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Surgical instrument counting

Current practice and staff perspectives on technological support

Kooijmans, A. M.; de Rouw, L.; van der Elst, M.; van den Dobbelsteen, J. J.

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Surgical instrument counting: Current practice and staff perspectives on technological support

A.M. Kooijmans [a,b,*], L. de Rouw [a], M. van der Elst [a,b], J.J. van den Dobbelsteen [a]

[a] Department of BioMechanical Engineering, Faculty of Mechanical Engineering, Technical University Delft, Delft, The Netherlands
[b] Department of Surgery, Reinier de Graaf Gasthuis, Delft, The Netherlands

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ABSTRACT

Background: Surgical instrument counting is a manual, attention-intensive task of the operating room (OR) nurse. Many labour-saving technologies have been proposed, but implementation remains challenging. Knowledge of current counting methods and staff preferences could guide future developments towards effective application.
Approach: We observed OR nurses counting materials and instruments in 50 surgical procedures performed by various surgical specialties in a regional teaching hospital in Delft, The Netherlands. Additionally, we surveyed them on their preferences concerning the methods of counting.
Key findings: Variations in approaches of surgical counting were observed, with OR nurses using multiple strategies and counting techniques to manage disruptions and limit workload. Interest in using supportive technology is limited to the preoperative and postoperative phase.
Relevance: This research relates observational data to staff preferences. Our findings may guide future developments of labour-saving innovations regarding surgical counting towards developing more effective applications and to ensure successful implementation.

1. Introduction

1.1. Background

Globally, healthcare is facing challenges which necessitate new strategies to save time and resources (Dutch National Institute for Public Health and the Environment (RIVM), 2020; World Health Organization, 2016). In this light, sustainable employability of personnel is becoming an increasingly discussed topic. *Labour-saving innovations* have the potential to improve workflows and thereby reduce workload, as well as save money, and improve quality of care. However, implementing these innovations remains challenging due to the complexity and dynamics of daily practice in healthcare. (Gupta Strategists, 2022)

Currently, operating room (OR) nurses manually keep track of all instruments and materials used during surgery with *instrument counting* (see Fig. 1 for an overview). Manual counting is a labour-intensive process, especially considering the complex and often acute conditions of an OR. According to AORN best practice principles, counting should be performed before the patient enters the OR (preoperative phase), during surgery (intraoperative phase), and during closure of the surgical wound (postoperative phase) (Cochran, 2022). It is recommended that two individuals perform these counts concurrently. There are three main categories of surgical materials, namely instruments (such as graspers, wound spreaders, or clamps), gauzes, and sharps (such as needles or cutting blades). Counting of these materials is done to prevent a retained surgical instrument (RSI). Despite processes, protocols, and the best intentions, RSI's still occur in 1 in 5500 to 1 in 18000 operations in general, and in up to 1 in 1000 intra-abdominal procedures, and could have serious consequences for patient outcomes, such as infection, reoperation, or even death (Cima et al., 2011; Dagi et al., 2007; Gawande et al., 2003). OR nurses alternate between the role of scrub nurse (sterile) and circulating nurse (unsterile). They are responsible for multiple tasks before, during, and after a surgical procedure (see Fig. 1). These responsibilities can occur simultaneously, sometimes causing interruptions. For instance, while counting materials, the circulating nurse might need to answer the surgeon's phone, or the scrub nurse might have to assist the surgeon. OR nurses try to find the best moments to count materials as to reduce the chance of disruptions. (Bubric et al., 2021; Edel, 2012)

Supporting technology, which can detect and recognise the instruments being used, could potentially reduce OR nurses' workload (Yamashita K, 2018), as well as improve OR workflow (Kranzfelder

* Corresponding author.
E-mail address: a.m.kooijmans@tudelft.nl (A.M. Kooijmans).

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et al., 2009; Toti et al., 2015). Potential uses beside automatic counting include preventive maintenance, automatic registration of used materials, and automatic OR scheduling (Hanada E, 2015; Meissner & Neumuth, 2012; Olivere et al., 2021). A large variety of technologies for various surgical materials have been investigated, such as data matrices (i.e., barcodes and QR codes) (Cima et al., 2011; Greenberg et al., 2008; Kranzfelder et al., 2009), weight sensors (Glaser et al., 2015; Webster et al., 2015), radiofrequency identification (RFID) sensors (Dinis H, 2015; Hanada E, 2015; Hill et al., 2022; Hosaka, 2019; Kranzfelder et al., 2013; Matsumura T, 2012; Neumuth & Meissner, 2012; Olivere et al., 2021; Rogers et al., 2007; Yamashita K, 2018; Zamith M, 2015), computer vision (Al Hajj H, 2017; Glaser et al., 2015; Hossain M, 2018; Lee et al., 2021; Nakano & Nagamune, 2022; Shimizu et al., 2021; Toti et al., 2015), and even robotics (Nakano & Nagamune, 2022; Zhou & Wachs, 2017). However, most solutions fall short in addressing the complexity of real-life OR conditions (Guedon et al., 2016). For instance, many studies were performed in a lab environment with ideal conditions or an approximation of OR conditions (Dinis H, 2015; Glaser et al., 2015; Hosaka, 2019; Kranzfelder et al., 2012; Nakano & Nagamune, 2022; Webster et al., 2015; Zhou & Wachs, 2017). Similarly, many proposed solutions interfere with regular surgical workflow, requiring specific instrument layouts, individual scanning of instruments, or a substantial setup time for each procedure (Greenberg et al., 2008; Hanada E, 2015; Hill et al., 2022; Kranzfelder et al., 2009; Lee et al., 2021; Olivere et al., 2021; Toti et al., 2015; Yamashita K, 2018; Zhou & Wachs, 2017).

Some empirical research on the performance of the surgical instrument count exists. Reported challenges that increase the probability of counting errors are interruptions and distractions (leading to multitasking), time pressure, and the pressure of an emergency procedure (Bubric et al., 2021; Edel, 2012; Fang et al., 2021; Warwick et al., 2021). Solutions are often sought in changing the dynamics of the OR environment: eliminating interruptions and distractions or performing audits to ensure strict protocol adherence.

1.2. Problem statement

The above-mentioned technologies are often considered to be a replacement for the OR nurse's work with the main goal of reducing RSIs. However, the question whether the use of technology actually reduces RSIs and increases patient safety is still topic for debate (Sirihorachai et al., 2022). The application of technology to reduce OR nurse's workload is currently not considered a priority, with some studies only briefly mentioning this topic (Weprin et al., 2021; Yamashita K, 2018). A broader analysis of the current counting practice and effective applications of counting technology from the OR nurse's perspective does not exist yet.

This study aims to analyse the current counting practice and explore OR nurse's preferred applications of technology in general to aid in counting. By observing OR nurses during their work and conducting a survey on their perspective, we gathered valuable data which could guide future development of adjunct instrument counting technology.

2. Methods

2.1. Study design

This work consists of two parts: an observational study combined with a survey. For the observations, we developed a data collection form based on the hospital's counting protocol (Appendix A), national guidelines and standards, relevant literature, and feedback from OR nurses. We formulated the survey questions to gauge the opinion of OR nurses on the current process of the instrument count and the potential of adjunct technology in it.

2.2. Study setting

This study took place in the OR complex of a regional teaching hospital in Delft, the Netherlands.

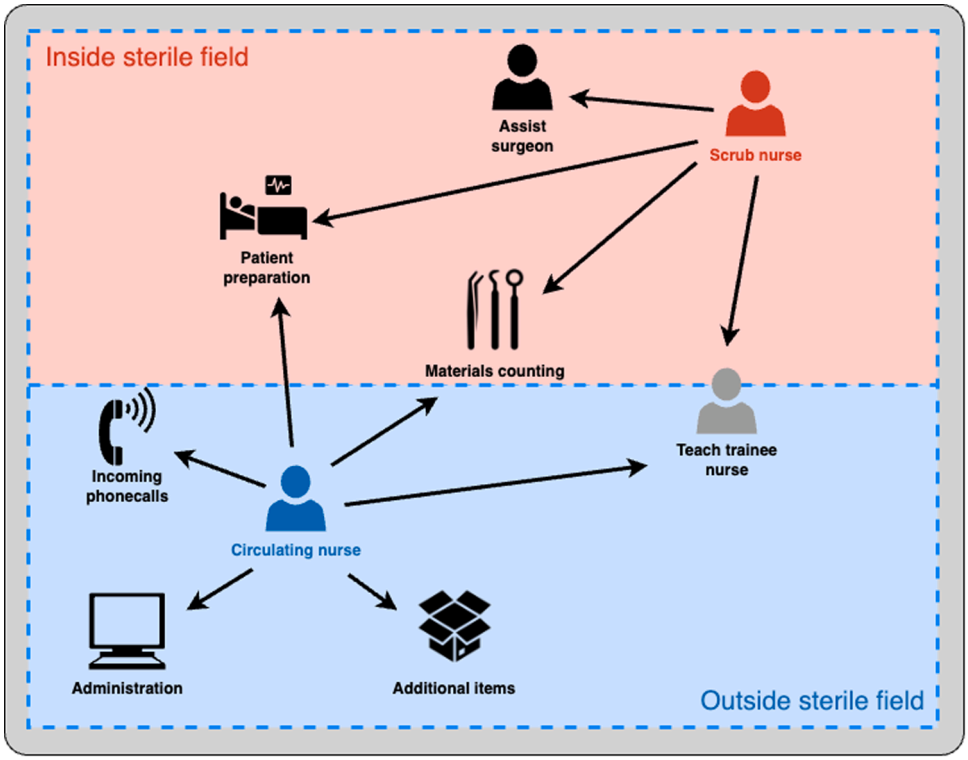

Fig. 1. OR nurses' responsibilities that may require attention during surgical material counting.

2.3. Data collection

We attended 50 surgical cases from various surgical specialties (see Table 1) between March and May 2023. Verbal consent was obtained from the OR team to observe the surgical counting performance, conduct a survey, capture images of surgical materials, and identify opportunities for technological applications. We aimed to minimise disruptions of the regular OR workflow. Personal data of OR staff and patients were not recorded.

Observations were structured according to a data collection form (see Appendix A). Descriptive data such as surgical specialty, nature of surgical procedure (elective or emergency), time of surgery, and number of instrument trays used were noted. Furthermore, we recorded how the counting of each type of surgical material (instruments, gauzes, sharps) was performed: location, number of staff involved, method used, occurrence of interruptions, and discrepancies.

Survey questions were administered to the current circulating nurse. As both OR nurses alternate the role of scrub nurse and circulating nurse, we could survey both OR nurses while minimising disruptions to the surgical procedure. Trainee nurses were excluded from this study. See Appendix B for an overview of the questions.

3. Results

Table 1 shows baseline characteristics. Across all 50 observed procedures, 87 instrument trays were used (1-7 trays per procedure).

3.1. Observations

3.1.1. Location

The location of the counting process varied only in the preparation phase, as can be seen in Fig. 2. In general, preparations were done in the preparation room, except for ENT procedures. It was explained to the researcher that these surgeries are inherently unsterile and thus allow the preparation to be carried out in the OR itself, thereby saving time. All other instances of counting during and after surgery occurred within the OR.

3.1.2. Number of staff counting

Instruments were checked and counted only by the scrub nurse in each phase of surgery (preoperative, intraoperative, postoperative). The circulating nurse was not available for assistance in any of the cases. In some cases, a nearby logistics worker was able to assist.

Sharp materials such as needles were counted intraoperatively if needed, and upon closing of the surgical wound. In 32 cases, sharp materials were used. Procedures that did not use sharps were for example microscopic laryngeal surgeries, in which microscopic instruments are used. A total of 39 counting instances were observed, of which 36 (92%) were performed by two persons.

Gauzes were counted in all phases of surgery. In 9 cases, gauzes were not counted (microscopic instruments were used, or incision was deemed too small to lose gauze). Of 36 initial gauze counts observed, 33 (92%) were done by two persons. Intraoperative gauze counting occurred in 9 cases, of which 7 (78%) were performed by two persons. Three cases required a second intraoperative count, two of which were done by two persons. 39 closing counts were observed, of which 34 (87%) were performed by two people. In total, 87 instances of gauze counting were observed, of which 76 (87%) were done by two persons (see Fig. 3).

Across both gauzes and sharps, 14 instances of counting were done by one person. Eight instances occurred during vascular surgical procedures, three during trauma surgery, two in gynaecology, and one in orthopaedics. Of these, three occurred during emergency procedures.

Table 1
Observed surgical procedures.

Surgical specialty	Frequency	Percentage
Ear-nose-throat (ENT)	14	28%
Trauma surgery	11	22%
Vascular surgery	7	14%
Gynaecology	6	12%
Robot general surgery	5	10%
General surgery	4	8%
Orthopaedic surgery	2	4%
Plastic surgery	1	2%
Nature of procedure	Frequency	Percentage
Elective	47	94%
Emergency	3	6%

3.1.3. Counting method used

Surgical instrument counting techniques varied between nurses and instrument tray arrangements. For loosely arranged trays, scrub nurses focused on keeping track of the number of instruments removed from the surgical tray by placing them on the instrument table in even numbers or pairs, to 'facilitate memorisation and ease of counting'. Similarly, some practitioners group instruments by threading a specific number of them through one instrument's ear.

In most surgeries, a complete count of all instruments present is not carried out. Only instruments that are prepared on the instrument table are counted, also known as a *partial count*. A precise scissor count is conducted exclusively in abdominal procedures (general surgery and gynaecology). Fragile instruments were placed in specifically arranged trays with silicone clips. By scanning these, the nurses could determine if the surgical tray was complete. The number of surgical trays equipped with silicone clips could not be determined.

After use, instruments were returned to the instrument table if they might be needed again. If they were not needed anymore, they were returned to the tray intermittently, during moments where the surgeon did not need assistance at the surgical site (see Fig. 4). The nurse kept track of the instruments using the same counting techniques as during the preparation, returning them in pairs, and checking if all silicone clips were occupied. The nurses explained that this technique saves time, as all instruments are accounted for as they are returned to their tray, instead of having to perform a complete check after the procedure has concluded.

Sharps and gauzes were counted using the following method in all cases. Whenever new materials were added to the sterile field, their amounts were noted on the OR's whiteboard. When counting was necessary, the materials were counted and checked with the noted amount.

3.1.4. Occurrence of interruptions

The process of returning and counting of instruments was interrupted on many occasions, mostly due to the surgeon requesting assistance or a specific instrument from the scrub nurse. We noted interruptions in 29 cases (58%), with a total of 41 interruptions, and a maximum of 6 in a single case. Fig. 5b shows that the number of interruptions increases with the number of trays in use.

The number of interruptions increased with the number of surgical instrument trays in use. Instrument counting was most often interrupted during orthopaedic procedures. During counting of gauzes and sharp materials, a total of four interruptions were noted. Afterwards, counting was restarted from the beginning.

3.1.5. Discrepancies

During preparation, a full inspection with each tray's accompanying contents list was deemed unnecessary. Trays arrived from the sterilisation department wrapped in either blue or green wrapping paper. Blue paper indicated a complete tray, and green paper indicated a missing instrument. The contents lists were only used when a shortcoming such as a defective or missing instrument was noticed, which occurred in 8% of cases.

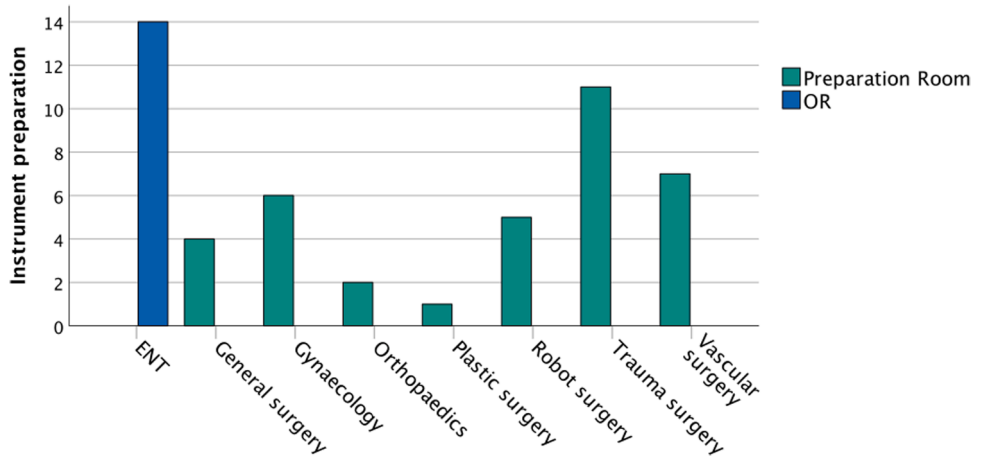

Fig. 2. Preparation location of surgical instruments. All ENT preparations took place in the OR itself, while all other specialties used the preparation room.

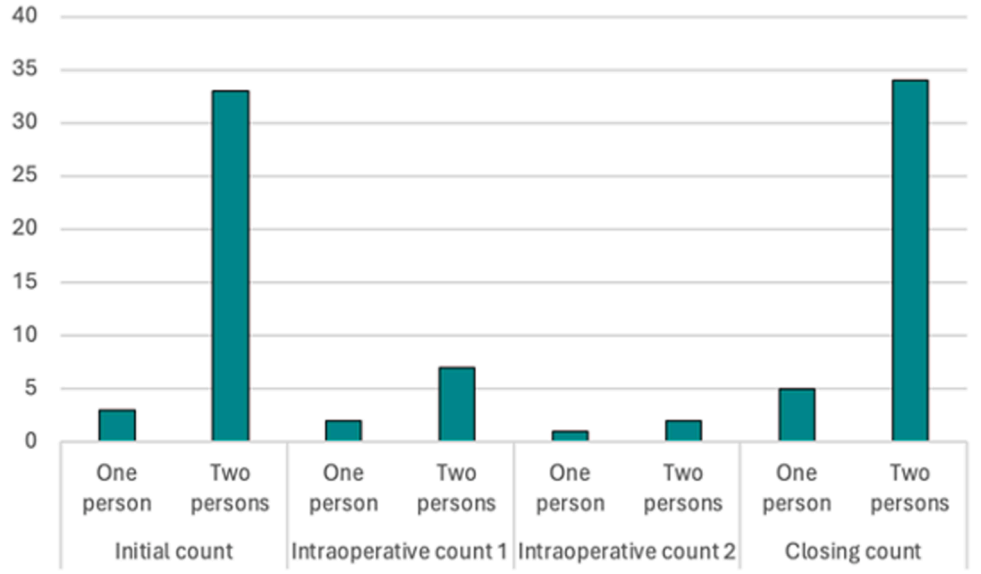

Fig. 3. Number of counting instances of gauzes, shown per phase of surgery.

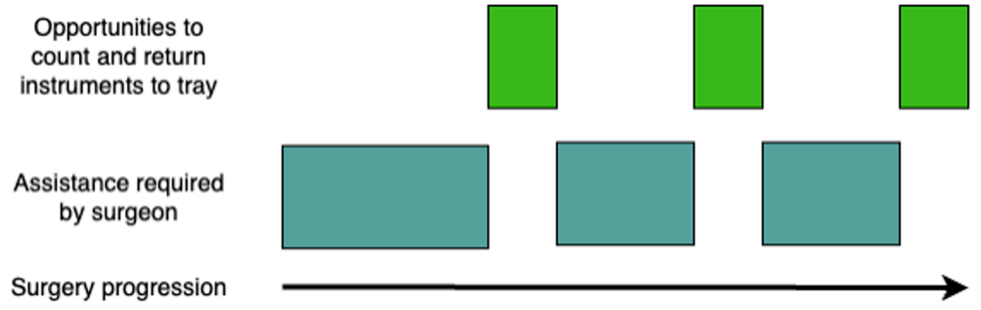

Fig. 4. Representation of scrub nurse's opportunities to count and return surgical instruments to their tray during surgery.

In eight cases (16%), an additional surgical tray was opened (see Table 2). Five were opened in the preoperative phase and three were opened during surgery. During the preoperative phase, additions were necessary to replace an incorrect instrument or part of an instrument, or to replace a missing instrument. During surgery, additions were done because an instrument fell on the floor, or because the surgeon preferred a different instrument. The researcher could not determine the reason for one addition. In all cases, the issues were resolved before the instrument in question interacted with the patient. During closing of the wound, all instruments were complete in all cases.

Regarding gauzes and sharp materials, some counting discrepancies occurred during the final count of surgery. In two cases, a gauze was misplaced, and in one case a needle was misplaced. All misplaced items were found, and counts were reconciled. All three cases occurred during elective procedures (general surgery, vascular surgery, gynaecology) with two people carrying out the count.

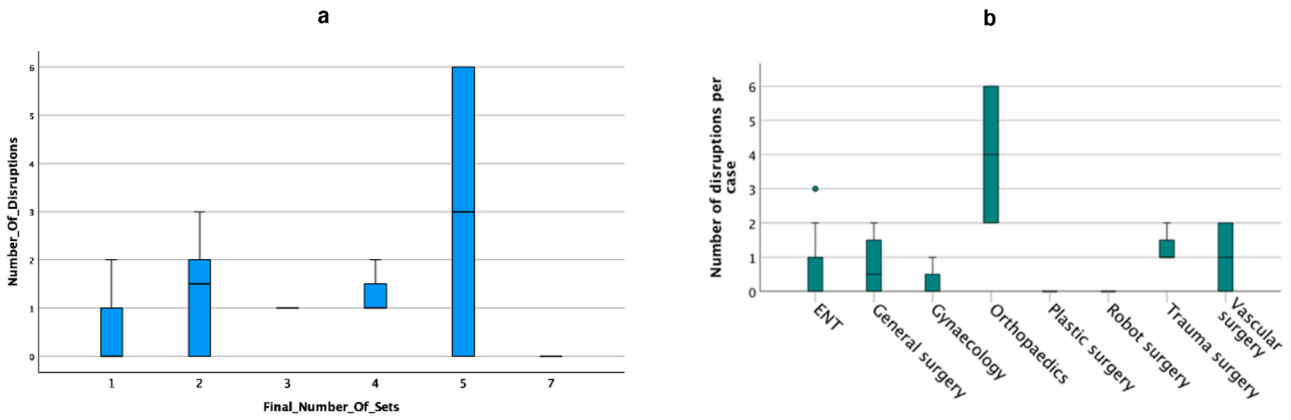

Fig. 5. a (left) The number of disruptions during counting and returning of instruments, related to the final number of surgical trays used. No procedures were observed where six trays were used. **b (right)** The number of disruptions related to surgical specialty.

Table 2
Reasons for opening additional surgical instrument trays and their frequency.

Reason for additional tray	Frequency
Incorrect instrument or part of instrument	3
Missing instrument	2
Instruments not in accordance with surgeon's preference	1
Unsterile instrument	1
Reason unknown	1

3.2. Survey

Key findings will be discussed below. For a complete overview of the survey questions and results, see Appendix B.

3.2.1. Key findings

In total, 21 nurses participated in this survey. 39% of nurses indicate they do not count the entire surgical tray before surgery. 60% of nurses experience an increased workload while counting surgical instruments, with the number of surgical trays being the most important reason (62%).

Most nurses (85%) see potential in reconfiguring the counting process to be more efficient, and all nurses are open to the use of technology, but only in the preoperative and postoperative phase of a procedure. None of the participants would be willing to use technology to aid in counting during surgery, as they consider that an unwanted additional distraction.

4. Discussion

In this study, we observed a wide variety of procedures: from open to minimally invasive surgery, and from elective to emergency procedures. While the hospital's surgical item counting protocol was developed according to the best practice principles as laid out in the AORN guidelines (Cochran, 2022), counting processes are tailored to the needs and requirements of specific surgeries, to maintain an efficient workflow while ensuring patient safety.

The preoperative check of instrument trays is often adjusted to a specific procedure and its requirements. When procedures are inherently unsterile, as is the case with ENT procedures, the team bypasses the PR, thus saving time. Sometimes performed by the scrub nurse only, workload is managed by only counting instruments taken out of a tray to be placed on the instrument table, also known as a partial count. Abdominal procedures carry a greater risk for instrument loss and warrant a more precise scissor count. While the use of partial counting enables OR nurses to manage workload and save time, the addition of a tray during surgery was necessary in some cases, of which at least one could have been prevented in the preparation phase. While these approaches did not cause harm to the patients, there is potential for improvement. Instead of performing the preoperative check by themselves, technology might function as a second person would, providing an extra layer of security.

During surgery, nurses look for the best moments to count instruments and materials, when the circulating nurse is available to assist, and the probability of being interrupted is low. These conditions can not always be met, as the circulating nurse may have other responsibilities, and interruptions are difficult to predict. Despite this, the survey shows that nurses are quite satisfied with the current intra-operative counting process. The team members generally are quite attuned to each other, and often work in a state of elevated focus or 'flow'. The counting discrepancies that we observed occurred in relatively routine cases under favourable conditions – i.e. in elective surgery, and with two persons counting - where task familiarity and repetitiveness could play a more prominent role. As OR nurses do not want technology during the intra-operative phase, interventions to limit this task familiarity, such as an environment redesign or workflow changes could be considered. Considering post-pandemic changes in personnel makeup, and the fact that trainee nurses were excluded from our observations, it would be interesting to investigate team dynamics such as flow state and task repetitiveness in the new generation of operating room nurses.

Postoperatively, a final count is not performed, as all instruments have already been accounted for when they were returned to the tray intermittently. It was explained that manually performing a complete check would add more time to the procedure. This is in line with the partial counting method that is used. Like the preoperative phase, technology might provide an extra layer of security. Replacing manual counting completely would go against OR nurses' preferences.

Most research efforts to develop a tracking system for surgical materials focus on gauzes with barcodes or RFID sensors attached to them. However, the effectivity of these solutions remains topic for debate (Sirihorachai et al., 2022). When looking from the OR nurse's perspective, a similar sentiment is seen. While gauzes are the most frequently lost item in surgical procedures, only 27% of OR nurses would be willing to use technology to assist in counting them. It seems that counting gauzes is considered a core responsibility of the OR nurse, as errors have a direct effect on patient outcomes. This direct effect on patient outcomes could influence the openness to change or use of technology in specific counting processes. Further research should be done to investigate this possible relation.

4.4. Limitations

All observations were done in one hospital, which limits broader

applicability of our findings. Similarly, the observations were performed by one researcher (LR), which might have had a negative effect on noting intricacies of the counting performance. We have not used a standardized tool to measure workload such as the NASA-TLX (Hart & Staveland, 1988), and as such, conclusions that can be drawn are limited, highlighting the need for further research. Furthermore, we have not collected personal, descriptive data on the OR nurses, which could have provided insight into their working methods and preferences in relation to experience.

5. Conclusion

In this study, we explored surgical instrument counting from a practical perspective. We observed that OR nurses are faced with challenges that limit their ability to follow theoretical best practice principles. Depending on the specific requirements of each surgical procedure, various strategies and counting techniques are used to maintain an efficient workflow and limit workload. There is considerable interest in reconfiguring the counting workflow in the preoperative and postoperative phase among OR nurses, where they see potential for technology to assist in counting surgical instruments rather than gauzes or needles. There is little interest in the use of counting technology during a surgical procedure. This paper is the first to consider the instrument count and the place of counting technology from a workload perspective.

Implications and Applications

It has been put into question before whether the use of counting technology during a surgical procedure increases patient safety (Greenberg et al., 2008; Gunnar W, 2020), and our research suggests there is an obvious similar sentiment among OR nurses. Instead, there is substantial interest in applying counting technology to the preoperative and postoperative phase to alleviate workload. Performing a complete count of all instruments before and after a surgery is a time-consuming task which is currently managed with various strategies and counting techniques. Applying technology to these specific parts of the counting workflow could be a more effective way to improve OR processes and alleviate OR nurse's workload.

CRediT authorship contribution statement

A.M. Kooijmans: Writing – review & editing, Writing – original draft, Visualization, Supervision, Methodology, Data curation, Conceptualization. **L. de Rouw:** Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation. **M. van der Elst:** Writing – review & editing, Supervision, Resources, Project administration, Conceptualization. **J.J. van den Dobbelsteen:** Writing – review & editing, Supervision, Resources, Conceptualization.

Declarations competing interests

The authors declare no competing interests.

Impact Statement

Development and implementation of surgical instrument counting technology remains a challenge. This study shows that potential solutions should emphasise supporting OR staff in the preoperative and postoperative phase, rather than focus on intra-operative counting.

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Data availability statement

The data that support the findings of this study are not openly available due to reasons of sensitivity and are available from the corresponding author upon reasonable request.

Ethical approval

Not applicable.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.hfh.2024.100087.

References

Al Hajj, H, L, M., Cochener, B, & Quellec, G (2017). Smart data augmentation for surgical tool detection on the surgical tray Annu. In *Int Conf IEEE Eng Med Biol Soc*.

Bubric, K. A., Biesbroek, S. L., Laberge, J. C., Martel, J. A., & Litvinchuk, S. D. (2021). Prevalence and characteristics of interruptions and distractions during surgical counts. *Joint Commission Journal on Quality and Patient Safety, 47*(9), 556–562. https://doi.org/10.1016/j.jcjq.2021.05.004

Cima, R. R., Kollengode, A., Clark, J., Pool, S., Weisbrod, C., Amstutz, G. J., & Deschamps, C. (2011). Using a data-matrix-coded sponge counting system across a surgical practice: Impact after 18 months. *Joint Commission Journal on Quality and Patient Safety, 37*(2), 51–58. https://doi.org/10.1016/s1553-7250(11)37007-9

Cochran, K. (2022). Guidelines in practice: Prevention of unintentionally retained surgical items. *AORN Journal, 116*(5), 427–440. https://doi.org/10.1002/aorn.13804

Dagi, T. F., Berguer, R., Moore, S., & Reines, H. D. (2007). Preventable errors in the operating room–part 2: Retained foreign objects, sharps injuries, and wrong site surgery. *Current Problems in Surgery, 44*(6), 352–381. https://doi.org/10.1067/j.cpsurg.2007.04.002

Dinis, H, Z, M., & Mendes, PM (2015). Performance assessment of an RFID system for automatic surgical sponge detection in a surgery room. In *Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE Engineering in Medicine and Biology Society. Annual International Conference.*.

Dutch National Institute for Public Health and the Environment (RIVM). (2020). *Naar een toekomstbestendig zorgstelsel*. https://www.rijksfinancien.nl/bmh/bmh-2-naar-een-toekomstbestendig-zorgstelsel.pdf. Accessed on 4-10-2023.

Edel, E. M. (2012). Surgical count practice variability and the potential for retained surgical items. *AORN Journal, 95*(2), 228–238. https://doi.org/10.1016/j.aorn.2011.02.014

Fang, J., Yuan, X., Fan, L., Du, M., Sui, W., Ma, W., Wang, H., & Pan, A. F. (2021). Risk factors for incorrect surgical count during surgery: An observational study. *International Journal of Nursing Practice, 27*(4), e12942. https://doi.org/10.1111/ijn.12942

Gawande, A. A., Studdert, D. M., Orav, E. J., Brennan, T. A., & Zinner, M. J. (2003). Risk factors for retained instruments and sponges after surgery. *The New England Journal of Medicine, 348*, 229–235.

Glaser, B., Danzer, S., & Neumuth, T. (2015). Intra-operative surgical instrument usage detection on a multi-sensor table. *International Journal of Computer Assisted Radiology and Surgery, 10*(3), 351–362. https://doi.org/10.1007/s11548-014-1066-0

Greenberg, C. C., Diaz-Flores, R., Lipsitz, S. R., Regenbogen, S. E., Mulholland, L., Mearn, F., Rao, S., Toidze, T., & Gawande, A. A. (2008). Bar-coding surgical sponges to improve safety: A randomized controlled trial. *Annals of Surgery, 247*(4), 612–616. https://doi.org/10.1097/SLA.0b013e3181656cd5

Guedon, A. C., Wauben, L. S., van der Eijk, A. C., Vernooij, A. S., Meeuwsen, F. C., van der Elst, M., Hoeijmans, V., & Dankelman, J. (2016). Where are my instruments? Hazards in delivery of surgical instruments. *Surgical Endoscopy, 30*(7), 2728–2735. https://doi.org/10.1007/s00464-015-4537-7

Gunnar, W, S, C., Lynn, MM, Neily, J, Tesema, Y, & Nylander, W (2020). The impact of surgical count technology on retained surgical items rates in the veterans health administration. *Journal of Patient Safety, 16*(4), 255–258. https://doi.org/10.1097/PTS.0000000000000656

Gupta Strategists. (2022). *Uitweg uit de Schaarste (Dutch report)*. https://gupta-strategists.nl/studies/uitweg-uit-de-schaarste Accessed on 10-04-2023.

Hanada, E, O, A., Hayashi, M, & Sawa, T (2015). Improving efficiency through analysis of data obtained from an RFID tag system for surgical instruments. *IEEE 5th International Conference on Consumer Electronics*.

Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. *Human Mental Workload* (pp. 139–183). https://doi.org/10.1016/s0166-4115(08)62386-9

Hill, I., Olivere, L., Helmkamp, J., Le, E., Hill, W., Wahlstedt, J., Khoury, P., Gloria, J., Richard, M. J., Rosenberger, L. H., & Codd, P. J. (2022). Measuring intraoperative surgical instrument use with radio-frequency identification. *JAMIA Open, 5*(1), ooac003. https://doi.org/10.1093/jamiaopen/ooac003

Hosaka, R. (2019). Development of identification system for surgical instruments using UHF band RFID and low-intensity antennae. *World Congress on Medical Physics and Biomedical Engineering 2018*, 39–43. https://doi.org/10.1007/978-981-10-9038-7_8

Hossain, M, N, S., Hiranaka, T, & Kobashi, S (2018). Real-time surgical tools recognition in total knee arthroplasty using deep neural networks. In *Joint 7th International Conference on Informatics, Electronics & Vision (ICIEV) and 2nd International Conference on Imaging, Vision & Pattern Recognition (icIVPR)*. Kitakyushu, Japan.

Kranzfelder, M., Schneider, A., Blahusch, G., Schaaf, H., & Feussner, H. (2009). Feasibility of opto-electronic surgical instrument identification. *Minimally Invasive Therapy & Allied Technologies : MITAT : Official Journal of the Society for Minimally Invasive Therapy, 18*(5), 253–258. https://doi.org/10.1080/13645700903053717

Kranzfelder, M., Schneider, A., Fiolka, A., Schwan, E., Gillen, S., Wilhelm, D., Schirren, R., Reiser, S., Jensen, B., & Feussner, H. (2013). Real-time instrument detection in minimally invasive surgery using radiofrequency identification technology. *The Journal of Surgical Research, 185*(2), 704–710. https://doi.org/10.1016/j.jss.2013.06.022

Kranzfelder, M., Zywitza, D., Jell, T., Schneider, A., Gillen, S., Friess, H., & Feussner, H. (2012). Real-time monitoring for detection of retained surgical sponges and team motion in the surgical operation room using radio-frequency-identification (RFID) technology: a preclinical evaluation. *The Journal of Surgical Research, 175*(2), 191–198. https://doi.org/10.1016/j.jss.2011.03.029

Lee, J.-D., Chien, J.-C., Hsu, Y.-T., & Wu, C.-T. (2021). Automatic surgical instrument recognition—a case of comparison study between the faster R-CNN, Mask R-CNN, and single-shot multi-box detectors. *Applied Sciences*, (17), 11. https://doi.org/10.3390/app11178097

Matsumura, T, T, M., Saito, K, Yamamoto, E, & Ito, K (2012). *Performance evaluations on RFID tag antenna for managing surgical instrument International Conference on Electromagnetics in Advanced Applications*. South Africa: Cape Town.

Meissner, C., & Neumuth, T. (2012). RFID-based surgical instrument detection using Hidden Markov models. *Biomedizinische Technik. Biomedical engineering, 57*. https://doi.org/10.1515/bmt-2012-4047

Nakano, A., & Nagamune, K. (2022). A Development of robotic scrub nurse system - Detection for surgical instruments using faster region-based convolutional neural network. *Journal of Advanced Computational Intelligence and Intelligent Informatics, 26*(1), 74–82. https://doi.org/10.20965/jaciii.2022.p0074

Neumuth, T., & Meissner, C. (2012). Onlinerecognition of surgical instruments by information fusion. *International journal of Computer Assisted Radiology and Surgery, 7*(2), 297–304. https://doi.org/10.1007/s11548-011-0662-5

Olivere, L. A., Hill, I. T., Thomas, S. M., Codd, P. J., & Rosenberger, L. H. (2021). Radiofrequency identification track for tray optimization: An instrument utilization pilot study in surgical oncology. *Journal of Surgical Research, 264*, 490–498. https://doi.org/10.1016/j.jss.2021.02.049

Rogers, A., Jones, E., & Oleynikov, D. (2007). Radio frequency identification (RFID) applied to surgical sponges. *Surgical Endoscopy, 21*(7), 1235–1237. https://doi.org/10.1007/s00464-007-9308-7

Shimizu, T., Hachiuma, R., Kajita, H., Takatsume, Y., & Saito, H. (2021). Hand motion-aware surgical tool localization and classification from an egocentric camera. *Journal of imaging, 7*(2). https://doi.org/10.3390/jimaging7020015

Sirihorachai, R., Saylor, K. M., & Manojlovich, M. (2022). Interventions for the prevention of retained surgical items: A systematic review. *World Journal of Surgery, 46*(2), 370–381. https://doi.org/10.1007/s00268-021-06370-3

Toti, G., Garbey, M., Sherman, V., Bass, B., & Dunkin, B. (2015). A smart trocar for automatic tool recognition in laparoscopic surgery. *Surgical Innovation, 22*(1), 77–82. https://doi.org/10.1177/1553350614531659

Warwick, V. R., Gillespie, B. M., McMurray, A., & Clark-Burg, K. G. (2021). Undertaking the surgical count: An observational study. *Journal of Perioperative Nursing, 34*(3). https://doi.org/10.26550/2209-1092.1089

Webster, R. J., Yaniv, Z. R., Glaser, B., Schellenberg, T., Franke, S., Dänzer, S., & Neumuth, T. (2015). *Surgical instrument similarity metrics and tray analysis for multi-sensor instrument identification* Medical Imaging 2015: Image-Guided Procedures. *Robotic Interventions, and Modeling*.

Weprin, S., Crocerossa, F., Meyer, D., Maddra, K., Valancy, D., Osardu, R., Kang, H. S., Moore, R. H., Carbonara, U., F, J. K., & Autorino, R (2021). Risk factors and preventive strategies for unintentionally retained surgical sharps: A systematic review. *Patient Safety in Surgery, 15*(1), 24. https://doi.org/10.1186/s13037-021-00297-3

World Health Organization. (2016). *Global strategy on human resources for health: Workforce 2030*. https://iris.who.int/bitstream/handle/10665/250368/9789241511131-eng.pdf Accessed on 8-11-2023.

Yamashita, K, K, K., Ito, Y, Komino, M, Tanaka, K, Kurokawa, S, Ameya, M, Eba, D, Masamune, K, Muragaki, Y, Ohta, Y, Rinoie, C, Yamada, K, & Sawa, Y (2018). Evaluation of surgical instruments with radiofrequency identification tags in the operating room. *Surgical Innovation, 25*(4), 374–379. https://doi.org/10.1177/1553350618772771

Zamith, M, & M, P (2015). Towards an RFID microsystem for surgical instrument detection using millimeter waves. In *IEEE 4th Portuguese Meeting on Bioengineering (ENBENG)*. Porto, Portugal.

Zhou, T., & Wachs, J. P. (2017). Needle in a haystack: Interactive surgical instrument recognition through perception and manipulation. *Robotics and Autonomous Systems, 97*, 182–192. https://doi.org/10.1016/j.robot.2017.08.013