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Technostress in a Multi-Platform Robotic Surgery Environment: A Phenomenological Study of Operating Room Nurses' Lived Experiences in China

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Abstract

To explore the lived experiences of technostress among operating room nurses working in a multi-platform robotic surgery environment in China. A descriptive phenomenological study was conducted in a tertiary hospital in Wuhan between March and June 2026. Eighteen operating room nurses with robotic surgery experience were recruited through purposive sampling. Data were collected through face-to-face semi-structured interviews and analysed using Colaizzi's phenomenological method with MAXQDA 24. Four themes and twelve sub-themes were identified: system integration and cognitive adaptation across multiple platforms; physical layout, hardware adaptation, and environmental compatibility; digital ecosystem evolution and professional boundary shifts; and professional role evolution and institutional support mechanisms. Participants described sustained cognitive and operational demands arising from platform switching, differences in hardware and interface design, repeated software updates, remote surgery requirements, and expanding technical responsibilities. These experiences reflected multiple dimensions of technostress, including techno-overload, techno-complexity, techno-uncertainty, techno-invasion, and techno-insecurity. Technostress in multi-platform robotic surgery is therefore shaped not only by technological complexity, but also by the continuous need to adapt across systems and by insufficient platform-specific organisational support. Targeted training and stronger technical and organisational support may help nurses adapt to increasingly complex robotic surgery environments.

Introduction

Robot-assisted surgery (RAS) has expanded rapidly over the past two decades, with procedure volumes increasing worldwide across specialties including urology, gynaecology, general surgery, cardiothoracic surgery, and head and neck oncology [1–3]. Early research focused heavily on demonstrating clinical benefits, such as reduced blood loss, fewer postoperative complications, and shorter hospital stays compared with open approaches [4]. However, the rapid spread of these technologies has also reconfigured the daily workflow of the operating theater.

Within this global trend, China has developed a highly distinct multi-platform landscape. In North America and Europe, hospitals typically rely on a single vendor, primarily the da Vinci system. In contrast, Chinese hospitals have adopted a multi-platform approach since 2021, driven by national policies favoring domestic medical devices[5]. Following regulatory approvals from the National Medical Products Administration (NMPA), domestically developed systems including the MicroHand S, Toumai MT1000, KangDuo SR1000, and Edge MP1000 have entered clinical use alongside the da Vinci system [5, 6]. Leading Chinese medical centers now routinely operate three or more different robotic platforms—such as Toumai, KangDuo, and da Vinci—across overlapping surgical specialties [6, 7]. This unique co-existence creates an incredibly complex perioperative environment.

OR nurses are central to the safety of these complex procedures. However, a multi-platform environment changes the technical demands placed on the nursing workforce. While the surgeon interacts with only

one ergonomic console, scrub and circulating nurses must master every system deployed in their hospital [8, 9].

In daily practice, OR nurses are legally and clinically responsible for a wide range of hardware tasks. They must handle divergent docking procedures, unique sterile draping protocols, and platform-specific emergency undocking maneuvers for each system in use [8, 10]. As the global robotic ecosystem diversifies and new platforms with distinct console architectures enter clinical practice alongside established ones, nurses must execute rapid cognitive switching between incompatible user interfaces, sometimes within a single workday [11, 12]. This continuous, high-stakes adaptation generates substantial cognitive load, making the multi-platform operating suite a primary source of technology-induced occupational strain.

This clinical and cognitive strain is best understood through the theoretical lens of "technostress." Originally defined by Brod as a psychological and physical disease of adaptation to new technologies [13], the term was later refined into five distinct dimensions by Tarafdar and colleagues [14]. These dimensions include techno-overload (working faster and longer), techno-complexity (feeling skill deficits), techno-uncertainty (constant upgrades), techno-insecurity (fear of obsolescence), and techno-invasion (blurred work–life boundaries).

In general nursing, high technostress is directly linked to poorer clinical performance, increased medication errors, and severe burnout [15, 16]. Given that robotic surgery demands absolute precision, understanding how these five dimensions manifest in the high-stakes environment of robotic theaters is vital for patient safety.

Although existing robotic nursing literature has examined intraoperative workloads and training deficiencies [17, 18], an empirical gap remains remains regarding technostress within multi-platform environments. The single published qualitative investigation in this domain was limited to a single-platform setting, identifying generalized technical anxiety as a primary stressor [19]. However, those findings cannot be directly transferred to the Chinese healthcare context, which is uniquely characterized by the concurrent deployment of architecturally varied domestic systems and intense multi-platform task-shifting. This study therefore aimed to explore the lived technostress experiences of OR nurses working in Chinese multi-platform robotic surgery environments.

Methods

Design

This study employed a descriptive phenomenological approach, with data analysis guided by Colaizzi's method [20]. This design was chosen to capture nurses’ lived experiences of working with multiple robotic platforms as directly as possible, without imposing pre-existing theoretical categories. As no validated quantitative instrument exists to assess technostress in this specific context, a phenomenological approach provided the most suitable framework for exploring the phenomenon. The

study followed the 32-item COREQ checklist to ensure comprehensive reporting of qualitative research [21]. The semi-structured interview guide was developed specifically for this study and is provided in full as Supplementary File 1.

Setting and Participants

Data were collected in the operating room departments of a tertiary hospitals in Wuhan China, from March to June 2026. The hospital operated three robotic surgical platforms concurrently—the da Vinci Xi system alongside two domestically developed systems, the KangDuo SR-01 and the Toumai MT1000—across multiple surgical specialties including urology, hepatobiliary surgery, otolaryngology, paediatric surgery, and gastrointestinal surgery.

Participants were recruited purposively, targeting registered operating room nurses who had at least one year of robotic surgery experience and hands-on exposure to at least two different robotic systems. Nurses who were trainees, students, or had less than 12 months of experience with robotic surgery were not included. All participants provided written informed consent. Sampling continued until no new themes emerged, which occurred after the 16th interview. Two additional interviews confirmed saturation, resulting in a final sample of 18 nurses.

Data Collection

Semi-structured, face-to-face interviews were conducted in a quiet meeting room within the operating room department. An interview guide was developed from literature on technostress and robotic nursing and refined by a panel of three perioperative nursing specialists and one qualitative methodologist. Two pilot interviews allowed minor adjustments before formal data collection.

The guide explored participants' experiences of working with multiple robotic platforms, changes in workload and routines, perceived technical and psychological pressures, and types of support considered helpful. Interviews lasted between 32 and 51 minutes (mean 41 minutes), were audio-recorded with consent, and transcribed verbatim within 24 hours. Transcripts were returned to participants for review, and any clarifications or corrections were incorporated.

Data Analysis

Transcripts were analysed using Colaizzi's approach [20], which involves identifying significant statements, formulating meanings, clustering themes, and deriving an overall description of the phenomenon. The resulting description was reviewed by participants to confirm its alignment with their experiences. Two researchers independently coded the transcripts in MAXQDA (version 24), discussing discrepancies until consensus was reached, with a third researcher consulted if needed.

Trustworthiness

Rigour was addressed through several strategies. Credibility was strengthened via member checking and close engagement with the study sites. Dependability was supported by dual coding and maintaining a detailed audit trail. Reflexivity was ensured through a research journal documenting decisions and assumptions throughout the study. Transferability was supported by providing thick descriptions of the institutional context, the robotic platform configuration, and detailed participant sociodemographic characteristics.

Reflexivity

The lead researcher, an operating room nurse experienced in multi-platform robotic surgery, facilitated rapport and contextual understanding during interviews. To limit potential bias, at least one team member involved in data analysis had no direct experience in robotic nursing.

Ethical Considerations

The study protocol was reviewed and approved by the Institutional Review Board of Tongji Hospital, Tongji Medical College, Huazhong University of Science and Technology (Approval No. TJ-IRB202609008). All study procedures were conducted in accordance with the ethical principles set out in the Declaration of Helsinki. To protect participants' identities, each participant was represented by a unique code (P01–P18), and no personally identifiable information was included in the transcripts or study reports. Audio recordings, interview transcripts, and related research materials were stored on password-protected devices and were accessible only to members of the research team.

Results

3.1 Participant Characteristics

Eighteen operating room nurses participated in the study. Their mean age was 31.1 years (SD 4.2; range 25–40), and two-thirds were women (n = 12, 66.7%). All participants held a bachelor's degree. They had worked as registered nurses for a mean of 9.0 years (SD 4.5) and in the operating room for 8.8 years (SD 4.1). Experience in robotic surgery nursing varied considerably, ranging from 0.5 to 12 years (mean 4.3 years). Participants differed in the extent of their exposure to robotic technologies. All had experience with the da Vinci system, while exposure to domestic robotic platforms varied across the sample. The number of platforms reported as being used proficiently ranged from one to seven. Half of the participants (n = 9, 50.0%) had worked with two or more robotic platforms during the same working day, and eight (44.4%) had participated in remote robotic surgery. Most participants (n = 15, 83.3%) had received dedicated training in robotic surgery. Further demographic and professional characteristics are presented in Table 1.

Table 1
Demographic and professional characteristics of participants (N = 18).

Variables	Descriptive statistics
Demographic characteristics	
Age, years, mean ± SD	31.1 ± 4.2
Female sex, n (%)	12 (66.7)
Bachelor's degree, n (%)	18 (100.0)
Professional characteristics	
Primary professional title, n (%)	11 (61.1)
Intermediate professional title, n (%)	7 (38.9)
Nursing experience, years, mean ± SD	9.0 ± 4.5
Operating room experience, years, mean ± SD	8.8 ± 4.1
Robotic surgery experience	
Robotic surgery nursing experience, years, median (IQR)	3.0 (2.0–6.3)
Robotic surgery cases per week, median (IQR)	5.0 (3.0–9.5)
Received dedicated robotic surgery training, n (%)	15 (83.3)
Worked with ≥ 2 robotic platforms on the same day, n (%)	9 (50.0)
Participated in remote robotic surgery, n (%)	8 (44.4)

Four core themes and twelve sub-themes characterising OR nurses' technostress experiences in multi-platform robotic surgery environments were identified through Colaizzi's analytical process (Table 2). As illustrated in Fig. 1, the themes map onto the five dimensions of the Tarafdar technostress framework: Theme 1 (System Integration and Cognitive Adaptation Across Multiple Platforms) corresponds primarily to techno-overload and techno-complexity; Theme 2 (Physical Layout, Hardware Adaptation, and Environment Compatibility) to the somatic dimension of techno-complexity; Theme 3 (Digital Ecosystem Evolution and Professional Boundary Shifts) to techno-uncertainty and techno-invasion; and Theme 4 (Professional Role Evolving and Institutional Support Mechanisms) to techno-insecurity arising from organisational buffering deficits.

Table 2
Themes, Sub-themes, and Coded Categories of OR Nurses' Technostress Experiences in a Multi-Platform Robotic Surgery Environment

Theme	Sub-theme	Codes
Theme 1: System Integration and Cognitive Adaptation Across Multiple Platforms	1.1 Feature Awareness and Interface Alert Processing	Hypersensitive alert thresholds; Alarm fatigue; Ultrasonic scalpel recognition deficit; Auxiliary adapter integration; Tool tip degradation
	1.2 Instrument Compatibility and Workflow Continuity	Trocar calibre heterogeneity; Port verification burden; Split optical assembly; Line management complexity
	1.3 Component Specification Variety and Line Management	Laser alignment offset; Manual spatial recalculation; Needle holder suture trapping; Workflow interruption
Theme 2: Physical Layout, Hardware Adaptation, and Environment Compatibility	2.1 Manual Positioning and Docking Procedures	Fixed chassis design; Three-point alignment; Manual cart navigation; Intraoperative repositioning burden
	2.2 Operating Theatre Infrastructure Compatibility	Ceiling clearance insufficiency; Proprietary table requirements; Installation constraints; Spatial anxiety
	2.3 Material Maintenance and Safety Inspections	Complex draping systems; Adapter ring management; Brittle mechanical tabs; Foreign body contamination risk; Sterile field inspection
Theme 3: Digital Ecosystem Evolution and Professional Boundary Shifts	3.1 High-Density Digital Interfaces and Feature Integration	Multi-spectral visualisation; Consolidated interface design; Nested menu navigation; Intraoperative cognitive saturation
	3.2 5G Remote Telesurgery and Spatial De-localization	Console surgeon absence; Sole on-site custodianship; Independent fault management; Off-duty psychological rehearsal
	3.3 Iterative Software Updates and Knowledge Adaptation	Firmware patch cycles; Altered troubleshooting sequences; Knowledge obsolescence; Chronic learning fatigue
Theme 4: Professional Role Evolving and Institutional Support Mechanisms	4.1 Technical Quality Inspection and Scope Expansion	Hardware integrity audits; Role boundary erosion; Pre/post-procedural inspection burden; Clinical attention displacement
	4.2 Time Management Attribution and Efficacy Fluctuations	Equipment-induced delays; Surgical team misattribution; Professional self-efficacy erosion; Competence self-doubt
	4.3 Institutional Buffering Deficits and Absence of Operational Recognition	Absent platform-differentiated training; Legacy performance metrics; Institutional narrative disconnect; Perceived structural abandonment

Theme 1: System Integration and Cognitive Adaptation Across Multiple Platforms

Sub-theme 1.1: Feature Awareness and Interface Alert Processing

Participants emphasized that managing multiple domestic robotic systems exposes them to advanced telemetry features, which broadens their clinical technology proficiency. At the same time, this multi-platform environment introduces unique interface designs that require continuous cognitive adaptation. Early-generation domestic platforms feature highly sensitive telemetry parameters that output a large volume of technical alert codes. While these alerts ensure maximum patient safety by flagging minor operational variations, their frequency can lead to alarm fatigue, requiring bedside nurses to constantly re-verify the screen while maintaining concentration on the active surgical field.

"Working across different platforms is actually an amazing opportunity because you get to see how different engineering teams solve clinical problems, and it really builds up your technology skills." (P04)

"The main adjustment is how the domestic machine handles alerts. It is designed to be incredibly sensitive and throws alerts constantly for minor variations just to ensure maximum patient safety." (P10)

"The issue is that you can get trapped in a loop of high-frequency buzzing and blinking under pressure. It means we have to keep re-verifying the screen while trying to stay completely focused on the active surgical field." (P12)

Sub-theme 1.2: Instrument Compatibility and Workflow Continuity

The integration of specialized energy devices during complex surgeries showcases both the functional versatility of domestic platforms and the practical adaptations required from the nursing staff. Frontline nurses noted that while newer systems perform beautifully during tissue resection, certain platforms do not automatically recognize non-native advanced instruments. To maintain workflow continuity and bypass these software compatibility limitations, perioperative nurses have developed efficient manual workarounds, including preparing and attaching dedicated hardware adapters before the procedure begins.

"During complex liver resections, the domestic system performs beautifully and gives us great clinical outcomes." (P07)

"The only workflow break happens because the software doesn't recognize the ultrasonic scalpel profile automatically. We have to halt standard configuration to manually connect an auxiliary interface adapter." (P13)

"It adds a manual step and the tips can degrade fast under heavy use, triggering more codes, but our team has gotten really efficient at managing this transition." (P16)

Sub-theme 1.3: Component Specification Variety and Line Management

Operating a multi-platform surgical suite requires nurses to adapt to a wide variety of hardware specifications and geometric designs. Rather than using a single standardized port size, certain procedures utilize a combination of 8 mm and 10 mm trocars, which offers surgeons more tactical flexibility but requires the nursing team to maintain a higher level of visual verification to ensure smooth instrument passing. Additionally, some platforms utilize a split optical assembly where the light guide cable is a physically separate component from the endoscope, requiring careful line management to maintain an organized sterile field during high-turnover schedules.

"Managing a mix of 8 mm and 10 mm trocars for a single case actually gives the surgical team more options under pressure." (P09)

"But it adds a verification burden for us. During high-acuity moments, you cannot pass an instrument without pausing to confirm the port size to prevent any mismatch." (P05)

"Also, having a split optical assembly where the light guide cable is separate adds another step. When the setup time is tight, managing these separate lines requires very tight organization to keep the sterile field clear." (P11)

Theme 2: Physical Layout, Hardware Adaptation, and Environment Compatibility

Sub-theme 2.1: Manual Positioning and Docking Procedures

Participants acknowledged that the evolving platforms provide excellent structural stability once locked into place. However, the physical layout requires distinct manual adaptation compared to traditional setups. Because certain domestic platforms utilize a fixed mechanical chassis rather than an automated overhead boom, the initial setup relies heavily on the nursing team's physical coordination. Bedside nurses must manually guide the heavy patient cart to achieve a precise alignment among the camera arm, vertical pillar, and trocar port. When intraoperative surgical requirements necessitate changing the patient’s position, the team must physically unlock and reposition the platform across the floor.

"Once the arms are docked, the stability of the platform is incredible—there is absolutely no shaking during fine tissue dissection." (P14)

"The only challenge is the initial physical docking. Since it doesn’t have an automated overhead boom, we have to manually pull and align the heavy chassis to get the correct three-point angles." (P03)

"If the surgeon tilts the table mid-operation to shift the patient's position, the arm angles lock. We have to unlock the wheels and adjust the whole machine on the fly." (P06)

Sub-theme 2.2: Operating Theatre Infrastructure Compatibility

The introduction of diverse platform specifications has introduced a practical calibration process regarding existing hospital infrastructure. Advanced single-port systems offer immense clinical benefits by minimizing patient incision size and recovery time. At the same time, their vertical arm extensions and specialized weight profiles place strict demands on operating room dimensions. Modern standard suites often face narrow margins when accommodating maximum vertical extensions near overhead surgical lights, requiring precise preemptive spatial measurements by the nursing team during early installation phases.

"The clinical advantage of the single-port system is obvious—patients have fewer scars and heal much faster." (P01)

"However, its mechanical design requires a very high ceiling clearance during full arm extension. Our operating room is modern, but it barely meets the mandatory technical baseline." (P15)

"During the first few setups, we realized the upper links came within centimeters of our overhead surgical lights. It requires us to be highly precise during calibration to avoid any structural contact." (P02)

Sub-theme 2.3: Material Maintenance and Safety Inspections

The component designs of different domestic brands require specific adjustments to routine sterile maintenance. On one hand, the platform's multi-layered draping system provides a highly reliable sterile barrier for complex cases. On the other hand, the physical preparation involves more steps, such as manually securing separate intermediate adapter rings. Furthermore, participants noted that the small plastic clips on the arm housings can occasionally experience wear or fracture during high-speed instrument changes. This material characteristic requires the nursing staff to perform dedicated visual checks of the instruments and the sterile field.

"The draping material is robust and gives you complete confidence that the sterile field is secured throughout long cases." (P08)

"The only trade-off is that it has more separate pieces, like intermediate adapter rings, which takes extra time to fit precisely without tearing the drape." (P18)

"Also, we noticed that the tiny plastic clips on the arms can be brittle. If one snaps during a rushed instrument change, we must halt the procedure to do a quick visual check so nothing goes undetected in the deep field." (P17)

Theme 3: Digital Ecosystem Evolution and Professional Boundary Shifts

Sub-theme 3.1: High-Density Digital Interfaces and Feature Integration

Frontline nurses expressed high praise for the advanced visual functionality integrated into newer domestic systems, particularly the multi-spectral and fluorescence imaging controls. These features allow the surgical team to toggle instantly between imaging modes, significantly improving tissue differentiation and shared situational awareness in the room. However, because multiple subsystem controls are consolidated onto a single touch interface, the digital menus are deeply nested. When technical alerts or calibration requirements appear during critical moments, nurses must navigate through several screen layers to locate the specific sub-menu.

"The multi-spectral toggle is brilliant. During liver resections, switching to fluorescence mode instantly lights up the tumor boundaries, which helps the whole team track the progress perfectly." (P17)

"The integrated screen puts everything in one place, which sounds efficient but works poorly under pressure." (P13)

"The menus are deeply nested. When an error code pops up, you have to scroll through multiple layers of a high-density touch interface just to locate the calibration sub-menu." (P12)

Sub-theme 3.2: 5G Remote Telesurgery and Spatial De-localization

The deployment of cross-regional 5G remote telesurgery was recognized by participants as a groundbreaking achievement that successfully bridges geographical gaps, allowing patients in rural areas to receive expert surgical care. This technological leap, however, fundamentally shifts traditional operating room boundaries. With the primary surgeon operating from a distant city, the physical closed-loop communication in the room is altered. The bedside nurse becomes the primary physical guardian of local patient safety, independently managing technical sync issues or hardware adjustments. This expanded level of independence is professionally empowering, but it also creates a sense of isolation that can cause nurses to mentally rehearse emergency steps even during their off-duty hours.

"Completing these landmark remote surgeries is deeply rewarding; it feels amazing to see a surgeon hundreds of kilometers away operating perfectly via 5G." (P01)

"But from a nursing perspective, it completely changes your role. When a synchronization fault happens, the surgeon isn't physically next to you to look at the master console." (P05)

"The entire burden of local patient safety and emergency management falls onto your shoulders alone. That responsibility stays with you, and I found myself thinking about troubleshooting steps even at home." (P11)

Sub-theme 3.3: Iterative Software Updates and Knowledge Adaptation

Because domestic robotic platforms are evolving rapidly, engineering teams frequently roll out software updates and firmware patches to continuously optimize system performance and fix bugs. While these updates ensure the technology stays state-of-the-art, the rapid iteration requires constant learning from the nursing staff. Software updates distributed over weekends can alter technical override sequences, icon layouts, or alert thresholds, meaning that the practical troubleshooting habits nurses developed through hands-on experience can become outdated by their next shift.

"It is great that the manufacturers are so responsive—they release updates every few weeks to improve the system's software and fix bugs." (P14)

"But for us, it means we are in a permanent state of learning. Just when we finally memorise the troubleshooting steps for a specific error, a firmware update arrives." (P08)

"On Monday, you turn on the machine and find the entire alert icon layout and override sequence has changed. You constantly have to adapt your practical knowledge." (P04)

Theme 4: Professional Role Evolving and Institutional Support Mechanisms

Sub-theme 4.1: Technical Quality Inspection and Scope Expansion

As domestic platforms continue to refine their manufacturing tolerances, nurses have stepped up to act as crucial quality control partners. Frontline staff have expanded their traditional role—moving beyond standard sterile field monitoring to perform systematic pre- and post-operative hardware audits. This includes checking mechanical joints, verifying laser tracking offsets, and ensuring adapter compatibility for non-native energy devices. While this demands more prep time, it has elevated the nurse's role into a vital technical coordinator who bridges the gap between hardware limitations and clinical execution.

"With these new systems, our role has naturally expanded. I don't just pass instruments anymore; I spend the first twenty minutes acting like a quality inspector." (P04)

"I check the joints for hairline cracks, verify if the laser alignment is tracking slightly off-center, and make sure the adapters are secure." (P02)

"It takes more effort and shifts our primary focus away from clinical care temporarily, but it makes us the essential technical backbone of the entire robotic team." (P16)

Sub-theme 4.2: Time Management Attribution and Efficacy Fluctuations

Because multi-platform environments require extra manual steps—such as connecting separate light guide cables or fitting specific adapters—room preparation and case turnover times can be prolonged compared to highly standardized international systems. A major point of discussion among participants was how these delays are perceived. When surgical teams or surgeons arrive and face setup delays, they often attribute the slowdown to nursing inefficiency because they do not see the hidden engineering requirements. This misattribution can cause fluctuations in nurses' professional self-efficacy, making them feel criticized for structural delays beyond their control.

"Connecting separate cables and fitting extra hardware adapters simply takes time compared to standard systems." (P15)

"When the room isn't ready the exact minute the surgeons walk in, they sometimes comment that the nursing team is being too slow." (P10)

"They don't realize we are working as fast as possible to bypass hardware design limitations. Being blamed for things built into the machine can really make you question your own competence." (P07)

Sub-theme 4.3: Institutional Buffering Deficits and Absence of Operational Recognition

Hospital administrations have actively promoted and celebrated the clinical milestones achieved through domestic robotic surgeries, using them as key indicators of institutional innovation. However, a gap remains between this high-level celebration and the day-to-day operational support provided to frontline staff. Participants noted that while leadership is eager to adopt these technologies, institutional buffer systems—such as platform-differentiated training pathways, adjusted speed metrics for performance evaluations, and dedicated on-site technical support engineers—are still in development and have not yet fully matched the pace of technology adoption.

"The administration is very proud of our hospital completing these advanced robotic cases, and they publish great reports about it as a technological achievement." (P16)

"Behind the scenes, they still evaluate our performance using old speed metrics designed for standard surgical rooms." (P09)

"We need the institution to back us up with specialized training and realistic efficiency standards that match the actual technical risks we are managing every day." (P03)

Discussion

Our study demonstrates that working across diverse robotic platforms expands nurses' technical literacy through exposure to advanced visualizations, such as multi-spectral and fluorescence imaging. However, this multi-platform environment simultaneously demands intense cognitive adaptation due to high-frequency, hypersensitive telemetry alerts and the lack of automatic software recognition for non-native energy devices, which forces repetitive manual troubleshooting. This dual-natured experience mirrors the findings of Schuessler et al. (2019), who reported that while nurses value robotic systems as a gateway for professional development, complex device interfaces and recurring software-hardware mismatches frequently hinder operational efficiency [1]. Furthermore, continuous error codes accelerated mental fatigue among perioperative nurses. This finding directly aligns with healthcare human factors literature, which confirms that hypersensitive alert systems impair clinical focus [22, 23]. When interface parameters are too sensitive, they force clinicians into a loop of redundant screen verification rather than purposeful patient monitoring. When firmware patches alter troubleshooting layouts without notice, the practical knowledge developed by nurses quickly becomes obsolete. These dynamic software updates shift the technological interface from a stable clinical tool into a source of constant negotiation. Within the framework of technostress, this experience represents techno-uncertainty, where unpredictable systemic changes outpace the clinical staff's established routines [14]. Mitigating this cognitive burden requires collaborative standardizations of alert thresholds across engineering designs. Furthermore, our findings suggest a critical need for healthcare institutions to move away from legacy apprentice training, replacing it with structured, platform-differentiated education that addresses interface troubleshooting in real time.

In terms of the physical environment, participants highly valued the clinical outcomes of advanced single-port systems. However, managing diverse hardware profiles imposes a heavy physical burden on the surgical team. Operating across non-standardized platforms requires significant manual effort during initial positioning and docking. This spatial friction becomes more difficult when the physical dimensions of new technologies conflict with existing operating room infrastructure. These physical challenges support the conclusions of Randell et al. (2019), who noted that unrefined hardware configurations and rigid spatial demands drastically prolong room setup times [24]. TThe bodily fatigue experienced by our participants during equipment adjustments also reflects the findings of Uslu et al. (2019). Their data demonstrated that the physical management of heavy, high-tech devices remains a primary source of operational stress for perioperative staff [25]. This mismatch between hardware design and workplace reality illustrates techno-complexity, where multi-vendor engineering variations transform into practical clinical anxiety. To resolve this issue, healthcare institutions should conduct formal spatial screenings before installing new systems. Furthermore, equipment manufacturers need to prioritize ergonomic designs, such as motorized components, to reduce the physical workload on bedside nurses.

The integration of cross-regional remote telesurgery successfully expands surgical access, but it fundamentally reshapes traditional clinical boundaries. When the primary surgeon operates from a distance, the lack of physical co-presence removes the immediate safety backup that nurses historically relied on. Bedside nurses must assume independent responsibility for managing technical sync issues

and local patient safety. This expanded role creates a heavy psychological burden that often spills over into nurses' personal rest periods. This professional isolation extends the work of Redondo-Sáenz et al. (2023), who warned that while digital systems enhance surgical reach, they can distract perioperative staff from traditional patient-centered roles and lower job satisfaction [26]. The severe boundary blurring observed in our study, where technical anxiety follows nurses outside the hospital, provides a unique empirical expansion of earlier technostress literature. Our findings show that remote connectivity does not just compete for attention during surgery, but anchors professional responsibilities into personal time. This phenomenon represents techno-invasion, where digital ecosystems dissolve the physical and temporal boundaries of the nursing role. To counter this stress, institutions implementing remote protocols should deploy dedicated wireless communication systems, which have been shown to significantly improve teamwork and reduce mental load among robotic team members [27]. Furthermore, healthcare leaders must establish formal emergency protocols that clearly define the legal and operational responsibilities of the bedside nurse when the surgeon is not physically present.

The cumulative impact of hardware variability and software instability has expanded the robotic nursing role into unrecognized professional territory. In our study, nurses spent substantial clinical time conducting pre-operative and post-operative hardware integrity audits. When non-standardized platform limitations caused setup delays, the broader surgical team frequently misattributed these bottlenecks to nursing inefficiency rather than equipment design. This systematic misattribution turned structural engineering failures into personal professional guilt, severely eroding nurses' self-efficacy. This organizational pressure matches the findings of Uslu et al. (2019), who observed that role strain and a lack of institutional buffering consistently undermine nursing confidence during the adoption of high-stakes technologies [25]. Similarly, Schuessler et al. (2019) reported that without structured support frameworks, clinical staff experience the technical learning curve of robotic surgery as an isolating and professionally destabilizing process rather than a developmental opportunity [1].

Limitations

The primary limitation of this study is its geographic and institutional concentration, as the participants were recruited from three tertiary-level hospitals with relatively mature robotic surgery infrastructures. Therefore, the findings may not fully reflect the experiences of perioperative nurses working in low-resource regional hospitals or settings with different organizational support systems. Additionally, because of the cross-sectional qualitative design, this study captured nurses' technostress at a single point in time and could not trace how these stress dynamics evolve longitudinally across technology adoption cycles or entire nursing careers.

Conclusions

In conclusion, while multi-platform robotic systems and advanced telesurgery offer clear clinical and therapeutic benefits, they introduce significant cognitive, physical, and organizational stress for perioperative nurses. Coping with this modern technostress requires a coordinated approach combining individual adaptation with targeted institutional backing. To reduce the mental and physical burden on frontline staff, healthcare organizations must implement standardized cross-platform training, design

ergonomic workspaces, and establish supportive communication channels. Providing these key resources will protect nurses' professional well-efficacy, ensure high-quality patient care, and improve overall job satisfaction in rapidly evolving digital operating environments.

Implications for practice

While the clinical and therapeutic benefits of digital healthcare integration are widely recognized, the unique technostress experienced by perioperative nurses in multi-vendor and remote telesurgical environments remains critically overlooked and under-investigated. By revealing the precise cognitive, physical, and organizational stress creators within these modern operating workflows, this study is expected to be highly effective in helping healthcare administrators design platform-differentiated training pathways, recalibrate legacy efficiency metrics to credit mandatory hardware audits, and formalize clear operational boundaries that protect nursing well-efficacy and patient safety.

Declarations

Consent for publication

All participant quotations included in this manuscript are presented in anonymised form using alphanumeric identifiers (P01–P18). No identifying information, images, or personal clinical details that could compromise participant anonymity are included. Formal consent for publication of anonymised quotations was obtained from all participants as part of the written informed consent process prior to data collection. Not applicable for identifying images or clinical details.

Author Contributions

Qu Xi and Li Qiao contributed to the conceptualization of the study. Qu Xi was responsible for the methodology, project administration, and preparation of the original manuscript draft. Formal analysis was performed by Qu Xi, Li Qiao, and Guo Yue. Data curation was undertaken by Qu Xi and Zhang Chunjing. Li Qiao, Guo Yue, Zhang Chunjing, and Liu Yang contributed to the review and editing of the manuscript. Wang Ying supervised the study and served as the corresponding author. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board of Tongji Hospital, Tongji Medical College, Huazhong University of Science and Technology (Approval No. TJ-IRB202609008).

Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

Availability of data and materials

The datasets generated and analysed during the current study are not publicly available in order to protect participant confidentiality, but anonymised excerpts supporting the findings are presented within the manuscript and its supplementary materials. The full dataset is available from the corresponding author on reasonable request, subject to institutional ethics approval.

Conflicts of Interest

The authors declare no conflicts of interest.

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Figures

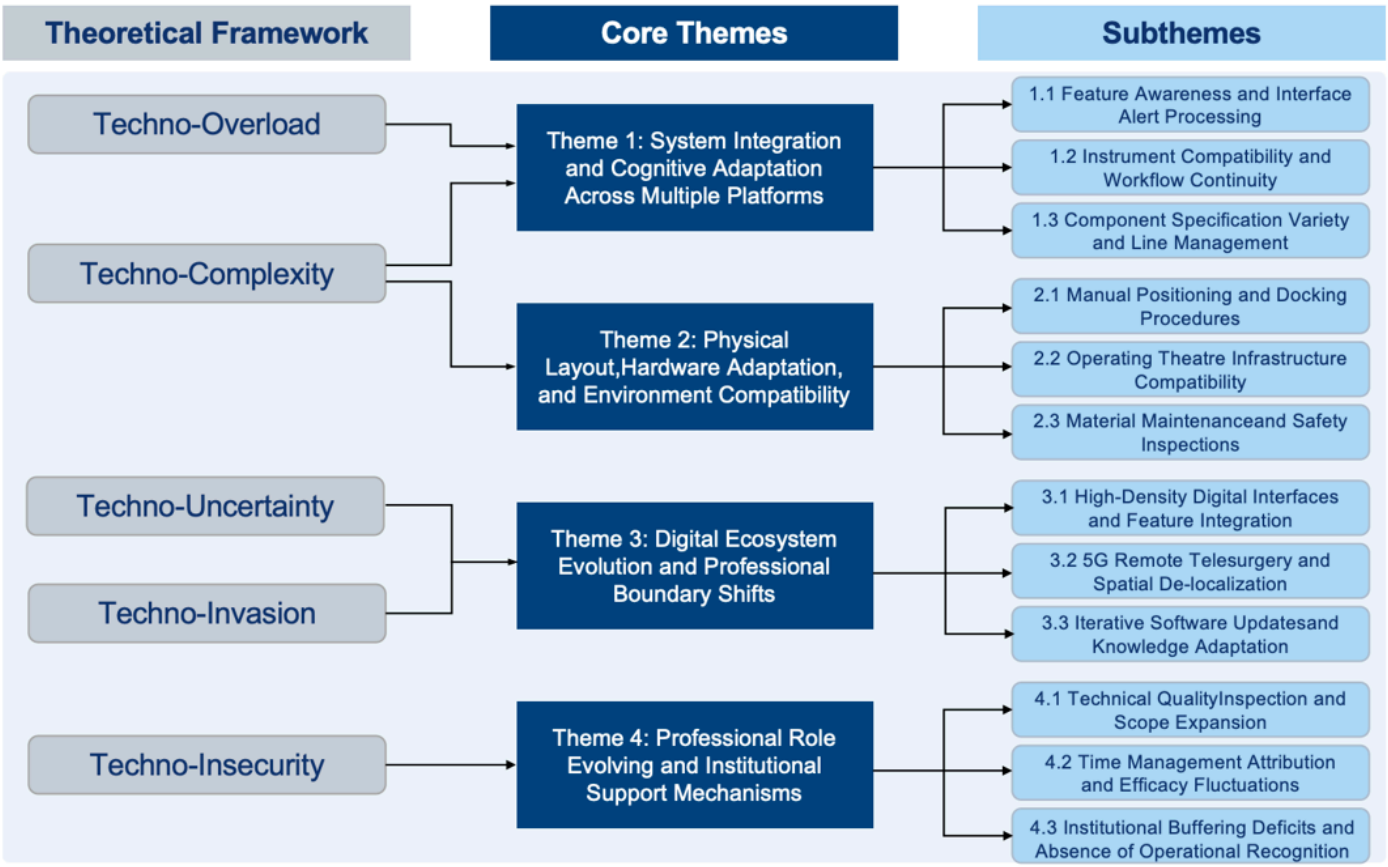


Figure 1

Thematic structure of technostress experiences among OR nurses in multi-platform robotic surgery environments.

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