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Development and implementation of a digital quality assurance solution for anesthesia technology: Enhancing efficiency, proactive risk management, and real-time incident response

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Abstract---In anesthesia technology, rigorous checklists are essential to ensure patient safety by verifying equipment functionality, confirming the presence of necessary supplies, and identifying issues before they impact procedures. However, traditional paper-based checklists, which can contain up to 110 items, often lead to “checklist fatigue,” where repetitive, exhaustive checks can overwhelm technologists and lead to human error, missed steps, and delays in responding to equipment or system issues. Additionally, quality control logs for vital resources, including blood and medication fridges, are often fragmented, making it difficult for technologists to maintain a comprehensive view of equipment readiness. Inspired by high-reliability organizations (HROs) such as aviation, this study explores the development and implementation of a digital, interactive Quality Assurance (QA) solution aimed at transforming checklist management, risk assessment, and real-time equipment monitoring.

Keywords---anesthesia technology, digital quality, proactive risk management.

Background

In anesthesia technology, rigorous checklists are essential to ensure patient safety by verifying equipment functionality, confirming the presence of necessary supplies, and identifying issues before they impact procedures. However, traditional paper-based checklists, which can contain up to 110 items, often lead to “checklist fatigue,” where repetitive, exhaustive checks can overwhelm technologists and lead to human error, missed steps, and delays in responding to equipment or system issues. Additionally, quality control logs for vital resources,

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including blood and medication fridges, are often fragmented, making it difficult for technologists to maintain a comprehensive view of equipment readiness. Inspired by high-reliability organizations (HROs) such as aviation, this study explores the development and implementation of a digital, interactive Quality Assurance (QA) solution aimed at transforming checklist management, risk assessment, and real-time equipment monitoring.

Objective:

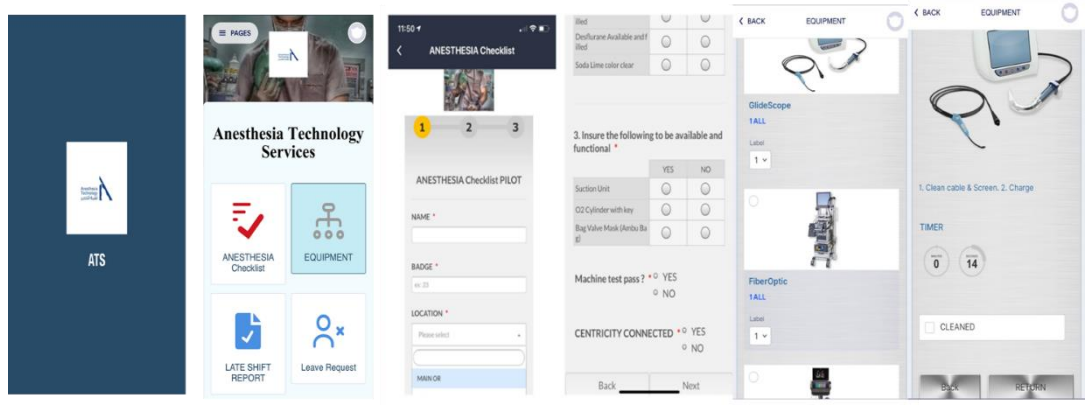
This study's objective is to evaluate a digital QA solution designed to enhance quality assurance in anesthesia technology. By digitizing checklists and integrating real-time reporting, the solution aims to reduce process times, optimize equipment tracking, improve reporting accuracy, and enable immediate intervention by Biomedical Engineering (biomed) and IT when issues are detected. Key design principles from HROs, including the "read-confirm" checklist format and real-time feedback loops, were incorporated to minimize cognitive load and improve operational flow during preoperative preparation.

Methods

A user-centered design (UCD) approach was employed, drawing on the success of HROs in using checklists to prevent human error and improve safety. This solution was developed with iterative user input, focusing on optimizing the flow and readability of checklists in a digital format, inspired by aviation and military settings (Blike & Biddle, 2000) . The checklist, embedded within an interactive interface, uses a "challenge-response" format to maintain engagement and prevent automaticity, where users may otherwise perform tasks with reduced attention (Thomassen et al., 2011) . Pre- and post-implementation data were analyzed to assess the solution's impact on process speed, incident response time, accuracy, and cost-effectiveness.

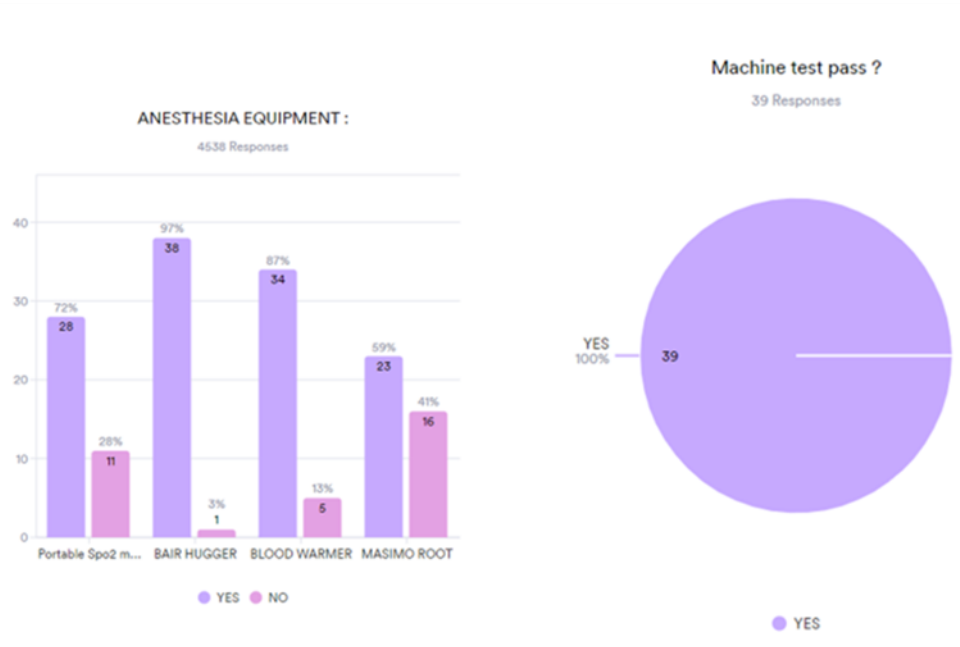
Solution Features and Capabilities:**1. Streamlined Digital Checklists**

The solution transforms a previously exhaustive checklist into a focused digital format, utilizing a "read-confirm" structure to guide technologists through essential steps only, reducing the cognitive load associated with traditional checklists. This format, shown effective in aviation and other high-stakes industries, is particularly beneficial in anesthesiology, where time-sensitive and accurate equipment preparation is crucial. The checklist interface integrates color-coded prompts for critical items, visually emphasizing priority tasks and allowing technologists to confirm each completed step.



2. Real-Time Reporting and Dashboard View

The solution consolidates data from multiple quality control logs into a centralized dashboard, providing technologists with a real-time “bird’s-eye view” of each room’s status, including essential metrics for blood fridge temperatures, medication storage conditions, and emergency supply levels. By centralizing this information, the solution enables instant data access and rapid decision-making, thus reducing the likelihood of delays due to missing or malfunctioning equipment.



3. Immediate Intervention Capabilities

The system's interactive reporting capabilities support immediate notifications to biomed or IT teams if equipment malfunctions or if there are connectivity issues affecting anesthesia charting. For instance, when a fault is detected in anesthesia machines, technicians can instantly notify biomed, reducing incident correction time and ensuring machine readiness. This functionality is crucial in emergency scenarios, where equipment or system failures can jeopardize patient safety.

4. Equipment Utilization and Tracking Insights

In addition to preoperative checklists, the solution provides equipment utilization statistics, tracking usage rates and helping to manage and allocate resources more efficiently. Equipment allocation tracking allows for rapid identification of available equipment in high-demand areas, reducing redundancy and ensuring that essential devices are available when needed.

5. Proactive Risk Management

The solution represents a shift from reactive monitoring to proactive risk management, allowing the healthcare team to identify and address potential issues before they escalate. This proactive approach draws from HRO principles that promote situational awareness and a commitment to resilience, helping technologists move from incident response to incident prevention.

Results

1. Significant Efficiency Gains:

The digital solution improved checklist process times by 85%, meaning that technologists could prepare rooms and equipment more quickly and accurately. These efficiency gains allow for faster room turnovers, freeing up resources and ensuring that operating rooms are prepared promptly without sacrificing thoroughness or safety.

2. Reduced Incident Response and Cost Savings:

With the digital checklist in place, the time required to correct incidents decreased by 25%, saving approximately 700 SAR per hour due to faster biomed and IT interventions. Additionally, proactive maintenance measures facilitated by real-time data helped reduce repair costs by 30%, amounting to an annual saving of approximately \$6,000. These savings reflect reduced labor costs and fewer disruptions to scheduled procedures.

3. Enhanced Accuracy and Data Availability:

Real-time reporting improved the accuracy of room status updates, ensuring that every technologist and anesthesiologist had up-to-date information on equipment and supply readiness. This improvement reduces the risk of procedure delays due

to missing items or equipment malfunctions. The solution's centralized dashboard facilitates this improved accuracy, making critical data accessible and actionable.

4. Improved Risk Prevention Through Proactive Monitoring:

Transitioning to a proactive risk management model significantly lowered the frequency of preventable incidents. The "challenge-response" checklist design mitigated checklist fatigue and helped ensure that critical items received focused attention. Proactive monitoring and alerts allow the team to respond before potential issues lead to incidents, increasing patient safety and procedural integrity.

Discussion

The digital QA solution's design draws heavily on the principles of high-reliability organizations, which emphasize simplicity, engagement, and proactive risk management in checklist design. Previous studies on the effectiveness of digital checklists in anesthesia support the use of "read-confirm" formats to avoid cognitive overload and automaticity (Blike & Biddle, 2000). This study further supports the argument made by Thomassen et al. (2011), who assert that shorter, user-friendly checklists yield higher compliance and promote a culture of safety.

The solution's integration of real-time data collection and interactive features aligns with the findings of Schild et al. (2019), who emphasize the importance of user-centered digital tools in high-stakes medical settings. Their study demonstrated that digital cognitive aids help manage intraoperative crises by reducing cognitive strain and ensuring seamless access to critical information. Additionally, this solution's equipment utilization and tracking capabilities promote efficient resource allocation, reducing redundancy and supporting operational flexibility across anesthesiology departments.

Aviation-inspired checklist design elements, including task indexing and visual prompts for priority items, allow the digital solution to align with the rigorous standards of HROs while remaining adaptable to the specific requirements of anesthesia technology. According to Degani and Wiener's "three Ps" model, effective checklist design should include a guiding philosophy, precise procedures, and consistent policies (Degani & Wiener, 1994). By aligning these principles with anesthesia-specific needs, the digital checklist facilitates a streamlined yet comprehensive QA process.

Conclusions

The digital QA solution represents a major advancement in anesthesia technology management by integrating high-reliability principles and modern digital functionalities to reduce process times, streamline incident response, and support proactive risk management. The system's capabilities in real-time data tracking, immediate intervention, and proactive monitoring provide robust safeguards against equipment and procedural errors, ultimately enhancing patient safety and operational resilience. This solution demonstrates that applying user-centered,

aviation-inspired checklist principles in anesthesia can significantly improve both operational efficiency and incident prevention.

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