampling velocity in relation to air flow patterns produced by different ventilation systems, and their impact on outcome data are needed.

Standardizing an optimal air sampling method would produce reliable data and facilitate comparisons between studies to provide insight into the protective capacity of different ventilation systems during operations. Upward-displacement ventilation systems have been demonstrated to more effectively remove particles compared with conventional systems.\(^\text{45,46}\) An experimental study\(^\text{47}\) comparing conventional ventilation and upward-displacement ventilation confirmed that the upward displacement system was more efficient in removing particles < 10 μm, but found no difference between the 2 ventilation systems for particles > 10 μm.\(^\text{47}\) More importantly, the bacterial air counts were generally higher in the displacement systems than in conventional systems. Considering this in the present study, it is possible that the displacement system produced higher mean CFU/m³ values than what would have been registered under the same circumstances in a conventionally ventilated OR. However, the present study demonstrates that even in a displacement ventilated OR, very low CFU/m³ levels could be obtained by keeping the doors closed and reducing the number of people present.

Even structured observations can be susceptible to bias.\(^\text{48}\) Human perceptual errors can affect the obtained information, as well as behavioral distortions, due to the presence of an observer. Several measures were taken to address potential bias: (1) The observational form was pretested and modified, (2) the observer had no previous connection with the ward under observation, and (3) the observer underwent self-training sessions to maximize accuracy. Concealed observations to reduce reactivity were not feasible and were considered a possible source of distrust between the observed and the observer. To estimate the effect of the presence of an observer, the traffic flow rates at the beginning of the study period (May) were compared with rates measured after 6 months (November); no statistically significant differences in traffic flow rates were detected.

**CONCLUSION**

This study has clearly linked elevated airborne bacterial counts in the surgical area to door openings in conventionally ventilated ORs, thereby providing the scientific evidence needed to initiate interventions aimed at preventing SSI by reducing traffic flow in the OR. In addition, analyzing the reasons for door openings seems to be of great importance to the success of any intervention implemented.

**Acknowledgment**

The authors thank the OR staff and orthopedic surgeons for their participation in this study, and L.O. Persson for statistical advice.

**References**

17. Hansen D, Krabs C, Benner D, Brauskeipe A, Popp W. Laminar air flow provides high air quality in the operating field even during real operating conditions,
but personal protection seems to be necessary in operations with tissue combustion. Int J Hygiene Environ Health 2005;208:455-60.