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Associations of workflow interruptions and patient care in the operating theatre

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Amelie Koch

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» Science and everyday life cannot and should not be separated. «

- Rosalind Franklin

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Abbreviations

BMI	Body-Mass-Index
FD	Flow Disruption (dt. AU; Arbeitsunterbrechungen)
ICU	Intensive Care Unit
NTS	Non-Technical Skills
MIS	Minimally Invasive Surgery
OR	Operating Room (dt. OP; Operationssaal)
RAS	Robotic-Assisted Surgery
SEIPS	Systems Engineering Initiative for Patient Safety

Zusammenfassung (deutsch)

Arbeitsunterbrechungen (AUs), wie Pager-Alarme, Geräteausfälle und Kommunikationsprobleme, sind alltäglicher Bestandteil chirurgischer Arbeit. Es hat sich gezeigt, dass Häufigkeiten von bis zu 20 Unterbrechungen pro Stunde im Operationssaal (OP) keine Seltenheit sind. Diese können über sämtliche chirurgische Disziplinen hinweg beobachtet werden. Aufgrund der fortschreitenden Technisierung der OPs (u.a. durch Einsatz von robotergestützter Technik) steigt auch das Risiko für Störungen durch defektes medizinisches Equipment an. Die Häufigkeiten, Ursachen und Arten von intraoperativen AUs wurden zuletzt vielfach untersucht und beschrieben. Eingeschränkt ist jedoch die vorliegende Evidenz zu den Auswirkungen dieser Störungen, insbesondere auf Basis eines soziotechnischen Verständnisses der Bedingungen chirurgischer Arbeit.

Die vorliegende, kumulative Dissertation hat folgende Teilfragestellungen: zunächst wird die Frage behandelt, welche Evidenz zu den Folgen von intraoperativen AUs auf Patienten, medizinisches Fachpersonal und chirurgische Arbeitsprozesse vorliegt (Systematischer Literaturreview). Nachfolgend wird eine empirische Erhebung vorgestellt, die anhand einer Stichprobe von roboterassistierten Eingriffen die Auswirkungen von AUs auf Patienten-Komplikationen und funktionelle Ergebnisse, das chirurgische Team und die OP-Dauer untersucht (Multi-Methoden Beobachtungsstudie). Zusätzlich wurden die Strategien des OP-Teams zur Vermeidung von AUs in Hochrisikoepisoden exploriert (Multi-Methoden Beobachtungs- und Interviewstudie). Operative Fertigkeiten des chirurgischen Personals bestimmen wesentlich die Patientenergebnisse: In einer weiteren Studie werden der Zusammenhang von AUs und technischer Leistung in einer simulierten OP-Umgebung untersucht (Simulationsstudie). Die technische Leistung des OP-Teams zeichnet sich zudem durch sogenannte nicht-technische Fähigkeiten aus (z.B. Teamarbeit). Die fünfte Publikation berichtet die Entwicklung und Validierung eines Beobachtungsinstruments zur Messung nicht-technischer Leistung von OP-Teams in roboterassistierter Chirurgie (Validierungsstudie).

Die durchgeführten empirischen Studien zeigen, dass AUs nicht zwingend einen negativen Einfluss auf Arbeitsabläufe im OP, das chirurgische Team und den zu behandelnden Patienten haben. Kontextfaktoren und adaptive Fähigkeiten des OP-Teams zum Umgang mit AUs spielen eine wesentliche Rolle und sollten in den Fokus zukünftiger Forschung gerückt werden.

Abstract (English)

Intraoperative flow disruptions (FDs), such as pager alarms, equipment failures, and communication problems are inevitable in surgical work. It has been shown that frequencies of up to 20 disruptions per hour in the operating room (OR) are quite common. This phenomenon can be observed across all surgical disciplines. Due to ongoing technological advancements in the OR (e.g., the integration of robot-assisted surgical technology) the risk of severe disruptions caused by defective medical devices is substantially increasing. Multiple studies recently explored and reported the prevalence, sources, and nature of intraoperative FDs. However, the available evidence on the impact of these events is limited, particularly taking into account a socio-technical understanding of the conditions of surgical work.

This cumulative dissertation thesis has the following research objectives: first, it addresses the question of which evidence is available on the consequences of intraoperative FDs on patients, healthcare professionals, and surgical work processes (systematic literature review). Following is an empirical investigation focussing on the associations of FDs with patient complications and functional outcomes, surgical staff workload, and surgery duration in a sample of robot-assisted urological procedures (multi-method observational study). In addition, strategies of the surgical team to prevent FDs in high-risk episodes were explored (multi-method observational and interview study).

The technical performance of surgical staff significantly determines patient outcomes of surgical care. Therefore, in the following, the relationship between FDs and technical performance in a simulated OR environment is investigated (simulation study).

Technical performance of surgical teams is accompanied by non-technical skills (e.g., teamwork). The fifth and last publication describes the development and validation of an observational instrument for measuring non-technical performance of OR teams in robot-assisted surgery (validation study). The conducted empirical studies indicate that FDs do not necessarily have a negative impact on work processes in the OR, the surgical team, and the patient. Contextual factors and resilience skills of the OR team are key factors and should be the focus of future research.

1. Introduction

1.1 Operating Rooms as Socio-Technical Work Systems using the SEIPS Model

Adverse events in the operating room (OR) are still a major challenge to the ongoing efforts to enhance and safeguard patient safety [1]. Due to the high-risk setting, errors can lead to serious harm to the patient [2], such as wrong site surgeries, surgical site infections, or unstoppable bleeding. In addition, surgical personnel are likely to experience anxiety, guilt, and other negative feelings after an adverse event [3, 4]. Compared to other care environments, ORs pose the most significant risk for adverse safety events [5, 6]. A recent study reported that 63% of patients who died after surgery experienced an error in care (i.e. medication error, diagnosis failure, technique error) [7]. In addition to the immediate negative effects on patients, adverse events also cause tremendous costs for healthcare organisations [8]. At least since the highly cited *To Err is Human* report published in 2000 by the Institute of Medicine [9], there has been an intensified international focus on preventing harmful incidents in health care. Nevertheless, safety research is often retrospective and focused on clinical outcomes preventing a deeper understanding and determination of crucial process factors [10].

In the past, surgical failures have often been primarily attributed to the responsibility and individual skills of surgeons or other team members [11]. Today, we are aware that a large number of factors and circumstances determine the outcomes of surgical work [12, 13]. These contributing factors can be addressed by adopting a systems perspective. The complex OR working system includes not only surgeons and other surgical staff members (e.g. nurses) but also the organisation's (i.e., hospital) management, legislative preconditions, and technical characteristics that all determine the nature, conditions and outcomes of work in the OR [14]. Adopting this perspective, it can be assumed that conditions at different system levels (i.e., latent factors) can lead to risks arising and creating space for errors in patient care [15].

The well-established SEIPS model (Systems Engineering Initiative for Patient Safety) developed by Pascale Carayon and colleagues describes relevant system parts and determinants of clinical work from a human factors perspective [16]. The original model consists of three essential components: the 'work system', the 'process', and the 'outcomes' (see Figure 1).

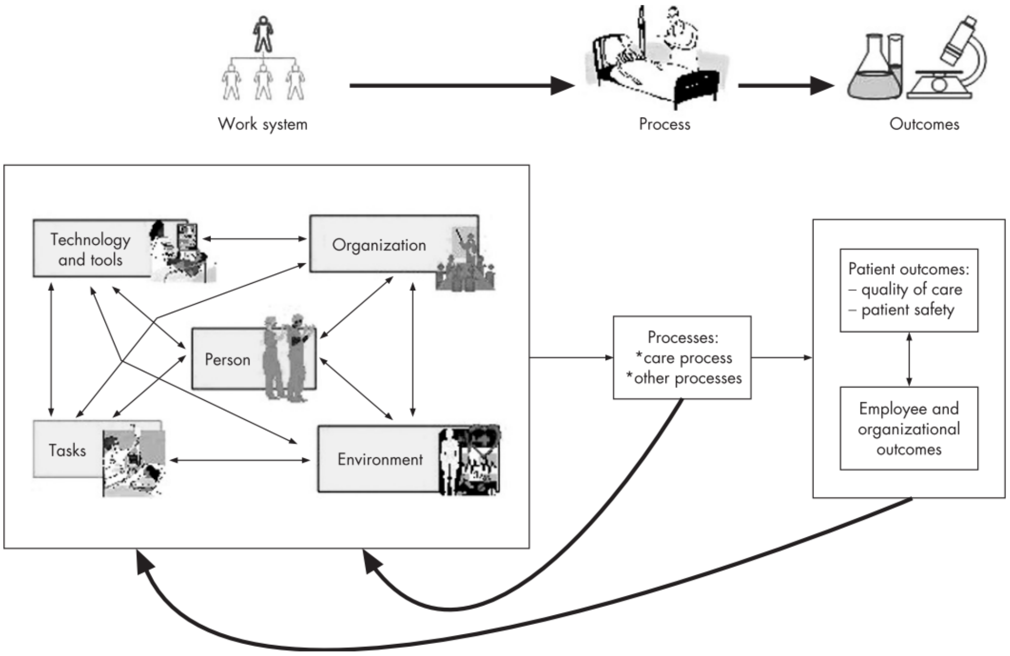

Figure 1. Original SEIPS Framework
(Source: Carayon et al., 2006)

The SEIPS framework highlights the interaction of multiple factors in the working system and emphasises that each component individually contributes to the working process and the outcomes. Applied to the working environment in the operating room, the model component 'person' represents the individual surgeons, nurses, anaesthetists, and other members of the OR team (e.g., technical assistants), 'tasks' describes the surgical task itself (e.g., liver transplantation, hip replacement), 'environment' stands for room design, noise, light, and temperature, 'organisation' involves management components and organisational working culture, and the component 'tools and technology' covers everything from a scalpel to highly technical robotic assistant systems. All these components have an impact on each other: e.g., a circulating nurse's work is restricted by the room design, supported by their colleagues, determined by the specific upcoming surgery, and accompanied by a range of different tools and medical equipment. Their work and behaviours, vice versa, affect all these parts of the surgical socio-technical working system. The different components and interactions together shape the 'process' (here: surgical care) and determine the outcomes of the process (e.g., patient complications, staff workload).

The SEIPS model was later upgraded by adding new concepts (e.g. adaption as a system's mechanism of evolvement) into the SEIPS 2.0 model [17]. The most up-to-date version, SEIPS 3.0 (Figure 2), extends the original model with more specific and timely components during the process, accounting for aspects of the whole patient journey and interaction with different parts of the health care system at different times of this journey [18].

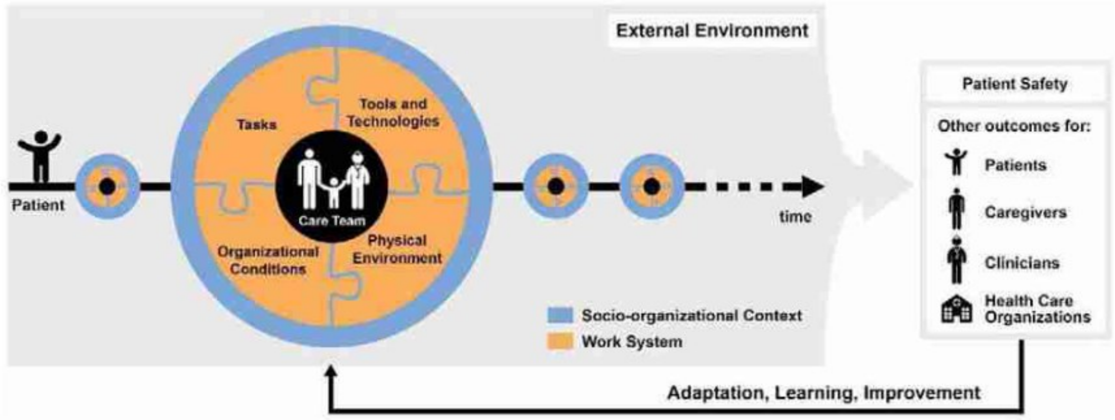

Figure 2. SEIPS 3.0 Model
(Source: Carayon et al, 2020)

The key implication and claim of the model are that investigations of patient safety incidents and other challenges in health care (e.g., stress of hospital staff) should always take the complexity of the interplay between the different involved stakeholders and contextual factors into account instead of searching for *the one to blame* [19]. This socio-technical perspective on the interaction of various work system factors represents the core principle of the research projects presented in this thesis.

1.2 Flow Disruptions in Surgical Work

1.2.1 Definition, Prevalence and Nature of Flow Disruptions

Building on the theory that quality and safety of surgical care depend on the functionality of a complex system with a variety of factors such as individual performance, teamwork, task demands, and systemic preconditions, this leads to the assumption that slight deviations in surgical workflow can throw the system out of balance and result in suboptimal patient care [20]. Therefore, intraoperative flow disruptions and the consequences for surgical work and patient safety have been in the focus in recent years [21].

Flow disruptions (FDs) have been defined as 'deviations from the natural progression of an operation' [22] or as 'any event that diverts attention away from the task in hand' [23] and are an integral part of everyday surgical practice [24]. Beeper calls, communication failures, defective equipment, door openings, teaching activities – a broad spectrum of FDs may occur daily across all surgical specialities [25]. These events occur in a work environment that is already demanding due to noise, time pressure, high demands on surgical skills, multidisciplinary teamwork, and responsibility for the lives of patients [26]. Technology plays a critical role in this context, as the work environment in the OR is increasingly dependent on (digital) tools and technical advancements. Although technology provides essential benefits in terms of safety, ergonomics, and efficiency in the OR, it may also be a source of FDs (i.e. surgical device failures) [27].

In the literature, the terms (surgical flow) 'disruption', 'interruption, and 'distraction' are, in some cases, used to describe the same and, in others, to describe different incidents. Because this work focuses on disruptive events and not on continuous background conditions (e.g., noise, music; often referred to as *distraction*), the term '(flow) disruption' is used in the following. In line with other studies, flow disruptions include events that require a break from the primary task in the OR (e.g., surgeon stops suturing to answer a question; referred to as *interruption*) and those that coincide without a break in task activity (e.g., small talk while suturing; referred to as *disruption*) [28, 29].

A range of studies described the occurrence of intraoperative FDs in various settings (e.g., general surgery, orthopaedic surgery, laparoscopic surgery), reported prevalence, and proposed categorisations. FD events are reported to occur very frequently and approximately every three to four minutes intraoperatively [30, 31]. The extent of FD occurrence is determined by several factors, such as the presence of trainees, external policies (e.g., on-call responsibilities), and the surgical procedure itself [24]. Reported prevalence also depends essentially on the FD definition applied: Jung et al. [20] found that the OR door (only one type of event) opened every two minutes on average, Zheng et al. [32] reported 1.9 events per minute through including conversations that did not require breaks in task activity, Sevdalis et al. [33] found one event every 10 minutes with a focus on communication events.

The nature (i.e., specifications) of FD events have also been described in several different ways. The following list shows a selection of proposed options for characterising intraoperative FDs:

- **Source**: The cause or source of a disruptive event has often been used to classify and sort these incidents. The number of different classification systems is almost as high as the number of studies proposing these classifications. However, some similar categories of FD sources can be found across multiple studies: Equipment-related (e.g., failure of technical devices), teamwork- and communication-related (e.g., small talk, communication failures), teaching/training-related (e.g., demonstrating surgical techniques), external (e.g., door openings, phone calls), and environmental (e.g., OR layout) [34–40].

  Although these taxonomies might be a practical option for observational purposes as well as to establish some order to many different incidents, the term *source* in this context is only half the truth: the actual *root cause* (i.e., system conditions leading to the event) is not accounted for with these rather superficial descriptions [22].
- **Severity**: In addition to the classification of FDs' sources, many studies determine the degree of severity (i.e., the extent of the disruptive event). For example, Bouquet et al. [41] emphasise that besides the *frequency*, also the duration of FD events is critical. Others determine how many team members are affected by the event [1, 29, 42] or if a break in task activity is required [35, 43]. Findings from other settings (e.g., medication administration) indicate that also the timing of an FD event determines the severity of its impact [44].
- **Preventability**: Preventable FDs have been described as disruptions caused by controllable variables [45]. A study in a robotic-assisted surgery setting showed that about 14% of disruptions were preventable (e.g. small-talk) and did not fulfil any necessary function [46]. This might be especially relevant for designing purposeful interventions.

The data diversity on the prevalence and nature of FDs in the literature highlights the importance of considering the context in which FDs are studied [47]. It is also an indicator of the complexity of the phenomenon in real-world surgical care with various demands and dynamic requirements [44].

1.2.2 Impact of Flow Disruptions on Surgical Work and Patients

Recently, it has been assumed that the majority of FD events, individually, have little impact on surgical work (minor events) [48]. Nevertheless, it is expected that an accumulation of minor events and harmful environmental factors might actually cause adverse events in the OR [49, 50]. From a human factors perspective, FDs have been described as events that create an error space, increase the vulnerability of the OR work system, and therefore open the door for adverse events [36, 41]. One FD event does not necessarily result in a negative outcome, but the probability of an adverse event might be increased [51].

The empirical evidence on these assumptions is limited so far. However, it has been shown that even minor, frequent FDs lead to longer operating times, which eventually result in prolonged anaesthesia for the patient, an extended working day for the OR team, and shifts in the surgery scheduling plan for the hospital, potentially leading to higher costs [52, 53]. Furthermore, a study by Bouquet et al. [54] found that 8% of total surgery time was spent to resolve FDs, and similar findings are reported by Henaux et al. [55], with almost 10% of surgical time devoted to disruptions. Therefore, a negative impact on the efficiency of OR management, hospital economy, and thus on health care costs can be conceived [56].

A range of studies addressed the impact of FDs on health care professionals working in the OR. Psychological models suggest that task disruptions lead to increased working memory demands, reduced attention capacity, and, consequently, to higher workload and stress [57, 58]. To illustrate: a nurse assisting in a critical situation during cardiac surgery (primary task) needs to be entirely concentrated and might have problems answering an outside telephone call (FD event) simultaneously without losing cognitive capacity for the primary task.

The surgical work environment is already complex and challenging, requires a high level of psychomotor skills (e.g., suturing techniques, instrument handling), and the ability to focus, concentrate, and make quick decisions [23, 59]. In addition, these working conditions are complicated by frequent external stressors such as long working hours and high time pressures [60]. Several studies have explored the impact of FDs as an additional stressor in this already demanding working environment: Weigl et al. [61] found that disruptions led to higher levels of workload in general and orthopaedic surgery; Silver et al. [62] asked clinicians about their perceived impact of FDs and staff burnout was one of the main consequences named.

Besides negative implications for healthcare professionals themselves, it has been concluded that an increased workload and higher cognitive demands would lead to decreased technical performance of OR staff members [63]. In simulation studies, it has been shown that task performance (e.g., task time, errors) decreased as a consequence of disruptions [64].

Concerning the implications of intraoperative FDs for patients, the current knowledge base is limited [58]. Patient outcomes are closely linked to technical surgical performance [50, 65]. As FDs might impair task performance, they have been proposed as a risk to patient's safety [44]. Few attempts to determine the implications of FDs for patient safety have been made: Blikkendaal et al. [66] found increased *potential* patient safety concerns in surgeries with high occurrences of FDs in minimally invasive surgery (MIS); Yoong et al. [42] reported that, although FDs were frequent with 26 events per case, complication rates of gynaecological surgeries have not been affected. However, primarily, the question of whether patient safety is affected by intraoperative FDs remains empirically unanswered [67].

One could think that the goal would be to avoid all intraoperative FDs to guarantee a workflow that is free of disturbances, as smooth as possible, with a maximum of safety and efficiency [68, 69]. In aviation, this is known as the *sterile-cockpit concept* [70]. The *sterile-cockpit rule* bans all unnecessary communication and other distractive activities during critical flight episodes from pilots in the cockpit [71]. Some attempts have been made to apply this concept of a totally disruption-free environment to the OR [56]. In surgical practice, however, many FDs fulfil elementary functions to external processes of the hospital system: beeper calls, for example, guarantee patient care outside of the OR, and FDs, due to shift changes, ensure safe working conditions for the clinical staff [26, 67]. Additionally, it is believed that certain FDs can even improve surgical work in the OR in terms of working as an *intervention* [72, 73]. Small talk, for example, may function as a resource to enhance social support, reduce fatigue or maintain concentration [74]. A study of Glarner et al [75] showed that FDs were used by attending surgeons as 'teachable' moments.

From a learning psychological perspective, attributable and potentially avoidable FDs offer the chance to learn from them and develop a capacity to avoid them next time [11]. As stated by Cohen et al. [22], FDs can be functional and dysfunctional – depending on their nature and the environment (i.e., surgical setting). Even a single event can be necessary (functional) for a safe healthcare process of one patient (e.g., a perioperative phone call from the ICU) and potentially harmful (dysfunctional) for another patient (i.e., the patient under surgery).

Another issue concerning FDs is that they do not happen independently [47, 76]. Sometimes a particular event triggers another, leading to a cascade effect of critical events [77]. This could be a defective medical device (first FD), requiring the circulating nurse to leave the OR and get a new one (second FD), leaving the sterile nurse alone, which might cause a conflict if, meanwhile, a task comes up that cannot be done sterilely (third FD). Such situations can also be exacerbated by factors such as ineffective communication or increased workload [1]. Beside *interdependent* FDs leading to a cascade of events that might result in critical and unsafe situations, multiple FDs can also *independently* occur at the same time (i.e., overlapping), such as a phone call during a teaching activity or a device failure while an unanticipated patient condition (e.g., respiratory problems). Both cases can potentially multiply the risk of a negative impact compared to one single event.

1.3 Framework: Systemic Perspective on Intraoperative Flow Disruptions

Flow disruptions interact with different aspects of all system levels, such as patients, surgical staff, and organisations [78]. Moreover, FDs interact with all system levels *over time* (i.e., during the course of a surgical procedure). Some have described FDs as indicators (i.e., symptoms) of underlying structural deficiencies in surgical system levels and workflow [22, 40]. Based on the SEIPS model and the current knowledge of the role of intraoperative FDs, a framework with an integrative view on FDs as a relevant factor to the work system OR is introduced in the following (see Figure 3). It features relevant system components and illustrates the contextual role of FDs. The different system levels of the framework and mutual interactions with FDs are explained in the following.

On the left-hand side of the model, five system levels of healthcare related to surgical work are introduced. Although not relevant at all levels for this thesis, *technology* interacts with all of these systems levels. The right-hand side illustrates the initial status (preconditions) of the respective system levels, how they peri-operatively interact with FDs, and how results (outcomes) might be influenced by FDs. In addition, it is indicated that the outcomes (rightmost) cause feedback (adaptation) to the preconditions (i.e., set the preconditions of following surgeries). Included variables (e.g., preconditions for each system level) serve as examples and represent further (unexplored) factors.

In the following, preconditions, FD interaction, and outcomes at the different system levels are described in more detail. Several factors that have been found or presumed to influence the occurrence or the consequences of intraoperative FDs are explained.

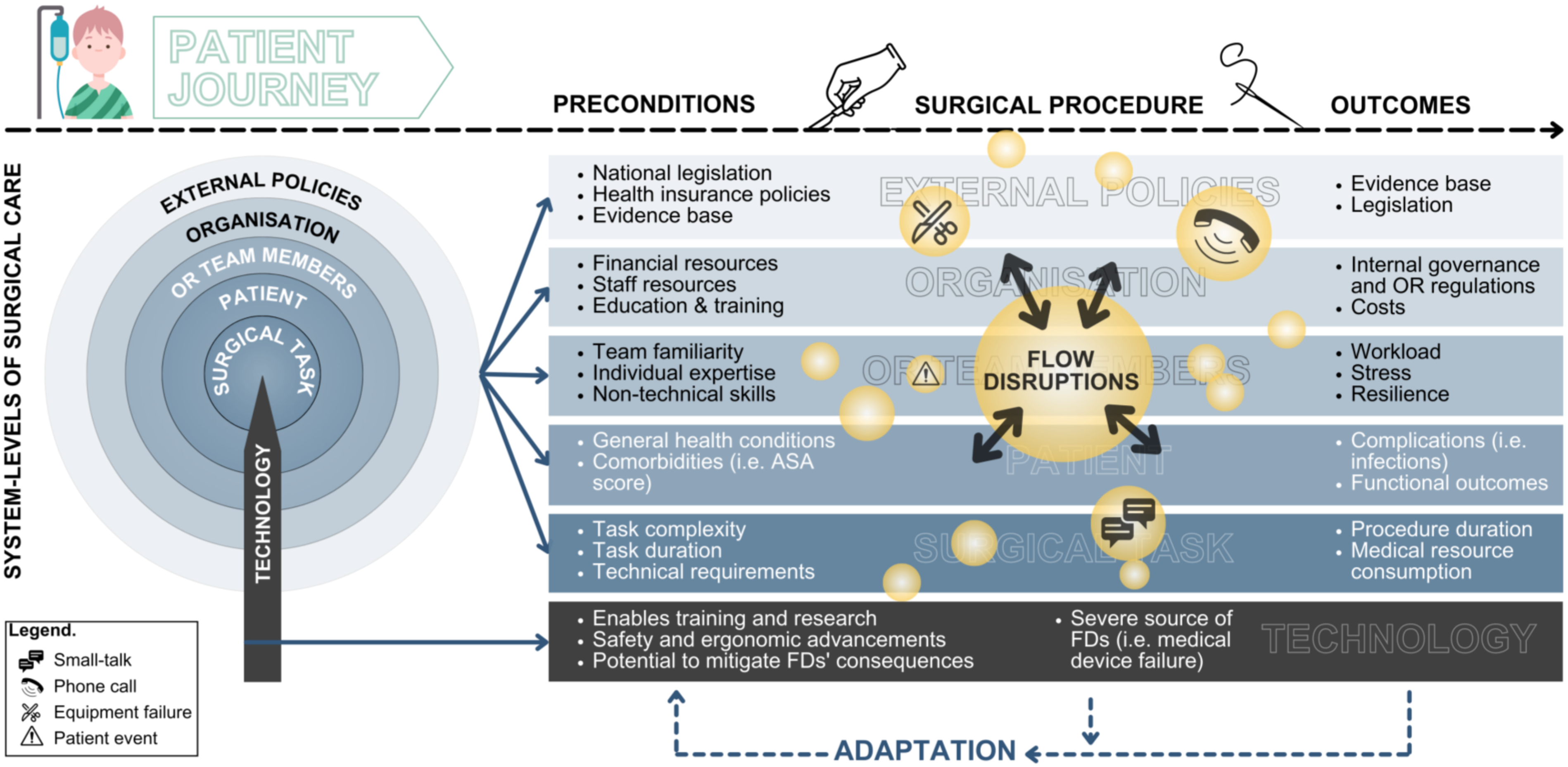

Figure 3. Systemic Perspective on Intraoperative Flow Disruptions in the Context of Surgical Work

[Source: Author's illustration, designed with Canva]

1.3.1 First and Second System Level: Patient and Surgical Task

The complexity of a surgical patient's case and the related surgical task is determined by patients' preconditions (e.g., BMI, health conditions) and the required surgical procedure (e.g., liver transplantation) [79]. Also, the task complexity changes in the course of a surgical procedure: some episodes are highly complex and pose higher risks to patients' safety, while others might be less challenging [80, 81]. It should be considered that the subjective complexity of the surgical task might differ for individual surgical team members at different points in time [82]. The impact of the same FD event might substantially vary when occurring in a complex task situation compared to a routinely carried out procedure or an everyday situation [83]. For example, small talk among surgeons about the past weekend can be motivating during final suturing but also dangerous when it is hectic, and things do not go as planned. It has been shown that the frequencies and nature of FDs also change between different surgical phases [40].

Patients' preconditions, such as a high body mass index (BMI) or chronic diseases (e.g., coronary heart diseases), might generate intraoperative FDs, such as the need for additional equipment or anaesthesia difficulties [77].

Outcomes on both system levels (patient & task) can include functional patient outcomes (e.g., short- and long-term physical rehabilitation), subjective patient outcomes (e.g., pain, quality of life), patient safety outcomes (e.g., infections, blood loss, morbidity, and mortality), and procedural outcomes (e.g., resource consumption, surgery duration) [19, 84–86].

1.3.2 Third System Level: Individual Performance and Teamwork of OR teams

OR professionals’ individual skills (e.g., acquired technical skills and knowledge) and team skills (e.g., effective communication and coordination, team culture) have been identified as crucial markers of surgical performance and excellence [87].

On the individual level of surgical team members (e.g., nurse, surgeon), acquired technical and social skills, years of gaining experiences, and current conditions such as fatigue or state of health (e.g., headaches) might be relevant determinants of how well FDs can be handled [55, 88]. It has been assumed that training and expertise can increase the cognitive capacity to manage unexpected events and FDs [57]. It has also been shown that surgeons with higher levels of expertise are less likely to be affected by FDs and other stressors compared to novice surgeons [25]. Also, the individual workload, decision-making competencies, situational awareness, and individual adaptive resilience can be relevant [88–90].

In the past, the focus of error analysis sought to identify the person suspected to be responsible for an error [11]. Today, however, the complex dynamics of an interactive team are also taken into account: OR teams are multidisciplinary and consist of surgeons, nurses, anaesthesiologists, technicians, and other specialists [59]. The quality of teamwork (i.e., non-technical skills) substantially determines the outcomes of surgical work [6, 91, 92]: in cases where teamwork was rated low, teams have been shown to commit more technical errors [93], and patients experienced more complications [94, 95]. The familiarity of teams has been identified as a relevant factor for building trust, understanding team roles [13], improving communication, and conducting fewer errors [48]. Deficits in communication and information transfer are associated with poor patient care [96]. Analogical to the individual level, better teamwork skills have been assumed to increase teams' ability to handle FDs [40]. Some FDs even require mutual support and a joint effort to be resolved [63]: for example, if a significant device malfunction occurs, one team member might be responsible for repairing/getting a new one while others take care of the patient and compensate for the broken device. Also, ineffective teamwork might itself cause FDs, such as communication failures, disagreements, and coordination/logistic issues [97]. As Cohen et al. [98] demonstrated, FD events affect individual team members differently. Therefore, team roles must be considered when assessing the impact of FDs.

1.3.3 Fourth and Fifth System Level: Organisation and Legislation

Inside the OR, factors and preconditions determined by hospital policies, national and international legislation, or ethical considerations can be described as structural and underlying facilitators and barriers to safe and efficient surgical care [84]. They might be less *present* than the previously described system levels and, therefore, harder to address in empirical studies. Although these system levels set the framework and the most basic requirements for surgical work, these conditions are more stable and less dynamic during surgery (i.e., they do not change short-term or substantially for different surgical phases) [67].

Several components of hospital management cause intraoperative FDs, such as general policies (e.g., decisions on duration of equipment reuse), planning and scheduling (e.g., availability of staff), communication channels (e.g., beeper, phone calls), resource planning (e.g., investments in staff training, new tools), and organisational culture (e.g., promoting teamwork and effective communication) [87]. On the outcome-side, FDs have been shown to increase surgery duration, leading to time inefficiencies and higher costs for hospitals [78]. Healthcare systems and legislators might perceive these effects in further consequence.

1.3.4 Technology: Chances and Risks of High-Technology Work Environments

Implementing (digital) technology into surgical work, such as monitoring devices, ultrasound equipment, or respirators, is intended to enable new treatment options, improve safety and efficiency [99]. However, technology integration impacts work conditions, requires the acquisition of skills and sets new challenges for individual staff members and teamwork [19, 100]. Especially, high-technology surgical robotic systems require a very substantial adoption to new requirements in the OR. A review of studies by Catchpole et al. [101] highlighted the additional demands for all team members in RAS (robotic-assisted surgery). The introduction of the da Vinci Surgical System (Intuitive Inc., Sunnyvale, CA), for example, substantially changed the conventional team set-up, traditional equipment arrangement, previous walking paths, and team communication modalities in the OR [102]. The principal surgeon changes his primary position from proximity to the patient to working remotely from a console without direct contact to the sterile field. New ways of team communication, interaction, and leadership needed to be invented, because non-verbal clues would not be recognised anymore. Besides these new challenges, the ergonomic advancements of RAS are enormous: surgeons don't lean over the patient's body anymore and stand for long hours but can instead sit quite comfortably [103]. It is, therefore, less physically demanding on posture [104].

Another downside of integrating new surgical technology in OR workflows is the increased reliance on these innovations. Technology- and equipment-related FDs (e.g., software failures, breakdowns) are quite common and often result in high-severity incidents [40, 105]. It has been estimated that in 87% of surgical cases, device- or equipment-related FDs occur [88]. Allers et al. found that disruptions due to technology in RAS settings increased compared to open or laparoscopic surgery [46], indicating that ongoing technical advancement exacerbate these challenges. Moreover, technical difficulties have been found to increase stress for surgical staff [106].

2. Thesis Objective

Based on the current evidence base on the effects of intraoperative disruption and the identified gaps in research, this cumulative thesis aims to address the following objectives:

1. To systematically explore the current literature base and outline the most critical shortcomings of OR flow disruption research.
2. To assess the impact of intraoperative FDs on patients, OR staff, and organisations (i.e., considering outcomes on multi-levels of the working system) in an up-to-date surgical work setting.
3. To explore the role of technology in the context of FDs in surgical work.
4. To consider as many parts and relevant factors of the complex socio-technical work system in the OR as possible to ensure a comprehensive view.
5. To identify implications for future research, surgical work and training, and healthcare organisations.

3. Publications

Table 1. Overview of Publications, Journal Rankings, Study Contributions, and Personal, Co-Author and Supervisor Contributions

No.	Journal & Ranking in Year of Publication: JIF[1] Percentile (Category)	Publication Type	Study Contribution	Personal Contribution	Co-Author Contribution	Supervisor Contribution	Citation
I	**'Associations of workflow disruptions in the operating room with surgical outcomes: a systematic review and narrative synthesis'**						
	BMJ Quality and Safety **93.12** (Category: Health Care Science & Services)	Systematic review	There had been no review or meta-analysis of the available findings concerning the impact of FDs on surgical work and patients. This study systematically synthesised and evaluated existing literature.	Study concept and design, Acquisition and interpretation of data, Statistical analysis, Manuscript writing	Statistical analysis, Manuscript review	Study concept and design, Acquisition and interpretation of data, Statistical analysis, Manuscript writing	Koch A, Burns J, Catchpole K, Weigl M. Associations of workflow disruptions in the operating room with surgical outcomes: a systematic review and narrative synthesis. BMJ Qual Saf. 2020;29:1033–45. doi:10.1136/bmjqs-2019-010639
II	**'Associations of flow disruptions with patient, staff, and process outcomes: a prospective observational study of robotic-assisted radical prostatectomies'**						
	Surgical Endoscopy and other interventional Techniques **72.07** (Category: Surgery; Year 2021[1])	Original study	The evidence base on the consequences of FDs for patients, care providers and procedural outcomes is limited. The study comprehensively addressed the relationship of FDs with surgical outcomes taking	Study concept and design, Acquisition and interpretation of data, Statistical analysis, Manuscript writing	Data acquisition, Manuscript review	Study concept and design, Acquisition and interpretation of data, Statistical analysis, Manuscript writing	Koch A, Quartucci C, Buchner A, Schlenker B, Becker A, Catchpole K, Weigl M. Associations of flow disruptions with patient, staff, and process outcomes: a prospective observational study of robotic-assisted radical prostatectomies. Surg Endosc. 2023 Sep;37(9):6964-6974. doi: 10.1007/s00464-023-10162-2

No.	Journal & Ranking in Year of Publication: JIF[1] Percentile (Category)	Publication Type	Study Contribution	Personal Contribution	Co-Author Contribution	Supervisor Contribution	Citation
			into account several system factors such as team familiarity.				
III	**'Operating room team strategies to reduce flow disruptions in high-risk task episodes: resilience in robot-assisted surgery'**						
	Ergonomics **45.63** (Category: Psychology; Year: 2021[1])	Original study	Surgical teams' approaches and practices to manage intraoperative FDs remain widely unexplored. Team strategies and behaviours to reduce FDs or the negative consequences of FDs, respectively, were investigated.	Study concept and design, Acquisition and interpretation of data, Statistical analysis, Manuscript writing	Data acquisition, Manuscript review	Study concept and design, Interpretation of data, Statistical analysis, Manuscript writing	Koch A, Schlenker B, Becker A, Weigl M. Operating room team strategies to reduce flow disruptions in high-risk task episodes: resilience in robot-assisted surgery. Ergonomics. 2022:1–14. doi:10.1080/00140139.2022.2136406
IV	**'Intraoperative dynamics of workflow disruptions and surgeons' technical performance failures: insights from a simulated operating room'**						
	Surgical Endoscopy and other interventional Techniques **72.07** (Category: Surgery; Year 2021[1])	Original study	Flow disruptions have been suspected to negatively affect surgical performance and therefore to compromise patient safety. This study indicates that surgeons in a disruptive environment do not necessarily commit *major* performance failures.	Study concept and design, Acquisition and interpretation of data, Statistical analysis, Manuscript writing	Data acquisition, Statistical analysis, Manuscript review	Study concept and design, Acquisition and interpretation of data, Statistical analysis, Manuscript writing	Koch A, Kullmann A, Stefan P, Weinmann T, Baumbach SF, Lazarovici M, Weigl M. Intraoperative dynamics of workflow disruptions and surgeons' technical performance failures: insights from a simulated operating room. Surg Endosc 2021. doi:10.1007/s00464-021-08797-0

No.	Journal & Ranking in Year of Publication: JIF[1] Percentile (Category)	Publication Type	Study Contribution	Personal Contribution	Co-Author Contribution	Supervisor Contribution	Citation
V	**'RAS-NOTECHS: validity and reliability of a tool for measuring non-technical skills in robotic-assisted surgery settings'**						
	Surgical Endoscopy and other interventional Techniques **72.07** (Category: Surgery; Year 2021[1])	Original study	Due to the substantially changed team setting in RAS procedures, there was a need for an adjusted tool to measure the quality of teamwork in RAS settings: The study addresses this gap by adopting the well-established NOTECHS tool with new RAS-specific behavioural markers.	Study concept and design, Manuscript review	Study concept and design, Acquisition and interpretation of data, Statistical analysis, Manuscript writing	Study concept and design, Acquisition and interpretation of data, Statistical analysis, Manuscript writing	Schreyer J, Koch A, Herlemann A, Becker A, Schlenker B, Catchpole K, Weigl M. RAS-NOTECHS: validity and reliability of a tool for measuring non-technical skills in robotic-assisted surgery settings. Surg Endosc 2021. doi:10.1007/s00464-021-08474-2.

Note. All papers are published and meet the criteria for inclusion in this cumulative thesis. JIF: Journal Impact Factor; FD: flow disruptions; RAS: robotic-assisted surgery; NOTECHS: non-technical skills; [1]latest available JIF.

4. Discussion

This thesis reports five studies with a broad range of methodological approaches. Four of these studies directly addressed the role of intraoperative flow disruptions and their relation to surgical outcomes. One study focused on a closely related research question (i.e., surgical teamwork in RAS). The consideration of human-technology interaction in surgical work systems, as an inherent part of modern ORs, has been a key objective of each study.

Overall, for the purpose of this work, 88 physical and eleven simulated patient cases have been directly observed, the technical performance of eleven surgeons has been measured, and 243 surgical staff self-reports have been included. Eleven experts (i.e., surgeons and nurses) have been interviewed, 59 original studies have been reviewed in-depth. Additionally, extensive pilot observations have been conducted, and several not reported/excluded patient cases and thousands of screened papers have been part of this work.

The five objectives of this thesis could be sufficiently addressed: The initially conducted *systematic review* (*Publication I*) on studies assessing the relationship of FDs with surgical outcomes comprehensively included relevant literature and outlined the current knowledge base (**Objective 1**). In two original investigations (*Publications II and IV*), the relationship of FDs with surgical outcomes was assessed (**Objective 2**). Three studies were conducted in RAS settings and addressed the role of modern tools and human-technology interaction in the OR. Moreover, the benefits and limitations of surgical simulations, as high-end options for surgical skills assessment and training, have been discussed as part of *Publication IV* (**Objective 3**). Adopting a systems perspective and including relevant system factors has been an objective of all publications. Different team roles and the relationship of FDs with outcomes on all system levels have been in focus (**Objective 4**). Specific implications for research and surgical practice have been outlined in each publication. Especially reported team strategies to prevent FDs provide clear and practice-oriented examples that surgical teams can apply (*Publication III*). Further elaborations on recommendations for future research directions and more general thoughts for effective improvement of OR working conditions and safety can be found in Chapter 4.3 (p. 33; **Objective 5**).

Based on the overall findings of this thesis, the role of intraoperative FDs can be described as one piece of a bigger puzzle: Figure 4 illustrates the role of FDs in the context of other protective and risk factors for negative and positive outcomes of surgical work. It demonstrates that even dysfunctional FDs do not necessarily lead to errors and adverse events if there are enough individual and team resources, such as effective communication and excellent technical skills on the left side of the bar. However, if enough stressors and unsafe conditions accumulate, then there is a chance for an error to occur, potentially harming the patient, and/or causing negative consequences for the surgical team [25]. Also, highly frequent minor disruptions might impair the ability of surgical staff to deal with complications or complex situations [107]. Important to notice is that this ratio of protective and risk factors does not only vary between different surgical settings (e.g., speciality, hospital, team composition) but also might change multiple times during a surgical procedure.

Figure 4. ‘Put Weight on the *Right* Side of the Bar’
[Source: Author’s Illustration, designed with Canva]

A second point that can be illustrated here is that future interventions to reduce the adverse effects of FDs should potentially address both sides of the bar [108]: For example, supporting the resource side with practical skills training or teamwork interventions might have the same positive effect as eliminating dysfunctional and preventable FDs or reducing other stressors. This aligns with the Safety-II perspective [109]: we cannot only learn not from errors but also from success [87].

4.1 Implications

4.1.1 For Future Research

Despite all efforts and advancements in surgical safety, too many adverse events and errors are still being made. A systematic review conducted by Anderson et al. [8] revealed that adverse events occurred in 14.4% of surgical patients and that in 5.2% of patients, these events were potentially preventable. For this reason, any determinant potentially contributing to unsafe care needs to be strictly assessed.

Prevalence of FD events has been described, but – as stated by Wiegmann et al. [47] – the aim of analysing FDs is not to describe them but to develop a comprehensive understanding of how they interact with other components of the surgical work system to eliminate the negative impact they might have. Unfortunately, there is still a lack of studies applying a comprehensive and holistic approach.

In essence, there are six points that should be taken into account for future studies on surgical FDs: First, the critical challenge of conducting research on the effects of FDs is to gather sufficient data (e.g., number of included surgical cases) to quantify effects given the large number of determinants that need to be taken into account. The required amount of data can hardly be obtained by manual and direct observations, which is today's standard procedure. Video and audio recordings would be the first step to a better database. Automatic detection and capturing systems for surgical FDs offer enormous potential for future research [20, 47].

Second, direct OR observations have been proven to be an excellent method to capture a wide range of FDs and describe basic specifications. Catchpole et al. [110] have outlined the high value of observational approaches to explore *work-as-done* in its complexity. However, direct observations in often busy clinical environments might not be accurate enough for exact time measurements (i.e., durations of FDs) and the differentiated assessment of complex situations [44]. Also, causality of FD-outcome relationships can hardly be addressed with observational study designs

[111]. Randomised-controlled trials with manipulations of FDs (i.e., intentionally causing FDs) would be needed to assess causal relationships systematically. However, laboratory studies pose the risk of underestimating real-world complexity and are therefore limited in terms of the transferability of the findings [110]. Ultimately, the best approach would be to combine multiple study designs and apply systematic RCTs as well as real-life OR observations of *work-as-done* to ensure highly reliable and valid findings.

Third, most studies are focused on the (potential) negative implications of FDs. But as described earlier, FDs may also fulfil essential functions and, therefore, can have a *positive* impact. For example, Schneider et al. [112] found that patients perceived patient-initiated FDs as beneficial to providers' efficiency. Since this study investigated FDs in an emergency department, more research is needed to explore the positive or essential aspects of FDs in the OR. Future studies should address the question who (or what) is harmed *while* who (or what) benefits from the same FD. Furthermore, as there has been a focus on the negative aspects of FDs, especially more investigations on the beneficial sides are needed.

Fourth, on the one hand, as has been described by Wiegmann et al. [107], surgical safety research needs to be interdisciplinary to enable a profound understanding of the complexity and generate approaches for interventions [113]. On the other hand, the perspectives from which FDs have been studied and applied methodologies are diverse, making it hard to draw a comprehensive picture out of these study bases [22, 72]. Finding an in-between balance, supporting interdisciplinary collaboration, and referring to already existing findings will be helpful to shape a common view on surgical FDs.

Fifth, a common mistake is to conduct research for research purposes only. Engaging practitioners (e.g., surgeons, nurses) in study design, prioritising research questions, and incorporating their real-life experiences can be essential to get meaningful results.

Sixth and finally, surgeries are conducted everywhere all over the world, and FDs occur all over the world. Also, as mentioned before, the organisational and surgical setting substantially determines the role of FDs. Nevertheless, there is a significant lack of studies exploring the role of FDs in low- and middle-income countries, where working conditions and cultural background may be even more demanding than in high-income countries. Therefore, the role of resources should be considered when developing guidelines and interventions to effectively manage FDs to improve surgical safety.

FDs are not a surgical phaenomenon and have not been assessed in surgical settings but also in other healthcare settings, such as medication administration and trauma care and completely different high-risk areas, such as aviation and driving. Consistently, FDs have been found to increase task time and error rates [44]. Although the setting where FDs occur is a crucial determinant of their nature, and findings from one setting cannot be transferred one to one, sometimes it might be helpful to look at these insights to gain new ideas and potential solutions for FDs in the OR.

4.1.2 For Surgical Practice and Education

The transfer and application of research findings to the real world should be a key objective for every researcher. Surgical flow disruption research can help develop guidelines, hospital policies, and training for medical teams to improve workplace conditions and patient safety. Based on the findings of this thesis, some practical recommendations can be made that may help prioritise interventions and effective FD handling strategies.

In general, preventable and dysfunctional FDs (i.e., no positive impact at all, such as a broken device) need to be minimised [46]. For non-preventable disruptions or FDs essential to other hospital processes (i.e. urgent beeper calls), adverse effects need to be prevented [114]. One option to address this challenge is to control the timing of FDs [115]. For example, in highly complex surgical episodes, beepers could be turned off or interim answered by someone outside the OR. Managing the timing of FDs has been identified as a key ability to prevent harmful effects [57, 63]. In addition, it has been shown that postponing FDs to opportune moments with low workloads can reduce delays and perceived disruption [116].

It is essential to state that OR team members are not *victims* of disruptive events but also a frequent cause of FDs (e.g., small talk, human errors) and do have the capability to take an active role in the management of FD frequency and timing – to some extent. This capability of actively tackling the adverse effects of frequent FDs has been called resilience [117]. In a broader focus, resilience has been defined as the ability of complex adaptive systems to safely and effectively handle unanticipated situations [108]. Imparting knowledge on the role and effects of FDs to surgical teams and fostering situational awareness could be a step toward less harmful effects of FDs. Surgical simulations, for example, offer great opportunities for safe and controlled training without any risks to patient safety (individual skills and team training) [118–120].

There was an interesting finding by Schraagen et al. [111]: they reported from a study in paediatric cardiac surgery that patient outcomes declined in cases with teamwork being rated high. Their explanation for this surprising finding was that in patient cases that were easy to handle, with smooth workflows, teams were not challenged to show high-quality communication and coordination skills; therefore, teamwork was rated lower in these cases. Conversely, in complex and stressful cases, more teamwork behaviours were used. Adaptive team mechanisms that step in when required may explain these results. The findings are also supported by a study by Wheelock et al. [1]: They found that more case-irrelevant communication (FD events) occurred in intraoperative episodes were workload was low. Both studies indicate that adaptive team mechanisms are in place, seem to work quite well, and might only need more encouragement and training. Preoperative briefings and guidelines, such as the WHO surgical safety checklist, are an excellent option to enable shared mental models and facilitate good team communication [121]. Also, team training targeting situational awareness, communication, and leaderships has been shown to be effective in improving communication behaviours and surgical performance [6].

Nevertheless, as mentioned before, some FDs cannot be addressed or managed within the surgical teams. Structured interventions to address the adverse effects associated with FDs on a broader base (i.e., system levels) are needed [122]. For example, effective OR scheduling can reduce disruptions due to coordinative issues. As it has been shown that most FDs occur as minor events with no significant impact, rigorous polices, such as the *sterile-cockpit-concept,* may only be applied to extremely high-risk settings or situations [70]. And finally, since FDs occur in various shapes across institutions, the context should always be considered when designing and applying interventions and guidelines [47].

4.2 Strengths and Contributions

The presented projects, studies, and publications in this thesis contribute to a deeper and more differentiated understanding of the role of flow disruption events in surgical work. Starting with a descriptive overview of prevalence and previously reported relations with surgical outcomes, subsequently, unaddressed relationships of FDs with outcomes on different work system levels have been assessed, and adaptive team strategies to handle FDs have been explored. All studies have considered the role of up-to-date technology.

Three major strengths of this thesis can be named: First, in line with a systems perspective, multiple factors and *players* on different system levels have been considered, such as task complexity, patient preconditions, teamwork, and dynamics over time. Theoretical assumptions have been based on the holistic view of the SEIPS Framework. Second, this thesis includes five publications with several different, yet complementary methodological approaches: a systematic review, direct OR observations, expert interviews, patient and staff-reported outcome measurements, objective performance measurements and clinical patient outcomes. This mixed-method approach, with the adoption of different views on FDs, allows for a deeper understanding. Third, the settings of the original studies (i.e., RAS and surgical simulation) are up-to-date and future-oriented, as it is expected that the degree of technology application and robotic system implementations in the OR will further evolve.

4.3 Limitations

Limitations of the study results have been named in the related publications. However, in the following, four more general and recurring limitations of this thesis and the conducted research will be described in more detail.

First, to start at the very beginning of a research project, during the phase of theoretical conceptualisation, background research, and development of initial ideas for study designs, there will always be a particular bias related to the scientific background and (cultural) context of the researchers. Coming from psychology, it is likely that from the beginning, an occupational psychological and human-factors perspective has driven the development of this thesis. This might have affected the design of research questions, methodological approaches, and choice of relevant concepts and variables to be included. In other words: a researcher with another theoretical background might have approached the overall research question of this thesis differently. Nevertheless, through a thorough consideration and inclusion of available research from other scientific areas (i.e., surgery, ergonomics), and close collaboration with researchers and practitioners with different backgrounds (e.g., urologists, orthopaedists, public health specialists, epidemiologists), efforts have been made to broaden the point of view of this thesis.

Second, the included samples of patients and surgical staff members are limited in diversity what eventually limits external validity of the findings. All in this thesis included data collections assessed samples in an academic urological department as well as surgical specialists for spine surgery. Unfortunately, the Covid-19 Pandemic hit during the data collection for the main study of this thesis (*Publications II and III*). Although the data collection could continue after a short break (i.e., *lockdown*), the planned inclusion of other hospitals and surgical specialities could not be realised. This led to substantial restrictions in terms of sample diversity and, therefore, limitations regarding the generalisability of the reported findings. Additionally, despite the efforts to include relevant system factors, the full complexity of surgical work might not have been totally accounted for.

Third, as an inherent problem of observational studies that have been the primary methodological approach of this thesis, causality (i.e., to distinguish between cause and effect) of assessed relationships can hardly be determined [123]. Conclusions cannot be drawn about whether FDs (partly) cause a specific outcome (e.g., high surgical workload) or reversely, high surgical workload cause FDs. Studies with systematic manipulation of FD occurrences would be needed to allow conclusions on causation. However, due to ethical considerations, such study designs cannot be conducted in real-world ORs. Laboratory studies could safely address this research objective but might not be able to replicate the complexity of real-world surgical settings [110]. Therefore, combining both seems to be the most effective way, and observational studies have been shown to be valuable in this context.

Fourth, a key challenge of studies including direct observations in the OR is to avoid observer effects that might influence the data collection process and quality and, therefore, the reported findings. Observer effects relate to the potential change in behaviour of observed individuals when they are aware of being observed, also known as the *Hawthorne Effect* [124]. This challenge was met by conducting extensive pilot observations in the OR to allow the surgical team to familiarise themselves with the observer's presence. Also, due to the university hospital environment and frequent perioperative visits of students and other physicians, the surgical team was already used to foreign persons in the OR.

Furthermore, there have been some non-anticipated obstacles during the development of this thesis: First, in the scope of the conducted systematic literature review, the aim was to add a meta-analysis of reported findings. Due to the heterogeneity of reported methods and results, this has not been possible. Second, a relatively high drop-out rate for patient participants in the observational study (*Publication II and III*) was faced due to frequent last-minute changes in the OR schedule. Third, as mentioned before, already organised observations in additional hospital sites had to be cancelled last minute due to the Covid-19 pandemic-related restrictions.

4.4 Conclusion

Ensuring high-quality patient care, a safe work environment for healthcare professionals, and cost-effective care interventions are all ultimate goals of healthcare evolution. Flow disruptions in surgical work are suspected to impair all three domains. However, understanding the complexity and various aspects of the nature and role of flow disruptions in the OR remains challenging. Still, more comprehensive studies with larger samples are needed to identify FDs needing prioritised attention. The next step will be to design, implement, and evaluate interventions to reduce preventable and dysfunctional FDs, and enhance systems resources to counteract unpreventable or FDs necessary for secondary processes. The second is especially relevant because 'to err is human' [9], and there will never be a perfect functioning, disruption-free OR working system.

Timeline Doctoral Thesis

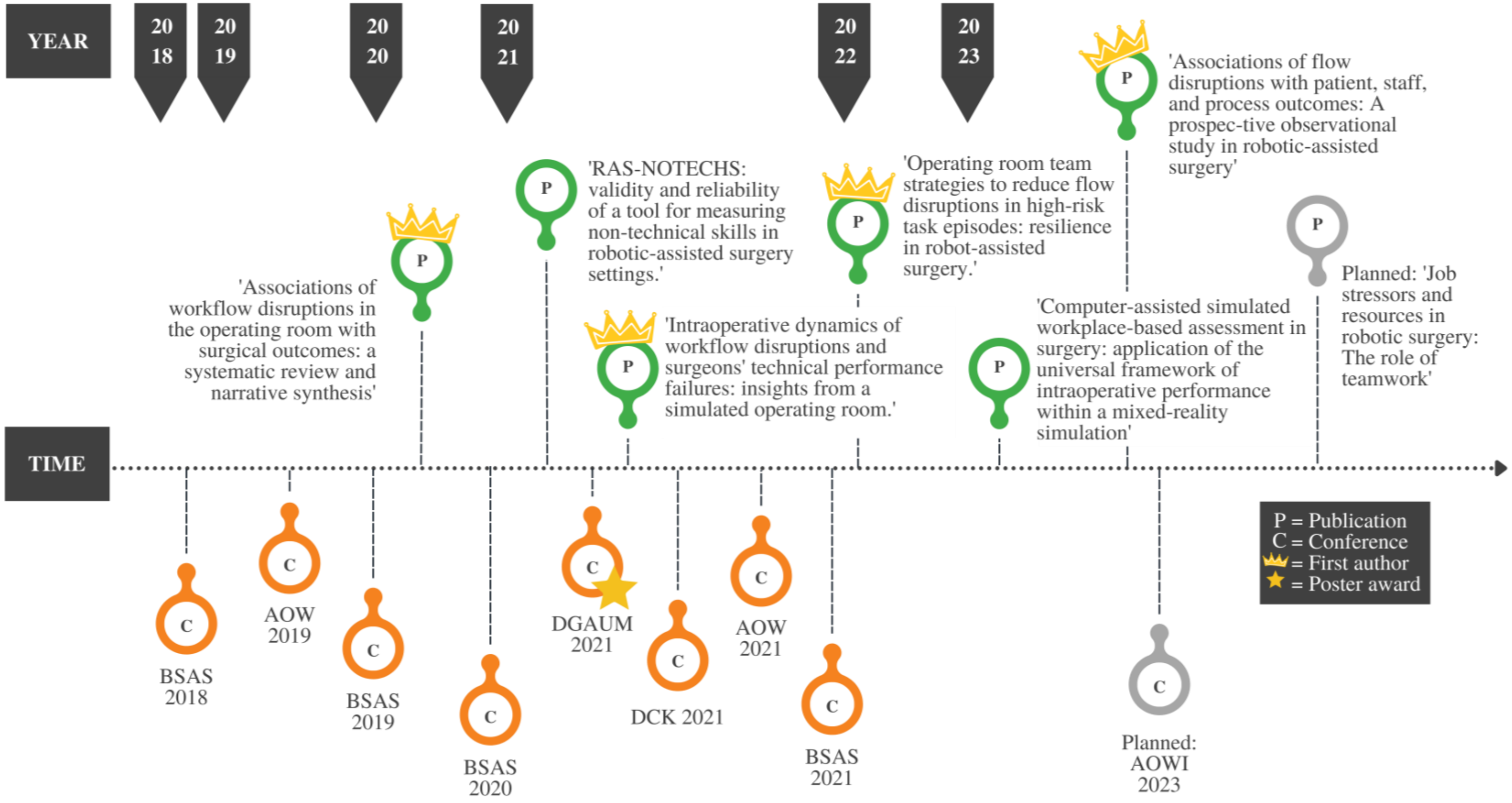

Figure 5. Timeline Doctoral Thesis: Publications and Conference Presentations

[Source: Author's Illustration, designed with Canva]

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List of Figures

Glossary

[Definitions refer to the context of surgical work]

Adverse event	Incident in health care with potentially negative consequences; in surgery: associated with harm for the patient.
DaVinci Surgical System	Robotic surgical system with a minimally invasive approach; the system includes a console and a patient cart with interactive robotic arms that are operated from the console. Besides a camera, several surgical instruments can be attached to the arms.
Disruption	Events that potentially cause a break in primary task execution and may require a momentary attention shift to a secondary task.
Distraction	Conditions or incidents, such as noise, with the potential to bind attention.
Error	Unintended, potentially harmful events in surgical care (i.e. wrong-site-surgery).
Interruption	see **'Disruption'**
Resilience	The ability to adaptively react to unanticipated situations or events; in surgery: effective management of unexpected incidents.
Safety-I perspective	Traditional approach of reducing errors through root cause analysis; focuses on identifying risks and eliminating adverse conditions.
Safety-II perspective	Instead of focusing on errors, the Safety-II perspective aims to understand why things go right. Learning from success and developing resilience is the key objective.

Situational awareness	Ability of an individual or surgical team to recognise and understand what is happening in their environment.
Socio-technical work system	Interaction of humans and technology in a specific work environment; emphasises the complex interplay of different system levels in surgical work (i.e., surgical teams, organisations).
Work-as-done	Approach of considering what actually happens at the front line of surgical work instead of relying on theories and beliefs that have been made 'far away' from practice.

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