Identifying methods to improve heart surgery: an operative approach and strategy for implementation on an organizational level

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Abstract

Background: Previous research has found teamwork failures to be strongly associated with the occurrence of surgical error. There have been few efforts to prospectively collect data regarding teamwork failures and technical errors in order to create interventions that would maximize teamwork effectiveness thereby minimizing technical error. Methods: Thirty-one cardiac surgical cases were prospectively observed by a trained human factors observer. Events were characterized according to human factors theory and included teamwork failures and technical errors. Surgical team structure was also evaluated in an effort to identify if it had an impact on surgical team performance. Results: A strong correlation (r = 0.67, p < 0.001) was recognized between the occurrence of technical error (n = 155) and teamwork failures (n = 178). Teamwork failures consisted of surgeon—technical team failures (n = 90, 51%), procedural information failures (n = 36, 20%), surgeon—anesthesiologist—surgeon failures (n = 36, 20%), surgeon—anesthesiologist—surgeon failures (n = 36, 20%), surgeon—anesthesiologist failures (n = 27, 15%), surgeon—perfusionist failures (n = 18, 10%), and failures due to handoffs (n = 7, 4%). Teams made up of members that were familiar with the operating surgeon had significantly fewer total event failures (8.6 ± 1.6 vs 22 ± 3.1, p < 0.0001) and teamwork failures (5.6 ± 1.8 vs 15.4 ± 1.9, p < 0.0001) in comparison to those teams where the majority of members were unfamiliar with the operating surgeon. Conclusions: These results indicate that the process of cardiac surgery would benefit from interventions to improve teamwork and communication. Such interventions could include preoperative briefings, revised approach to structuring of operative teams to favor members that have gained familiarity with the operating surgeon, standardized communication practices, and postoperative debriefings.

Keywords: Patient safety; Error; Human factors; Teamwork; Communication

1. Introduction

As the complexity of the practice of cardiac surgery increases due to increasing comorbidities of patients and the introduction of advanced technologies, the achievement and maintenance of surgical excellence has become more challenging. In fact while there has been significant reduction in the morbidity and mortality after cardiac surgery since its inception over 50 years ago, there continues to be instances of surgical error and avoidable complications. Commonly, surgical error has been thought of as the consequence of lack of skill or ability, and is the result of thoughtless actions. However, recent work has shown that error is often the result of a mismatch between the work system and the capabilities and limitations of the human doing the work [1,2]. There exists an evolving science of human factors that is built upon these core concepts which focuses on integrating human capabilities and limitations into the design of work systems. Cardiac surgical care, therefore, could be improved by introducing effective error management approaches including efforts to reduce the frequency of errors, increase their capture, and enhance the ability to compensate for them when they occur.

Our work focuses on investigating team dynamics by applying human factor principles used in high consequence industries that may be applicable in the operating room. We recently reported our findings of the application of human factors theory to the analysis of events in the cardiovascular surgery operating room [3]. By observing 31 cardiac surgical cases, the principal findings of our studies were two-fold: first, we found the human factors analysis and classification method to be a beneficial tool for identifying latent failures that predispose to the occurrence of surgical error. Additionally, we were able to appreciate that the etiology of surgical error is deeply ingrained in the effectiveness of teamwork [4]. Specifically, our analysis identified a
significant association between surgical errors and surgical flow disruptions. Furthermore, by grouping surgical flow disruptions into teamwork and non-teamwork related events, teamwork related disruptions were found to be the only independent predictors of surgical error.

A limitation of our initial analysis was its failure to provide suitable interventions that might maximize the effectiveness of teamwork, with the ultimate goal of reducing the incidence of surgical error. The primary purpose of the current analysis is to identify patterns of teamwork failures that would benefit from intervention. Our second purpose is to develop an effective strategy to allow for its successful implementation in the cardiac surgical setting.

2. Methods

A convenience sample of 31 cardiac surgical operations performed by 5 attending surgeons was obtained across a 3-week study period. All operations were performed at the Mayo Clinic and involved observations of multiple procedures, including coronary artery bypass grafting (CABG; \( n = 13 \)), valve repair/replacement (\( n = 6 \)), CABG and valve repair (\( n = 4 \)), aortic root replacement (\( n = 3 \)), and other procedures (\( n = 5 \)). The OR teams were informed that the observer would be monitoring the case for the purpose of understanding surgical team interaction. The data presented here reflect approximately 42 h of observation. The Mayo Clinic Foundation Institutional Review Board approved this study.

3. Data collection and definitions

Primary event data concerning surgical errors and flow disruptions were collected by an individual observer who monitored each operation while standing at the anesthesiology station located at the head of the patient. The observer had 2 years of medical training and had 6 months of first-assistant training in cardiovascular surgery. Additionally, as part of this study, the observer also received 10 h of didactic instruction on human factors, human error, and systems safety from a senior human factors scientist. While performing the observations, the observer documented each event during the operation. ‘Events’ were defined as any occurrence that disrupted the flow of the operation, including errors on part of the surgical team. Surgical flow disruptions, the first major subset of ‘events’, were defined as those instances due to systemic factors such as teamwork/communication, supervisory/training related disruptions, and resource-based issues. Errors, the second major subset of ‘events,’ were defined as technical events in which a planned sequence of activities failed to initially achieve its intended outcome, given such failures could not be attributed to the intervention of some chance agency [1]. The observer recorded descriptions of each event on a notepad and then later transcribed this information onto a computer spreadsheet. Results were categorized according to human factors theory based on consensus agreement between the original observer, a senior cardiac surgeon, and a senior human factors scientist. Additional information such as the surgeon, grouping/characteristics of team members (including team member experience), and patient clinical characteristics were also collected. Of note, operations were documented as to whether they were performed with the primary surgical team or a secondary surgical team. Primary surgical teams were defined as those in which the majority of team members (CST, circulating nurse, resident/fellow, perfusionist, CRNA/anesthesiologist) were routinely matched together at the beginning of surgical cases, whereas secondary surgical teams consisted of a majority of members who had little familiarity with the operating surgeon and/or team. Individual team member experience was also collected in order to assure this was not a confounding factor with regard to team staffing. It was hypothesized at the inception of the study that there may be difficulty in characterizing primary and secondary teams, however the operations in this study were clearly definable; primary cardiac teams occurred such that >80% of the team consisted of those who attained familiarity with the operating surgeon whereas all secondary surgical teams had <40% (two members) who attained familiarity with the operating surgeon. For purposes of quality assurance, the observer was monitored periodically by senior staff while making observations. As a result of this monitoring and review process, the data collection procedures were deemed acceptable, and the observer continued observations until the end of the 3-week study period.

4. Statistical analysis

The data were analyzed using both quantitative and qualitative approaches. A quantitative analysis was performed to assess performance between surgical teams according to team structure (primary vs secondary surgical teams). Total surgical flow disruptions and teamwork-only surgical flow disruptions were compared using Student’s \( t \)-test for correlated samples. Continuous variables are expressed as a mean ± standard deviation. \( \chi^2 \)-analysis was utilized to determine significant differences between categorical variables whereas analysis of variance (ANOVA) for correlated samples was used to determine if there were significant differences between the numbers of events within each surgical team structure (primary vs secondary). For all analyses, a \( p \) value < 0.05 is considered statistically significant.

A qualitative analysis of teamwork disruptions was subsequently performed by categorizing events based on the individuals between whom the event occurred. These events were then grouped according to timing of the event (with regard to the surgical procedure) and context in which the event occurred. This method of analysis allowed for the categorization of events with similar etiologies. Based on the findings of these analyses, the scientific and human factors literature was searched in an effort to identify strategies that have proven beneficial in addressing such occurrences. Implementation strategies from the management and organizational literature were also used to create methodologies that would increase the likelihood of successful implementation.
5. Results

As previously reported [4], a total of 155 technical surgical errors (5.0/case), and 341 surgical flow disruptions (11.0/case) were observed across 31 operations. The majority of these disruptions included teamwork disruptions (n = 178, 52%); however disruptions also included external interruptions (n = 58, 17%), supervisory/training disruptions (n = 41, 12%), equipment technology problems (n = 38, 11%) and resource accessibility issues (n = 27, 8%). Of these disruptions, there was a significant association between teamwork disruptions and surgical errors (r = 0.67, p < 0.001) [4]. No other factors were correlated with surgical error on either a univariate or multivariate level.

5.1. Quantitative analysis

Overall, 17 (55%) operations were performed by primary surgical teams, whereas 14 (45%) were performed by secondary surgical teams. As demonstrated in Fig. 1, there was a significant difference in the number of total events per case (surgical flow disruptions + surgical error) between primary and secondary surgical teams (8.6 ± 1.6 vs 22 ± 3.1 respectively, p < 0.0001). There was also a significant difference in the incidence of teamwork-only failures between primary and secondary surgical teams (Fig. 1); primary surgical teams on average committed 5.6 ± 1.8 teamwork failures per case compared to secondary teams, which had 15.4 ± 1.9 teamwork failures (p < 0.0001) per case. A stratified ANOVA test of primary and secondary surgical teams revealed that there was no significant difference between the number of teamwork failures (p = 0.56) or total events per case (p = 0.64) in each stratum, suggesting that the number of failures per case in each strata was comparable and that there were no significant case outliers. Individual team member surgical experience did not appear to be a confounding factor in those cases performed by primary and secondary surgical teams (9.1 ± 6.8 years vs 8.2 ± 7.6 years, respectively). A stratified analysis of individual surgeon performance with primary and secondary surgical teams was also consistent with improved primary team performance (four surgeons had data with primary and secondary surgical teams, all p < 0.05 with secondary team failures > primary team failures for total surgical flow disruptions and teamwork-only disruptions).

5.2. Qualitative analysis

A secondary qualitative analysis was performed which revealed five main axes of teamwork failures (Fig. 2). These main axes included surgeon—technical team (resident/fellow, CST, scrub RN) interaction (Fig. 2A, n = 90, 51%), failures secondary to a lack of knowledge of patient/procedure information (Fig. 2B, n = 36, 20%), surgeon—anesthesiologist/CRNA communication (Fig. 2C, n = 27, 15%), surgeon—perfusionist communication (Fig. 2D, n = 18, 10%), and handoffs occurring between any of the non-surgeon members of the group (n = 7, 4%).

5.2.1. Surgeon—technical team failures

Surgeon—technical team failures predominantly consisted of coordination, communication, and team familiarity events. Examples of these events included a team member not providing adequate exposure, the handing off of a wrong surgical instrument when requested properly, or a surgeon instructing a team member of his preferred method of performing a specific maneuver during a technical procedure. Of these events, 68 (4.9/case, 76%) occurred in the context of a secondary team and 22 (1.6/case, 24%) occurred in the context of a primary surgical team (p < 0.0001).

5.2.2. Patient information/procedure information

All intraoperative teamwork failures that occurred secondary to a lack of knowledge of patient/procedure information centered on the following issues: (1) unique aspects of the operation that were known before the operation were initiated but deviated from standard protocol utilized for similar cases, (2) misunderstanding of surgeon preference regarding set-up, instruments required, valves etc., and (3) patient information that should have altered intraoperative routine and/or resources (i.e., latex allergies). Overall, 33 (92%) events that originated in the procedural information domain but manifested intraoperatively could have been prevented by a preoperative briefing which highlighted major patient and intraoperative factors as shown in Fig. 3A. While not designed to be a comprehensive
model, this preoperative briefing covered all preventable intraoperative teamwork failures that occurred in this axis.

5.2.3. Surgeon—anesthesiologist and surgeon—perfusionist communication

These communication axes were grouped together because their root causes were similar. The main causes of teamwork failures were due to requests/commands that were not effectively communicated (n = 40, 89%) either due to an environmental obstacle (i.e. noise) or a failure of the recipient to appreciate the meaning of the message delivered. These communicator—recipient mismatches resulted in a surgical flow disruption after the communication event had occurred (i.e. aortic cross-clamp removal, timing of heparin administration, timing of cardioplegia administration, temperature and flow of CPB pump, etc.) but did not manifest until the communicator requested additional information about the status of the message (i.e. ‘When was the last time cardioplegia was given?’). In this situation, the time interval for administration of cardioplegia had already been exceeded.

5.2.4. Handoffs

Handoffs between non-surgeon members of the surgical team constituted a small percentage of total teamwork disruptions that occurred intraoperatively. All disruptions (n = 7) occurred when individuals were handing off during two critical parts of the operation: attempting to initiate CPB and weaning the patient from CPB.

6. Discussion

The teamwork disruptions described here did not result in significant patient morbidity or mortality, however, studies have shown that such ‘minor’ events predispose to the occurrence of an adverse outcome by negatively impacting the surgical team’s ability to compensate for a major event [2,5]. Thus, while many of these disruptions may appear to be singularly inconsequential, they have the potential to result in negative patient outcomes if not addressed with effective interventions [5]. Furthermore, our previous analysis indicated that these teamwork disruptions significantly increased the likelihood of a surgical error occurring [4]. The human factors approach utilized in this analysis produced both qualitative and quantitative data, rendering us capable of conducting a comprehensive analysis of intraoperative teamwork failures.

Overall, primary surgical teams had a lower incidence of total surgical flow disruptions, surgical error, and teamwork failures. The major benefit of utilizing primary surgical teams equated in improved surgeon—technical team performance. We attempted to identify surgeon—technical team issues that could have been prevented by use of a prospective intervention, however, these failures mainly constituted team chemistry or team coordination factors that are likely to be improved only by increased team cohesiveness and familiarity. Secondary surgical teams in this study represented a conglomeration of individual members who infrequently (if ever) operated with a particular surgeon (or even in cardiac surgery, i.e. OB-GYN CSTs, neurosurgery CRNAs, etc.) despite having the same overall surgical experience as primary team members. While global teamwork training has been proposed as a mechanism of improving teamwork, the effectiveness of this approach in improving specific team dynamics is unclear since teamwork training is most beneficial when performed in the context of the team performing the operation. Equally, other interventions aimed at mitigating the effect of such unfamiliarity must be explored.

The second major implication of this analysis is that events which disrupt the natural progression of an operation may be ameliorated by administration of a preoperative briefing and the use of standardized language. This confirms findings of other studies [6—8] which have found that an appreciable number of communication failures may be prevented by a briefing that highlights the main issues of patient and operative procedure to be performed. The briefing shown here (Fig. 3A) was derived from an analysis of actual operating room events that disrupted the flow of an operation. With regard to the use of standardized communication practices, while the communication failures that occurred due to communicator—recipient mismatch were likely confounded by the presence of secondary surgical teams that lacked familiarity with the operating surgeon/team, the diversity of human communication has been illustrated in many industries, and the necessity of standardization to assure the intended message has been received and understood should not be ignored.

6.1. Strategies for improvement

These findings argue for implementation of a new process (Fig. 4) of cardiac surgery which may include a preoperative briefing, restructuring of the method of staffing surgical teams, standardized intraoperative communication, and a postoperative debriefing.

6.1.1. Preoperative briefing

Preoperative briefings have been shown to increase team satisfaction [8,9], patient safety [8], and safety climate [10]...
while decreasing the frequency of nursing turnover [9] and wrong-site surgery [8]. There continues to be much debate about the specific factors that should be included in preoperative briefings; however, the similarities between briefings published in the literature [8,9] and ours is striking despite being derived in vastly different ways. The importance of this intervention has recently been highlighted by the World Health Organization’s Safer Surgery Project; a global effort which uses a basic intraoperative checklist as a mechanism to improve surgical outcomes in various surgical subspecialties [11]. Thus, the administration of discipline-specific preoperative briefing identifying critical patient/procedure/equipment information may be more important than creating an ideal comprehensive one. Surgical teams should, however, adhere to specific criteria shown to improve the implementation success of preoperative briefings [10] such as minimization of the duration of the briefing (<5 min [12]). Equally, team members must feel a sense of responsibility as well as empowerment to speak up if they perceive a problem. Accordingly, a briefing may be structured such that each team member be responsible for addressing aspects of patient care that are under his/her direct control (Fig. 3B, i.e. surgeon describing critical operative steps and site of cannulation, perfusionist discussing specific parameters of perfusion flow and temperature, etc.). Interventions encouraging all members of the surgical team to take active involvement in patient care may also provide for better detection and management of surgical errors [3].

6.1.2. Surgical team restructuring

Of significant importance is the clear value of a surgical team that has obtained familiarity with the operating surgeon. This is particularly true for complex or unusual cases. In many settings there is an informal ad hoc means of accomplishing this, with teams self-selecting to the case/surgeons in which they feel most comfortable. Our data suggest, however, that this factor should be recognized appropriately by those assigning staff to operating rooms and formal procedures be put in place to match the team to the procedure. For example, the decision whether to include a trainee on a case should be made on the basis of the case itself and not the trainee’s schedule. Logistically, it may be difficult to only pair primary surgical team members with a particular surgeon. In these situations, a compromise to the primary-only operating team and the randomly assigned team would be the training and staffing of alternate team members with a predetermined group of surgeons. This pairing between surgeon and alternate team member, for example, might be based on similar operative schedules, ultimately allowing for the creation of an interchangeable group of OR team members. Ideally, these team members should become acquainted with the surgeons’ specific technique and preferences using either a real-time method (i.e. the selected alternate team member should be scheduled for a predetermined number of cases with both surgeons), or by using a simulated method (either through simulation training with the operating surgeon or by participating in operations as an observer).

Given the complexity of staffing patterns in busy hospital settings, one cannot always assure that familiar staff will be present. This may be particularly true during off-hours when emergency cases are most likely to occur. Studies have shown that it is these types of cases in which errors and adverse events are most common given the unstable state of patients and inherent disorganization and chaos [13]. In these critical cases where high team performance is most sought after, yet staffing of familiar teams is least likely, the potential downside of organizations that regularly staff highly familiar teams is that team performance may be particularly poor due to difficulty of adaptation. Thus, these situations further emphasize the necessity to implement the methods of standardization in an effort to mitigate the effects of team unfamiliarity. In such settings, the preoperative briefing, standardized communication between team members, as well as specific interventions to engage staff aimed at creating rules of shared responsibility, are crucial to the success of the surgical team. For example, a recent course based on the principles of crew resource management (CRM) recently administered to trauma surgical teams [14] found that teams were more comfortable and capable during surgery. While this intervention may be suitable for emergency surgical teams, it is unclear as to the optimal approach of teamwork training in settings where obtaining team familiarity may not be feasible, thereby emphasizing the necessity of future research in this area.

6.1.3. Standardized intraoperative communication

Although surgeon to anesthesiologist (CRNA)/perfusionist communication was also a reflection of poor secondary team performance, these communication events could have been directly prevented by a modification of the communication style between team members. Nearly all communication failures were the result of environmental interference (i.e. noise) or a failure to fully understand the meaning of the message delivered. A recent study of surgical malpractice claims indicated that adverse events were often the result of the communication failures described here [15]. By implementing a standardized communication pattern where the speaker’s message is repeated by the recipient (speak-repeat, read-repeat, etc.), the communicator creates a closed-loop communication model where both parties are acutely aware of the status of the message. The predictability of standardized language has been shown to increase the effectiveness of management in complex medical situations [10,16]. Standardized language has also long been used in high-risk industries to prevent the occurrence of
communication mishaps; this analysis further emphasizes its applicability to the operating room setting.

6.1.4. Postoperative debriefing

A potentially powerful component of this process may be the postoperative debriefing. The postoperative debriefing allows for the surgical team to reflect on the surgical case, discussing positive and negative aspects that might benefit from modification or re-intervention. Formal structuring to this component of the process may not be as significant, and may simply consist of a brief discussion, assuming that an environment of psychological safety has been created. Any recommendations that result from this debriefing should then be implemented into the preoperative briefing (if deemed that significant patient/procedure information was left out) and/or operative setting (i.e., an additional modification to the communication style). By creating a dynamic process, surgical teams gain the ability to identify and correct their shortcomings as well recognize their strengths.

6.1.5. Human error training

Surgical team restructuring complimented by standardized communication and pre/postoperative briefings will likely result in improved team performance; however, even primary stable teams are prone to the occurrence of teamwork failures and surgical error. The inability to acknowledge that error is common in the medical setting can best be illustrated by a study which identified 30% of nurses and physicians in a critical care setting who denied committing errors [17]. Despite a plethora of information in the medical literature [18,19], the failure to acknowledge error in medicine may be due to a culture of blame leading to fear and ignorance. An appreciation of the importance of teamwork, the nature of error, and its overall role in team performance [20] will likely further maximize team effectiveness. Our study and others [21], found that teamwork was critically important to the capture and compensation of errors; a finding which may not be intuitive to those without formal training. Thus once stable teams, standardized communication methods, and effective briefings have been developed, a process of formal training and education in human factors and human error should be instituted. If surgical teams are carefully selected, this training and process change will provide teams with the knowledge and environment that will facilitate the breakdown of the hierarchical structure that currently impedes the development of effective patient safety programs.

6.2. The role of the surgeon as team leader

A recent study that identified characteristics of cardiac surgical teams that were able to successfully implement minimally invasive cardiac surgery (MICS) identified a number of factors that predicted success [22]. Of primary importance was the surgeon’s outlook toward the new technology. Those surgeons who actively recruited team members, created an environment of psychological safety, and viewed the technology as a fundamental change in the way surgery is performed, had much greater success compared to those who viewed the technology as simply a ‘plug-in’ change, ultimately making no effort to challenge the surgical team. Although the process discussed here is not a disruptive technology, it does represent a ‘process innovation’ that requires leadership characteristics similar to those surgeons who were able successfully implement MICS. Successful adoption will require instruction, training, resources, and change from organizational routine that will be burdensome to those who do not believe in its potential effects. Thus, successful adoption of this process will also be dependent on leadership throughout the organization. Organizations that view quality of patient care as an organizational priority may be best suited to adopt this new process, assuming that divisional leadership priorities are aligned. Cardiac surgeon ‘champions’ should be targeted as the initial institutional adopters. By carefully selecting those teams willing to fully embrace this new process, the probability of success increases, which in turn increases exposure to the late adopters and those who are initially skeptical about its benefits. As the institutional culture transitions to the adoption of such interventions, creating an effective incentive mechanism for full adoption is likely to be accomplished on an organizational and payer level. These incentives will serve to attract late adopters who might otherwise show reluctance.

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References

This paper by ElBardissi and colleagues [1] applies the human factor analysis techniques to cardiac surgery. In the study, a trained observer watched 31 operations and noted disruptions to the smooth flow of the operation as technical errors and teamwork failures. The latter were further subclassified as surgeon–anaesthesiologist failures, surgeon–perfusionists failures and so forth. The authors have found strong correlation between technical errors and teamwork failures, and these were all reduced in teams composed of members who normally work together and are familiar with the operating surgeon, when compared with teams where the majority of members were not familiar with the surgeon.

The strengths of this paper are in its relative novelty of analysis and in its innovative application of human factor theory to this field. As efforts continue to improve further the already excellent results of heart surgery, it is natural that attention should be directed to human factors, and the possibility of improving results is a valid reason to venture further in exploring this field of study, which is still in its infancy. We have already shown that the outcome of heart operations can be affected by the recent on-table death of a preceding patient [2] and possibly by burnout, whereas a break from work such as a holiday is likely to be associated with better outcomes [3]. There is therefore little doubt that human factors, such as the surgeon’s state of mind at the time of surgery, can influence cardiac surgical outcomes, and the impact of another human factor, namely team familiarity is a legitimate area for further study.

The authors have provided a useful tool which allows the assessment of the flow of an operative procedure. The main conclusion of the study is that familiarity within the surgical team reduces flow disruptions, but for this to translate into better outcomes requires a controlled, preferably randomised study comparing the outcomes of operations of familiar and unfamiliar teams. The issue of familiar versus unfamiliar teams is a fascinating one which has been elucidated in the paper. The disadvantages of unfamiliar teams are clearly stated in the paper. The disadvantages of familiarity, however, include the perpetuation of suboptimal practice by the loss of challenge, the risk of teams becoming complacent and the slowing down of development and innovation.

Furthermore, the transfer of good techniques and practice between teams is hampered when operations are carried out exclusively or nearly so by established familiar teams. Much can be learnt in surgery by cross-fertilisation of ideas and techniques. These issues are important in the long run and it is hoped that further research by the authors and others will help elucidate the relative merits of the two approaches.

**References**


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