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Complexity of the pediatric trauma care process: Implications for multi-level awareness

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Abstract

Trauma is the leading cause of disability and death in children and young adults in the US. While much is known about the medical aspects of inpatient pediatric trauma care, not much is known about the processes and roles involved in in-hospital care. Using human factors engineering (HFE) methods, we combine interview, archival document and trauma registry data to describe how intra-hospital care transitions affect process and team complexity. Specifically, we identify the 53 roles directly involved in patient care in each hospital unit and describe the 3324 total transitions between hospital units and the 69 unique pathways, from arrival to discharge, experienced by pediatric trauma patients. We continue the argument to shift from eliminating complexity to coping with it and propose supporting three levels of awareness to enhance the resilience and adaptation necessary for patient safety in health care, i.e. safety in complex systems. We discuss three levels of awareness (individual, team and organizational) and describe challenges and potential sociotechnical solutions for each. For example, one challenge to individual awareness is high time pressure. A potential solution is clinical decision support of information perception, integration and decision making. A challenge to team awareness is inadequate “non-technical” skills, e.g., leadership, communication, role clarity; simulation or another form of training could improve these. The complex, distributed nature of this process is a challenge to organizational awareness; a potential solution is to develop awareness of the process and the roles and interdependencies within it, by using process modeling or simulation.

Keywords

Complexity; Awareness; Sociotechnical systems; Patient safety; Pediatric trauma care; Fluid teams

1. Introduction

In the United States (US), trauma is the leading cause of disability and death in children and young adults (Centers for Disease Control and Prevention 2015; Stewart et al. 2003). About 9 million emergency room visits and 250,000 hospital admissions resulted from injury to children under the age of 15 (Segui-Gomez et al. 2003), causing a total economic impact estimated at $70 billion annually (Centers for Disease Control and Prevention 2010). Research in pediatric trauma has primarily focused on care rendered prior to arrival to a pediatric trauma center; such as care provided by emergency medical services (EMS) (Ebben et al. 2013), coordination between EMS and the emergency department (ED) receiving the patient (Bergrath et al. 2013; Moulton et al. 2010; Van Veen and Moll 2009), and teamwork during trauma resuscitation (Sarcevic et al. 2012). Prior to arrival to a pediatric trauma center, levels of patient acuity are characterized in a systematic manner and are widely utilized in trauma triage (Bevan et al. 2009; Muhm et al. 2013; Williams et al. 2011). Level 1 trauma patients are typically the most acute, severely injured, while level 2 patients are also critically injured but typically more stable. Several studies have demonstrated the value and impact of treating pediatric trauma patients in dedicated pediatric trauma centers (Beaudin et al. 2012; Chatoorgoon et al. 2010; Cowley and Durge 2014; Potoka et al. 2001; Potoka et al. 2000; Stroud et al. 2013).

After arrival at the pediatric trauma center, the injured child is typically cared for in the ED where clinicians must stabilize the patient, determine the extent of the injury and develop an initial treatment plan. Quick and accurate decisions regarding ED disposition and future care are critical to avoid adverse events and diagnosis error as well as using resources efficiently (Barata et al. 2007; Fitzgerald et al. 2006; Furnival et al. 1996). Treatment of the patient beyond the ED can include hospital care in a variety of physical locations, or units, such as the operating room (OR), pediatric intensive care unit (PICU), medical units and/or surgical units (Shook et al. 2016). During the transitions between units, transitions also occur between multiple clinical teams (e.g., pediatric emergency medicine, trauma surgery, anesthesiology, critical care, hospitalist team). Thus, pediatric trauma care relies on coordination and communication interactions, which constitute team cognition (Cooke et al. 2013), during transitions between multiple clinical teams. Care transitions, which include the transfer of information, authority and responsibility for a patient (Abraham et al. 2014), can have a positive or negative impact on the patient’s care, depending on how they are designed and implemented (Carayon et al. 2013). When well designed and implemented, care transitions can be an opportunity for resilience, with errors caught, decisions revisited and care reviewed by the receiving clinicians (Cooper et al. 1982; Perry 2004; Wears et al. 2003). On the other hand, care transitions can lead to information loss, inaccurate information flow and ambiguity in authority and responsibility for patient care when poorly designed and implemented (Arora et al. 2009; Solet et al. 2005).

While research has increased our understanding of what the appropriate medical care of a trauma patient should be during hospitalization (Farach et al. 2015), best practices for transporting patients (Wallen et al. 1995) and long-term psychological impacts of pediatric trauma (Aitken et al. 2005; Moore et al. 2015), it has not increased our understanding of the entire process of caring for pediatric trauma patients, i.e., the patient journey in the hospital. The patient journey is “the spatio-temporal distribution of patients’ interactions with multiple care settings over time” (Carayon and Wooldridge In press). The patient journey, used in a broader sense, can be used to examine patient safety longitudinally, including the patient’s perspective of patient safety as *they* experience in *their* lives, *across* care settings (Vincent and Amalberti 2016). Recently, Mathews and colleagues (2018) studied a small part of the journey of hospitalized patients, the decision to admit patients to the intensive care unit (ICU) from the ED, finding that longer ED boarding times, related to delays in the admission decision, are associated with higher patient mortality. In this study, we move beyond a single portion of the inpatient patient journey to understand the whole hospitalization process, from ED arrival through discharge, since we know little about who participates in the pediatric trauma care process outside of the ED (Raley et al.) and how care team membership changes throughout the process. As argued by Walker and Carayon (2009), shifting focus from singular tasks to process-level analysis will facilitate the improvement of care processes and, therefore, patient outcomes (Eason et al. 2012; Wooldridge et al. 2017). Systems engineering, particularly human factors and ergonomics (HFE), provides the tradition of process analysis and system design to address complex sociotechnical issues of health care (Kaplan et al. 2013; Reid et al. 2005), such as those found in hospital-based pediatric trauma care.

1.1 System Complexity

The behavior of sociotechnical systems (i.e. both the social and technical subsystems that interact in organizations and environments) is heavily dependent on interactions within and between system components (Carayon 2006; Hettinger et al. 2015; Wilson 2000; Wilson 2014). Therefore, in recent years, the HFE community has reached a general consensus that sociotechnical systems fall into the class of complex, adaptive systems. Complex adaptive systems are characterized as dynamic, emergent, sensitive to change and unpredictable as they respond and adapt to both internal and external changes, actions and perturbations (Carayon et al. 2015a; Miller and Page 2007; Plsek and Greenhalgh 2001). In particular, sociotechnical systems in health care are complex (Carayon 2006), as caring for patients inherently cannot be fully predicted (Effken 2002) and involves a high degree of uncertainty and ambiguity (Gurses et al. 2008; Perry and Wears 2012), and boundaries between systems are somewhat indistinct (Plsek and Greenhalgh 2001). While early approaches to system complexity were to eliminate complexity (e.g., rigidly defining a single correct approach in Scientific Management), modern approaches are to cope with complexity by supporting human adaptation and resilience in the design of the systems, organization and tools provided (Flach 2012). This requires describing complexity to identify potential solutions for sociotechnical system design.

1.2 Study Objective

Our goal is to understand how care transitions of pediatric trauma patients affect process and team complexity, as indicated by the number of roles providing care in different physical locations. Further, we describe the temporal pathways of pediatric trauma patients, i.e., the sequence of units in which the patient receives care, which is the patient's journey while they are in the hospital. We then considered our results in light of the three levels of individual, team and organizational awareness (Schultz et al. 2007).

2. Methods

This study was conducted in the context of a large study on designing health information technology (IT) to improve teamwork and care transitions in pediatric trauma care (http://cqpi.wisc.edu/teamwork-and-care-transitions-in-pediatric-trauma/).

2.1 Setting and Sample

The participating hospital is an American College of Surgeons verified Level 1 pediatric and adult trauma center (Acosta et al. 2010; Notrica et al. 2011), with an 87-bed children's hospital, a 21-bed PICU and 8 pediatric operating rooms. The IRB at the University of Wisconsin-Madison approved this study.

We used purposeful sampling to identify clinicians who are experts about the pediatric trauma care process, i.e., attending physicians on involved services and the pediatric trauma program manager. We contacted potential participants via email with a description of the project; participation was voluntary. Our sample included the pediatric trauma program manager (a pediatric nurse practitioner by training) and six physicians from four services: emergency medicine (two), pediatric critical care (two), pediatric anesthesiology (one) and pediatric trauma surgery (one). We monitored saturation during data collection to justify our sample size – no new units were mentioned as involved in pediatric trauma care after the first interview and no changes were made to the role matrix after the fifth interview.

We included all of the leveled, accidental (i.e., not resulting from abuse) pediatric trauma patients treated between January 1, 2013 and December 13, 2017 in the sample of patients for our pediatric trauma registry data analysis. In other words, the sample was the population of patients within that timeframe; the pediatric trauma program manager was not confident in the reliability and validity of the data in the registry prior to that date so we did not include earlier patients.

2.2 Interviews about the Pediatric Trauma Process

We conducted semi-structured interviews to understand the pediatric trauma process on each participant's service. The interviews were recorded and transcribed. Each participant was asked, "Can you please briefly describe the admission process of a pediatric trauma patient on your service?" and, "Who are the key teams and people involved in admission of pediatric trauma patients? What are their roles?" Follow-up questions and probes were used to clarify interviewee responses and gather additional details.

2.3 Documentation about the Pediatric Trauma Care

We collected various documents on the pediatric trauma care process: American College of Surgeons' reverification documentation (used for the Level 1 trauma center certification) and the trauma pager list used by this hospital to notify the members of the trauma team of the anticipated arrival of a pediatric trauma patient.

2.4 Pediatric Trauma Registry Data

We extracted data from the pediatric trauma registry, which is required for trauma center accreditation and contains data such as discharge time and disposition from each unit (Nwomeh et al. 2006). The pediatric trauma registry data extraction included each unit a patient departed from and the unit they went to for every pediatric trauma patient treated at the participating hospital between January 1, 2013 and December 31, 2017.

2.5 Data Analysis

An HFE researcher reviewed all interview transcripts and recorded the units/services involved in the patient care process to develop an initial flowchart showing the temporal sequences of units caring for pediatric trauma patients. The researcher also recorded the care team roles directly participating in patient care in each unit as identified by the interviewee; this was used to develop a role matrix. The researcher added to the role matrix by reviewing the reverification documentation and trauma pager list, noting the roles the documents specify should be involved in patient care in the ED and other units.

Clinical members of the research team reviewed the flowchart and role matrix to provide individual feedback directly to the research team. Their feedback was combined, and the researcher most knowledgeable about the process related to that area resolved conflicting responses (i.e. the pediatric emergency medicine physician clarified discrepancies in the emergency department; the pediatric critical care attending resolved differences in the PICU, etc.). From the role matrix, we computed the number of locations where each role was directly involved in patient care, as well as the number of roles involved in each location. Roles, not individuals, were identified in this analysis; when care spans multiple shifts, shift changes increase the number of individuals involved in care.

The trauma registry data were inspected to verify data quality. Due to the efforts of a dedicated team of trauma registrars at the participating site, overseen by the pediatric trauma program manager, the pediatric trauma registry is well maintained and contains high quality data. The registrars follow strict data dictionary definitions, demonstrate competence with these definitions in monthly assessments and participate in annual in-person training. In addition, reliability is demonstrated through inter-rater reliability testing by another fully trained registrar for at minimum 5%, and up to 15%, of pediatric trauma cases per year. In the extracted data set, there were no missing or incomplete data fields. Further, the timestamps between discharge from one unit to admission to the subsequent unit were compared; of the 1901 total transitions identified, 2 (0.1%) had data entry errors in the timestamps of discharge/admission where an adjacent number key was entered rather than the correct value (e.g., 3 rather than 2). These were corrected before further analysis.

The trauma registry data were analyzed in Excel© (Microsoft Office 2013) to calculate the number of transitions among units. These data were included in the flowchart to describe the frequency of each transition. Out of the 1487 pediatric trauma patients in 2013–2017, 188 patients were level 1 (the highest acuity), 1289 were level 2 and ten patients were upgraded from level 2 to level 1 (see table 2). No patients were downgraded from level 1 to level 2. Changes in level classification were made shortly after arrival to the ED; therefore, these ten patients were included in the analyses with the patients initially designated as level 1. The average injury severity score (ISS) (Baker et al. 1974) of level 1 patients was 25.3 (median: 25; range: 1–75); the average ISS of level 2 patients was 7.2 (median: 5; range: 0–75). The average age of level 1 patients was 10.5 years (median: 12 years; range: 42 days to 17 years); the average age of level 2 patients was 10.2 years (median: 12 years; range: 21 days to 17 years). The average length of stay (LOS) for level 1 patients was 8.8 days (median: 4 days, range: 1 to 102 days); the average LOS for level 2 patients was 1.9 days (median: 1 day, range: 1 to 46 days). Due to the skewed distribution of care transitions per patient, we conducted a Mann-Whitney U test to compare the number of transitions experienced by level 1 and level 2 patients using RStudio© (RStudio Team 2015).

Based on the arrival times to each unit, we identified the pathway of each patient, i.e. the sequence of units caring for that patient. This allowed us to count the number of transitions experienced by each patient and to report descriptive statistics. Further, using an inductive consensus-based process, four researchers reviewed these pathways and categorized them into groups of similar sequences. We identified 8 mutually exclusive pathway categories that are defined in table 1. Clinicians on the research team reviewed and validated these categories. We conducted a Chi-Squared test using RStudio© (RStudio Team 2015) to determine if the patient level and pathway category are independent.

3. Results

3.1 Pediatric Trauma Care Process

Four locations were identified as places pediatric trauma care was provided: (1) the ED, (2) OR, (3) PICU and (4) a pediatric medical/surgical unit (which was called the “floor” at the participating hospital and is so noted in figures). The OR included both pediatric and adult ORs, as well as interventional radiology (IR) and the post-anesthesia care unit (PACU). Intermediate care (IMC) is included in the PICU because the physical location of the patient is in the PICU; however, IMC represents a different staffing ratio and billing status at this facility. A neonatal intensive care unit (NICU) opened at this facility in the last year of data collection; only 1 patient received care in this unit so it was included in the PICU. There were 1487 patients included in this study; 198 (13%) were designated as trauma level 1, the highest acuity level, and the remainder were designated as level 2 (see table 2). The level 1 patients experienced 803 transitions, e.g., movement between physical locations, in the course of treatment from ED to discharge (mean per patient: 4.06 transitions; median per patient: 3 transitions; see table 2 for breakdown by year). The level 2 patients experienced 2521 transitions in the course of treatment from the ED to discharge (mean per patient: 1.96

transitions; median per patient: 2 transitions; see table 2 for breakdown by year). The Mann-Whitney test indicated that the number of transitions was greater for level 1 than level 2 pediatric trauma patients (U = 204990, $p < 0.001$).

Figure 1 shows the flowchart depicting the care process, including the number of roles associated with care after arrival to the ED and number of transitions for level 1 and 2 patients.

3.2 Pediatric Trauma Care Team Membership

We identified 53 roles directly involved in patient care in the pediatric trauma care process (see table 4 in Appendix A); most roles were clinical healthcare professionals (47 roles, 89%). These roles included physicians of various specialties (e.g., orthopedics, neurology, surgery, anesthesiology, critical care medicine, hospitalists and emergency medicine, radiology), physicians-in-training, pharmacists, advanced practice providers, nurses, technicians (on emergency medicine, surgery and radiology services). Other support roles were also identified: child life specialists, social workers, case managers and trauma program manager as well as chaplains and patient parents/family caregivers (6 roles, 11%).

The number of roles on the team varied by trauma level in the ED: for level 1 patients, 33 roles were on the team in the ED whereas there were only 18 roles for level 2 patients (see figure 1). For both levels, 23 roles were on the team in the OR, 32 in the PICU, and 22 in the medical/surgical unit (see figure 1). Given that 53 roles in total were identified, not every role was part of the care team in each location; team membership overlap varied by trauma level (see figure 2). For level 1 trauma care, 24 roles were on the care team in only 1 unit, 11 in 2 units, 10 in 3 units and only 8 roles in all units. For level 2 trauma care, 31 roles were on the care team in only 1 unit, 9 in 2 units, 7 in 3 units and only 6 roles in all units.

3.3 Patient Pathways

Using the pediatric trauma registry, we identified a total of 69 patient pathways, 41 of which were experienced by only one patient (see full listing of the pathways in Appendix B). The 198 level 1 trauma patients experienced 45 pathways, with 26 experienced by only one patient. The 1289 level 2 trauma patients experienced 36 pathways, with 17 experienced by only one patient. The two most common level 1 pathways accounted for 36% of level 1 patients, while the five most common accounted for 53%. The two most common level 2 pathways accounted for 81% of level 2 patients, while the five most common accounted for 95%.

Figure 3 shows the percentage of pediatric trauma patients in each of the 8 pathway categories that are described in table 1. The chi-square test of independence was calculated comparing the frequency of pathway categories for level 1 and 2 patients. A significant interaction was found ($\chi^2(7) = 481.46$, $p < 0.001$) indicating that there was a significant relationship between patient level and pathway categories. A higher proportion of level 1 patients were included in the pathway categories with more transitions, including those with OR loops and increases in level of care.

4. Discussion

4.1 Summary of Results

Pediatric trauma care is a complex process and involves many roles (53), several care transitions (average: 2.24, median: 2, range: 1–24) and variable patient pathways (69, 41 experienced by one patient); this study describes that complex process at one Level 1 pediatric trauma center. Pediatric trauma care is complex because it is distributed both spatially and temporally, as pediatric trauma patients are cared for in up to four different physical locations (ED, OR, PICU and the medical/surgical unit) during their hospitalization. On average, each patient experienced two care transitions (one on admission to a hospital unit from the ED, and one when they were discharged). However, higher acuity patients, i.e. level 1 patients, experienced significantly more care transitions than lower acuity patients, i.e. level 2 patients, with on average 4.06 (median: 3) versus 1.96 (median: 2) transitions occurring in the course of their care.

Caring for pediatric trauma patients requires many individuals from multiple medical specialties (e.g., pediatric emergency medicine, pediatric trauma surgery, pediatric anesthesiology, pediatric critical care, pediatric hospitalist) and professions (e.g., physician, nurse, social worker, case manager, chaplain) who may or may not be collocated. Fifty-three roles were identified as being directly involved in pediatric trauma care, with at most 33 roles involved in one unit (ED, level 1 patients). In addition, roles involved in caring for these patients, i.e. team members, change as transitions of care occur (Catchpole et al. 2014). For the purposes of our discussion, we are referring to the team as the care team members involved at *a specific point in time* during the hospitalization. The different care contexts require different capabilities, and are therefore staffed by healthcare professionals of different specialties; this variation in the skills needed at different stages of the team's work is one reason why fluid teams may be implemented (Bushe and Chu 2011). In this study, we described these team members and the locations they care for the patient, showing that the team is comprised of different roles during different stages of the hospitalization, as well as the dynamic nature of the team during care transitions.

Care team membership changed with each transition. Very few roles (8 [15%] for level 1 patients, 6 [11%] for level 2) were involved in all four hospital units, and nearly half were only involved in one unit (24 [45%] for level 1, 31 [58%] for level 2). Fluid team membership can have important implications for team performance (Bushe and Chu 2011; Stanton et al. 2006). Fluid teams can struggle to work together effectively, and may have to cope with the loss of individual knowledge and lack of shared mental models and cohesion as well as low individual commitment to group success (Bushe and Chu 2011). Additionally, fluid team membership means that team members can lack experience working together, which can negatively impact team cognition and team performance. Teams who have experience working together outperform teams that do not have experience working together, even in a novel task environment, i.e. doing work that they had not done before (Cooke et al. 2007). Further, care team members may not be collocated, instead working in different physical areas (i.e., spatially distributed). Therefore, not only is the care team a fluid team, it is a distributed team as well. Distributed teams are groups of people with interdependent tasks and shared goals, but who interact across boundaries of space, time and/or organization (Maznevski and Chudoba 2000). Communication and coordination are especially important in fluid and distributed teams, as members must often complete nonroutine tasks without the benefit of nonverbal cues associated with face-to-face interactions (Majchrzak et al. 2005; Maznevski and Chudoba 2000). In addition, communication patterns and flow in distributed teams differ from those in collocated teams. Distributed teams tend to have less consistent communication patterns, which can influence team cognition, and thus team performance (Cooke et al. 2005).

Our data on pathways show that the pediatric trauma care process varied greatly from patient to patient, with nearly 60% of identified pathways being unique to a single patient (41 of 69 identified pathways for a total of 1487 level 1 and 2 patients). The pathways varied in particular for the sickest, most complex trauma patients, i.e. level 1 patients (n = 198), with the five most common level 1 pathways only accounting for 53% of those patients. Twenty-six of level 1 patients (13%) had completely unique sequences, demonstrating the high variation of the pediatric trauma care process. This variability makes it more challenging for team members to anticipate subsequent care, which can cause delays or poor preparation for the next step. Nonroutine, complex care pathways can lead to flow disruptions (Catchpole et al. 2013) and increased operations tempo and cognitive and cooperative demands (Woods and Patterson 2001) in the care of urgent, higher acuity trauma patients, which can impact patient safety.

A major factor contributing to the complexity of pediatric trauma care is, of course, the critical nature of the patient, who has traumatic injury(ies), perhaps to multiple organ systems, and who needs care quickly in order to survive (Furnival et al. 1996). This, in turn, results in pediatric trauma care involving a large, fluid team, both a tempo-spatially distributed team and process, and a demanding and highly variable process. Since it is impossible to eliminate complexity, we must shift to designing work systems to cope with complexity. As argued earlier, supporting and enhancing awareness is one way to cope with complexity in sociotechnical systems (Effken 2002; Hettinger et al. 2015; Plsek and Greenhalgh 2001), and, therefore, in improving outcomes such as patient safety and quality of care (Schultz et al. 2007).

4.2 Awareness to Support Coordination in Complex Systems

System complexity influences the vulnerabilities, failures and errors in health care (Kohn et al. 1999). Patient safety, which can be impacted positively (i.e., through error identification and recovery from fresh perspectives) and negatively (i.e., through information loss) by care transitions (Carayon et al. 2013; Wears et al. 2003), is an important dimension of quality of care (Institute of Medicine Committee on Quality of Health Care in America 2001) and has been conceptualized as an emergent system property (Carayon et al. 2015a). Vincent and Amalberti (2016) describe three contrasting approaches to safety: ultra safe (avoiding risk), high reliability (managing risk) and ultra adaptive (embracing risk). Trauma care, which involves significant uncertainty, variability and risk, requires the ultra adaptive approach, which gives power to experts and relies on personal resilience and expertise (Vincent and Amalberti 2016). Similarly, Flach (2012) concludes that, in order to cope with complexity, we must "support the creative capacities of the humans so that they can invent solutions in real time to problems that could not have been anticipated in advance". As identified by Flach (2012), ways of accomplishing this could include self-organizing systems, mutual adjustments (a type of coordination), resilience and adaptation. In order for individuals to coordinate their activities, they must have a shared understanding of the process and how they fit in the process (Flach 2012). One way of accomplishing this shared understanding is to support and enhance awareness. As suggested by Schultz et al. (2007), awareness is the state of knowledge an individual has regarding the environment, the work system and the process. This conceptualization distinguishes three levels of awareness: individual (situation awareness as described by Endsley (1995)), team (similar to the concept of shared awareness discussed in, for instance, the computer-supported cooperative work literature (CSCW) (Randell et al. 2010)) and organizational awareness (described, for instance, in the high-reliability organizing literature (Weick and Sutcliffe 2001)). In the remainder of this section, we describe the challenges to the three levels of awareness suggested by Schultz et al. (2007; we then recommend possible solutions to address those challenges (see table 3).

Individual-level awareness is situation awareness (SA) as defined by Endsley (1995): each individual must be aware of what is happening in their environment (i.e. perception) and how it impacts both current and future system states, i.e. comprehension and projection/forecasting, respectively. Designing a work system, in particular tools and technologies, to support individual awareness is one approach to human-centered design (Endsley and Jones 2012). The primary goal of this approach is to avoid threats to SA. There are many threats to SA in the pediatric trauma care environment. For example, trauma care inherently includes working under high time pressure, which negatively impacts cognitive processing and can result in unsafe acts and increased errors (Committee on Quality of Health Care in America and Institute of Medicine 2000; Karsh et al. 2006; Reason 1990; Reason 2000). Pediatric trauma care is high stress. Additionally, there is a risk of attention tunneling, while addressing the most obvious, dangerous injury and forgetting a less-conspicuous one, particularly as the patient transitions from one unit to the next and team membership changes. Potential solutions to address the stressful nature of pediatric trauma include simulation-based training to familiarize clinicians and staff with high-stress situations and increase their comfort levels with subsequent situations. There are also potential applications of health IT to support SA: clinical decision support (CDS) can enhance clinical decision making in a high time pressure situation, particularly if data entry can be automated. Health IT could be designed to help prevent attention tunneling and errors by cuing clinicians of other injuries to consider. Well-designed, usable and useful health IT can also help manage data overload issues and support all three levels of individual SA (Endsley 1995), which can help individuals perform their work and coordinate with other care team members (i.e., actors in the sociotechnical system). Coordination is necessary to support resilience in light of uncertainty (Nyssen 2011), such as that found in the pediatric trauma care process we have described.

Team awareness has been defined as team SA, or the combination of the individual team members' SA and team processes such as communication, adaptability and leadership (Prince and Salas 2000; Salas et al. 1995). In the computer-supported cooperative work (CSCW) literature, awareness has focused on the collaborative team process, i.e. how team members convey their activities to and monitor the activities of others (Randell et al. 2010). CSCW research distinguishes two types of awareness: by-product awareness (effortless, developed as part of the work) and add-on awareness (requires extra activities to develop) (Simone and Bandini 2002). The interest in awareness in CSCW stems from the need to develop awareness in distributed teams, such as those we see in the pediatric trauma care process. The pediatric trauma care team is very large (total of 53 roles), which can inhibit communication and information flow. Additionally, the potential for unclear leadership and ambiguous roles or task assignments exists and can negatively impact team performance (Westli et al. 2010). Given the fluid and distributed nature of the pediatric trauma team – remember, only nearly half of involved roles are only involved in care in one unit – it may be hard for individuals to know who is on the team and for by-product awareness to occur, let alone for team members to engage in the processes required for add-on team awareness. Simulation-based training is a potential solution to develop communication and leadership skills (Salas and Cannon-Bowers 2001); this could be extended to include team members who are not collocated. Training is not, however, the only solution. Health IT designs that facilitate awareness, without requiring additional work by team members (by-product awareness), could also be solutions. For example, health IT could push information to distributed team members automatically and make information available when it is needed. This could support social awareness and temporal awareness as described in Randell et al. (2010).

Organizational awareness is understanding how the individual's role fits within the organizational structure and the up- and down-stream impacts of their actions (Schultz et al. 2007). This awareness is important because it includes understanding relationships with others who are not on the same team; in the case of fluid teams, this might include individuals who are not currently on the care team but may be later. This is particularly important when considering care transitions within the pediatric trauma care process. For example, when a patient is admitted to the PICU from the ED, the ED care team members must understand who they should communicate information to in the PICU; further, for this information to be useful, some understanding of the perspective of the PICU team is needed (e.g., what information they need). Mapping the transition processes identified in this study can help develop organizational awareness (Schultz et al. 2007; Wooldridge et al. 2017). Process mapping provides an opportunity to foster beneficial discussion among extended care team members and document who does what in the process and how those actions impact later steps in the process. Technology can also play a role in supporting organizational awareness. Health IT can be used to identify team members in specific roles as membership changes, using our results as a starting point, and therefore facilitate communication, such as the CORES handoff and rounding software solution (Van Eaton et al. 2004; Van Eaton et al. 2010). The CORES system is a computerized tool that downloads existing patient data from the medical record, facilitates entry of new data by residents and integrates communication tools within the user interface. It was developed by a group of residents based on their description of existing rounding and shift-change handoffs (Van Eaton et al. 2004), and was subsequently evaluated and found to improve resident efficiency without negatively impacting patient safety (Van Eaton et al. 2010). Health IT could also highlight what information needs to be communicated to cue individuals how to tailor their communication with others involved in care, similar to a checklist. Health IT can provide feedback and updates on what happened to the patient after a care transition, which could build understanding and anticipation of downstream consequences of actions. For example, providing ED clinicians feedback and updates after the patient has left the ED and has received care in other units may help them understand how their actions impact the care of the patient in the receiving unit and beyond, through patient discharge.

Our sociotechnical solutions to support awareness through the inpatient pediatric trauma care process target various stakeholders in the healthcare system, including individual clinicians, healthcare organizations (e.g., individual clinics or hospitals as well as healthcare systems) and health IT developers/vendors (see table 3). Individual clinicians should seek continuing education opportunities or training in (1) providing care in uncertain, high-pressure trauma situations to increase their comfort and familiarity during these cases and (2) non-technical skills such as (inter-professional) communication and multi-disciplinary teamwork. Ideally, they should complete hands-on training with those they will be working with to build implicit as well as explicit coordination mechanisms to support resilience in the process (Nyssen 2011) as well as increasing team familiarity, which may enhance team performance (Cooke et al. 2007). However, healthcare organizations must provide these training opportunities for clinicians to participate in those programs. In addition, healthcare organizations should work with individual, frontline clinicians to understand specific processes, such as the care transitions identified in this study, with the emphasis on describing activity (or work-as-done) rather than task (work-as-imagined) (Hollnagel et al. 2015; Leplat 1989). That process analysis and mapping will not only help develop organizational awareness, but can be used in inputs to support tasks, such as checklists to cue information exchange. Health IT, when developed using human-centered design processes, also presents significant opportunity to support all three levels of awareness, via clinical decision support (CDS), information synthesis and integration, enhanced information flow, etc. Health IT developers and vendors should work to develop these tools, and healthcare organizations should consider these when making purchasing and implementation decisions. It is important to note that we, as HFE researchers, can and should contribute to this work, in particular the work of designing technology to support processes and teams rather than just tasks and individuals (Walker and Carayon 2009).

4.3 Limitations

Our study has some limitations. The study took place in a single academic hospital in the Midwest. We did not include all stakeholders in our data collection, particularly nurses, patients or their family/caregivers. Future research must include these perspectives. For example, while we know most parents prefer to be present during resuscitation in the ED (Meeks 2009) and parental presence can improve medical care and communication (O'Connell et al. 2007), we know less about the role of parents throughout inpatient pediatric trauma care. Similar investigations should be conducted at institutions varying in size, geographic region, urban/rural environments, as well as teaching and non-teaching settings. A strength of our study is the use of multiple methods of data collection and analysis to gain a deep understanding of the process (Carayon et al. 2015b; Creswell et al. 2011; Hignett and Wilson 2004). We combined interview, documentation and registry data to develop a rich understanding of the complexity of the pediatric trauma care process. Future work should combine multiple methods of data collection and/or data analysis to conduct detailed studies of the care transitions identified in the results of this study, particularly those that are early in the process (i.e., under more time pressure and uncertainty) or those that occur more frequently.

5. Conclusion

Our study identifies 53 roles, 4 physical locations and 69 pathways of pediatric trauma care. An understanding of who participates in pediatric trauma care and how team membership changes as the trauma care process unfolds is a critical step in defining potential sociotechnical system interventions, such as health IT or simulation exercises. In our study hospital, pediatric trauma care was provided in up to four different units with up to 33 roles involved in a single unit and 53 total roles throughout the hospitalization of a pediatric trauma patient. The dynamic membership of this large team is important for care providers, designers and researchers to understand so they appreciate the team structure as well communication, coordination and cooperation challenges faced by the team. Understanding team complexity in pediatric trauma care, both in terms of team size and changing membership, is needed before offering recommendations on work system design, including health IT design. We suggest that these recommendations address ways to support individual, team and organizational awareness. Several challenges to maintaining awareness in the pediatric trauma process have been identified, and sociotechnical solutions were suggested. Potential solutions to support each level of awareness can be designed, implemented and evaluated.

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Appendix A: Role Matrix

Table 4

Role Matrix

	ED	OR	PICU	Medical/Surgical Unit
Pediatric EM attending	1,2			
EM resident	1,2			
Trauma attending	1	1,2	1,2	1,2
Trauma chief (Yr. 4–5)	1,2	1,2	1,2	1,2
Trauma resident (Yr. 2–3)	1,2	1,2	1,2	1,2
Trauma intern (Yr. 1)	1,2		1,2	
ED APP (PA or NP)	1,2			

	ED	OR	PICU	Medical/Surgical Unit
ED pediatric emergency nurse - bedside	1,2			
ED nurse – recording	1,2			
ED technicians (paramedics)	1,2			
Anesthesiology attending	1	1,2		
Pediatric anesthesiology attending	1	1,2	1,2	
Anesthesiology fellow	1	1,2		
Anesthesiology senior resident	1	1,2	1,2	
Anesthesia CRNA/C-AA	1	1,2		
Perfusionist			1,2	
Respiratory therapist	1,2		1,2	
Pharmacy	1		1,2	
Pediatric trauma surgery attending	1	1,2	1,2	1,2
Pediatric surgery resident (junior)		1,2	1,2	1,2
Pediatric surgery APP (NP)			1,2	1,2
Pediatric surgery scrub technician	1 (one nurse)	1,2	1,2 (one nurse)	
Pediatric surgery circulating nurse	1 (one nurse)	1,2	1,2 (one nurse))	
Pediatric surgery technicians		1,2		
Orthopedic surgery attending	Backup	1,2	1,2	1,2
Orthopedic surgery resident	1,2	1,2	1,2	1,2
Neurosurgery attending	Backup	1,2	1,2	1,2
Neurosurgery resident	1,2	1,2	1,2	1,2
Interventional radiology attending		1,2		
Interventional radiology resident		1,2		
Radiology attending		1,2		
Radiology technician	1,2	1,2	1,2	
PACU nurses		1,2		
PICU attending (intensivist)	1		1,2	
PICU fellow	1		1,2	
PICU resident	1		1,2	
PICU APP			1,2	
PICU nurse manager			1,2	
PICU bedside nurse	1	Cardio trauma only	1,2	
PICU nursing assistant/technician			1,2	
Hospitalist attending				1,2
Hospitalist fellow				1,2
Hospitalist resident				1,2
Hospitalist APP				1,2
Hospitalist nurse manager				1,2

	ED	OR	PICU	Medical/Surgical Unit
Hospitalist nurse				1,2
Child life specialist	1,2		1,2	1,2
Social worker	1,2		1,2	1,2
Case manager			1,2	1,2
Pediatric trauma manager	1		1,2	1,2
Chaplain	1		1,2	1,2
Parents	1,2		1,2	1,2

Note: These entries indicate trauma level (1 = level 1, 2 = level 2, backup = paged but not required to respond)

Appendix B: Patient Pathways

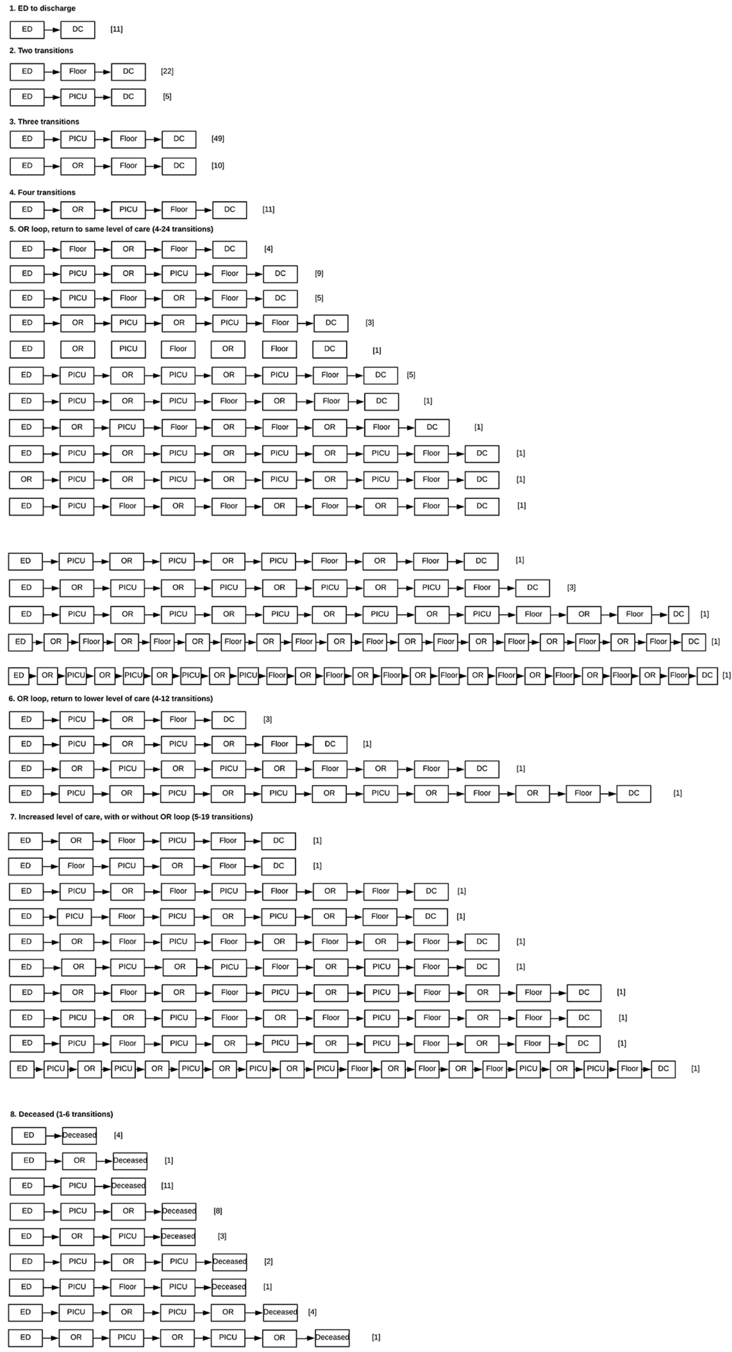

Fig 4.

Level 1 patient pathways

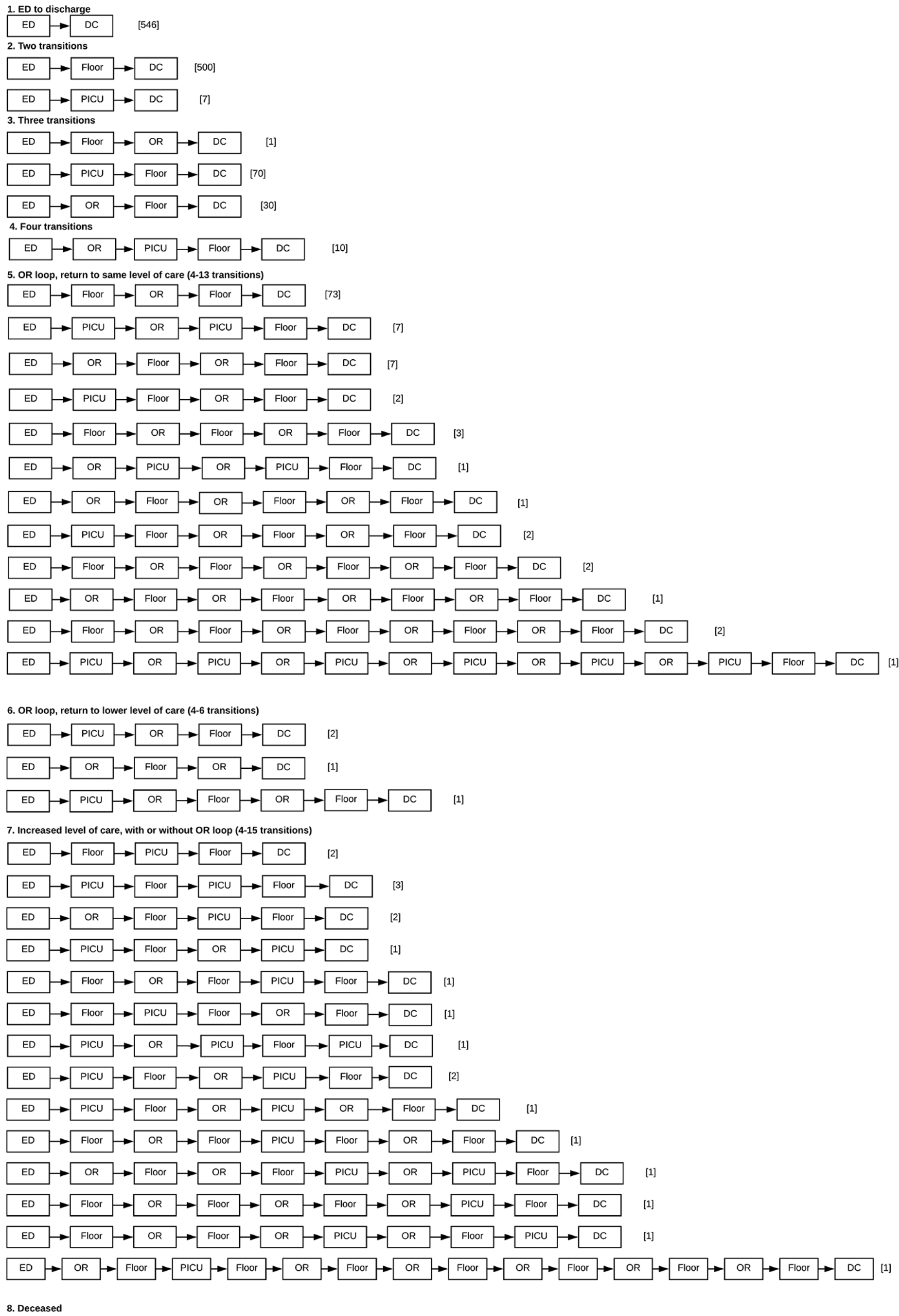

Fig 5.

Level 2 patient pathways

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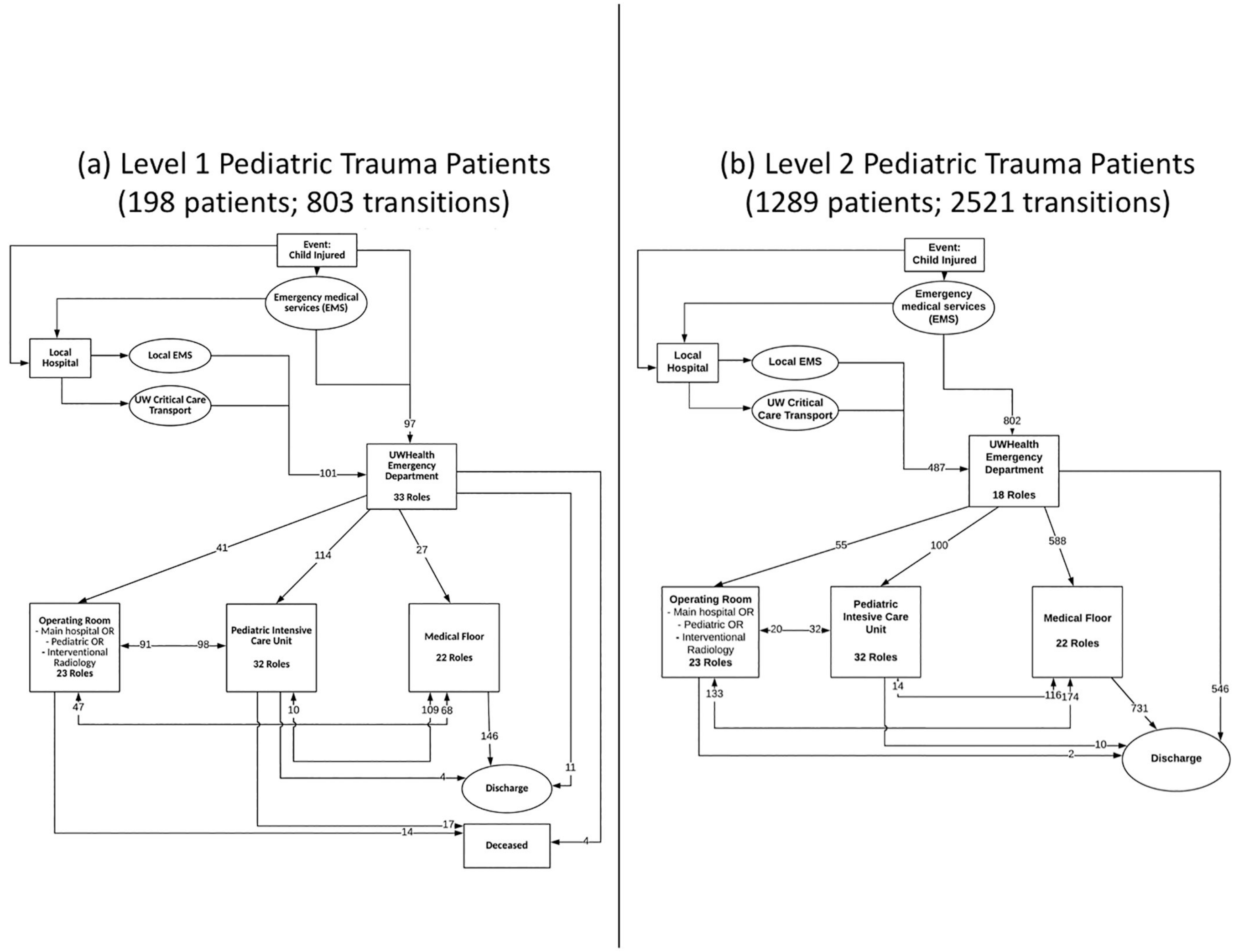


Fig 1.

Flowchart for level 1 and level 2 (1487 patients; 3324 transitions) patients

Note: All children transferred from outside facilities are supposed to go through the ED, but one level 1 patient went directly to the OR.

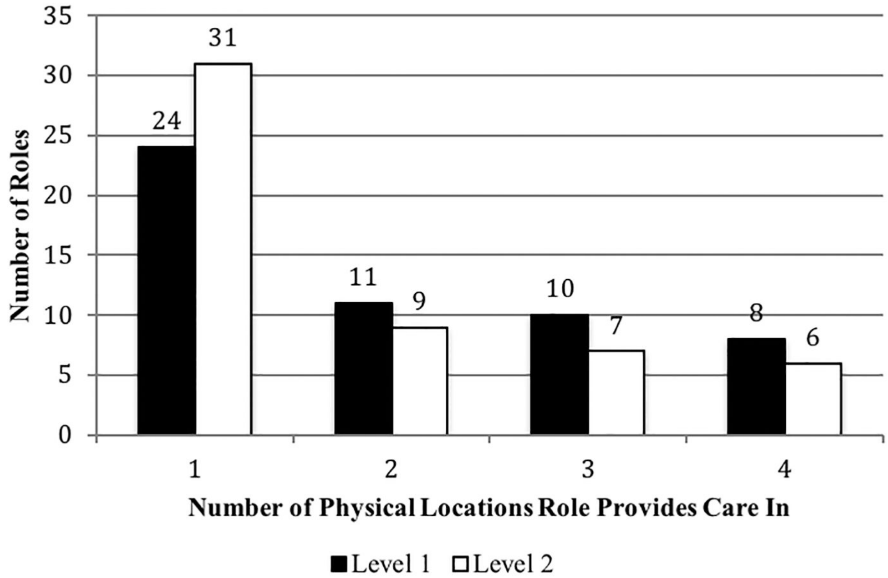


Fig 2.

Team membership overlap by trauma level

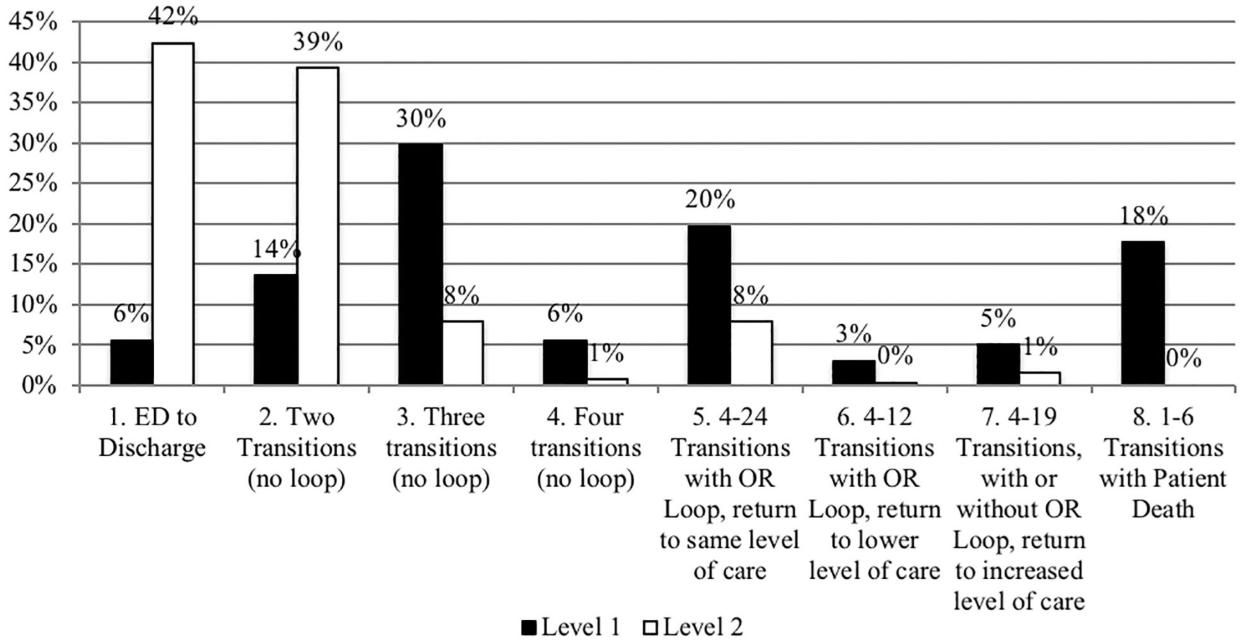
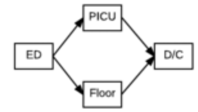
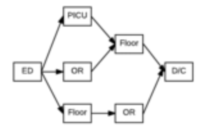


Fig 3.
Pathway group patient proportion, by level

Table 1

Patient pathway group definitions

	Pathway Group Name	Definition
1	ED to discharge	The patient is discharged directly from the emergency department.
2	Two transitions[a]	The patient experiences two transitions before being discharged from the hospital, from the ED to another unit[a], and then from that unit to discharge. 
3	Three transitions	The patient experiences three transitions before being discharged from the hospital, from the ED to a unit, from that unit to another, and then is discharged from the second unit. This could include going to the OR from the ED. 
4	Four transitions	The patient experiences four transitions before being discharged from the hospital: from the ED to the OR to the PICU to the floor and then are discharged. 
5	Four to twenty-four transitions with OR loop and return to same level of care	The patient experiences a range of transitions (4 to 24), at least 2 of which include going from one unit (e.g. PICU, floor) to the OR and back to that same unit. 
6	Four to twelve transitions, with OR loop, and return to lower level of care	The patient experiences a range of transitions (4 to 12, at least 2 of which including going from one unit (e.g. PICU, floor) to the OR and back to a lower care level unit (e.g. floor or discharge). ` 
7	Four to nineteen transitions, with or without OR loop, with increased level of care	The patient experiences a range of transitions (4 to 19, which includes at least one increase in level of care (e.g. medical/surgical unit to PICU, medical/surgical unit to IMC, IMC to PICU). This may or may not include going from one unit to the OR and back to another unit. 
8	One to six transitions with patient death	The patient expires.

[a] ED = emergency department, PICU = pediatric intensive care unit, Floor = a combined medical/surgical unit, OR = operating room, D/C = discharge

Table 2

Number of transitions by level and year

	Total Patients	Total Transitions	Transitions per Patient Avg. (median)	Min	Max
Level 1	198	803	4.06 (3) *	1	24
2013	48	182	3.79 (3)	1	13
2014	30	116	3.87 (3)	1	9
2015	46	167	3.63 (3)	1	11
2016	42	207	4.94 (3)	1	24
2017	32	131	4.09 (4)	1	9
Level 2	1289	2521	1.96 (2) *	1	15
2013	270	526	1.95 (2)	1	7
2014	257	477	1.86 (2)	1	9
2015	224	434	1.94 (2)	1	10
2016	289	565	1.96 (2)	1	13
2017	249	519	2.08 (2)	1	15
Total	1487	3324	2.24 (2)	1	24
2013	318	708	2.23 (2)	1	13
2014	287	593	2.07 (2)	1	9
2015	270	601	2.23 (2)	1	11
2016	331	772	2.33 (2)	1	24
2017	281	650	2.31 (2)	1	15

* indicates significant difference at $p<0.05$.

Table 3

Awareness in Pediatric Trauma Care: Challenges and Proposed Solutions

Levels of Awareness	Definition	Challenges within Pediatric Trauma Care	Potential Sociotechnical Solutions to Challenges [Healthcare Stakeholder Targeted]
Individual Awareness	What is happening in that environment (i.e. perception) and how it impacts both current and future system states (i.e. comprehension and projects, respectively) (Endsley 1995)	• High time pressure • Potential to forget/miss injuries across care transitions, resulting in forgotten/missed injuries • Stressful situation • Many care transitions	• CDS to support information perception, integration and decision making [health IT vendors, healthcare organization] • EHR cues to check for/remember other injuries [health IT vendors, healthcare organization] • EHR to support entry (possibly automated), access and management of large volume of information [health IT vendors, healthcare organization] • Training/simulation to increase familiarity/confidence with trauma care process [healthcare organization, individual clinicians]
Team Awareness	Collective, combined individual awareness and the team processes used to share/monitor status of team members' activities	• Large, distributed care team • Dynamic team membership • Inadequate role definition, leadership and communication skills	• Training/simulation to develop non-technical team skills [healthcare organization, individual clinicians] • Health IT that provides information to team members who need it, when they need it [health IT vendors, healthcare organization] • Automatically populating data (such as vital signs) in EHR for easy access by team members [health IT vendors, healthcare organization] • Checklists to support information flow between team members by explicitly cuing information elements to be shared [healthcare organization, individual clinicians]
Organizational Awareness	Understanding how the individual's role fits within the organizational structure and the up- and down- stream impacts of their actions	• Little overlap of team membership • Large number of roles • Complex, distributed process spanning organizational boundaries • Care transitions heighten importance of anticipating downstream consequences of actions	• Process mapping to develop awareness of process, role in the process and interdependencies within the process [healthcare organization, individual clinicians] • Information about team members, and changes in team membership, including how to communicate with them, easily accessible in EHR [health IT vendors, healthcare organization] • Providing longitudinal, dynamic view of pediatric trauma care process in EHR [health IT vendors, healthcare organization] • Providing feedback on process and downstream impact of completed care in EHR [healthcare organization, health IT vendors]