Assessing Visualization in Robotic-Assisted Surgery: Demystifying a Misty Lens

Jessica Y. Dae (jessica.dae@utexas.edu)
The University of Texas at Austin
Mahija Ginjupalli
The University of Texas at Austin
Zachary Rickmeyer
The University of Texas at Austin
John M. Uecker
Department of Surgery and Perioperative Care, Dell Medical School
Aaron Laviana
Department of Surgery and Perioperative Care, Dell Medical School
Christopher R. Idelson
ClearCam Inc.

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Abstract

Background

Despite major technological advancements in robotic-assisted laparoscopic surgery (RAS), there remain shortcomings yet to be addressed. This study assesses the prevalence of suboptimal vision in minimally invasive RAS and corresponding factors regarding related surgical conditions.

Methods

45 minimally invasive robotic surgeries, performed using Da Vinci XI, were observed across three surgical subspecialties: general, urology, and OB/GYN. Lens occlusion events were monitored and defined as the presence of a visual distortion caused by debris deposition on the scope lens. Lens occlusions and cleanings, and “active instrumentation” were recorded. Descriptive statistics summarized duration-based variables, and one-factor ANOVA compared the presence of active instrumentation.

Results

Cases averaged 127 ± 76 minutes. Active instrumentation ANOVA during lens occlusions demonstrated significant variation between categories ($F_{7, 256}$ = 11.63, P = 2.558e-13). Post-hoc Tukey HSD found electrocautery devices were active significantly more during occlusion events (37.9%) than other instruments. On average, lens cleaning occurred every 36.5 ± 39.8 minutes despite lens occlusion occurring every 24.5 ± 15.7 minutes. Of the operative time observed, 41.4% ± 28.1% was conducted with visual distortion. 1.16% ± 0.97% of time observed was spent cleaning.

Conclusions

Although only 1.16% of operative time was spent cleaning, surgeons experienced suboptimal conditions for nearly 35x the time it would take the clear lens, potentially indicating a tendency to avoid cleaning the lens to disrupt surgery. Future research may examine the impact of occluded visualization and lens cleaning on other aspects of surgery.

Introduction

Robotic-assisted laparoscopic surgery (RAS) is a rapidly growing field within the surgical landscape due to its efficacy, affirmed by continued evidence demonstrating improved patient outcomes [1–3]. Hospitals have been quick to adopt RAS systems given the benefit provided to patients. A cohort study of 73 hospitals involving over 150,000 patients showed an increase in RAS from 1.8–15.1% of all general surgeries performed between 2012 and 2018 [4]. Furthermore, upwards of 693,000 robotically assisted surgeries were performed in the US alone in 2017 [5]. Current projections suggest that RAS usage will further expand between 2020 and 2026 with a compound annual growth rate of 22.18%; this is reflected in its market growth from a 2020 valuation of USD 8.307 billion to a projected USD 28.34 billion in 2026 [6]. Worldwide, the most popular robotic surgery platform is Intuitive Surgical's Da Vinci robot, although both Johnson & Johnson [7] and Medtronic [8] have recently entered the space.

The rapid adoption of the Da Vinci robot in RAS systems can at least be partly attributed to some key patient and surgeon benefits–including greater precision, shorter recovery times, and reduced pain and bleeding–which are linked to the technological features of the robot [9]. One primary area of innovation is vision enhancement. During surgery, a display monitor exhibits a 3-dimensional high-definition video feed of the surgical area through the hood of the surgeon console; the camera position is controlled via a toggle on the hand control activated by an available foot clutch. Despite the efforts that have yielded such improvements in visualization, there are still some shortcomings in this arena [1]. One of the most common and frustrating issues is visual impairment requiring pausing to clean the scope. Suboptimal visualization as a result of lens occlusion has been explored most extensively for the case of traditional, or Straight Stick (SS), laparoscopic surgery where common mechanisms for lens occlusion include condensation, debris splatter or build-up, and bodily fluid deposition on the lens [10]. Visualization challenges in RAS have key similarities and differences from those faced in SS laparoscopy. Although both depend on camera visualization of the surgical site, the RAS camera is robotically controlled directly by the surgeon and differs in aspects such as scope optics, geometry, and some general functionality/add-ons. Additionally, the method for lens cleaning differs in RAS relative to SS laparoscopy in that the camera interfaces with a robotic arm in addition to the body port. This adds additional steps to the cleaning process such as unclipping the camera from the arm and ensuring that, when replacing the camera, it interfaces correctly with the robotic arm. Despite the notable variation observed between SS and RAS, there is a dearth of materials specifically assessing RAS visualization in the present literature.

Scope lens cleaning has been encountered as a point of difficulty in both SS and RAS laparoscopy. While the literature has mainly focused on this issue in SS laparoscopy, its prevalence in RAS warrants further exploration as well. This is supported by studies examining the impact of poor visualization on surgical safety, focusing on potential complications during the procedure as a result of lens occlusion and subsequent cleaning. Sutton et al. showed that surgeons experience a high rate of gaze disruptions from their central task owing in part to obscured vision and subsequent instrument cleaning/exchange [11]. Furthermore, an observational study by Yong et al. revealed that 56% of laparoscopic surgery is spent without a clear display on the surgical monitor [13]. The impact of this issue is clearly felt by surgeons who report feeling frustrated due to repetitive cleaning, an action that doubly results in an interruption in surgical flow [11, 13]. In a high-stakes environment such as surgery, the effects of poor visualization have the potential to cause harm to patients.

Given the impact of poor visualization resulting from lens occlusions, there currently exists a quickly expanding field within the medical community focused on investigating methods of lens cleaning. Because lens fogging is one of the most common issues during laparoscopy, a multitude of antifogging methods/products are employed by surgeons today, including surfactants, mechanical and material technology, and warmers [12]. For general occlusions, methods involving dry/wet cloths, warm water, or bringing the scope into contact with nearby viscera are utilized [13]. While there is extensive research on lens cleaning for SS laparoscopy, less is known about this topic with regards to the robotic space.

In order to add to the current body of knowledge on RAS, we designed the present study to provide a broad assessment of the prevalence of and factors contributing to suboptimal vision in RAS. Our primary objectives within this schema were to (1) explore active correlations of instrument activity and surgical specialty relative to image occlusions in RAS and (2) track debris events to observe associated impaired vision and lens cleaning times. Ultimately, we aimed to bridge the gap in knowledge of impaired visualization in RAS by quantifying cleaning time and occurrence of lens occlusion by various mechanisms specific to RAS.

Materials And Methods

This was an observational study of 45 robotic-assisted laparoscopic surgeries split among three surgical specialties: general surgery (n = 19), urology (n = 17), and obstetrics & gynecology (OB/GYN; n = 9). All surgeries were minimally invasive and performed with the Da Vinci XI surgical robot. In order to investigate the surgical conditions associated with suboptimal vision in RAS, we collected data on length of time, type of active instrumentation, and surgical procedure associated with each occlusion and cleaning event throughout each RAS case. During the cases observed, the lens was cleaned using either a Da Vinci cloth or Clearify device [14].

All data was collected by tracking data on a custom survey sheet that indicated the occurrence of events during a surgical case. This included case events, lens occlusion events, and lens cleaning events. Timestamp data was simultaneously captured to aid in visualizing the frequency and duration of these events. Case events were defined as either camera insertion or camera removal, which were used in conjunction with timestamps to begin or terminate periods of data collection for the surgical case–unless the insertion/removal was related to a lens cleaning event. Lens occlusion events occurred when there was a visible distortion through the scope. Occlusions could be a result of fluid, debris, fog, or other substances accumulating on the lens. In order to determine if any correlations existed, the instruments active during the occlusion event were recorded. These instrument options included cautery, suction, irrigation, scissors/cutting, camera movement, instrument movement, inserting/removing an instrument, or other. The last type of event recorded was a lens cleaning event, which occurred when the scope was removed from the body to be cleaned. Lens cleanings were recorded with the method of cleaning (by Da Vinci cloth or by Clearify) and the duration of the cleaning in seconds. The two observers established criteria, as per the Definitions and Classifications section below, in order to ensure robust alignment and standardization for all collected data. This effort mitigated the potential of inter-observer variability. This study was IRB exempt as no patient data was captured.

Definitions and Classifications

We defined suboptimal vision as any moment in which the screen was obscured by a visual occlusion; relatedly, clear vision indicated no presence of such visual obfuscation. An occlusion event was defined as any additional distortion present on the screen as compared to the previous image. A cleaning event was defined as the removal of the scope from the body cavity for the purpose of clearing debris from the lens. Camera insertion was defined by the scope being inserted through the trocar to the body cavity and then attached to the robotic arm. This was recorded at the moment when the surgeon had control of the scope, which was indicated by a sound emitted by the robot. Camera removal was defined similarly, where the timestamp was recorded at the moment the camera was undocked from the robot and subsequently removed through the trocar. Aligned with the above insertion/removal definitions, the bounds of the recorded cleaning time were defined by when the scope was undocked and docked to the robot arm. An exception to this procedure was that some cases required a period of manual laparoscope driving prior to docking the robot. These periods were noted, and events were recorded in the same manner but with camera insertion time defined by when the field of view was entirely inside the body cavity. When recording cleanings, occasionally the scope would have to be cleaned multiple times because there was still debris remaining on the lens. If the scope did not meet the criteria for being fully inserted when it was removed again to be cleaned (i.e., it was not entirely inside the body or attached to the robot), the entire process was recorded as a single cleaning event. If the scope was fully attached in between cleanings, two separate cleaning events were recorded, even if one immediately followed the other.

Data Analysis

A timestamp was recorded for every data submission, allowing us to quantify numerical variables such as the total duration of the case, time spent with suboptimal vision, and the frequencies of occlusion and cleaning events. Accompanying these events were additional categorical variables including the instruments that were active during occlusions and the method of cleaning. A one-way ANOVA statistical test followed by Tukey-Kramer post-hoc analysis was used to test for significant differences between the myriad of factors, such as the frequency of different instruments active during occlusions and the time spent with suboptimal vision for different surgical specialties.

Results

The total operative time tracked over 45 cases amounted to 5,696 minutes with the average surgical case lasting 127 ± 76 minutes. It should be noted that case length was highly variable between specialties. Urology had the highest average case length at 181 minutes while General Surgery and OB/GYN respectively averaged 89.4 and 102 minutes. The average time for a single scope cleaning over all specialties was 28.7 ± 21.0 seconds with 156 cleaning events across all cases. There was an average of 1 cleaning event every 36.5 ± 39.8 minutes and 3.5 ± 3.7 cleaning events per case. Only 1.2 ± 1.0% of surgery time was spent cleaning the scope while 41.4 ± 28.1% of the operative time was spent under suboptimal vision. The percentage of operative time with suboptimal vision was highly variable between specialties as well, with Urology, General Surgery, and OB/GYN at 47.6 ± 20.4%, 42.9 ± 33.8%, and 28.4 ± 25.5% respectively (see Table 1).

Table 1
Occlusion and cleaning statistics by surgical specialty

Specialty	Cases Observed	Average Length [minutes]	Occlusions per Case	Cleaning per Case	Suboptimal Vision [% of surgery]	Minutes per Occlusion
Urology	17	181.1 ± 64.2	10.5 ± 1.2	5.0 ± 0.9	47.6 ± 20.4	18.2
General Surgery	19	89.4 ± 67.6	4.4 ± 1.1	2.3 ± 0.8	42.9 ± 33.8	18.5
OB/GYN	9	102.1 ± 51.5	5.1 ± 1.7	3.1 ± 1.2	28.4 ± 25.5	16.9
Total	45	126.6 ± 75.6	6.8 ± 5.6	3.5 ± 3.7	41.4 ± 28.1	17.9

A total of 338 occlusion events across all cases yielded an average of 1 occlusion every 24.5 minutes of surgery and 6.8 occlusions per case. Of these, the use of cautery (37.9%), camera movement (22.2%), instrument movement (12.4%), and insert/remove instrument (9.2%) were the most frequent activities during an occlusion event (Table 2 Column D). A Pareto Analysis (Fig. 1) affirmed that those 4 instrumentation activities accounted for 82% of all occlusions. None of the remaining 4 activities constituted more than 8% of the total occlusion count.

Table 2
Occlusion statistics by active instrumentation

Instrument (A)	Total Occlusion Count (B)	Occlusion count preceding cleaning (C)	% Instrument Activity during all Occlusions (D)	% Occlusions Preceding Cleaning per Instrument (E)
Suction	6	2	1.8%	33.3%
Cautery	128	44	37.9%	34.4%
Irrigation	18	11	5.3%	61.1%
Scissors/Cutting	24	7	7.1%	29.2%
Insert/Remove Instrument	31	21	9.2%	67.7%
Other	14	5	4.1%	35.7%
Instrument Movement	42	17	12.4%	40.5%
Camera Movement	75	40	22.2%	53.3%

A subset analysis included only occlusion events directly preceding cleaning events. Active instrumentation in this subset of data was compared to that among the overarching dataset including all occlusion events. Both camera movement (22.2% versus 27.2%) and inserting/removing instruments (9.2% versus 14.3%) were more likely in this subset versus all occlusion events, while cautery usage was less (37.9% versus 29.9%). Other types of activity had a less severe decrease, such as instrument movement which dropped less than 1% (12.4% versus 11.6%). A more thorough analysis of this metric for each instrument was performed by finding the ratio of the subset of occlusion events recorded prior to a cleaning event over the total number of occlusion events for the given instrument (see Table 2 column E). This is expressed in the below equation.

$$\%occlusionsprecedingcleaningperinstrument = \frac{Occlusioncountprecedingcleaning}{Totalocclusioncount}$$

The percentage of total ‘Cautery’ events which preceded a cleaning was 34.4% (128 events). This was low relative to other categories such as ‘Insert/Remove Instrument’ (67.7%, 31 events), ‘Irrigation’ (61.1%, 18 events), and ‘Camera Movement’ (53.3%, 75 events).

There was a statistically significant difference between the use of electrocautery devices and all other instrument categories during occlusion events ($p < 0.05$). Additionally, there was a significant difference in occlusion counts between camera movement and non-specified laparoscopic instruments ($p = 0.010$) and a trend toward camera movement and irrigation use ($p = 0.177$). All other comparisons between active instrumentation categories did not yield statistically significant results ($p > 0.05$). Additionally, there was a statistically significant difference between occlusion counts for general surgery and urology cases ($p = 0.0021$) along with urology and OB/GYN cases ($p = 0.0326$). While occlusion counts were significantly different between specialties, the rate of occlusions per minute was not. There was no statistically significant difference between surgical specialties with regards to the time spent cleaning or the number of cleaning events. However, there was a statistically significant difference between average occlusion times for urology and OB/GYN cases ($p = 0.002$) along with urology and general surgery cases ($p < 0.001$).

Discussion

Upon assessment of the data collected, a common trend was the presence of much variability in visual acuity from surgery to surgery, supported by the standard deviations of average cleaning and occlusion times. A variety of factors may contribute to this variability including the nature of the occlusion, experience of the surgeon and robot technician, differences in patient characteristics, or operating room (OR) equipment and team structure. Anecdotal data collected during OR observations suggests that surgeon and surgical technician's comfort with RAS techniques play a major role in clear visualization. Despite not collecting quantifiable data on this metric, raw feedback suggested that some surgical technicians were able to interface with the robotic system more effectively than others; this variability may be partially reflected in the high standard deviation observed in cleaning times (28.7 ± 21.0 seconds). Variability in occlusion and cleaning times may also be explained by the nature and severity of the occlusion, given there are numerous types of debris variables that can lead to lens occlusion such as blood smearing, miscellaneous fluids contacting the lens, lens location for obstruction, or even manufacturing and equipment performance variations. In addition, relative standard deviations (RSDs) for time spent with occluded vision were larger for surgeries lasting under one hour (RSD = 115%) than for those over one hour (RSD ~ 50%). This may be due to shorter case times lending themselves more readily to high variation, though such a large decrease may also indicate that overall surgery length affects the variability of time spent with suboptimal vision.

When assessing the potential impact of surgical specialty on laparoscopic outcomes, the data showed a significant increase in occlusion count and time spent with occluded vision for urology cases versus general surgery or OB/GYN cases. There did not appear to be a significant difference between OB/GYN and general surgery cases, though the raw data showed that OB/GYN had a longer average occlusion time. In addition, the rate of occlusions per minute was not significantly different between specialties. Given that the average length of urology cases was longer than the other surgical specialties and the occlusion rate was similar between specialties, the significantly higher occlusion counts and time spent with occluded vision in urology is likely attributed to longer case length, not a higher frequency of occlusions occurring. Despite this, an interesting dichotomy can be seen between OB/GYN and general surgery cases where OB/GYN had a longer average surgery length but a lower average occlusion time than that of general surgery. In addition to this, OB/GYN cases had a significantly lower occlusion count than urology cases. While this could be for a number of clinically related reasons, it is interesting to note that the data shows debris events occurring less in OB/GYN compared to the other specialties observed. This difference may also be attributable to the type of case, step in the procedure, and location/anatomy of the operative area (i.e., deep within the pelvis behind pubic bone versus anteriorly). More case counts would help further explore and validate the significance of this potential trend. In contrast to occlusion counts and time, there was no observed difference in cleaning count and cleaning time between different surgical specialties. This suggests that surgeons across specialties may only be willing to clean at certain points in surgery and/or only every so often despite significant differences in occlusion counts.

In the comparative analyses performed, there was a significantly greater presence of active electrocautery devices in the surgical field during lens occlusion events than any other instrument category. The statistical significance in this dataset shows an interesting relationship between cautery activity and distorted surgical vision. Despite this putative connection, this study has raised the question of whether cautery use can be directly correlated with visualization that is poor enough to warrant subsequent cleaning. Subset analysis was performed on the data that exclusively comprised the final occlusion event before a lens cleaning. When comparing active instrumentation in all occlusion events to the subset of occlusion events, camera movement increased in proportion while cautery decreased. Further data collection surrounding the metric of occlusions preceding cleanings could validate the significance of that trend. Although active cautery occlusions made up a significantly larger proportion of total occlusion events, camera movement occlusions preceded a cleaning slightly more often. In addition, of all camera movement occlusions, 53.3% preceded a cleaning while only 34.4% of all cautery occlusions preceded a cleaning. The higher proportion of occlusions preceding a cleaning for camera movement may be attributed to the surgeon's preference to clean the lens at a time in which they may be searching for a new visual angle by moving the camera, which could, in turn, be further connected to the position of the visual distortion related to pursuit of a better viewing angle. Other notable categories where a high proportion of a specific occlusion type preceded a cleaning were 'Insert/Remove Instrument' (67.7%) and Irrigation (61.1%). Data here, given the type of active instrumentation preceding the occlusion event, may indicate that such instruments could create debris events severe enough to warrant an immediate cleaning. Conversely, this may also suggest these instruments are used at points in the surgery where the surgeon deems it more acceptable to stop the surgery and clear the lens based on their assessment of the risk threshold.

Perhaps the most intriguing finding within this study involves a comparison between average time spent cleaning the scope and time spent under suboptimal vision. Although cleaning the lens comprised 1.16% of the operative time, 41.4 ± 28.1% of all surgical observation time was spent with distorted visualization. Given that surgeons operated under suboptimal conditions for nearly 35 times as long as it would take to clear the lens, this may indicate a tendency to avoid interrupting surgical progress to clean the lens. As hinted at above, this is further supported by data from this study showing that active instrument categories such as cautery and scissors/cutting less commonly preceded a cleaning event when compared to transitional events such as camera movement and inserting/removing equipment. In other words, when using instruments for a critical part in a procedure, such as manipulation or destruction/repairing of tissue, the surgeon may be less likely to stop the procedure and clear the lens. Conversely, during less involved portions of surgery, such as when instruments needed to be swapped, a cleaning event was executed more often since the risk level to the patient was deemed lower and the need for enhanced operative focus may be deemed less critical at such a time. This is particularly important as one would surmise that surgeons prefer clear visualization in more critical moments; however, the data suggests that operating under suboptimal vision may still be preferred to the interruption and total loss of visualization that is required by a lens cleaning. This is an interesting "surgical catch-22” to consider, given the data. Anecdotal evidence via surgeon and surgical technician feedback also supports this hypothesis.

Lens occlusions were commonly discussed by surgeons and other OR personnel as a frequent inconvenience or source of frustration. One surgeon commented on his personal dislike for removing the lens to be cleaned, as it left him blind while surgical instruments were still inside the body cavity. Several surgeons and surgical residents expressed their irritation with occlusions and cleanings interrupting workflow and stated that they clean the lens as infrequently as possible to avoid that interruption. Of note, there was a high degree of variability observed for operative time spent with suboptimal vision. Based upon our observations, we postulate that this is due to the personal preference of the surgeon operating, with some tending to clean immediately and often, and others operating with an occluded lens for longer. Again, this appears to be due to frustration surrounding the prospect of interrupting surgical progress. Future research should investigate potential trends seen in different surgeons and surgical specialties.

The importance of clear visualization in RAS cannot be understated and is important for surgical success. However, this study has shown that it is impacted by a number of factors surrounding lens occlusions, including surgeon reluctance to remove and clean the scope to prevent disruption of the surgery, based on raw interview feedback. This has potential implications for surgical efficacy and at the very least reveals a need for future research that may examine the impact of occluded visualization and lens cleaning on other aspects of surgery.

Despite this study showing how profound visual disruptions are in the operating room for RAS, there are several limitations that need to be addressed. First, data collection for this study was conducted at a teaching institution where surgeons of multiple subspecialties performed RAS. All surgeons had received specialized training for RAS, but some variability in experience exists due to the participation of surgical residents during the cases. This variability is also true of the surgical technicians who handled scope cleaning. Second, a variety of procedures and surgeons were observed in order to gain a broad understanding of lens occlusions and cleanings across different uses of RAS. Following this study, we acknowledge that a larger scale inquiry would be able to further explore the explanations for some of the results seen. For example, variation in time spent operating with suboptimal vision between individual surgeons and variation in lens cleaning time between types of occlusions would be valuable. Third, a more formalized method of collecting surgeon interview data about visual acuity and lens cleaning could yield concrete conclusions on the impact of occlusions on their actions during a case.

Conclusion

This study provides an initial quantitative groundwork into visualization variability within the field of RAS and its ubiquitous impact across all observed surgical specialties in terms of the rate of occlusions and cleanings throughout an operation. Given the extensive amount of time surgeons spend with occluded vision, further study is warranted to more intently explore and understand the underlying causes for lens occlusion events with additional consideration to focus on consequential clinical impact. Additional avenues for research may include studies focused on variability between surgical procedures within specialties, variability between individual surgeons and surgical technicians, and degree of occlusion severity between events. These and other avenues could provide substantial evidence to support enhanced clinical decision-making surrounding these undesirable surgical events and ultimately may ideally improve surgical efficiency.

Declarations

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This is an observational study. No ethical approval is required.

References

1. DengW,LiuX,LiuW,ZhangC,ZhouX,ChenL,GuoJ,WangG,FuB(2021)Functional and Oncological Outcomes Following Robot-Assisted and Laparoscopic Radical Prostatectomy for Localized Prostate Cancer With a Large Prostate Volume: A Retrospective Analysis With Minimum 2-Year Follow-Ups.Front Oncol11:3786.https://doi.org/10.3389/FONC.2021.714680/BIBTEX
2. SecretariatMA(2010)Robotic-Assisted Minimally Invasive Surgery for Gynecologic and Urologic Oncology: An Evidence-Based Analysis.Ont Health Technol Assess Ser10:1
3. LeitaoMM,MalhotraV,BriscoeG,SuidanR,DholakiyaP,SantosK,JewellEL,BrownCL,SonodaY,Abu-RustumNR,BarakatRR,GardnerGJ(2013)Postoperative pain medication requirements in patients undergoing computer-assisted (“Robotic”) and standard laparoscopic procedures for newly diagnosed endometrial cancer.Ann Surg Oncol20:3561–3567.https://doi.org/10.1245/S10434-013-3064-9/TABLES/4
4. SheetzKH,ClaflinJ,DimickJB(2020)Trends in the Adoption of Robotic Surgery for Common Surgical Procedures.JAMA Netw Open3:e1918911–e1918911.https://doi.org/10.1001/JAMANETWORKOPEN.2019.18911
5. Robotic Surgery Statistics Show Movement Towards More Minimally Invasive Procedures - iData Research.https://idataresearch.com/robotic-surgery-statistics-show-movement-towards-more-minimally-invasive-procedures/.Accessed29Jan2022
6. Medical Robotic SystemMarket|2022–27|IndustryShare,Size,Growth-MordorIntelligence.https://www.mordorintelligence.com/industry-reports/global-medical-robotic-systems-market-industry.Accessed29Jan2022
7. Johnson & Johnson Announces Agreement to Acquire Auris Health, Inc.|Johnson&Johnson.https://www.jnj.com/johnson-johnson-announces-agreement-to-acquire-auris-health-inc.Accessed29Jan2022

8. Hugo™RASSystem|Robotic-assistedSurgery|Medtronic.https://www.medtronic.com/covidien/en-us/robotic-assisted-surgery/hugo-ras-system.html.Accessed29Jan2022
9. MaesoS,RezaM,MayolJA,BlascoJA,GuerraM,AndradasE,PlanaMN(2010)Efficacy of the Da Vinci surgical system in abdominal surgery compared with that of laparoscopy: a systematic review and meta-analysis.Ann Surg252:254–262.https://doi.org/10.1097/SLA.0B013E3181E6239E
10. (2021)Da Vinci X/XiInstrument & Accessory Catalog
11. SuttonE,YoussefY,MeenaghanN,GodinezC,XiaoY,LeeT,DexterD,ParkA(2010)Gaze disruptions experienced by the laparoscopic operating surgeon.Surg Endosc24:1240–1244.https://doi.org/10.1007/S00464-009-0753-3
12. ManningTG,PereraM,ChristidisD,KinnearN,McgrathS,O'beirneR,ZotovP,BoltonD,LawrentschukN(2017)Visual Occlusion During Minimally Invasive Surgery: A Contemporary Review of Methods to Reduce Laparoscopic and Robotic Lens Fogging and Other Sources of Optical Loss.J Endourol31:327–333.https://doi.org/10.1089/END.2016.0839
13. YongN,GrangeP,Eldred-EvansD(2016)Impact of Laparoscopic Lens Contamination in Operating Theaters: A Study on the Frequency and Duration of Lens Contamination and Commonly Utilized Techniques to Maintain Clear Vision.Surg Laparosc Endosc Percutan Tech26:286–289.https://doi.org/10.1097/SLE.0000000000000289
14. Visualization Accessories | Medtronic.https://www.medtronic.com/covidien/en-us/products/visualization-solutions/visualization-accessories.html.Accessed29Jan2022

Figures

Figure 1

Pareto Analysis of active instrumentation during occlusion events