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Research article

# Behind the pattern: General surgery residsent autonomy in robotic surgery

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## ABSTRACT

*Objective:* Robotic surgery is increasingly utilized and common in general surgery training programs. This study sought to better understand the factors that influence resident operative autonomy in robotic surgery. We hypothesized that resident seniority, surgeon work experience, surgeon robotic-assisted surgery (RAS) case volume, and procedure type influence general surgery residents' opportunities for autonomy in RAS as measured by percentage of resident individual console time (ICT).

*Methods:* General surgery resident ICT data for robotic cholecystectomy (RC), inguinal hernia (RIH), and ventral hernia (RVH) operations performed on the dual-console Da Vinci surgical robotic system between July 2019 and June 2021 were extracted. Cases with postgraduate year (PGY) 2–5 residents participating as a console surgeon were included. A sequential explanatory mixed-methods approach was undertaken to explore the ICT results and we conducted secondary qualitative interviews with surgeons. Descriptive statistics and thematic analysis were applied.

*Results:* Resident ICT data from 420 robotic cases (IH 200, RC 121, and VH 99) performed by 20 junior residents (PGY2-3), 18 senior residents (PGY4-5), and 9 attending surgeons were extracted. The average ICT per case was 26.8 % for junior residents and 42.4 % for senior residents. Compared to early-career surgeons, surgeons with over 10 years' work experience gave less ICT to junior (18.2 % vs. 32.0 %) and senior residents (33.9 % vs. 56.6 %) respectively. Surgeons' RAS case volume had no correlation with resident ICT ($r = 0.003$, $p = 0.0003$). On average, residents had the most ICT in RC (45.8 %), followed by RIH (36.7 %) and RVH (28.6 %). Interviews with surgeons revealed two potential reasons for these resident ICT patterns: 1) Surgeon assessment of resident training year/experience influenced decisions to grant ICT; 2) Surgeons' perceived operative time pressure inversely affected resident ICT.

*Conclusions:* This study suggests resident ICT/autonomy in RC, RIH, and RVH are influenced by resident seniority level, surgeon work experience, and procedure type, but not related to surgeon RAS case volume. Design and implementation of an effective robotic training program must consider the external pressures at conflict with increased resident operative autonomy and seek to mitigate them.

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## 1. Background

Robotic-assisted surgery (RAS) is the use of a robotic operative assistant controlled via a console to perform operations. Since its introduction, the use of robotic-assisted surgery (RAS) has rapidly increased [1], bringing to question how surgeons and surgical residents can be best trained to perform RAS proficiently and independently. Likewise, few validated training curriculum and evaluation instruments are available to systematically assess residents' surgical proficiency and autonomy in RAS procedural components [2,3]. Some studies examining learning curves suggest that 20–25 RAS cases are required for surgeons to achieve proficiency with a dual-console system [4] and 50 cases with a single-console system [5]. However, such estimations may not apply to general surgery residents because training in the operating room (OR) is a type of situated learning [6]. Differences in content (e.g., case complexity), context (e.g. operate under an attending surgeon's supervision), and social interaction (e.g., OR team support) between RAS performed by attending surgeon and those by resident may derail this estimated learning curve.

Varying levels of supervision may lead to lack of opportunities for independent practice and autonomy [7]. Resident autonomy is the progressive development of appropriate increased responsibility and decision-making by surgical trainees. Although measurement tools of resident autonomy in RAS are in the process of development/validation, automated objective measures (e.g., time, instrument movement) demonstrate a good potential in assessing intraoperative autonomy [8]. Moreover, a predominant concern regarding RAS is its relatively high cost compared to laparoscopic equivalents. Cost concerns may lead to pressure to shorten RAS operative time, in turn undermining residents' learning and practice opportunities in RAS [9–11].

Existing studies of surgical resident autonomy in robotic surgery have identified barriers such as lack of effective intraoperative teaching and expectation mismatch between trainees and faculty [12,13]. Although additional factors influencing resident autonomy and entrustment are not yet well investigated in robotic-assisted surgery, many studies have identified these in traditional laparoscopic and open surgery. Autonomy and entrustment have been correlated with resident postgraduate year (PGY), resident skill, and attending surgeon experience, as well as possible interventions for improvement [14–19]. As expected, surgical residents' self-reported intraoperative autonomy tends to increase with PGY level, especially in laparoscopic and open index surgical procedures [20]. However, it is unclear whether similar trends of resident intraoperative autonomy would be observed in RAS cases given that 1) these previous studies do not separate RAS from laparoscopic surgeries, 2) RAS is a new surgical technique with a comparatively small case volume, and 3) unlike laparoscopic or open surgery, RAS typically requires one surgeon to be the solely operating surgeon, resulting in possible differences in development of autonomy during training. We sought to better understand resident learning and practice patterns in RAS, as well as to explore the factors influencing how attending surgeons grant residents time to learn and practice RAS in the OR. This study is the first to explore attending surgeon considerations on resident intraoperative autonomy in RAS by utilizing a mixed-methods approach, combining semi-structured interviews with objective RAS console data.

We hypothesized that general surgery resident seniority level (assessed by PGY), surgeon work experience (assessed by year), surgeon RAS case volume, and procedure type influence residents' opportunity for autonomy granted by attending surgeons. These factors involve both attending surgeon comfort with each procedure as well as the anticipated competence of the surgical resident. Autonomy was defined as the percentage of resident individual console time (ICT) in each RAS case and examined three common RAS procedures: robotic cholecystectomy (RC), robotic inguinal hernia repair (RIH), and robotic ventral hernia repair (RVH).

## 2. Methods

### *2.1. Study design, participants, and setting*

Thought ICT is an objective measure showing a pattern of resident's practice time in the OR, it is unable to reflect potential subjective factors that may influence such a learning/teaching process, especially attending surgeons' decision-making on resident autonomy. Therefore, we chose a two-phase explanatory sequential mixed-methods study design to better understand surgery residents' ICT patterns and potential reasons behind these patterns from the attending surgeon as intraoperative teacher and supervisor perspective. In Phase 1, a retrospective quantitative analysis of resident objective ICT data; in Phase 2, interviews with attending surgeons who were included in the Phase 1 ICT data to better understand the ICT patterns via a purposeful sampling approach. The mixed-methods approach was chosen as a novel approach to understand attending surgeon motivations in RAS, which have not been previously explored in the literature. All attending surgeons were faculty in the Ohio State University (OSU) Department of Surgery. All resident participants were from OSU General Surgery residency, which is an Accreditation Council for Graduate Medical Education (ACGME) accredited residency training program. This program has seven categorical general surgery residents each year, and residents undergo a formal RAS simulation curriculum in their PGY1 year. The Institution Review Board (IRB) approved this study (2021H0154). All participants voluntarily participated in the study. Verbal consent was obtained from each participant per the IRB protocol.

### *2.2. Data collection and analysis*

#### *2.2.1. Quantitative approach*

General surgery resident real-time tracking ICT per case, which was recorded by the Da Vinci® surgical system (Intuitive Surgical Inc, Sunnyvale, CA), were retrospectively extracted from RAS procedures between July 2019 and June 2021. Parameters extracted included active console time, operation performed, operating surgeon and resident and total case time. This is a detailed objective measurement of surgical processes, which represents a significant advancement in surgical education research. Only cases in which a

PGY 2–5 resident participated as a console surgeon were included, as PGY 1 residents do not operate as console surgeon at this training program. No residents were excluded. Resident and attending surgeon information was obtained from departmental administrative records. For the purposes of analysis, PGY2-3 residents were classified as junior residents and PGY4-5 residents as senior residents. Attending surgeons' work experience was defined based on number of years the surgeon had worked as an independent licensed surgeon since graduation from residency/fellowship training; surgeons with fewer than 10 years' experience were considered early-career surgeons, and surgeons with more than 10 years' experience were considered late-career surgeons. Surgeon RAS case volume was calculated based on the number of RAS cases they had completed by June 2021. Resident ICT was defined as the percentage of active console time (i.e., when the resident's console had control over the operative arms) per case; total case length refers to the time between the robotic console being "on" and "off".

Three core RAS index procedures were included in the analysis: RC, RIH, and RVH, chosen because they are common surgical operations with which general surgery residents should be familiar, and because they are frequently enough encountered that trainees should have an opportunity to serve as the console surgeon rather than bedside assistant. Descriptive statistical analysis and *t*-test was conducted to examine resident robotic console time trends by PGY levels and procedures. All ICT data with intact dual-console data was included. All statistical analyses were performed using JMP, version 16.0 (SAS Institute Inc).

#### 2.2.2. Qualitative approach

We performed purposeful recruitment of attending surgeons for secondary individual interviews after reviewing the preliminary results of resident ICT data. We intentionally selected attending surgeons who represented 1) different divisions, 2) different experience levels, 3) different RAS case volumes, and 4) both genders available. Each interview took approximately 30 min and focused on two key interview questions: 1) their reasoning for allowing a resident time to operate as the console surgeon on a RAS case and 2) what factors they felt impacted their actions of increasing and/or decreasing resident ICT in a case. These questions were chosen to explore potential differences in responses from attending surgeons.

All interviews were audio-recorded, de-identified, and transcribed. Interviews were conducted via video conferencing software (Zoom Video Communications, Inc, San Jose, CA). Three investigators (XC, IW, and TW) conducted content analysis using the framework method on Dedoose (SocioCultural Research Consultants LLC, Manhattan Beach, CA) [21]. The primary investigators read several transcripts independently to become familiar with texts and develop initial impressions and codes. Codes were factors influencing resident autonomy that were categorized as resident factors versus non-resident factors, encouraging versus discouraging autonomy, and attending surgeon versus non-attending surgeon factors. These were subsequently organized into the consistent themes described below. The research team then met regularly to discuss and refine the codes and identified potential themes until reaching thematic saturation, at which point no additional themes were identified [22]. Finally, the research team combined the quantitative results and qualitative results to interpret the study findings.

**Table 1**
Demographics of attending surgeons and residents.

| Descriptors | Distributions |
|---|---|
| Attending Surgeons | |
| Total Number | N = 9 |
| Specialty - General/GI Surgery | 66 % (n = 6) |
| Specialty - Acute Care Surgery | 33 % (n = 3) |
| Years In Practice | |
| <10 | 55 % (n = 5) |
| 10+ | 44 % (n = 4) |
| Robotic Cases Performed | |
| Median [IQR] | 189 [IQR 73–274] |
| Robotic Case Experience | |
| <100 cases | 3 |
| 100–299 cases | 4 |
| >300 cases | 2 |
| Surgeon Gender | |
| Female | 22 % (n = 2) |
| Male | 77 % (n = 7) |
| Resident Training Level[a] | |
| PGY 2 | 13 |
| PGY 3 | 7 |
| PGY 4 | 8 |
| PGY 5 | 10 |
| Resident Gender | |
| Female | 12 |
| Male | 18 |

[a] Training level at time of operation; PGY=Postgraduate training year.

## 3. Results

### 3.1. Descriptive statistical analysis of resident individual console time

A total of 420 eligible RAS cases were included in this study: RIH (n = 200), RVH (n = 99), and RC (n = 121). All were elective cases performed by 30 residents and 9 attending surgeons using a dual-console Da Vinci surgical robotic system (Table 1). At time of operation, the residents were 52 % junior residents and 47 % senior residents. Six of nine attending surgeons (66.7 %) were from the general/gastrointestinal surgery division and three (33.3 %) were from the division of acute care/trauma surgery. 55.6 % (5/9) were early-career surgeons and 22.2.% (2/9) had performed more than 300 RAS cases by June 2021. Two surgeons were women, and seven were men.

Resident ICT significantly increased with seniority (PGY level) (Fig. 1a): on average, junior residents were allowed 26.8 % ICT per case vs. 42.4 % for senior residents ($p < 0.001$). As demonstrated in Fig. 1b, resident ICT also varied significantly based on procedure type ($p = 0.043$), with the most ICT per case in RC (45.8 %, range 25.6–61.5 %), less in RIH (36.7 %, range 29.0–52.8 %), and the least in RVH (28.6 %, range 19.1–47.2 %). Average resident ICT was inversely related to attending surgeon work experience, ranging from 23.7 % to 61.1 %. Compared to early-career surgeons (Fig. 2a), attending surgeons with more than 10 years' work experience on average gave less ICT to junior (18.2 % vs. 32.0 %, $p < 0.001$) and senior residents (33.9 % vs. 56.6 %, $p < 0.001$) respectively. However, resident ICT (Fig. 2b) demonstrated no correlation with attending surgeon RAS case volume ($r = 0.003$, $p = 0.0003$). There were no significant differences in resident ICT between cases in the general and/or gastrointestinal surgical and acute care/trauma surgical services.

### 3.2. Explanatory thematic analysis of resident individual console time

Totally 6 of 9 attending surgeons included in the ICT dataset were interviewed. The sequential explanatory mixed-methods approach was utilized with the goal of exploring attending considerations on resident autonomy in RAS, as the ICT dataset had identified differences in autonomy granted by resident training time and by attending operative experience. Two main themes emerged when attending surgeons discussed allowing residents independent operative time: 1) attending surgeon assessment of resident training year and experience correlated to resident ICT, and 2) attending surgeons perceived operative time pressure was inversely correlated to resident ICT.

ICT data patterns showed that junior residents operated on the console for a significantly lower proportion of case time than senior residents. On average, PGY2-3 residents had an ICT of 26.8 % (range 25.3–28.2 %) per case, and PGY4-5 residents had a console time of 42.4 % (range 33.2–51.5 %). Attending surgeons' comments highlighted their thought process behind allowing more ICT for higher PGY level residents to practice RAS skill and independence. As one surgeon said:

> "It somewhat depends on the [resident's] level of training. Second year [PGY2] residents I'll take over faster than a fifth year [PGY5] sometimes." [Excerpt 1.1]

Knowing the resident's surgical experience and having confidence that the resident will operate safely also impacts the amount of ICT an attending surgeon offers to the resident in an RAS case. For example, attending surgeons stated that they would not allow a junior resident with whom they are unfamiliar a lot of console time to practice independence in the OR due to concerns for safety:

> "If I'll have a new PGY2 [resident] who has done just a couple lap choles, and I don't know what this resident is gonna do, and I'm not sure if the resident would do something terrible, whether I can fix it. [Excerpt 2.1]"

In our data, attending surgeon RAS case volume (i.e., robotic surgical experience) did not correlate with resident ICT. This finding aligned with the secondary interviews with attending surgeons. None of the surgeon interviewees related their personal RAS experience and comfort level to their behavior of granting resident ICT. However, early-career surgeons on average gave more ICT to residents across PGY levels when compared to attending surgeons with more than 10-year experience: PGY2-3: 18.2 % vs. 32.0 %, PGY4-5: 33.9 % vs. 56.6 %. According to the interviews, "interest in resident education" and "clinical productivity requirements" were

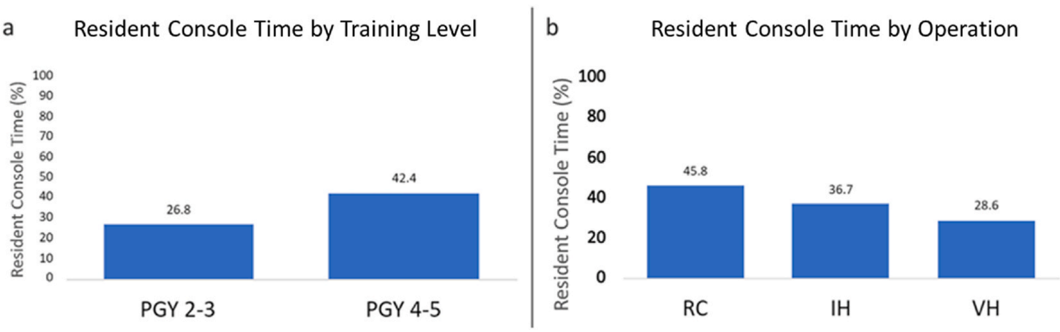


**Fig. 1.** a) Resident Console Time by Training Level (at time of operation) and b) Resident Console Time by operation.

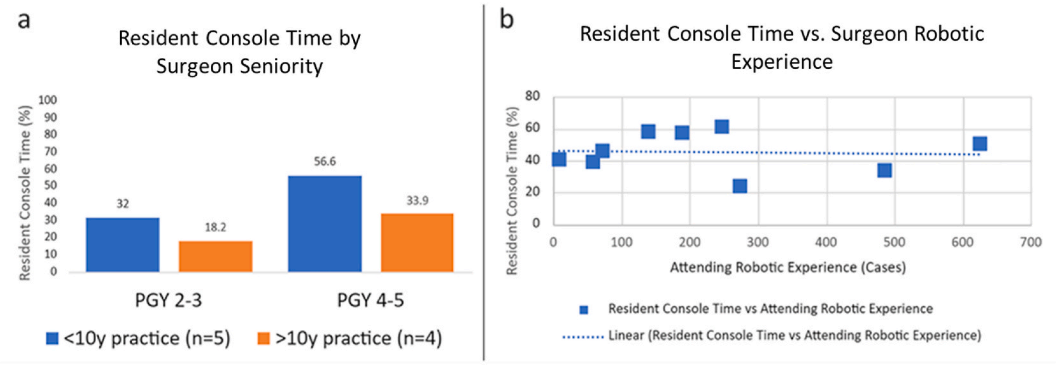


**Fig. 2.** a) Resident Console Time by Surgeon Seniority (defined as years in practice), and by b) Resident Console Time vs. Surgeon Robotic Experience (defined as prior number of RAS cases performed).

two inter-related reasons that contributed to this resident ICT finding.

### *3.3. Interest in resident education and competing incentives*

Several surgeons whom we interviewed emphasized prioritizing resident education in RAS cases. Notably, they also discussed that they were on a salary-based compensation model and not on a productivity-based compensation model. These attending surgeons described intentionally booking RAS cases for longer durations to accommodate teaching time and noted that including teaching time when booking a RAS case might decrease the time pressure of allowing a resident more ICT to do more in the OR. As one attending surgeon said,

> "I add an hour and a half to two hours onto every single [RAS] case when I book it compared to how long I think it should take me to do the operation to allow for extra time for teaching … I've gotten some flak for it because it means I only can do maybe three cases in a day instead of four cases in a day, but I do find it really valuable." [Excerpt 2.2]

Senior surgeons, on the other hand, described being explicitly thoughtful about the amount of teaching time spent on any portion of the case via a stepwise approach. This was a distinct consideration which was sometimes stated out loud to the resident. For instance,

> "Operations can be broken down into steps, and I'm constantly checking the clock to say this step, we should have progressed by this stage if we aren't there yet, it's probably time for me to step in and give a hint or do that part of the case." [Excerpt 4.1]

Early-career surgeons also commented explicitly on financial incentives for clinical productivity influencing operative efficiency, especially after entering relative value unit (RVU) based reimbursement. They brought up concerns that RVU-based reimbursement was directly in conflict with teaching resident in the OR, potentially leading to reduced resident ICT. As one attending surgeon commented:

> "[My division] will schedule six cases in a day and then they have the fellows do them, not the residents because otherwise you can't get through six cases in a day, and if you do less than six cases in a day, you're taking a pay cut … The RVU payment system … does not advocate for teaching in any way, shape, or form …" [Excerpt 2.3]

Senior attending surgeons shared similar concerns about how clinical productivity or OR scheduling time requirements had an impact on allowing resident ICT. As one surgeon said:

> "I also want the resident to struggle [in the OR] so the resident can learn, but with limited time and the crunch that I am going over my block time, I have to move the case along so sometimes I end up taking the case over" [Excerpt 5.1]

Although the perceived pressure of time and clinical productivity might restrict attending surgeons from granting resident ICT, the surgeon interviewees agreed that the utility of the dual console and the ease of transferring operative control make teaching a resident in RAS become easier. This was described in contrast to laparoscopic surgery, which can require moving around the patient and operating table to change the operative surgeon.

## 4. Discussion

In the operating room, attending surgeons' expert subjective judgment guides their intraoperative teaching actions, and the objective patterns of resident ICT are a result of attending surgeons' subjective assessment and judgement. Our study suggests that resident opportunities for autonomy in RC, RIH, and RVH are influenced by resident seniority level, surgeon work experience, and procedure type, which is consist with literature [14–17] and supported by the situated learning theory. Interviews with surgeons revealed that resident training year and experience, and the attending surgeons perceived operative time pressure, are the major influences on granting resident ICT; these are similar factors to those found in non-RAS operations reported in literature [14,16,23].

We thus encourage residency programs to provide faculty development for attending surgeons to improve their intraoperative teaching and performance evaluation skills for working with residents performing RAS in aid of robotic surgical workforce training and patient safety.

While this study reinforces existing literature that the RAS interface facilitates teaching, we also found that attending surgeons tend to allow residents less operative time in RAS than in non-RAS operations [24–26]. When the quantitative ICT data was reviewed, senior residents were performing an average of 42 % of the operation in our study sample, compared to 50–75 % of operations in other studies of laparoscopic and open surgery [27–29]. In a previous study, we also found that residents on average are only allowed to perform 22.8 % of the individual tasks of an RC case as the console surgeon, raising concerns about the development of residents' robotic proficiency [30]. While we found that resident ICT proportions seem low, operative time is not a perfect marker of operative autonomy as it does not reflect critical portions of the operation or verbal instructions by the attending surgeon. However, robotic ICT has been demonstrated to have a strong correlation with subjective operative autonomy scores from both attending surgeons and the operative resident, and a prior study found that autonomy scores of "minimal guidance" were achieved with ICT varying widely between 40 and 100 % [31]. This suggests that the ICT learning curve of RAS may differ from what has been found in the laparoscopic and open surgery literature and warrants further study. Further exploration of the anticipated resident learning curve for specific RAS operations would be novel and of interest for developing benchmarks. In addition, as more advanced data analytics from RAS consoles becomes available, this study lays the groundwork for further research on more detailed learning trajectories and competency-based assessments.

Interestingly we also found that attending surgeon robotic experience, as assessed by his/her prior RAS case volume, did not influence resident ICT based on both quantitative and qualitative results. One possible explanation may be that all the surgeons included in the study were also regularly performing laparoscopic and open operations, and individually felt that they had achieved proficiency robotically performing these operations; thus, once a minimum level of attending surgeon competence was achieved in RAS, further experience did not influence their perception of safety in allowing residents to operate. In our study samples, however, attending surgeon work experience impacted resident ICT. Interview comments on clinical productivity requirements related to compensation model, operative efficiency, and OR scheduling suggest that external pressures play a considerable role in preventing attending surgeons from permitting resident ICT in RC, IH, and VH, especially for surgeons with more than 10 years of experience. Rather than conclude that this relates broadly to surgeon seniority, it is likely that attending surgeon awareness of these external pressures tilt the balance of permitting a resident more ICT. Particularly, interviewed surgeons highlighted their concerns regarding the conflict of priority between RVU-based reimbursement and resident education in the OR [32], revealing discontents with some of these external pressures. Overall surgeon's annual work RVUs approximately increased by 9 % in surgery after implementation of the productivity-based compensation plan [33], Thus, educational programs and surgical departments are recommended to consider the value and role of resident education in its tension with cost and efficiency, with the acknowledgement that intraoperative resident education takes time.

Finally, this study suggests that resident ICT is variable by RAS operation: residents are allowed the most console time in RC while RVH has the least. While cholecystectomy, inguinal hernia repair, and ventral hernia repair are all classic general surgery operations used for resident training, residents may have been most familiar with non-RAS cholecystectomy which has a high case volume and thus were permitted to perform more of the operation on the robotic equivalent. Robotic and laparoscopic cholecystectomy are nearly identical, whereas there are frequently more technical differences between robotic and laparoscopic inguinal and ventral hernia repair.

### 4.1. Strengths and limitations

This study is the first mixed-methods study combining real-time automated recorded ICT data with semi-structured interviews to examine what influences general surgery residents' opportunities for autonomy in RAS. Surgical robots are equipped with various sensors which can capture ICT and specific intraoperative actions, such as robotic arm position and motions, making objective measurement feasible in RAS. Therefore, our study approach is applicable for other clinical specialties using RAS, such as urology, obstetrics & gynecologic surgery in academic medical centers and/or teaching hospitals in the U.S. and other countries. With the advent of advanced data analytic techniques such as machine learning, future research can focus on corroborating these objective measurements to actual case steps, further delineating learning trajectories. Associating objective measurements with patient outcomes may form the basis for future competency-based assessment. Teaching remains a human engagement, and our explanatory design provides a basis for improved teaching patterns in the RAS operating room. Future studies that explore alternative measures of autonomy, investigate the impact of teaching and learning styles, and expanding this study to multiple institutions would increase our understanding of developing effective training programs in RAS.

This study has several limitations. Qualitative data interpretation has inherent potential for subjective bias, though provides a richness of information that researchers may otherwise overlook. We had a small sample of surgeon interviews in the study, though this sample size is acceptable per literature on qualitative studies [34,35]. Secondly, this study is limited to a single institution; institutional differences, such as resident training curriculum and RAS case volume, may influence the findings. Our institution introduces a robotic simulation curriculum during PGY1 and residents are expected to actively operate on the robotic console by PGY2, which may not be the experience at other residency programs. Critics of console time as a surrogate for resident autonomy suggest that it does not capture completion of the critical portions of the case or verbal guidance. Previously published data from our group demonstrated strong correlation between ICT and both resident self-reported autonomy scores and attending surgeon-reported resident autonomy scores [36]. Until case segmentation becomes more feasible and widespread, console time remains the best available surrogate. Future investigation on the impact of case complexity on resident ICT patterns and efficient methods of measuring case complexity are needed. Finally, this study is performed in the United States which has a specific healthcare payer system which may exert specific external pressures on operative time. The international applicability of our identified considerations on resident autonomy in RAS may vary depending on external pressures on operative time.

## 5. Conclusion

In conclusion, this study suggests that residents' ICT (i.e., opportunities for autonomy) in RC, RIH, and RVH are influenced by resident seniority level, surgeon work experience, and procedure type from surgeons' perspective, but not related to surgeon RAS case volume. Residency programs are recommended to consider surgeons' external pressures at conflict with resident operative autonomy and seek to mitigate them when designing and implementing an effective robotic training program.

## Funding

This study was supported by an Intuitive Education Research Grant. The authors have no other competing interests to declare.

## Meeting presentation

Partial findings have been presented at the Annual Meeting of the Association of Surgical Education, May 3–5, 2022, San Antonio, TX, USA.

## Ethics statement

The Ohio State University Institution Review Board (IRB) approved this study (2021H0154). All participants voluntarily participated in the study. Verbal consent was obtained from each participant per the IRB protocol.

## Data availability statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to their containing information that could compromise the privacy of research participants.

## CRediT authorship contribution statement

**Theresa N. Wang:** Writing – review & editing, Writing – original draft, Visualization, Investigation, Formal analysis, Data curation, Conceptualization. **Ingrid A. Woelfel:** Writing – review & editing, Writing – original draft, Investigation, Data curation. **Emily Huang:** Writing – review & editing, Writing – original draft, Resources. **Heidi Pieper:** Writing – review & editing, Writing – original draft, Project administration. **Michael P. Meara:** Writing – review & editing, Writing – original draft, Supervision, Conceptualization. **Xiaodong (Phoenix) Chen:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

## Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Theresa Wang reports equipment, drugs, or supplies was provided by Intuitive Foundation. Michael P. Meara reports a relationship with Intuitive Surgical Inc that includes: consulting or advisory.

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## Appendix A. Supplementary data

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## References

[1] K.H. Sheetz, J. Claflin, J.B. Dimick, Trends in the Adoption of robotic surgery for common surgical procedures, JAMA Netw. Open 3 (1) (2020 Jan 3) e1918911, https://doi.org/10.1001/jamanetworkopen.2019.18911. PMID: 31922557; PMCID: PMC6991252.

[2] D.L. Crawford, A.M. Dwyer, Evolution and literature review of robotic general surgery resident training 2002–2018, Updates Surg 70 (2018) 363–368, https://doi.org/10.1007/s13304-018-0573-x.

[3] J.Y. Lee, et al., Best practices for robotic surgery training and credentialing, J. Urol. 185 (4) (2011) 1191–1197.

[4] P.C. Lim, E. Kang, D.H. Park, Learning curve and surgical outcome for robotic-assisted hysterectomy with lymphadenectomy: case-matched controlled comparison with laparoscopy and laparotomy for treatment of endometrial cancer, J. Minim. Invasive Gynecol. 17 (6) (2010 Nov-Dec) 739–748, https://doi.org/10.1016/j.jmig.2010.07.008. PMID: 20955983.

[5] JP Jr Lenihan, C. Kovanda, U. Seshadri-Kreaden, What is the learning curve for robotic assisted gynecologic surgery? J. Minim. Invasive Gynecol. 15 (5) (2008 Sep-Oct) 589–594, https://doi.org/10.1016/j.jmig.2008.06.015. PMID: 18722971.

[6] B.C. O'Brien, A. Battista, Situated learning theory in health professions education research: a scoping review, Adv. Health Sci. Educ. 25 (2020) 483–509, https://doi.org/10.1007/s10459-019-09900.

[7] B.T. Carpenter, C.P. Sundaram, Training the next generation of surgeons in robotic surgery, Robot Surg 4 (2017 Apr 21) 39–44, https://doi.org/10.2147/RSRR.S70552. PMID: 30697562; PMCID: PMC6193443.

[8] K.M. Quinn, X.P. Chen, L.T. Runge, H. Pieper, D. Renton, M. Meara, C. Collins, C. Griffiths, S. Husain, The robot doesn't lie: real-life validation of robotic performance metrics, Surg. Endosc. 37 (7) (2023 Jul) 5547–5552, https://doi.org/10.1007/s00464-022-09707-8. Epub 2022 Oct 20. PMID: 36266482.

[9] C.P. Childers, M. Maggard-Gibbons, Estimation of the Acquisition and operating costs for robotic surgery, JAMA 320 (8) (2018) 835–836, https://doi.org/10.1001/jama.2018.9219.

[10] J.H. Mehaffey, A.D. Michaels, M.G. Mullen, et al., Adoption of robotics in a general surgery residency program: at what cost? J. Surg. Res. 213 (2017) 269–273, https://doi.org/10.1016/j.jss.2017.02.052.

[11] S. Patel, M.M. Rovers, M.J.P. Sedelaar, et al., How can robot-assisted surgery provide value for money? BMJ Surg Interv Health Technol 3 (1) (2021) e000042 https://doi.org/10.1136/bmjsit-2020-000042.

[12] R.D. Shaw, M.A. Eid, J. Bleicher, et al., Current barriers in robotic surgery training for general surgery residents, J. Surg. Educ. 79 (3) (2022) 606–613, https://doi.org/10.1016/j.jsurg.2021.11.005.

[13] V.L. Wang, H. Pieper, A. Gupta, X. Chen, S. Husain, M. Meara, Expectations versus reality: trainee participation on the robotic console in academic surgery, Surg. Endosc. 35 (8) (2021) 4805–4810, https://doi.org/10.1007/s00464-020-07874-0.

[14] N.R. Teman, P.G. Gauger, P.B. Mullan, J.L. Tarpley, R.M. Minter, Entrustment of general surgery residents in the operating room: factors contributing to provision of resident autonomy, J. Am. Coll. Surg. 219 (4) (2014 Oct) 778–787, https://doi.org/10.1016/j.jamcollsurg.2014.04.019. Epub 2014 Jun 6. PMID: 25158911.

[15] X.P. Chen, A.M. Sullivan, J.M. Bengtson, J.L. Dalrymple, Entrustment evidence used by expert gynecologic surgical teachers to determine residents' autonomy, Obstet. Gynecol. 130 (Suppl 1) (2017) 8S–16S, https://doi.org/10.1097/AOG.0000000000002201.

[16] Z.J. Senders, J.T. Brady, H.A. Ladhani, J. Marks, J.B. Ammori, Factors influencing the entrustment of resident operative autonomy: comparing perceptions of general surgery residents and attending surgeons, J Grad Med Educ 13 (5) (2021) 675–681, https://doi.org/10.4300/JGME-D-20-01259.1.

[17] X.P. Chen, R.G. Williams, D.S. Smink, Dissecting attending surgeons' operating room guidance: factors that affect guidance decision making, J. Surg. Educ. 72 (6) (2015) e137–e144, https://doi.org/10.1016/j.jsurg.2015.06.003.

[18] G. Sandhu, N.R. Teman, R.M. Minter, Training autonomous surgeons: more time or faculty development? Ann. Surg. 261 (5) (2015) 843–845, https://doi.org/10.1097/SLA.0000000000001058.

[19] L. Torbeck, A. Wilson, J. Choi, G.L. Dunnington, Identification of behaviors and techniques for promoting autonomy in the operating room, Surgery 158 (4) (2015) 1102–1110, https://doi.org/10.1016/j.surg.2015.05.030. ; discussion 1110-1112.

[20] R.G. Williams, B.C. George, S.L. Meyerson, J.D. Bohnen, G.L. Dunnington, M.C. Schuller, L. Torbeck, J.T. Mullen, E. Auyang, J.G. Chipman, J. Choi, M. Choti, E. Endean, E.F. Foley, S. Mandell, A. Meier, D.S. Smink, K.P. Terhune, P. Wise, D. DaRosa, N. Soper, J.B. Zwischenberger, K.D. Lillemoe, J.P. Fryer, Procedural Learning and Safety Collaborative, What factors influence attending surgeon decisions about resident autonomy in the operating room? Surgery 162 (6) (2017 Dec) 1314–1319, https://doi.org/10.1016/j.surg.2017.07.028. Epub 2017 Sep 23. PMID: 28950992.

[21] N.K. Gale, G. Heath, E. Cameron, S. Rashid, S. Redwood, Using the framework method for the analysis of qualitative data in multi-disciplinary health research, BMC Med. Res. Methodol. 13 (2013) 117, https://doi.org/10.1186/1471-2288-13-117.

[22] E.H. Bradley, L.A. Curry, K.J. Devers, Qualitative data analysis for health services research: developing taxonomy, themes, and theory, Health Serv. Res. 42 (4) (2007) 1758–1772, https://doi.org/10.1111/j.1475-6773.2006.00684.x.

[23] X.P. Chen, A.M. Sullivan, J.M. Bengtson, J.L. Dalrymple, Entrustment evidence used by expert gynecologic surgical teachers to determine residents' autonomy, Obstet. Gynecol. 130 (Suppl 1) (2017 Oct) 8S–16S, https://doi.org/10.1097/AOG.0000000000002201. PMID: 28937513.

[24] E. Fernandes, E. Elli, P. Giulianotti, The role of the dual console in robotic surgical training, Surgery 155 (1) (2014) 1–4, https://doi.org/10.1016/j.surg.2013.06.023.

[25] B. Zhao, J. Lam, H.M. Hollandsworth, et al., General surgery training in the era of robotic surgery: a qualitative analysis of perceptions from resident and attending surgeons, Surg. Endosc. 34 (4) (2020) 1712–1721, https://doi.org/10.1007/s00464-019-06954-0.

[26] A.L. Smith, E.M. Scott, T.C. Krivak, A.B. Olawaiye, T. Chu, S.D. Richard, Dual-console robotic surgery: a new teaching paradigm, J Robot Surg 7 (2) (2013 Jun) 113–118, https://doi.org/10.1007/s11701-012-0348-1. Epub 2012 Apr 4. PMID: 23704858; PMCID: PMC3657076.

[27] H. Hoops, A. Heston, E. Dewey, D. Spight, K. Brasel, L. Kiraly, Resident autonomy in the operating room: does gender matter? Am. J. Surg. 217 (2) (2019) 301–305, https://doi.org/10.1016/j.amjsurg.2018.12.023.

[28] E. Igwe, E. Hernandez, S. Rose, S. Uppal, Resident participation in laparoscopic hysterectomy: impact of trainee involvement on operative times and surgical outcomes, Am. J. Obstet. Gynecol. 211 (5) (2014 Nov) 484.e1–484.e7, https://doi.org/10.1016/j.ajog.2014.06.024. Epub 2014 Jun 17. PMID: 24949539.

[29] G. Sutkin, E.B. Littleton, S.L. Kanter, Maintaining operative efficiency while allowing sufficient time for residents to learn, Am. J. Surg. 218 (1) (2019 Jul) 211–217, https://doi.org/10.1016/j.amjsurg.2018.11.035. Epub 2018 Nov 27. PMID: 30522695.

[30] M. Meara, T. Wang, X.P. Chen, Resident independent practice opportunities in robotic cholecystectomy: a quantitative descriptive study, in: Presented at: Association for Surgical Education 2023, April 2023. San Diego, CA.

[31] T.N. Wang, I.A. Woelfel, H. Pieper, K.R. Haisley, M.P. Meara, Chen Xphoenix, Is robotic console time a surrogate for resident operative autonomy? J. Surg. Educ. (2023) https://doi.org/10.1016/j.jsurg.2023.05.008. Published online June 7.

[32] E. Abahuje, K.S. Smith, D. Amortegui, J.S. Eng, S.E. Philbin, R. Verma, J.D. Dastoor, C. Schlick, M. Ma, N.I. Mackiewicz, J.N. Choi, J. Greenberg, J. Johnson, K. Y. Bilimoria, Y.Y. Hu, See one, do one, improve one's wellness: resident autonomy in US general surgery programs, A mixed-methods study, Ann. Surg. 278 (6) (2023 Dec 1) 1045–1052, https://doi.org/10.1097/SLA.0000000000006002. Epub 2023 Jul 14. PMID: 37450707.

[33] S.J. Poteet, A. Harzman, A.H. Chao, Surgical residents' perceptions of the impact of productivity-based faculty compensation at an academic medical center, J. Surg. Res. 259 (2021 Mar) 114–120, https://doi.org/10.1016/j.jss.2020.11.025. Epub 2020 Dec 3. PMID: 33279836.

[34] J.W. Creswell, Qualitative Inquiry and Research Design: Choosing Among Five Traditions, Sage Publications, Inc, 1998.

[35] N. Emmel, Sampling and Choosing Cases in Qualitative Research: A Realist Approach, SAGE, 2013.

[36] D.Z. Benissan-Messan, R. Tamer, H. Pieper, M. Meara, Chen Xphoenix, What factors impact surgical operative time when teaching a resident in the operating room, Heliyon 9 (6) (2023) e16554, https://doi.org/10.1016/j.heliyon.2023.e16554.