Published: 29 November 2025

Citation in BibTeX format

OZCHI '25: 37th Australian Conference on Human-Computer Interaction
November 29 - December 3, 2025
Gadigal | Sydney, Australia

SHORT-PAPER

Exploring Human-Robot Collaboration in Surgery: Initial Insights from Mako Product Specialists

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Open Access Support provided by:

Queensland University of Technology

OZCHI '25: Proceedings of the 37th Australian Conference on Human-Computer Interaction (November 2025)
https://doi.org/10.1145/3764687.3769935
ISBN: 9798400720161

Exploring Human-Robot Collaboration in Surgery: Initial Insights from Mako Product Specialists

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Abstract

Human-Robot Collaboration (HRC) in surgery is often explored from the perspective of surgeons. However, many robotic procedures require the expertise of technical specialists. Their experiences and perspectives in achieving robotically assisted surgeries remain underrepresented. This paper explores the real-world experiences of technical specialists who work alongside Stryker's Mako surgical robotic system in the operating theatre. This work presents initial insights from five expert interviews with Mako Product Specialists (MPSs), who play a central role in supporting Mako-assisted joint replacement surgeries. We identified three themes relating to the MPSs' ergonomic challenges, teamwork negotiations, and workflow disruptions experienced in the operating theatre. Our findings indicate that surgical HRC extends beyond the surgeon–robot dyad, involving distributed expertise and social negotiation across the surgical team. While robotic systems aim to enhance surgical performance, we argue that their designs should consider the full ecology of human collaborators in the operating theatre.

CCS Concepts

• **Human-centered computing**; • **Human-computer interaction (HCI)**; • **Empirical studies in HCI**;

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ACM ISBN 979-8-4007-2016-1/2025/11
https://doi.org/10.1145/3764687.3769935

Keywords

Human-Robot Collaboration, Mako Robotic System, Expert Interviews, Robot-Assisted Surgery, Ergonomics

ACM Reference Format:
Jasper T Vermeulen, Glenda Amayo Caldwell, Muge G Teixeira, Alan G Burden, and Matthias Guertler. 2025. Exploring Human-Robot Collaboration in Surgery: Initial Insights from Mako Product Specialists. In *37th Australian Conference on Human-Computer Interaction (HCI) (OZCHI '25), November 29–December 03, 2025, Sydney, Australia.* ACM, New York, NY, USA, 9 pages. https://doi.org/10.1145/3764687.3769935

1 Introduction

Human-Robot Collaboration (HRC) is becoming increasingly common in surgical settings, with robotic systems designed to support surgeons, for instance, by providing haptic feedback during bone cutting in high-precision procedures. While prior research has demonstrated that robotic assistance can enhance surgical accuracy and, consequently, improve patient outcomes [10, 24, 28, 34], most studies have focused narrowly on the experiences of surgeons or the technical capabilities of the robots themselves. This perspective overlooks the complex, collaborative nature of real-world operating theatres, where multiple human and non-human actors must work together under time pressure and high cognitive demand [9, 17].

Surgical robotic systems, such as the da Vinci (Intuitive Inc.), have been widely studied, particularly regarding their impact on communication, spatial dynamics, and surgical team coordination [6, 8, 9, 11, 23, 30]. However, other surgical robotic systems, such as Stryker's Mako, have received less attention [37, 39]. The Mako robotic arm is a collaborative system used in joint replacement surgeries. As a so-called passive cobot [13, 36], it assists the surgeon in executing predefined plans and restricts motion during bone cutting, but cannot move independently. Unlike teleoperated systems (e.g. da Vinci surgical system), the Mako remains in the shared surgical space and is directly manipulated by the surgical team. An interesting aspect of the Mako system's usage is the presence of a Mako Product Specialist (MPS), a technical expert who sets up the robot (positioning, robotic calibration, and preparing the planning software for the case), supports intraoperative coordination, and manages troubleshooting. In contrast, the da Vinci surgical system does not have such on-site technical support present within the operating theatre. MPSs are present for every Mako-assisted surgery; however, their experiences have not been examined in the existing HRC literature. This is a notable gap, given the critical role they play in facilitating collaboration between the surgeon, the robot, and other surgical staff [37, 39].

This study builds on a growing interest in understanding how HRC unfolds in real-world, high-stakes environments. In recent years, the OzCHI and allied communities have increasingly turned their attention to how individuals experience HRC outside laboratory or controlled settings [20, 22, 27, 36, 38]. Recent work from Opie et al. [28, 29] has pointed to the potential of surgical robotics as a domain for advancing HCI and interaction design research. At the same time, there are increasing calls for more in-the-world studies that move beyond controlled environments to engage with the complexity of practice [21]. This study responds to both trends by exploring how MPSs experience HRC as it unfolds in surgical operating theatres across Australia. This paper presents early findings from five expert interviews with MPSs who work closely with surgeons and robotic systems during joint replacement procedures. The interviews examined how MPSs perceive their role at various stages of the surgical workflow and the physical, cognitive, and collaborative challenges they encounter. As this work explores expert perspectives and real-world experiences, the data provides valuable insights into the human factors that influence the successful use of collaborative robots in surgery. Our goal in presenting this work as a Late-Breaking Work submission is to share early insights into these experiences of MPSs and invite reflection from the OzCHI community on how HRC in surgery might be better supported. While surgical robots are often designed with a single primary user in mind (e.g. the surgeon), our findings suggest that a broader, multi-user perspective may be needed, particularly in high-stakes environments such as operating theatres, which rely on complex and seamless collaboration. By incorporating the perspectives of technical staff, such as MPSs, we aim to contribute to ongoing conversations in HCI and HRI about how robotic systems are integrated into practice and how designs can better support the full team involved in surgical collaboration.

2 Background and context

2.1 Human Factors in Robot-Assisted Surgery

Robot-Assisted Surgery (RAS) has advanced significantly over the past few decades, supporting improved outcomes in surgical precision and patient recovery times [14, 16, 35]. These robotic systems (e.g., teleoperated and semi-autonomous robotic systems) are increasingly integrated into operating theatres to address the limitations of traditional surgical techniques and enhance surgical performance [2]. However, while technical performance is well-studied (e.g. bone cut accuracy and implant survivability rates), the human factors involved in using these systems are still emerging as a research focus. Research on human factors is an interdisciplinary field that examines how people interact with systems, environments, and technologies. In the context of human factors and RAS, Catchpole et al. [7] identify four key areas: (a) physical and cognitive workload, (b) workflow disruptions, (c) communication and teamwork, and (d) environmental constraints. These categories provide a contextualization for understanding and researching the impact of surgical robots on team dynamics and individual working conditions. However, most existing studies apply these theoretical lenses and areas of interest merely to the surgeon's experience, leaving the experiences of other surgical team members largely unexplored.

2.2 Moving Beyond the Surgeon

HCI researchers have begun addressing this gap by examining how robotic systems affect broader surgical teams. Cheatle et al. [9] explored how the da Vinci system alters communication and coordination, showing that robotic assistance can disrupt established team practices. Pelikan et al. [30] and Randell et al. [31, 32] further illustrated how teamwork is reconfigured in response to the implementation of the da Vinci system. It is evident that, in response to the introduction of surgical systems into practice, the way work is performed, both in relation to other personnel and in relation to the surgical robot, is significantly altered. In a different context, Wong et al. [40] examined the ergonomic risks faced by bedside assistants during robotic colorectal procedures, recommending design changes to improve conditions for these secondary users. These studies collectively show the value of expanding HRC research beyond the surgeon to include others involved in the surgical process. Despite these contributions, little is known about how other robotic systems, particularly collaborative systems, influence the reshaping of roles, responsibilities, and human factors in the operating theatre. The current body of literature in this space has focused on teleoperated systems, such as the da Vinci system, which physically separates the surgeon from the rest of the team. Collaborative systems, such as the Mako (Fig. 1), operate within the same space and involve more fluid, shared control across the team. As a result, such collaborative systems are likely to give rise to uniquely different challenges compared to teleoperated systems in *robotic operating theatres*.

2.3 The Mako and The Mako Product Specialist

Stryker's Mako robotic arm system is such a collaborative robot system. It is widely used in joint replacement surgeries, including Total Knee Arthroplasty (TKA) and Total Hip Arthroplasty (THA), where it enables surgeons to perform precise bone cuts within predefined boundaries prior to implant insertion [25, 33, 34, 37, 39]. To reiterate, the Mako system is not teleoperated. Instead, it assists the surgeon in real time, providing haptic boundaries, limiting movement if the cutting tool deviates from the planned trajectory (planned by the surgeon). A distinctive aspect of the Mako workflow is the involvement of a Mako Product Specialist (MPS). MPSs are highly trained technicians who are present for

Figure 1: [Left] The da Vinci Surgical System (Intuitive Inc.), a non-autonomous teleoperated robot. [Right] The Mako Robotic System (Stryker Inc.), a semi-autonomous robotic arm.

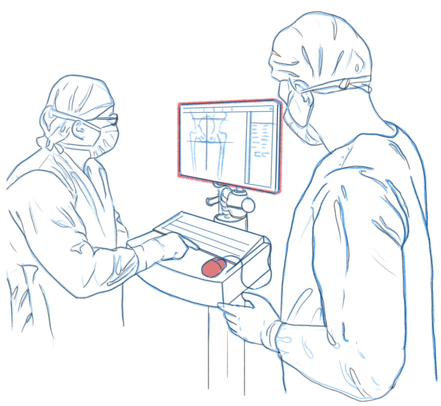

Figure 2: [Right] A surgeon and [left] a Mako Product Specialist are discussing and planning the surgical approach in the Mako software (illustration by authors).

every Mako-assisted surgery. They assist the surgeon with surgical planning using the Mako software at the start of the operation (as illustrated in Fig. 2). Moreover, they are responsible for setting up the system preoperatively, supporting the surgeon and scrub nurse intraoperatively, and ensuring the robot is cleaned and ready for future use. MPSs also troubleshoot issues and help adapt workflows to the needs of the procedure. While their role is central to the functioning of the Mako system, they are notably underrepresented in existing human factors research, which has examined the Mako system [15, 18, 26, 37].

This study addresses this gap by examining how MPSs experience HRC in the operating theatre. Using expert interviews, we explore the physical and cognitive challenges the MPSs face, the collaborative teamwork dynamics with other surgical staff, and their role in managing workflow disruptions during Mako-assisted joint replacement surgeries. These early insights foreground the experiences of a key but underrepresented group in surgical HRC, contributing to a more human-centred and multi-user perspective on how robotic systems are integrated into real-world surgical practice.

3 Methodology

This study is part of a broader doctoral project investigating HRC in real-world surgical environments. In this study, we asked: How do Mako Product Specialists experience Human Robot Collaboration in joint replacement surgeries? To explore the experiences of MPSs, we conducted expert interviews with five participants (N = 5) who have a breadth of knowledge in supporting Mako-assisted joint replacement procedures in hospitals across Australia.

3.1 Participants and Recruitment

Given the challenges of recruiting MPSs due to their highly demanding schedules and presence in surgical environments, participant recruitment required a flexible approach. MPSs often work across multiple hospitals, travel frequently as a result, and can be called into surgery with little notice, which complicates the scheduling of interviews and contributes to the sample size at this stage. Despite these recruitment challenges, we conducted five expert interviews over a 9-month period. Each participant had a breadth of knowledge and contributed rich insights grounded in their real-world experiences from supporting Mako-assisted surgeries in hospitals across Australia. Our qualitative approach prioritized depth and richness over quantity, focusing on capturing detailed, experience-based insights from these highly specialized roles. It is essential to understand the nature of how MPSs work; they tend to be transferred frequently between several hospitals and, consequently, work with a wide range of surgeons and nurses throughout their careers. As a result, these interviews offer rich, contextually grounded perspectives on how HRC unfolds in real surgical environments, based on the expertise and experiences of individuals who frequently participate in HRC during surgery.

We used two recruitment strategies. First, we employed convenience sampling [3] in an earlier study, during which we observed Mako-assisted surgeries. During these observations, we invited three MPSs (N = 3) to participate in follow-up interviews. Second, we employed snowball sampling [3], whereby initial participants referred us to additional MPSs in their professional networks who

Table 1: List of Mako Product Specialists

Participant	Experience in the role	Identifier
1	6000+ Mako cases supported	MPS_1
2	1000+ Mako cases supported	MPS_2
3	500+ Mako cases supported	MPS_3
4	3000+ Mako cases supported	MPS_4
5	250+ Mako cases supported	MPS_5

were willing to participate (N = 2). These other two participants were working in different parts of Australia. This combined strategy resulted in five participants, summarized in Table 1.

3.2 Data Collection

The interviews were conducted virtually using Microsoft Teams. Each session lasted between 55 and 65 minutes, with an average duration of 60 minutes. Before consenting to partake in the online interview, participants received a detailed information sheet outlining the purpose of the study and confidentiality measures. Ethics approval was granted by the lead institution's Human Research Ethics Committee (approval number 8382).

Based on prior work, the research team identified the various tasks to which MPSs are involved and used these insights to design a semi-structured interview guide. As such, participants were asked to reflect on their experiences across different stages of the surgical workflow, including:

- Preoperative tasks (e.g. preparing the robot, transporting equipment into the theatre),
- Intraoperative collaboration (e.g., supporting troubleshooting and assisting with coordination), and
- Postoperative tasks (e.g. disassembling, cleaning, and preparing the robot for reuse)

Furthermore, the interviews focused on how MPSs collaborate not only with the Mako system but also with various members of the surgical team, such as surgeons, scrub nurses, and circulating staff. Follow-up questions often aimed to unpack participants' challenges, including instances where routine procedures deviated from plan or required on-the-spot adaptation. Interviews were audio recorded and transcribed verbatim using institution-licensed transcription services.

3.3 Data Analysis

We analyzed the transcript data using *reflexive thematic analysis* as outlined by Braun and Clarke [5], combining both inductive and deductive modes of analysis. This approach facilitated an iterative process that enabled us to engage critically with the data while remaining attentive to patterns rooted in participants' lived experiences. The primary author conducted an inductive coding of the transcripts, generating open codes without predefined categories. These initial codes were selected as they captured the nuances and different aspects related to how the MPSs experience and perceive HRC. The initial codes were reviewed and discussed in regular collaborative sessions with the broader research team. The data was visualized using the qualitative coding software Atlas.ti. These collaborative sessions with the broader research team helped identify areas of conceptual overlap, challenge assumptions, and refine emerging interpretations. As themes began to converge, we worked iteratively to develop candidate themes grounded in participant narratives. Following this, we conducted a deductive coding phase informed by existing literature on human factors and teamwork in robot-assisted surgery (e.g. Catchpole et al. [7, 8]; Cheatle et al. [9]). We revisited the data through the lens of these prior works to examine how our themes aligned with or diverged from known issues such as workload, communication breakdowns, and role negotiation in surgical settings. Through ongoing discussion, the team refined the findings into three key themes that illuminate how surgical HRC with the Mako is performed in real-world settings, from the perspective of MPSs.

4 Findings

Applying reflexive thematic analysis [5] in Atlas.ti, we initially created 241 in vivo codes. These codes were further grouped into six categories and further clustered into three themes: (a) Ergonomics, (b) Teamwork, and (c) Workflow Disruptions (as depicted in Table 2). These themes highlight the various physical and cognitive challenges that MPSs face when supporting Mako-assisted surgeries. Furthermore, we identified how collaboration and teamwork unfold in the operating theatre, both between robotic and non-robotic team members. Finally, a key theme in the data pertains to workflow disruptions, specifically understanding when and how MPSs are required to intervene and engage in troubleshooting. A brief overview of themes, codes, and their groupings is provided in Table 2.

4.1 Ergonomics

4.1.1 Physical Ergonomics. MPSs described a range of physical challenges when moving the Mako system between and within operating theatres. Weighing around 400 kg, the Mako is challenging to maneuver. As MPS_1 put it, "*The Mako is pretty bulky*," while MPS_4 called it "*quite clunky*." Pushing the robot between surgeries was physically demanding, especially with its stiff wheels and size. Participants noted that this strain was a regular part of the job. There was also a learning curve. MPS_2 shared, "*It is a bit awkward. . . you do get good at knowing how the wheels work, so you get a bit better. But it is a bit heavy and a little bit awkward*."

Positioning the Mako inside the operating theatre brought its own challenges. Getting the robot into the right spot often required trial and error, as the system needed to be precisely aligned to suit the surgeon's preferences. MPS_1 explained: "*The MPS will be running between the sides of the operating theatre to push the robot in, then go back to the other side to move to the cutting sequence in the software and then go back to unlock the arm*." If the robot wasn't parked correctly, it could delay the procedure or cause frustration. MPS_2 noted, "*That's a manual process [parking the robot arm for cutting], and if I push it into the wrong spot, it can cause issues with the surgeon. If the robot could help with finding the optimum positioning, that would make things easier*."

4.1.2 Cognitive Ergonomics. In addition to the physical workload, MPSs described significant cognitive demands. Ensuring that all tools, trays, and implants were correctly sourced and prepared was

Table 2: Brief overview of Themes and Codes

Theme	Code Group	Example Code	Example Quotation
Ergonomics	Physical	Mako is heavy	*"Moving the Mako it's a bit heavy."*
	Cognitive	Intraoperative MPS stress	*"It can be overwhelming because you're just stressing about everything."*
Teamwork	MPS and surgeon	Need MPS-surgeon trust for collaboration	*"You build that rapport, so they [surgeons] trust you."*
	MPS and scrub nurse	Scrub nurse can support or 'distract' MPSs	*"If they are happy to help with the setup [Mako], I can focus on the surgeon instead of them."*
Workflow Disruptions	Human-related	Bumping into the Mako	*"Unbeknownst to me, someone had whacked the camera with something, and there was a bump light on the camera, and I had a connection error...we had a half-hour delay"*
	Mako-related	Mako stops when there are too many vibrations	*"When the blade struggles to cut...there are heaps of vibrations, and then the [Mako robotic] arm will just cut out."*

a considerable source of stress, often more taxing than technical concerns related to the robot itself or emergent challenges (troubleshooting) in the OR. MPS_2 described it as "*a juggling act... making sure instruments and implants are there.*" Similarly, MPS_3 noted, "*Having to borrow a tray [sterile, case-specific instrument and implant kits] from another hospital... that's almost more stressful than robot troubleshooting, because I've been trained to deal with robot troubleshooting.*" This anticipatory workload contributed to end-of-day exhaustion, even when no issues occurred, as equipment that had been carefully prepared could still be dropped or taken by other staff. MPS_2 reflected, "*It can be overwhelming because you're stressing about everything... you're stressing about things before they happen.*" They added, "*Even if nothing goes wrong, by the end of the day, you're just so mentally cooked because you're burning energy worrying about things that could happen.*" Others acknowledged the emotional highs and lows that come with the role. MPS_4 described it as "*a massive learning curve... very rewarding, but some days it's very frustrating.*" These accounts reveal how the MPS role involves managing both visible and invisible pressures, constantly balancing logistical coordination with technical vigilance, while carrying both physical and cognitive burdens. MPS_5 reinforced this dual burden, highlighting how much of the mental stress comes from non-robotic tasks that must be managed in parallel: "*It's all of the peripheral stuff that's not actually really related to the robot... like how to order stuff, how to find where things are, what to do if something breaks or if you can't find something... you figure out a lot of that on the fly.*" These unstructured, often invisible responsibilities contribute to a constant mental load that goes beyond the immediate demands of robotic operation and troubleshooting.

4.2 Teamwork

Managing teamwork, building trust, and navigating team dynamics emerged as a core theme. MPSs highlighted how communication styles, shared understanding, and relational experience shaped and influenced their collaboration with other surgical staff.

4.2.1 Collaborating with Surgeons. The surgeon–MPS relationship was described as evolving over time, shaped by trust, familiarity, and repeated collaboration. While surgeons remain the primary decision-makers in the operating theatre, MPSs often feel responsible for ensuring the robotic system runs smoothly, and at times, for guiding less experienced users (surgeons). As MPS_2 explained, "*At the end of the day, it's their [surgeon's] surgery... it's not our job to tell them what to do.*" They added, "*It's normally a conversation... not so much of them directing you. With surgeons you work a lot with, you build rapport, and they trust you.*" This was echoed by MPS_3: "*When you build a relationship with the surgeon, they trust you and give you more responsibility.*" Still, tact was often required in more delicate situations. MPS_3 noted, "*Some surgeons don't ask for help, but when I see they are struggling, I might carefully suggest an alternative approach... but you have to be tactical about it.*" MPS_1 summed up this dynamic succinctly: "*It comes down to the surgeon knowing the MPS, and the MPS knowing the surgeon's preferences.*" While the MPS role is primarily one of support, these accounts suggest that their expertise can lead to level-headed discussions with surgeons about how best to proceed, highlighting the nuanced and collaborative nature of surgical teamwork in Mako-assisted surgeries. MPS_5 described how building this dynamic also involved navigating subtle interpersonal cues: "*It's trying to read the room and know when to offer input and how to offer it... You have to be confident and say what you know... then adjust based on their reaction.*" This type of social calibration reflects the relational sensitivity necessary to balance authority and deference in high-stakes environments.

4.2.2 Collaboration with Scrub Nurses. While MPSs and scrub nurses both work closely with the Mako, their collaboration is shaped by varying levels of experience and support. MPS_3 highlighted this interdependence: "*You're checking with the nurses to see if they're happy with the trays, and they trust you that you're happy with the implants... It's like a little team.*" When scrub nurses were familiar with the system, they could support Mako setup (see Fig.

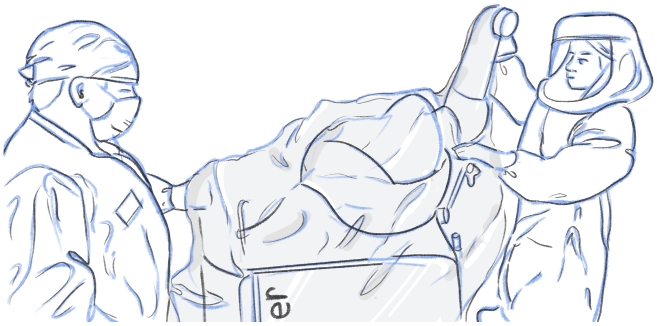

Figure 3: [Left] Mako Product Specialist and [right] scrub nurse are putting a protective drape over the robotic arm to prepare it for the cutting process within the sterile field (illustration by authors).

3), reducing delays. As MPS_3 explained, "*If the scrub is happy to help me with the Mako setup, I can focus on the surgeon... this speeds up the surgery.*" Conversely, a lack of familiarity could slow things down: "*Especially if they are new or not familiar with the Mako... trying to do the Mako side of things with the surgeon and teaching the scrub nurse how to drape the robot, it takes a few extra minutes.*" MPS_4 added, "*None of the nursing staff at the hospital are really trained to use it [Mako], we teach them on the spot.*" These accounts illustrate how effective teamwork in robotic surgery depends not only on individual expertise but also on defined roles and organisational investment in shared training and cross-role collaboration. Despite both focusing on how they, in their role, can support the surgeon, how MPSs and nurses work together can influence the overall fluency of a Mako-assisted surgery.

4.3 Workflow Disruptions

Participants frequently described how unexpected events, whether stemming from technical or human factors, interrupted the surgical flow and required rapid adaptation. We categorized these disruptions into human-related and robot-related events.

4.3.1 Human-Related Disruptions. MPSs frequently encountered issues caused by the accidental disturbance of key system components, such as the optical arrays used for tracking. As MPS_4 explained, "*There is a checkpoint base next to each array. If that relationship changes... we've bumped things, and we've had to reregister the bone completely.*" Even minor contact could lead to significant delays. MPS_4 recalled, "*Unbeknownst to me, someone had whacked the camera with something, and there was a light bump on the camera... we had a connection error and a half-hour delay.*" Another human-related disruption stemmed from differences in surgeon familiarity with the system. MPS_3 contrasted novice and experienced users (see Fig. 4): "*Newer Mako users are more focused on the patient, and then you have to tell them to move because they are outside the haptic boundary, and it [the Mako] is not letting you cut.*" They continued, "*The experienced surgeons are mainly focused on the screen... they trust that what they are cutting on the screen is what is in front of them.*" These accounts highlight two key areas of disruption: movement within the operating theatre, particularly around sensitive components such as the arrays and camera, and individual differences in experience and familiarity with the robotic system, which are also echoed in previous sections.

4.3.2 Mako-Related Disruptions. Although less common, robot-related disruptions could significantly impact the flow of a procedure. The optical tracking system was described as a known point of sensitivity. As MPS_2 explained, "*If the patient has really hard bone, the saw blade works harder and vibrates more. When these vibrations occur... the [Mako] system stops.*" Repeated interruptions frustrated both MPSs and surgeons alike. MPS_2 continued, "*Every time they [the surgeon] push too hard, it shakes and cuts off, so they get frustrated.*" In these moments, MPSs were required to balance quick technical troubleshooting with interpersonal communication, working to resolve the issue while keeping the surgical team informed, focused, and coordinated. MPS_5 pointed to the unpredictability of the technical problems as a unique source of disruption: "*There's just some real random software bugs... you don't really know what causes half of them... you basically have to shut the whole robot down and power it back up again, which, depending on what point of the surgery you're in, can be a real hassle.*" These events not only threaten the timeline of the procedure but also place the MPS under heightened pressure to restore confidence and control quickly. In addition, MPS_5 followed up: "*Everyone's just kind of standing there watching you while you're trying to fix the problem... you're trying to maintain that façade that it's all good, even though it's obviously like stressful*" (MPS_5). This reflects a form of emotional labor where MPSs must manage both technical recovery and team perception under stress.

5 Discussion

This study contributes to the growing conversations in HCI and HRI about how HRC unfolds in real-world, high-stakes environments, such as surgery. Prior work has highlighted the benefits of surgical robots in improving precision and outcomes [10, 24], yet much of this literature focuses on the surgeon as the primary actor and interface user. Our findings build on and extend earlier HCI research on robot-mediated surgery [7–9, 23, 28–30], focusing on the experiences of MPSs, who are technical staff whose invisible labor enables effective collaboration between human and robotic agents.

5.1 Reframing Ergonomics in HRC

HCI research has often explored ergonomics in technology use, particularly in industrial and healthcare contexts. Our findings demonstrate that the integration of collaborative robots (albeit semi-autonomous), such as the Mako, generates new forms of physical and cognitive strain that are distinct from those seen in teleoperated systems, like the da Vinci. Whereas da Vinci removes the surgeon from the shared surgical space [9, 30], the Mako operates within that space and requires manual positioning, equipment transport, and close interaction; the Mako corrects surgical movement if a surgeon were to go outside the predefined boundaries during bone cuts. MPSs described how tasks such as robot positioning, troubleshooting, and equipment tracking placed high physical and mental demands on them, often exacerbated by unpredictable workflows and a lack of support from other hospital staff. HRC is frequently

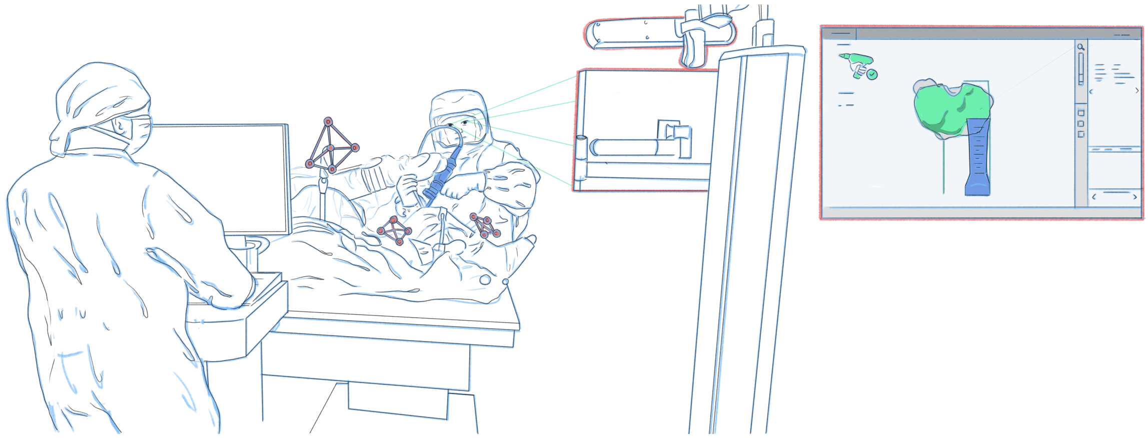

Figure 4: [Right] Experienced Mako surgeon looking at screen, instead of patient, while performing bone cuts (illustration by authors).

introduced to reduce the ergonomic burden of the (primary) user; however, these insights highlight a transference of ergonomic burden. Prior literature highlights how the Mako reduces both physical and cognitive strain in surgeons [1, 10, 13, 22, 23, 25, 36]; however, our findings reveal that other actors in the operating theatre, such as MPSs, are subject to an increased ergonomic burden. MPSs face substantial cognitive burdens, ranging from the demands of preoperative planning to intraoperative troubleshooting and managing complex, multifaceted roles within the operating theatre. This highlights the importance of examining not only the physical and ergonomic impacts of collaborative robots on users but also the cognitive and psychological dimensions of HRC [4, 36, 38].

These findings support existing concerns in HCI about the situated nature of human-robot ergonomics and the need for more context-sensitive system design (e.g., [19, 31, 32]). Rather than optimizing solely for primary users (e.g., surgeons), a more holistic approach to HRC design should account for the invisible, embodied work of crucial supporting roles.

5.2 Rethinking Surgical Teamwork

In HCI and HRI, collaborative work has long been understood as deeply socio-technical, where coordination, shared understanding, and familiarity are key to successful interaction [2, 7, 31]. Our findings extend this perspective to the surgical setting, showing how trust and rapport between MPSs and surgeons develop over time, enabling smoother collaboration. However, when team members are unfamiliar with the Mako system, MPSs often find themselves juggling technical tasks alongside informal training, all under the pressure of time constraints in the operating theatre. These dynamics reflect broader concerns in HCI regarding the design of ensemble practices rather than individual users [12]. They also draw attention to how institutional arrangements, like rotating teams or a lack of cross-role training, can unintentionally limit collaborative potential. In this context, the MPS takes on a boundary-spanning role, mediating between robotic technologies, surgical staff, and hospital protocols, yet often without sufficient structural support.

5.3 Human-Robot Collaboration as Socio-Technical Practice

Recent HCI research has called for moving beyond techno-centric views of HRC, advocating instead for more human-centred, practice-based perspectives [20–22, 38]. Our findings show that effective HRC in surgery is not just about how well the robot performs or how skilled the surgeon is. It also depends on subtle negotiations, tacit knowledge, and evolving relationships among team members. The design of the Mako system brings these dynamics to the surface, as it requires the ongoing presence, interpretation, and adaptation of the MPS throughout the procedure. By centering a peripheral yet essential actor, this study contributes to a more inclusive understanding of surgical HRC; one that sees robotic collaboration as distributed, contingent, and co-produced in the moment. These insights align with the broader HCI interest in in-the-wild research and highlight the need for design and qualitative approaches that account not only for how robots operate, but also for how teams work with them in practice.

6 Conclusion

This study has presented early insights into the experiences of Mako Product Specialists (MPSs), revealing how Human-Robot Collaboration (HRC) in surgical environments unfolds through the continuous negotiation of physical demands, cognitive load, and team dynamics. While robotic systems like the Mako are often evaluated in terms of their technical performance and clinical outcomes, our findings highlight that their successful use depends equally on the expertise, adaptability, and coordination of those who support them. By foregrounding the role of MPSs, technical staff who operate at the intersection of surgical workflows, robotic systems, and human teams, we extend existing HRC and surgical robotics literature toward a more inclusive, practice-informed perspective. The MPS's work often remains invisible, yet it is critical to maintaining fluency, trust, and safety in the operating theatre. Their experiences highlight the distributed and contingent nature of collaboration, as well as the social and institutional arrangements that shape what is possible in real-world HRC.

For the HCI and OzCHI communities, this research highlights the importance of investigating collaborative robotic systems in real-world settings. It shows that designing effective surgical robots is not just about enhancing individual performance but about supporting the collective practices and relationships that make robotic collaboration sustainable. As we continue to define what HRC means in healthcare and beyond, we must also reconsider who counts as a user, what kinds of labor are recognized, and how systems can be designed to support the whole ecology of human and non-human actors involved. Future work will build on these insights by extending the study to a larger and more diverse group of MPSs. In doing so, we aim to contribute to broader conversations about designing human-centred futures for collaborative robotics in healthcare.

Acknowledgments

The authors would like to acknowledge the support received through the following funding schemes of the Australian Government: ARC Industrial Transformation Training Centre (ITTC) for Collaborative Robotics in Advanced Manufacturing under Grant IC200100001.

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