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Teaching in the operating room: A risk for surgical site infections?

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ABSTRACT

Background/aim: To investigate whether teaching procedures and surgical experience are associated with surgical site infection (SSI) rates.

Methods: This prospective cohort study of patients undergoing general, orthopedic trauma and vascular surgery procedures was done between 2012 and 2015 at two tertiary care hospitals in Switzerland/Europe.

Results: Out of a total of 4560 patients/surgeries, 1403 (30.8%) were classified as teaching operations. The overall SSI rate was 5.1% (n = 233). Teaching operations (OR 0.78, 95% CI 0.57–1.07, p = 0.120), junior surgeons (OR 0.80, 95% CI 0.55–1.15, p = 0.229) and surgical experience (OR 0.997, 95% CI 0.982–1.012, p = 0.676) were overall not independently associated with the odds of SSI. However, for surgeons' seniority and experience, these associations depended on the duration of surgery.

Conclusions: In procedures of shorter and medium duration, teaching procedures and junior as well as less experienced surgeons are not independently associated with increased odds of SSI.

Introduction

Hands-on surgical training in the operation room (OR) is still of utmost importance since alternative training modalities such as virtual reality (VR) simulation or hands-on skills lab with box-trainers or cadavers may not fully replace training in the OR. This is especially true in the training of complex procedures. In the recent era of patient safety advocacy, ethical concerns of surgical training on patients have emerged. Furthermore, resident working time restrictions are being introduced in many countries which is based on solid evidence.[1] Patient safety advocacy groups would argue that surgical training in the OR can only be justified as long as it does not increase complication rates or jeopardize patient safety.

There is controversial literature on whether or not tutorial assistance increases the risk for surgical site infections (SSI), the most common hospital-acquired infection among surgical patients. SSI have been repeatedly shown to increase morbidity, mortality and hospital length of stay and they also have a substantial negative economic impact.[2,3] Some studies found no evidence for tutorial assistance being associated with higher rates of wound complications [4–10] when trainees were appropriately supervised and interventions carefully selected.[11,12] In contrast, other studies found an association of tutorial assistance and increased complication rates.[13–17] One could argue that tutorial assistance may increase the risk of SSI by increasing operating time which is well known to be associated with increased SSI rates.[18–20] However, apart from one large study,[7] most studies are retrospective cohort studies and include a limited number of procedures. The generalizability of their findings is therefore limited.

The purpose of this study is to investigate associations between surgical training in the OR and the risk of SSI.

Methods

This is a prospective observational study nested in a recently

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published randomized controlled trial (RCT) on the optimal timing of surgical antimicrobial prophylaxis,[21] which was done at the University Hospital Basel and the Hospital of Aarau, two tertiary referral centers in Switzerland, from February 2013 through July 2015. The local ethics committees approved the trial in April 2012 (Basel: Ref. No. EK 19/12; Aarau: Ref. No. EK 2011/037). The study protocol of the RCT has been published [22] and the trial has been registered on ClinicalTrials.gov (number NCT01790529).

Patients

Written informed consent was obtained from all patients. All patients ≥18 years of age undergoing inpatient general, vascular and orthopedic trauma procedures and who received surgical antimicrobial prophylaxis (SAP) according to international guidelines [23] were eligible. General surgery refers to gastrointestinal, oncologic breast, endocrine and hernia surgery and includes laparoscopic procedures.

Definitions of surgeons' experience, seniority and teaching operation

All involved surgeons were registered in the prospective database. Surgeon experience was defined as self-reported years in practice since graduation from medical school at the time of the surgical procedure. Board certified surgeons were defined as senior surgeons whereas residents without board certification were defined as junior surgeons. A teaching operation was defined as a procedure that was performed either by a junior surgeon under supervision by a senior surgeon or by a senior surgeon under supervision by a more experienced senior surgeon. For the latter discrimination between less experienced and more experienced senior surgeons, those were further divided into staff surgeons with a simple board certification (junior consultants) and those with additional subspecialty board certification (senior consultants). In general, surgical procedures were performed by junior and less experienced surgeons when they were deemed to have the necessary skills to handle the complexity of the case. However, no clearly defined algorithm was used to decide in advance what procedures to teach.

Follow-up

During inpatient stays, SSI were diagnosed by the surgical team, the ward physicians and members of the study team. For post-discharge follow-up, trained investigators at each study site contacted patients 30 days after surgery by telephone, and this information was supplemented with data abstracted from the patients' charts and primary care physicians in case of suspected SSI. All suspected SSI were validated by a board-certified infectious diseases specialist.

Variables

The outcome of interest was 30-day SSI rate. Predefined potential confounders were body mass index ≥30 kg/m^2, patient age, ASA class, wound class, urgent versus elective surgery and previous surgery during the same inpatient stay versus none. Focal predictor variables were teaching procedures versus none, junior versus senior surgeons and surgeons' experience in years. Effect modifiers were the duration of procedures and the surgical department (general, orthopedic trauma and vascular).

Statistical analysis

Baseline data, focal variables and potential confounders are summarized, with categorical variables reported as frequencies and percentages and continuous variables as either mean and standard deviation, or median and the first and third quartile (inter quartile range, IQR). Associations with risk of SSI were investigated using Generalized Estimation Equations (GEEs), with a logit link and an independence correlation structures.[24] Surgeon ID was included as a random effect accounting for the non-independence of surgeries performed by the same surgeon. Odds ratios and 95% confidence intervals are reported.

To assist in the interpretation of results related with continuous variables, expected values were simulated from the model using the R package Zelig [25,26] and their distribution plotted.

To find the best model explaining the association of SSI rate and focal variables, we compared different GEEs based on their goodness of fit using their QICu value. Models included all possible combinations of the focal variables and their interactions with predefined potential effect modifiers.

After examining each of the focal variables on its own, and the significance of its interactions with the defined effect modifiers, another model was fit, in which all pre-defined potential confounders were added – in bulk. Thus, this model contained the focal variable, the effect modifiers and their interactions with the focal variables (if found significant beforehand) and all the potential confounders. This was repeated for the best model found based on QICu. All analyses were performed using R version 3.4.0.[27]

Results

A total of 5175 procedures were included in the underlying RCT of which 579 patients were lost to follow up and hence, the 30-day SSI status is known of 4596 procedures. Surgeons' experience was unknown in 36 procedures. Therefore, 4560 procedures were analyzed. The overall SSI rate was 5.1% (n = 233). Overall, 151 surgeons performed procedures, including 84 junior surgeons (n = 55.6%), 48 senior surgeons (31.8%) and 18 consultant surgeons (11.9%). The median duration of surgery was 1.37 h for teaching procedures and 1.57 h in non-teaching procedures. The median number of procedures performed per surgeon during the trial period was 18 (IQR 6.50, 44.50). The median of the mean years of experience of participating surgeons over the course of the trial was 6.52 years (IQR 3.08, 11.03). However, because the majority of procedures were performed by senior surgeons, the median surgical experience across all procedures was 10 years. Procedure characteristics are shown in Table 1. Those procedures complicated by SSI were less likely to have been classified as teaching procedure and to have been performed by junior surgeons. SSI were more likely to occur in general surgery compared to orthopedic trauma and vascular surgery, in higher wound classes, in higher ASA-classes and in older patients.

Teaching procedures

Associations between teaching operations and odds of SSI are shown in Table 2. Examined alone, patients undergoing teaching operations had significantly lower odds of experiencing SSI (OR 0.63, 95% CI 0.45–0.88, p = 0.007) compared to non-teaching operations. This effect was smaller and no longer significant when controlling for the duration of procedures (OR 0.78, 95% CI 0.57–1.07, p = 0.131). We found no significant interaction between teaching procedures and duration of procedures (p = 0.265) and therefore did not include it in the model. Increasing duration of surgery itself was associated with a 60% increase in the odds of SSI per hour (OR 1.60, 95% CI 1.48–1.74, p < 0.001). The interaction term between teaching procedures and the surgical department was not significant either (p = 0.441), but the subgroup analysis still demonstrates that the odds ratio of experiencing SSI after

Table 1
Patient, surgeon and procedure characteristics.

	All	No SSI	SSI	p
n	4560	4327	233	
Patients				
Male patients n (%)	2469 (54.2)	2323 (53.7)	146 (62.7)	0.008
Age mean (SD[a])	57.26 (18.55)	56.96 (18.65)	62.73 (15.70)	<0.001
BMI[c] ≥30 kg/m^2 n (%)	1085 (23.8)	1020 (23.6)	65 (27.9)	0.134
ASA[d] class n (%)				<0.001
1	812 (17.8)	796 (18.4)	16 (6.9)	
2	2416 (53.0)	2327 (53.8)	89 (38.2)	
3	1282 (28.1)	1160 (26.8)	122 (52.4)	
4	50 (1.1)	44 (1.0)	6 (2.6)	
Surgeons				
Teaching procedure n (%)	1403 (30.8)	1351 (31.2)	52 (22.3)	0.005
Junior surgeon n (%)	1317 (28.9)	1271 (29.4)	46 (19.7)	0.002
Surgeon experience y median [IQR[b]]	10.00 [6.00, 19.00]	10.00 [5.00, 19.00]	11.00 [7.00, 21.00]	0.057
Procedures				
Surgical division n (%)				<0.001
General	2263 (49.6)	2109 (48.7)	154 (66.1)	
Orthopedic trauma	1705 (37.4)	1666 (38.5)	39 (16.7)	
Vascular	592 (13.0)	552 (12.8)	40 (17.2)	
Wound class				<0.001
1	3550 (77.9)	3411 (78.8)	139 (59.7)	
2	739 (16.2)	677 (15.6)	62 (26.6)	
3	215 (4.7)	191 (4.4)	24 (10.3)	
4	56 (1.2)	48 (1.1)	8 (3.4)	
Duration of surgery h median [IQR]	1.50 [1.00, 2.32]	1.47 [0.98, 2.24]	2.60 [1.58, 3.90]	<0.001
Urgent surgery n (%)	847 (18.6)	815 (18.8)	32 (13.7)	0.062

T-test was used for the variables with mean/SD.
Kruskal-Wallis test was used for variables with median/IQR.
Fisher exact test was used for categorical variables.
Percentages may not sum up to 100% due to rounding.
[a] Standard deviation.
[b] Interquartile range.
[c] Body mass index.
[d] American Society of Anesthesiologists.

teaching operations compared to non-teaching operations was lower in vascular surgery compared to general and orthopedic trauma surgery. Finally, Fig. 1 shows the multivariable analysis of teaching procedures and confounders in terms of the odds of SSI. While teaching procedures were not independently associated with the odds of SSI (OR 0.78, 95% CI 0.57–1.07, p = 0.120), ASA class (OR 2.00, 95% CI 1.55–2.57, p < 0.001), wound class (OR 1.51, 95% CI 1.23–1.87, p < 0.001) and duration of surgery (OR 1.49, 95% CI 1.39–1.59, p < 0.001) were. In addition, orthopedic trauma surgery compared to general surgery was associated with significantly decreased odds of SSI (OR 0.61, 95% CI 0.41–0.89, p = 0.011).

Surgeons' seniority

As shown in Table 2, procedures being performed by junior surgeons were associated with a significant reduction in the odds of SSI (OR 0.59, 95% CI 0.42–0.83, p = 0.002) on univariable analysis. However, this association depended significantly on the duration of procedures, with a highly significant interaction term between surgeons' seniority and duration of surgery (p < 0.001). For operations of median duration (1.5h) there was no significant difference in the odds of SSI (OR 0.82, 95% CI 0.58–1.16, p = 0.266); However, while in shorter procedures the odds of experiencing SSI were decreased when performed by junior surgeons, the opposite applied in longer procedures where SSI rates increased much more steeply with increasing duration in procedures performed by junior surgeons (Fig. 2). In contrast, the association between seniority and the odds of SSI did not significantly depend on the surgical department (interaction p = 0.144) although the odds of SSI in procedures performed by junior surgeons tended to be lower in general and orthopedic trauma surgery compared to vascular surgery. On multivariable analysis, the association between procedures performed by junior surgeons and the odds of SSI lost its significance (OR 0.80, 95% CI 0.55–1.15, p = 0.229). The only significant associations were between the odds of SSI and ASA class (OR 1.96, 95% CI 1.52–2.51, p < 0.001), wound class (OR 1.53, 95% CI 1.23–1.91, p < 0.001) and duration of surgery (OR 1.45, 95% CI 1.36–1.53, p < 0.001). Furthermore, the interaction test between seniority and duration of surgery remained significant (p = 0.003) and orthopedic trauma surgery compared to general surgery was again associated with significantly lower odds of SSI (OR 0.62, 95% CI 0.42–0.91, p = 0.016).

Surgeons' experience

Surgical experience alone was not significantly associated with the risk of SSI (OR 1.013, 95% CI 0.995–1.031 p = 0.151) (Table 2). As shown in Table 2 and visualized in Fig. 3, the interaction between surgeons' experience and duration of surgery was significant (p = 0.014), with the odds of SSI increasing more steeply with duration of surgery when procedures are performed by less experienced surgeons. As an example, for the median surgical experience in this study, a 1-h increase in the duration of surgery is associated with a 70.7% increase in the odds of SSI (OR 1.707). With an interaction OR of 0.988, a 1-h increase in the duration of surgery for a surgeon with one year more experience than the median is associated with only a 68.7% increase in the odds of SSI ($1.707 \times 0.988 = 1.687$).

While the odds of SSI slightly increased per year of surgeons' experience in general surgery (OR 1.02, 95% CI 1.004–1.038) and

Table 2
Associations between teaching procedures, surgeon seniority and surgeon experience and the odds of SSI.

Association between teaching procedure and odds of SSI	n	Variable	OR[a] [95% CI[b]]	p
Univariable Analysis	4560	Teaching procedure	0.63 [0.45, 0.88]	0.007
Controlled for duration of procedure	4560	Duration of procedure	1.60 [1.48, 1.74]	<0.001
	4560	Teaching procedure	0.78 [0.57, 1.07]	0.131
	4560	Interaction		0.265
Controlled for surgical department	4560	Interaction		0.441
General surgery	2263	Teaching procedure	0.67 [0.44, 1.02]	
Orthopedic trauma surgery	1705	Teaching procedure	0.58 [0.27, 1.24]	
Vascular surgery	592	Teaching procedure	0.32 [0.11, 0.90]	
Association between surgeons' seniority and odds of SSI	**n**	**Variable**	**OR [95% CI]**	**p**
Univariable Analysis	4560	Junior surgeon	0.59 [0.42, 0.83]	0.002
Controlled for duration of procedure	4560	Duration of procedure	1.56 [1.45, 1.67]	<0.001
	4560	Junior surgeon	0.82 [0.58, 1.16]	0.266
	4560	Interaction	1.80 [1.28, 2.54]	<0.001
Controlled for surgical department	4560	Interaction		0.144
General surgery	2263	Junior surgeon	0.46 [0.31, 0.69]	
Orthopedic trauma surgery	1705	Junior surgeon	0.68 [0.31, 1.53]	
Vascular surgery	592	Junior surgeon	1.02 [0.53, 1.97]	
Association between surgeon experience and odds of SSI	**n**	**Variable**	**OR [95% CI]**	**p**
Univariable Analysis	4560	Surgeon experience	1.013 [0.995, 1.031]	0.151
Controlled for duration of procedure	4560	Duration of procedure	1.707 [1.562, 1.865]	<0.001
	4560	Surgeon experience	1.002 [0.986, 1.018]	0.787
	4560	Interaction	0.988 [0.979, 0.998]	0.014
Controlled for surgical department	4560	Interaction		0.038
General surgery	2263	Surgeon experience	1.020 [1.004, 1.038]	
Orthopedic trauma surgery	1705	Surgeon experience	1.017 [0.981, 1.055]	
Vascular surgery	592	Surgeon experience	0.973 [0.942, 1.005]	

Non-significant interaction tests were removed from the respective models.
For teaching procedures, the reference are non-teaching procedures.
For junior surgeons, the reference are senior surgeons.
For surgeon experience, odds ratios are shown per year of additional experience.
For duration of procedure, odds ratios are shown per hour.
[a] OR: Odds ratio.
[b] 95% CI: 95% confidence interval.

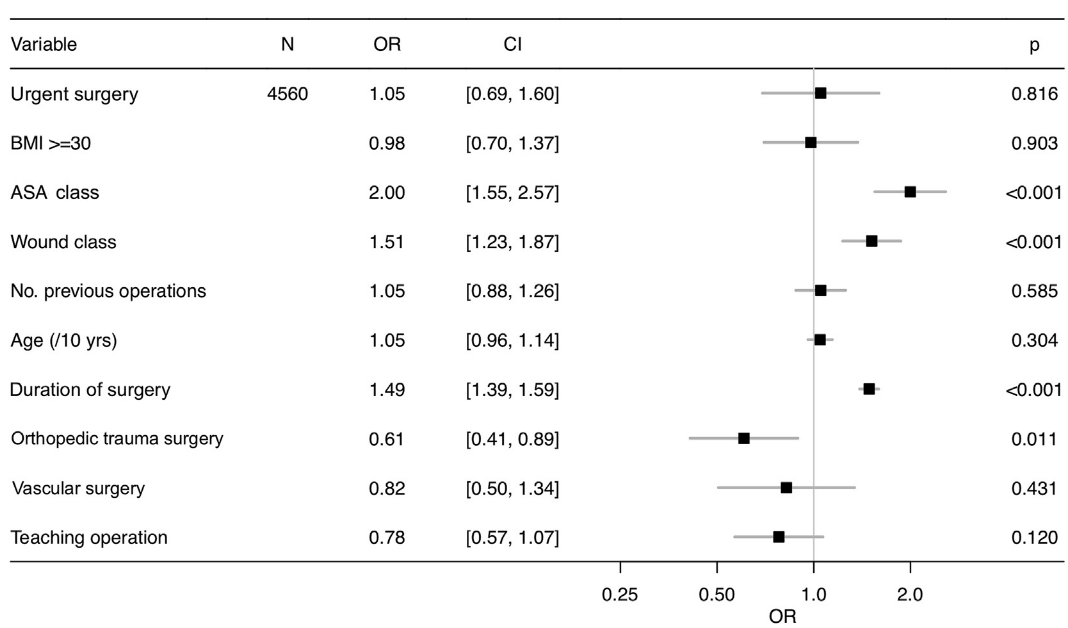

Fig. 1. Multivariable generalized estimation equation of the risk of SSI.
BMI: Body mass index in kg/m^2.
ASA: American Society of Anesthesiologists.

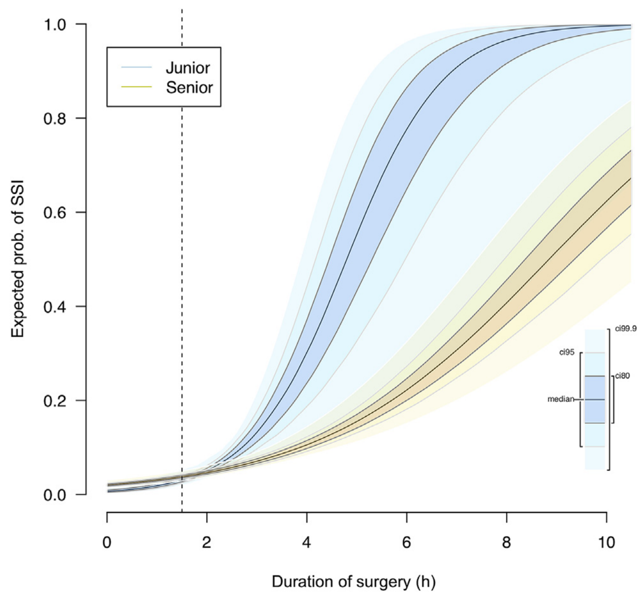

Fig. 2. SSI by duration of procedure, depending on surgeons' seniority. The dashed line represents the median duration of procedures.

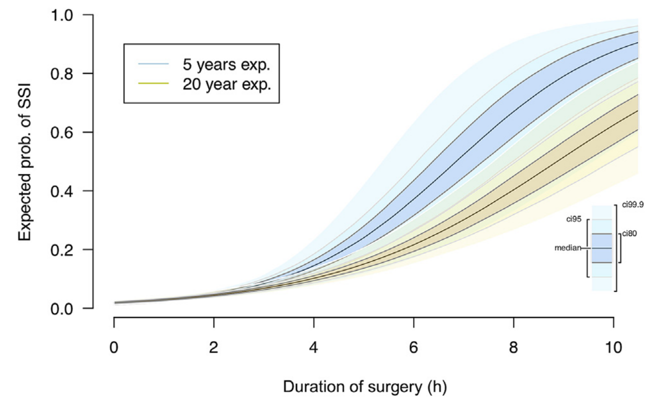

Fig. 3. SSI by duration of procedure, depending on surgeons' experience.

orthopedic trauma surgery (OR 1.017, 95% CI 0.981–1.055), they slightly decreased in vascular surgery (OR 0.973, 95% CI 0.942–1.005). The difference between these effects is significant (interaction test, $p = 0.038$). While this interaction again remained significant on multivariable analysis ($p = 0.037$), surgeons' experience was again not significantly associated with the odds of SSI (OR 0.997, 95% CI 0.982–1.012, $p = 0.676$). As in the previous models, ASA class (OR 1.983, 95% CI 1.546–2.545, $p < 0.001$), wound class (OR 1.513, 95% CI 1.221–1.876, $p < 0.001$) and duration of surgery (OR 1.576, 95% CI 1.455, 1.707, $p < 0.001$) were again significantly associated with the odds of SSI and orthopedic trauma surgery was again associated with significantly lower odds of SSI compared to general surgery (OR 0.616, 95% CI 0.415–0.914, $p = 0.016$).

Discussion

In this study, we found no evidence that teaching operations, junior surgeons or less experienced surgeons were independently associated with increased odds of SSI when controlling for potential confounders. The odds of experiencing SSI even tended to be lower in teaching operations and those performed by junior surgeons. However, we found several highly interesting interactions between the variables of interest and potential confounders.

First, the associations between both junior versus senior surgeons and surgeons' years of experience on one hand and the odds of SSI on the other hand depended significantly on the duration of procedures. While in shorter procedures, including the median duration of 1.5 h, the probability of SSI was decreased after procedures performed by junior surgeons, the opposite applied in procedures longer than 2 h and SSI rates increased much more steeply thereafter for junior surgeons. The most likely explanation is that the duration of procedures is a more important risk factor than the surgeon being junior. This means that in shorter and hence less complex procedures, it is less important who performs the procedure. This would also be understandable as one can imagine that the duration of a procedure like a simple inguinal hernia repair becomes only slightly longer when performed by a junior surgeon. In longer, complex procedures, on the other hand, the duration of the procedures could increase substantially when performed by a junior surgeon. In terms of surgeons' years of experience, SSI rates rise more steeply with increasing duration of surgery in less experienced surgeons, fitting well with the above explanation.

Second, the association between surgeons' years of experience and the odds of SSI depended significantly on the surgical division (general, vascular and orthopedic trauma surgery) and hence the types of procedures. While in general and orthopedic trauma surgery, the odds of SSI were slightly increased with each year of additional experience, they were slightly decreased in vascular surgery. The same trend applies in terms of junior versus senior surgeons although the interaction term is not significant. One possible explanation of this finding could be the distribution of types of procedures between more and less experienced surgeons and senior versus junior surgeons. While in general surgery, for example, procedures with higher SSI rates such as colon or esophagus resections tend to be performed by senior and more experienced surgeons and procedures with low SSI rates such as inguinal hernia repairs tend to be performed by junior surgeons, the opposite tends to apply in vascular surgery. While clean procedures with low SSI rates like aortic or carotid surgery tend to be performed by more experienced and senior surgeons, procedures with higher SSI rates such as amputations tend to be performed by less experienced and junior surgeons. However, in spite of a significant interaction term, the association between surgeons' experience and surgical division in terms of SSI must not be overinterpreted as the relevant odds ratios are very close to one in all 3 divisions.

Third, in terms of teaching procedures, those interactions were not significant, meaning that the odds of SSI in teaching procedures compared to non-teaching procedures neither depended on the duration of surgery nor the surgical division. This can be explained by our definition of teaching procedures. The surgeons performing more complex teaching procedures were quite experienced themselves, their "teachers" were simply more experienced. Therefore, it is likely that shorter and therefore less complex teaching procedures tend to be performed by a junior surgeon assisted by a senior surgeon while longer and more complex teaching procedures tend to be performed by a senior surgeon assisted by an even more senior surgeon.

Our results suggest that factors other than teaching status, experience of the operating surgeon or whether a procedure is performed by a junior or a senior surgeon are much more important in terms of SSI. Specifically, the duration of surgery continues to prove one of them. Therefore, it must be stressed that junior and less experienced senior surgeons need to be properly supervised, especially when performing more complex procedures. It is common sense in the two hospitals where this study was done that all procedures are supervised by senior surgeons.

Surgical education nowadays contains several inherent challenges [28] which have been suspected to negatively affect its quality and put patients at risk. Junior surgeons are faced with rapid technological developments which increase the complexity of surgical procedures, in turn potentially increasing the duration of procedures and therefore the risk of SSI.[19] This increases the necessity of additional efforts in surgical training and highlights the need for structured surgical education.[29] However, hands-on, real life training in the operating room has traditionally been the main pillar of surgical education. Our findings are highly relevant and contribute substantially to this issue by providing evidence suggesting that this is still safe and should therefore remain one of the most important pillars of surgical education. However, at the same time, our data suggests that factors such as the complexity (and therefore expected duration) of procedures may negatively impact outcomes of teaching procedures. Therefore, procedures to be taught to junior and less experienced surgeons may have to be carefully selected, again highlighting the importance of a well-structured surgical training. Furthermore, training modalities other than live surgery, such as simulators, may be as important and their further development is to be pursued.

This study has several strengths: Data were collected in a strictly prospective manner within a randomized controlled trial [21] including over 5000 patients. The quality of the data is also highlighted by the recurrent and clear identification of duration of surgery, wound class and ASA class as the only independent risk factors for SSI. Second, a wide variety of surgical procedures from 3 different surgical divisions were included which allows for a better generalizability of our results. Third, this study was done at two tertiary teaching hospitals with roughly one third of procedures performed by junior surgeons. The most important limitation is that it is an observational study and therefore potentially includes all inherent bias of such. Namely, it is obvious that more complex and thus longer lasting procedures with higher SSI rates tend to be performed by more experienced surgeons rather than trainees.

In conclusion, our results suggest that teaching operations are a safe pillar in the multimodal concept of surgical education.

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Declaration of competing interest

The authors have no conflicts of interest to disclose.

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