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Overlapping Induction of Anesthesia

An Analysis of Benefits and Costs

Robert Hanss, M.D., Björn Buttgereit, M.D.,* Peter H. Tonner, M.D.,† Berthold Bein, M.D.,* Andreas Schleppers, M.D.,‡ Markus Steinfath, M.D.,§ Jens Scholz, M.D.,‖ Martin Bauer, M.D., M.P.H.**

Background: **Overlapping induction (OI), *i.e.*, induction of anesthesia with an additional team while the previous patient is still in the operating room (OR), was investigated.**

Methods: **The study period was 60 days in two followed by three ORs during surgical Block Time (7:30 AM until 3:00 PM). Patients were admitted the day before surgery and were thus available and did not have surgery that day unless there was a time reduction. Facilities were already constructed. Number of cases, Nonsurgical Time (Skin Suture Finish until next Procedure Start Time), Turnover Time, and Anesthesia Control Time plus Turnover Time were studied. In addition, economic benefit was calculated.**

Results: **Three hundred thirty-five cases were studied. Using OI, the time of care of regularly scheduled cases was shortened, and the number of cases performed within OR Block Time increased (151 to 184 cases; $P < 0.05$). Nonsurgical Time (in h:min) decreased (1:08 ± 0:26 to 0:57 ± 0:18; $P < 0.001$), Turnover Time decreased (0:38 ± 0:24 to 0:25 ± 0:15; $P < 0.05$), and Anesthesia Control Time plus Turnover Time decreased (0:43 ± 0:23 to 0:28 ± 0:18; $P < 0.001$). Subgroup analysis showed a significant benefit of OI only in three ORs. In three ORs, economic benefit can be gained at a case mix index greater than 0.3 besides additional costs.**

Conclusions: **Overlapping induction increased productivity and profit despite the expense of additional staff. Subgroup analysis emphasizes the importance of the number of ORs involved in OI.**

WITH financial resources in hospitals being limited, measures to optimize operating processes gain increasing importance. To use hospital resources most efficiently, reorganization of all economically relevant key processes is necessary. Because of its high cost intensity, the productivity of an operating unit of a hospital is an important focus for measures of optimization.[1] Because of the key position in a surgical clinic with numerous related areas, such as peripheral wards and preanesthesia and postanesthesia care units (PACUs), process analysis in this particular field proves to be exceedingly complex. The aim is to improve the relation between costs and revenue.[2,3] To gain high productivity, first, measures should be performed without delays, and second, high-cost staff should be deployed efficiently. Anesthesiologists, in their function as operating room (OR) managers, are indispensable in the surgical team.[4–6] By calling for the next patient at the appropriate time, anesthesiologists ensure efficient, timely induction of anesthesia. Sufficient postoperative measures such as prompt recovery from anesthesia and well-organized discharge to the PACU or intensive care unit are important to avoid delays. During organization, the anesthesiologist prepares the best operating conditions in terms of both medical criteria, such as stable vital signs, and avoidance of delays for the surgical team, especially due to induction of and emergence from anesthesia.[4,7] From an economic point of view, justified demands arise to minimize anesthesia-related delays during the whole surgical process. But the question as to the contribution of overlapping induction of anesthesia (OI) to the improvement of OR processes has not been definitively answered. Previous studies are often not precisely interpretable because of differences between study and control groups, or they are based on computer models.[8,9]

In this study, we evaluated the effect of OI on productivity and performed an economic analysis. Our hypothesis was that OI would significantly reduce OR time of regularly scheduled cases, so that additional cases that would otherwise not be performed could be reliably added to the OR schedule within OR Block Time.

This article is accompanied by an Editorial View. Please see: Dexter F: Deciding whether your hospital can apply clinical trial results of strategies to increase productivity by reducing anesthesia and turnover times. ANESTHESIOLOGY 2005; 103:225–8.

Materials and Methods

After approval of the internal review board of the University Hospital Schleswig-Holstein, the study was performed in a visceral surgery unit. Two settings in four different modes of intraoperative processes were applied, and the effects on productivity were determined. Each intraoperative process was used for 15 days; the days of the control period were matched to the days of the study period.

* Staff Member, † Professor of Anesthesiology and Vice-Chair, § Professor of Anesthesiology, ‖ Professor of Anesthesiology and Chair, Department of Anaesthesiology and Intensive Care Medicine, University Hospital Schleswig-Holstein, Campus Kiel, Kiel, Germany. ‡ Staff Member, Department of Anaesthesiology and Intensive Care Medicine, University-Hospital Mannheim, Mannheim, Germany.

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Address reprint requests to Dr. Hanss: Department of Anaesthesiology and Intensive Care Medicine, University-Hospital Schleswig-Holstein, Campus Kiel, Schwanenweg 21, 24105 Kiel, Germany. Address electronic mail to: hanss@anaesthesie.uni-kiel.de. Individual article reprints may be purchased through the Journal Web site, www.anesthesiology.org.

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Table 1. Definition of Recorded Times and Calculated Time Intervals

AACD Procedural Time Glossary[10]	New Definition	Abbreviation
Anesthesia Induction		AI
Anesthesia Ready		AR
	Position Start	POS
	Position Finish	POF
Patient in Room		PIR
Prep Start		PREPS
Prep Complete		PC
Procedure/Surgery Start		PST
Procedure/Surgery Finish		PF
Patient Out of Room		POR
Arrival in PACU/ICU		APACU
Anesthesia Finish		AF
Time interval according to AACD		
Block Time		BT
Case Time		CT
Turnover Time		TOT
OR Utilization		ORU
Previously described interval		
Anesthesia-controlled Time[9]		ACT
Anesthesia-controlled Time plus Turnover Time[13]		ACT + TOT
Nonsurgical Time[1,2,16]		NST
	Surgical Case Length	SCL

Times and intervals were defined according to the American Association of Clinical Directors (AACD) Procedural Time Glossary.[10] Some intervals are defined as previously described.[9,13] Because of given study and control conditions, a few additional times and the time interval Surgical Case Length had to be defined.

ICU = intensive care unit; OR = operating room; PACU = postanesthesia care unit.

Definition of Times and Time Intervals

For definition of times and time intervals, we used the definitions from the Association of Anesthesia Clinical Directors Procedural Time Glossary (AACD) whenever possible.[10] In addition, we applied previously published terminology.[10–12] To more exactly analyze the data, additional times and time intervals had to be defined (table 1). Because of defined workflow (see Study Design section), the AACD's time Positioning/Prep Start was divided into Position Start until Position Finish and sterile Prep Start, the only measure to be performed in the OR before Procedure Start. Because the AACD defines only Procedure Conclusion Begun and Procedure Finish, we in addition defined Skin Suture Finish, the exact end of operation. The Surgical Case Length (SCL) was defined as the interval between Procedure Start and Skin Suture Finish.

Three time intervals were studied: Turnover Time (TOT), Anesthesia-controlled Time plus TOT (ACT + TOT), and Nonsurgical Time (NST). The AACD defines TOT as the time interval Patient Out of Room until next Patient in Room. Anesthesia-controlled Time, according to Dexter *et al.*, serves as the sum of the first patients Procedure/Surgery Finish until Patient Out of Room plus Patient in Room until Position Starts of the second patient.[8,9] Williams *et al.*[13] added Anesthesia-controlled Time to Turnover Time and phrased this sum ACT + TOT. Furthermore, NST was defined as Skin Suture Finish of the previous patient until Procedure Start Time of the succeeding patient.

Routine operations scheduled during surgical Block Time between 7:30 AM and 3:00 PM were included in the study. This modus operandi is commonplace at our institution. Emergency operations that were performed after the regular schedule later than 3:00 PM were excluded from the study. OR Utilization (ORU) and SCL were analyzed. ORU is an established measure in health system research.[14] In addition, the percentage ratio of SCL and ORU (SCL/ORU) was calculated. The Hours of Work per day of the additional anesthesia team were calculated in groups OI_2 and OI_3. Work performed by the additional team during the time interval Anesthesiologist First Available until Anesthesia Finish were calculated. Other assignments, *e.g.*, patients' premedication or taking over other cases not involved in the study, were not taken into account.

Patients

All patients included in the study were inpatients. They were admitted latest on the day before surgery (DBS) and routinely scheduled for one of the ensuing days because it is commonplace in our hospital. All preoperative measures such as laboratory values and informed consent, were obtained latest on the DBS. Additional patients were recruited by (1) inpatients scheduled for other ORs that were not included in the study on the same day, (2) inpatients scheduled for one of the next days with complete preoperative preparations, or (3) emergency cases within surgical Block Time. To secure an identical number of regularly scheduled operations per day and per OR, OI and control (C) were matched for the number of regularly scheduled cases.

Study Design

The conventional process of daily clinical routine was applied in the control groups C_2 in two ORs and C_3 in three ORs, respectively. Thus, one anesthesia team per OR, consisting of one anesthesiologist and one nurse, was on duty. Nurses were educated in health care for 3 yr and received special anesthesia training for another 2 yr. They were not allowed to induce, maintain, or end anesthesia. The team attended to the patients one after the other; Anesthesia Start of the next patient did not start until Anesthesia Finish of the previous patient. While OI was being performed, one additional anesthesia team (one anesthesiologist and one specially trained nurse) was available for either two (OI_2) or three (OI_3) ORs. Anesthesia Start of the consecutive patient started before Anesthesia Finish, thus aiming at Anesthesia Ready at the time of Room Ready for the next case. All team members were compensated by salary only, with

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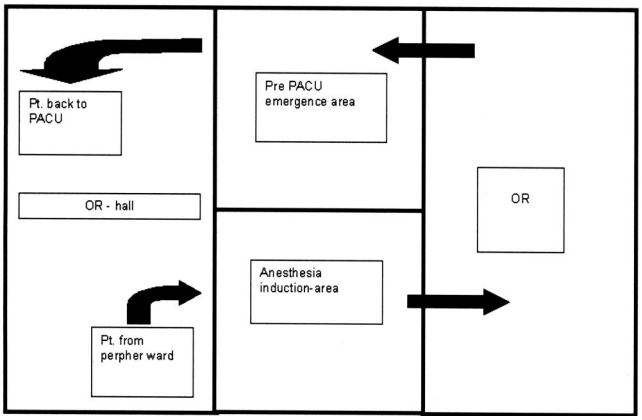

Fig. 1. Schematic diagram of the architectural conditions and operating sequences. Service staff brought the patients to the operating room (OR) and moved them to the anesthesia induction area. Anesthesia was established; after Anesthesia Ready, the interval Position Start until Position Finish was performed in the anesthesia induction area. Afterward, patients were moved to the OR. Sterile preparations were done in the OR. After Procedure/Surgery Finish, overlapping induction patients were moved to the pre–postanesthesia care unit (PACU) emergence area. After reestablishing routine anesthesia monitoring, anesthesia was ended. With the help of service staff, patients were moved to the PACU. Pt. = patient.

no bonuses or incentives for clinical productivity or workload.

Preoperative Measures. Induction of anesthesia was performed in an anesthesia induction area. This workflow is a routine procedure in our hospital and was recently described by Williams *et al.*[13] in patients receiving regional anesthesia. After Anesthesia Ready, Position Start began, performed by the surgical team, consisting of one surgeon and one surgical nurse. Positioning took place in the anesthesia induction area. After Position Finish, patients were moved to the OR. Only sterile preparations of the patient had to be performed in the OR.

Postoperative Measures. Control patients emerged from anesthesia in the OR after Procedure/Surgery Finish and were transferred to the PACU thereafter. To rule out any delays of the surgical workflow in the study group due to anesthesia processes, especially in Room Set-up Start of the next case, patients were moved to a special pre-PACU emergence area immediately after Procedure/Surgery Finish. The pre-PACU emergence area was equipped with a cardiocirculatory and respiratory monitor and a manual ventilation system. Patients emerged from anesthesia and were transferred to the PACU. The pre-PACU emergence area was not implemented in the control group because it was not daily clinical routine and resources were limited (fig. 1). The time interval Position/Prep Start to Procedure/Surgery Finish was not affected by the study. Room Set-up Start for the next case begun when the previous patient had left the OR. Transfer of the next patient into the OR was not performed until Room Set-up Finish.

Primary and Secondary Endpoints

The primary study endpoint was an increase in the number of cases (NC) during the defined OR Block Time. Regularly scheduled cases and, in addition, scheduled cases (if enough OR time was available) were studied. Besides total NC, the difference between OI and C is presented (ΔNC). ΔNC was transformed to value per day (ΔNC/day). The secondary endpoint was a reduction in TOT, ACT + TOT, and NST. To determine whether OI leads to an earlier end of the last regularly scheduled case, the daily end of Anesthesia Finish was studied.

Sensitivity Analysis and Economic Profit

Sensitivity analysis is a technique for measuring the impact on project outcomes of changing one or more key input values about which there is uncertainty. In our investigation, the workflow was modified in terms of OI (project) aiming for an increase in NC. To gain an increased profit, additional cases' revenue (uncertain variable) must exceed staff costs of OI. To distinguish negative and positive assumptions, a break point of the case mix index (CMI) was calculated based on the equations shown in the appendix. Two scenarios are conceivable: First, if the index of the additional case is below the required break point (worst scenario: if it is zero, no additional case can be performed, despite OI), OI results in financial losses. Second, if the index of the additional case exceeds the break point of the CMI, OI results in increased profit.

To estimate the cost–benefit ratio, the expense of all additional costs due to OI were compared to the benefit resulting from OI, calculated in dollars. Calculation of anesthesia staff costs were based on published literature.[15] For this study, special OI conditions were defined. Therefore, we established a pre-PACU emergence area. Because of constructional constraints, this area was implemented adjacent to the OR (fig. 1). However, emergence from anesthesia can be performed anywhere within the OR facility or even in the PACU itself. No additional costs had to be calculated for the area itself. In the pre-PACU emergence rooms, additional monitors and equipment were provided. The hardware cost per pre-PACU emergence room was $3,000. These costs are deducted over 4 yr, resulting in $750 per year. Calculating 250 days of work per year and 2.5 cases per day and per OR (OI: 114 cases/15 study days/3 ORs), the cost per case was $1.20. Economically, these marginal costs were negligible. Patients were moved to the OR facility on patient gurneys and were then transferred to OR tables. Transportations within the OR were performed on OR tables because it is the clinical routine in our hospital. During all measures within the OR facility, patients remained on their OR tables. These measures did not differ from clinical routine. OR tables are not a limited device, because two consecutive patients are not positioned on the same OR table. Therefore, OR tables were available

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Table 2. Demographic Data

	Age, yr			Weight. kg			Sex, M/F		
	TG	2 OR	3 OR	TG	2 OR	3 OR	TG	2 OR	3 OR
Overlapping induction	44 ± 26	45 ± 26	43 ± 29	61 ± 29	61 ± 29	60 ± 30	118/66	43/27	67/47
Control conditions	48 ± 27	45 ± 28	50 ± 25	62 ± 26	60 ± 27	65 ± 25	82/69	41/26	50/34

No significant differences between the groups in any of the shown parameters were found. Data are presented as mean ± SD. $P < 0.05$.
2 OR = subgroup of two operating rooms; 3 OR = subgroup of three operating rooms; TG = total group.

all the time. No additional OR tables were implemented during OI, and no additional costs had to be calculated.

Statistics

Data were acquired using a standardized form. All parameters, calculated time intervals, and their definitions are shown in table 1. For statistical analysis, standard software (PRISM GraphPad Software; San Diego, CA) was used. Data were checked for normal distribution according to the Kolmogorov-Smirnov test based on the Dallal and Wilkinson approximation to the Lilliefors method. Because all data were normally distributed, the Student *t* test was used. Statistically significant differences were double checked with the Mann–Whitney test for nonparametric data. All data are presented as mean ± SD, with a level of significance of $P < 0.05$.

Results

Demographics

There were no significant differences in types of operations or demographic data between OI and C in the total or in either subgroup (tables 2 and 3).

Control Parameters

Control parameters are shown in table 4. SCL and Procedure/Surgery Finish of the last case of the day were comparable in the total and in each of the two subgroups, without significant differences. Anesthesia Finish of regularly scheduled cases was significantly earlier during OI compared with C ($P < 0.05$). Anesthesia Finish of all cases (regular and additional cases) was comparable between OI and C. The average Hours of Work of the additional anesthesia team needed per day was 1:29 ± 0:51 h:min in the total group. During OI_2, the average Hours of Work was 1:20 ± 0:39 h:min, and during OI_3, the average Hours of Work was 1:37 ± 0:59 h:min. The average Hours of Work were not different, but there was a trend toward a more effective utilization of the additional anesthesia team in subgroup OI_3.

Study Endpoints

Study endpoints are shown in table 5. Over a period of 60 days, a total of 335 cases were analyzed. One hundred eighty-four cases were performed during OI, of which 33 cases were scheduled in addition. One hundred fifty-one cases were regularly performed during OI and C. OI led to a significant increase of the NC; 1.1 additional cases per day were performed in the OI group ($P < 0.05$). Subgroup analysis showed remarkable differences between two and three ORs: In $OI_3 + C_3$ (total cases examined, 198), OI showed an increase of NC of 2.0 cases per day ($P < 0.05$). In $OI_2 + C_2$ (total cases examined, 137), OI did not improve NC; it increased by only 0.2 cases per day ($P = 0.99$).

Significant differences were found in terms of TOT. The control group and either subgroup demonstrated significantly higher values compared with the study group. Considerable differences were found for ACT + TOT. In the total group, mean ACT + TOT decreased by 0:15 h:min as a result of OI ($P < 0.05$). In both subgroups, significance was reached, whereas mean time savings were smaller in $OI_2 + C_2$ ($P < 0.05$) than in $OI_3 + C_3$ ($P < 0.001$). NST in the total group ($P < 0.05$) and in subgroup $OI_3 + C_3$ ($P < 0.05$) showed significant

Table 3. Diversification of the Different Operations of Overlapping Induction and Control Conditions

Type of Surgery	Overlapping Induction	Control Conditions
Thoracotomies (wedge resection , partial lung resection)	7	5
Thoracoscopies (diagnostic biopsy, pleurodesis)	17	10
Upper laparotomies (gastric, liver, spleen, pancreas)	36	40
Lower laparotomies (small and large intestine)	40	37
"Small" pediatric surgery (hernia repair, phimosis, etc.)	29	23
"Large" pediatric surgery (thoracotomies, laparotomies)	13	12
Other short operations, SCL < 60 min	17	9
Other long operations, SCL > 60 min	25	15

No significant differences between the groups were found ($P < 0.05$). Total number of cases are shown.
SCL = Surgical Case Length.

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Table 4. Control Parameters: Results of the Total Group and of the Two- and Three-OR Subgroups

	Overlapping Induction (n = 184/33)	Control Conditions (n = 151/0)	*P* Value
SCL, h:min			
TG	2:18 ± 1:40	2:16 ± 1:51	NS
2 OR	2:25 ± 1:44	2:11 ± 1:30	NS
3 OR	2:02 ± 1:33	2:13 ± 1:24	NS
SCL, additional cases, h:min			
TG	1:02 ± 0:42	NA	
2 OR	1:07 ± 2:31	NA	
3 OR	1:03 ± 031	NA	
Procedure/Surgery Finish, all cases, h:min			
TG	15:12 ± 1:17	15:08 ± 1:30	NS
2 OR	15:02 ± 1:28	14:56 ± 1:37	NS
3 OR	15:15 ± 1:10	15:17 ± 1:26	NS
Anesthesia Finish, regular cases, h:min			
TG	13:41 ± 1:27	15:25 ± 1:32	< 0.05
2 OR	13:02 ± 0:56	15:13 ± 1:37	< 0.05
3 OR	13:35 ± 1:35	15:33 ± 1:26	< 0.05
Anesthesia Finish, additional cases, h:min			
TG	15:42 ± 0:49	NA	
2 OR	15:28 ± 1:26	NA	
3 OR	15:52 ± 0:19	NA	

Data are presented as mean ± SD. $P < 0.05$, statistical analysis based on the Student *t* test; significant differences were confirmed with Mann–Whitney test. Anesthesia Finish of regularly scheduled cases was significant earlier with overlapping conduction compared with control conditions. No other significant differences between the groups were found.

2 OR = subgroup of two operating rooms; 3 OR = subgroup of three operating rooms; n = number of cases demonstrated as total number and number of additionally scheduled cases; NA = values of additional scheduled cases were not available for control conditions; NS = not significant; OR = operating room; SCL = Surgical Case Length; TG = total group.

differences. No differences were found in two ORs with respect to NST.

Results related to ORU and SCL are shown in table 5. The total daily ORU showed no statistically significant differences between OI and C. The total SCL per day showed significant differences between OI and C. The mean total SCL per day of OI was 0:30 h:min longer compared with C ($P < 0.05$). This was confirmed by subgroup analysis. Therefore, the ratio between total SCL per day and total ORU per day was significantly higher in OI compared with C ($P < 0.05$). In both subgroups, results were significantly different, with higher values in the OI subgroups.

Sensitivity Analysis

Based on the equations shown in the appendix, a break point CMI was defined. The total group break point of CMI was calculated to be 0.5. Subgroup $OI_2 + C_2$ required a break point of 2.7 because of the smaller difference in NC, whereas the break point of subgroup $OI_3 + C_3$ was 0.3 because of a greater difference in NC.

Discussion

We analyzed the effects of OI on productivity in an operating unit. Three hundred thirty-five cases were studied, performed in two different settings. OI was performed in two and three ORs. During OI, an additional anesthesia team was available, anesthesia was induced in the anesthesia induction area, and emergence from anesthesia was performed in the pre-PACU emergence area. The workflow of the control group was managed in routine fashion with only the use of the anesthesia induction area. NC, TOT, ACT + TOT, and NST were analyzed. ACT + TOT was independent of surgical procedures, thus reflecting anesthesia productivity. OI led to significant time savings during regularly scheduled cases, resulting in an additional operations that could be reliably performed within OR Block Time. Therefore, productivity increased in terms of an increase of NC and a decrease of TOT, ACT + TOT, and NST.

Facilities Essential for OI

In the current literature, OI has been discussed controversially. Williams *et al.*[16] studied the concept of increasing the number of anesthesia providers (three providers for two ORs) to overlap anesthesia care for two consecutive cases. The effects of overlapping anesthesia characterized by the potential decrease of TOT were studied. The additional costs were analyzed and correlated with the effects of the measures. The methodology seems to be comparable to that of our study. However, there are some important differences: Anesthesia was induced and patients emerged from anesthesia in the OR because no special anesthesia induction or pre-PACU emergence area was available. After the first patient had left the OR, anesthesia care of the next patient started when housekeeping finished OR cleanup and when supplies as well as equipment were present in the OR (AACD: Room Ready). Overlapping of anesthesia

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Table 5. Target Parameters and OR Utilization per Day: Results of the Total Group and the Two- OR and Three-OR Subgroups

	Overlapping Induction	Control Conditions	*P* Value
NC			
TG	184	151	< 0.05
2 OR	70	67	NS
3 OR	114	84	< 0.05
TOT, h:min			
TG	0:25 ± 0:15	0:38 ± 0:24	< 0.05
2 OR	0:25 ± 0:14	0:37 ± 0:26	< 0.05
3 OR	0:25 ± 0:13	0:40 ± 0:21	< 0.05
ACT + TOT, h:min			
TG	0:28 ± 0:18	0:43 ± 0:23	< 0.05
2 OR	0:27 ± 0:18	0:34 ± 0:23	< 0.05
3 OR	0:28 ± 0:18	0:44 ± 0:20	< 0.05
NST, h:min			
TG	0:57 ± 0:18	1:08 ± 0:26	< 0.05
2 OR	1:00 ± 0:17	1:07 ± 0:28	NS
3 OR	0:55 ± 0:18	1:09 ± 0:24	< 0.05
ORU/d and OR, h:min			
TG	6:39 ± 1:21	6:18 ± 1:34	NS
2 OR	6:42 ± 1:34	6:08 ± 1:31	NS
3 OR	6:37 ± 1:13	6:25 ± 1:36	NS
SCL/d and OR, h:min			
TG	5:35 ± 1:15	5:05 ± 1:24	< 0.05
2 OR	5:44 ± 1:30	4:47 ± 1:35	< 0.05
3 OR	5:25 ± 0:57	4:57 ± 1.15	< 0.05
SCL/ORU, %			
TG	84 ± 11	79 ± 10	< 0.05
2 OR	84 ± 15	75 ± 11	< 0.05
3 OR	83 ± 13	78 ± 12	< 0.05

Data are presented as mean ± SD. $P < 0.05$, statistical analysis based on the Student *t* test; significant differences were additionally tested with the Mann–Whitney test.

2 OR = subgroup of two operating rooms; 3 OR = subgroup of three operating rooms; ACT + TOT = Anesthesia-controlled Time plus Turnover Time; NC = number of cases; NST = Nonsurgical Time; OR = operating room; ORU/d = total OR Utilization per day; SCL/d = total Surgical Case Length per day; SCL/ORU = ratio of Surgical Case Length and OR Utilization; TG = total group; TOT = Turnover Time.

consisted only of the first patient's discharge from the OR to the PACU and the succeeding patient's preanesthesia preparations, such as informed consent or intravenous line, performed in a preoperative facility. TOT differed only marginally between the groups, and economic benefit was not found.

The aim of our study was to decrease idle time between two operations by overlapping induction of and emergence from anesthesia. Therefore, patients of the study group were transferred to the pre-PACU emergence area right after Procedure/Surgery Finish, to make sure that OR preparations for the next case started as soon as possible. The succeeding patient was anesthetized in an anesthesia induction area, as introduced by Williams *et al.*[13] in another study. Using an anesthesia induction area for induction of regional anesthesia led to the shortest ACT compared with general anesthesia without an induction area. The concept of the anesthesia induction area is daily clinical routine at our hospital. During OI, anesthesia of the next case started as early as necessary, aiming at no idle time between Procedure/Surgery Finish of the previous case and Position Start of the next case. This concept (induction and emergence areas) leads to a significant decrease of TOT, ACT + TOT, and NST, as well as a significant increase of NC. We conclude that using OI may improve productivity (= NC), if performed in a special setting.

Number of Cases

In the current literature, OI is often criticized because an increase in productivity was not demonstrated. Some authors showed a significant increase of NC due to OI resulting in an economic benefit; others did not, and additional staff costs that in their studies could not balance the increase of NC were criticized.[6,8,14,17,18] A crucial point of any analysis is whether additional cases that could otherwise not be performed can be reliably scheduled within a defined OR Block Time and not in overtime or only if time is available. Therefore, the measure investigated must ensure time savings matching the SCL of the additional case.

Dexter *et al.*[9] retrospectively investigated the decrease in ACT in one OR suite necessary to reliably schedule an additional case. It was demonstrated that ACT would have to be decreased by more than 100% to permit one additional short operation in the same OR. A computer model investigated the decrease of case duration necessary to schedule an additional case, comparable to the length of the previous cases.[19] The required decrease of case duration was approximately half of the case length to result in an additional predictable case that could not have otherwise been performed. Decreases of this magnitude of ACT or case duration are in fact unlikely to be obtained. Certain differences between these two studies of Dexter *et al.* [9,19] and the current study must be emphasized: (1) Case length of the additional case had to be at least 30 min or match the case length of the previous cases. (2) Only workflow was modified, not the OR facilities used. (3) No additional team was implemented to increase NC. (4) Additional cases had to be reliably scheduled.

Our study included patients from the hospital ward, admitted at least on the DBS. They underwent surgery if time was available at the end of the routine schedule. *Prima facie*, this seems to be a limitation because in many hospitals, patients scheduled for routine cases are admitted on the day of surgery. However, this study was not performed on this routine organizational basis because under OI conditions, additional patients were supposed to be available in the hospital for surgery anytime if required without any pressure to operate on them anyway, even in overtime. As a result of OI, we demonstrated a significant time reduction of regularly scheduled cases. This leads to additional operations that could be reliably performed within OR Block Time. Based on these findings, once OI is established in routine daily OR

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organization, more patients per day can reliably be scheduled for surgery. Therefore, differences between the study of Dexter *et al.*[19] and our study must be considered only for study conditions and not for OI established in daily clinical routine.

There are different approaches to improve productivity by enhancing workflow in an operating room. We aimed at an increase of NC within a given time period (OR Block Time). Strum *et al.*[14] aimed neither to increase NC nor to reduce OR time. They investigated ORU and its impact on costs. The authors concluded that overutilization as well as underutilization of ORs increases costs and must be minimized. They concluded that optimizing surgical subspecialty block time using a minimal cost analysis model may significantly reduce costs. We agree with this statement and the considerably low ORU in our study during OI as well as C conditions are an indicator of less-than-optimal OR management. Causal for the (comparably) low ORU is a condition of our hospital management to avoid overtime. Routinely scheduled cases are operated only if they are reliably finished within OR Block Time. This was undisputable and based on the fact that costs of overtime hours exceed those of regular hours because of increased direct and indirect costs (*i.e.*, personnel must be compensated at a higher rate for unscheduled hours). This policy is comparable to that described recently.[20]

In a recently published study, Dexter *et al.*[11] introduced a methodology to try to minimize costs of a given NC by reduction of TOT. However, reduction of TOT of 3–19 min leads to reduction of staffing costs of only 0.8–4.0%. They concluded that staff cost reductions are generally very small and would be achieved predominantly by reducing allocated Case Length to the surgeons.[11] We disagree with this conclusion. Our results demonstrated a TOT reduction of 33% (OI_2) up to 38% (OI_3). In addition, ACT + TOT and NST were successfully and significantly decreased by OI. This led to significant time savings during regularly scheduled cases. Thus, additional short predictable cases were reliably performed within OR Block Time, leading to an increase of NC. The authors doubted any other potential benefit of decreased TOT. Some of these benefits were demonstrated in our study: (1) TOT reduction cannot provide sufficient additional OR time to perform another elective case that would not otherwise have been economically sound to perform. We demonstrated a significant reduction of TOT and other anesthesia-related time intervals leading to a significant reduction of daily OR time of regularly scheduled cases. (2) TOT reduction does not permit a surgeon to perform another case in his or her OR that could not otherwise be completed. We showed that additional cases were reliably performed within OR Block Time as a result of a reduction of TOT which was a result of OI workflow. The more cases are performed and the more ACT exceeds SCL, the more time savings between cases are pronounced. (3) TOT reduction cannot permit another add-on case to be performed that could not otherwise be completed within a fixed time period. If turnovers are reduced in many ORs, an add-on case can be done in one of them. As a result of OI, add-on cases were performed within OR Block Time. Especially the comparison of two and three ORs demonstrated that if the number of ORs included in OI workflow is increased, more additional cases can be performed. (4) TOT reduction does not prevent a case from being cancelled out of concern that case would finish after the end of regularly scheduled hours. It might be advisable to do the case anyway, even in overutilized hours, because costs of a cancelled case are generally higher than costs of a case performed in overtime. Nevertheless, if time savings lead to an earlier end of regularly scheduled cases (as was the case during OI), it reduces the risk of overutilization. (5) TOT reduction did not reduce staffing costs. We demonstrated a reduction of TOT leading to a decreased total OR time; therefore, it is most likely to decrease staff costs. This may be speculative because we did not analyze staff costs of regularly scheduled cases.

In a recently published study by Sokolovic *et al.*,[8] a significant increase of NC was found. This investigation differs considerably from our study. The increase of NC did not result from an increase in productivity. Because of differences between the study group and the control group in terms of a significantly greater number of short gynecologic operations and a relevant increase in overtime in the study group, the groups enrolled in this study were not comparable. Unlike Sokolovic *et al.*, we were able to demonstrate an increase of NC due to a decrease of OR time of regularly scheduled cases. This was confirmed by similar control parameters in all groups.

Subgroup analysis of our data showed no significant differences in subgroup $OI_2 + C_2$ but a significant increase of NC in subgroup $OI_3 + C_3$. During OI conditions in three ORs, ACT + TOT decreased by 0:16 h:min per case. On average, 2.5 cases per OR and per day were done (114 cases/15 study days/3 ORs). The ACT + TOT per OR and per day decreased by 40 min (0:16 h:min times 2.5 cases). Therefore, OI is likely to create sufficient SCL to reliably schedule an additional short predictable case that could not otherwise be performed.

We found an increase of NC of 2.0 in subgroup $OI_3 + C_3$ in contrast to 0.2 in subgroup $OI_2 + C_2$. We assume that productivity increases with the number of ORs involved in OI. We conclude that not only the speed of work (either of anesthesiologists or of surgeons) but also workflow (OI, additional teams) must be optimized.

Turnover Time, Anesthesia-controlled Time plus Turnover Time, and Nonsurgical Time

Nonsurgical Time is a parameter to evaluate the performance of intraoperative processes.[1,2,17] Our data

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showed a significant decrease in NST in the total group and in subgroup $OI_3 + C_3$ as a result of OI. In subgroup $OI_2 + C_2$, NST showed a lesser decrease, and significance was not reached, possibly because of smaller subgroup size. NST is influenced by anesthesia as well as surgical processes, *e.g.*, OR preparations for the next case or positioning of the patient. Thus, it is an imperfect parameter of anesthesia efficiency. Therefore, we also analyzed the recently defined ACT + TOT.[16] This parameter is, in contrast to NST, independent of surgical procedures. ACT + TOT showed significant differences in the total group as well as in either subgroup. In our study, the time-saving effects of OI on ACT + TOT were greater than the savings of NST. We assume that the positive effects of OI gained by optimized anesthesia workflow were diminished by suboptimal surgical procedures. Perioperative surgical activities are also important factors influencing the productivity of an operating unit.[9,18,21] However, this potential of further improvement is beyond the responsibility of anesthesiologists. For this reason, this part of perioperative scheduling was not studied.

OR Utilization

We demonstrated comparable ORU in OI and C despite a significant difference of NC. A longer ORU per case in the control group led to comparable daily ORUs in both groups. Preparations for the next case, which started after the previous Patient Out of Room, started earlier in the OI group. Patients of the OI group were moved to a pre-PACU emergence area outside the OR immediately after Procedure/Surgery Finish. In the control group, the patients emerged from anesthesia in the OR consistent with the routine workflow, utilizing the OR for a longer period because of nonsurgical activities. ORU has been used as a measure of productivity in several studies.[14,22,23] If it is low, it is thought to be a strong indicator of underutilization of OR Block Time and therefore an indicator of inefficiency. A high ORU (*e.g.*, close to 100%), however, may not be *per se* an indicator of efficient OR management. In this case, one must keep in mind what happens inside the OR and that only surgery itself can gain money, not anesthesia care, positioning of the patient, and so on. Strum *et al.*[14] defined OR overutilization and underutilization to better detect surgical inefficiency in the use of ORs. In a *post hoc* analysis, it was demonstrated that the traditional measure of OR efficiency, ORU, is often imprecise. Overutilization and underutilization were found to be more exact measures. Others studied anesthesia net staffing costs and showed that longer-than-average surgical durations increase costs.[20] In these cases, ORU was excellent because of a long SCL. We conclude that an increased SCL decreases productivity as well as an OR utilized by a patient who does not undergo surgery, *e.g.*, because of emergence from anesthesia in the OR. Therefore, we suggest in addition to measure the ratio of SCL and ORU. This ratio should be close to 100%. The smaller the ratio is, the more nonsurgical activities are performed in the OR. These may not only be anesthesia activities, such as induction of anesthesia and emergence from anesthesia, but also preoperative preparations or positioning of the patient. We showed an increase of this ratio in the OI group compared with control, indicating an increase of productivity. As discussed above, the ORU was considerably low during study and control conditions. This emphasizes that workflow of anesthesia teams is only one possible measure to increase productivity; another is improving ORU.

Sensitivity Analysis and Economic Benefit

For sensitivity analysis, the break point CMI was calculated to distinguish negative and positive assumptions. Two scenarios are conceivable: First, if the index of the additional case is below the required break point CMI (worst scenario: if it is zero, no additional case can be performed, despite OI), OI results in financial losses. Second, if the index of the additional case exceeds the break point, OI results in increased profit. This calculation is based on the hospital individual CMI and the hospital specific base rate ($2,300), reflecting the German Diagnosis Related Group system[24] on one hand and anesthesia staff costs published recently on other.[15] Equations 1–7 in the appendix detail the calculation of the specific CMI. In our study, the break point CMI of the total group was 0.5. For example, the index of an uncomplicated endoscopic cholecystectomy is 1.0, the index of an appendectomy is 0.5–0.9, and the index of a gastrectomy is 1.6–3.0. These examples emphasize that a relatively low CMI, typically associated with short SCL, is sufficient to gain economic benefit of OI. In contrast to a computer simulation study, our data resulting from clinical trials show that OI is likely to create sufficient SCL to reliably schedule an additional short predictable case.[17] Further analysis of the subgroups showed a greater break point in $OI_2 + C_2$ (2.7) than in $OI_3 + C_3$ (0.3). Therefore, this study confirms the theses of Viapiano and Ward,[25] who pointed out the necessity of weighing achievable values of any measure of optimization of hospital structures against additional costs.

Average Hours of Work of the OI team was only 1:20 h:min in OI_2 and 1:37 h:min in OI_3. Hence, the additional team was available to the anesthesia coordinator for approximately 6 h per day. This time can be used, for example, for assistance during difficult induction of anesthesia, teaching, release of colleagues during lunch break, or unscheduled premedication visits.

Extrapolations

Overlapping induction of anesthesia performed in more than three ORs may lead to further decreases in TOT, ACT + TOT, and NST, as well as an increase of the

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NC. This assumption is based on the economic fact of a reduction of fixed costs by increasing quantities.[25,26] It can be speculated that with a large number of ORs, it may be easier to finance the additional costs, because hours of work per day for the additional team may increase. Consequently, a better cost–value ratio and an increase in productivity will result. However, with increasing hours of work of the additional team, flexibility is reduced, and the team may not be available when needed.

Limitations

For scientific reasons, study and control conditions had to be defined. These conditions were defined as realistically as possible; however, it may be impossible to transfer them to daily clinical practice on a 1:1 basis. There was no way to perform this clinical study double blinded because the care of consecutive patients had to be coordinated. Therefore, anesthesia teams needed to know whether workflow of OI or C conditions had to be performed. Thus, there was only indirect proof that the OI workflow led to a decrease of OR time and an increase of NC. *Prima facie*, it seems to be a limitation of the study that only inpatients, admitted to the hospital at latest on the DBS, were enrolled in the study, because in many hospitals, patients scheduled for routine cases are admitted on the day of surgery. However, this study could not be performed on this routine organizational basis because additional patients were supposed to be available in the hospital for surgery if required. However, once OI is established in routine daily OR organization, more patients per day can reliably be scheduled for surgery. The workflow of C_2 and C_3 reflected the daily routine of our hospital; therefore, patients emerged from anesthesia in the OR without being transferred to the pre-PACU emergence area. An additional control group using the pre-PACU emergence area would have strengthened our results, but resources were a limiting factor.

Conclusions

Overlapping induction of anesthesia was performed during a period of 60 days, initially in two followed by three ORs during daily OR Block Time (7:30 AM until 3:00 PM). Patients were admitted on the DBS and were thus available and did not have surgery that day unless there was a time reduction resulting from OI. OR facilities in terms of anesthesia induction and emergence areas were already constructed. As a result of OI, TOT, ACT + TOT, and NST significantly decreased, resulting in a significantly earlier end of regularly scheduled operations. Thus, OR time was reliably available for an additionally scheduled operation that could be performed within OR Block Time. Therefore, NC increased significantly. Subgroup analysis of two *versus* three ORs showed that productivity increases with the number of ORs involved in OI. The current study is a result of tremendous teamwork not only within classic surgical, anesthesia, or facility teams but within the whole OR team. Old thinking, such as "This is my room, and this is your room," must be abandoned. We emphasize that all care providers must work as a team, working together on improvements and together sharing success.

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Appendix

1. Minimum requirements: additional staff costs = additional income
2. Staff costs = anesthesia team costs per minute × daily working time = \$2.69 × 462 min
3. Additional income = CMI × Base Rate × $\Delta NC/d$ = CMI × \$2,300 × $\Delta NC/d$
4. $\Delta NC/d = NC/d_{OI} - \Delta NC/d_C$
5. Equations 1–4 => \$2.69 × 462 min = CMI × \$2,300 × ($NC/d_{OI} - \Delta NC/d_C$)
6. Break up of equation 5 to CMI: CMI = \$1,242.78/[\$2,300 × ($NC/d_{OI} - \Delta NC/d_C$)]
7. Definition Break Point CMI: Clinic-specific CMI > Break Point CMI => additional income due to OI

1. Minimum requirement: From an economic point of view, the additional income resulting from overlapping induction of anesthesia (OI) must at least cover the cost of additional staff.

2. Calculation of staff costs: Staff costs are calculated with the product of staff costs per minute and the daily hours of work, based on 7:42 h:min = 462 min, with a full weekly workload being 38:30 h:min.

3 and 4. Estimation of additional income: The calculation is based on the product of the specific case mix index (CMI) of the Department of General Surgery, University Hospital Schleswig-Holstein, Kiel, Germany, and the specific base rate of our university hospital. The higher the CMI of a department is, the more sever the illnesses are and the more complicated the course of an average case is. The average additional income per case is the product of CMI, base rate, and difference in number of cases (NC) between OI and control conditions (C).

5. The equation of minimum requirement of OI shown in equation 5 is based on the minimum requirement of equation 1 and equations 2–4.

6. Equation 5 was broken up into the independent variable CMI.

7. The CMI can be used as a sensitivity analysis allowing the transfer of our results to other clinics. If the average CMI of any clinic is greater than the calculated break point, OI will lead to additional profit under the defined conditions.

$\Delta NC/d$ = difference of $NC/d_{OI} - NC/d_C$; NC/d_C = average NC per day of group C; NC/d_{OI} = average NC per day of group OI.

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