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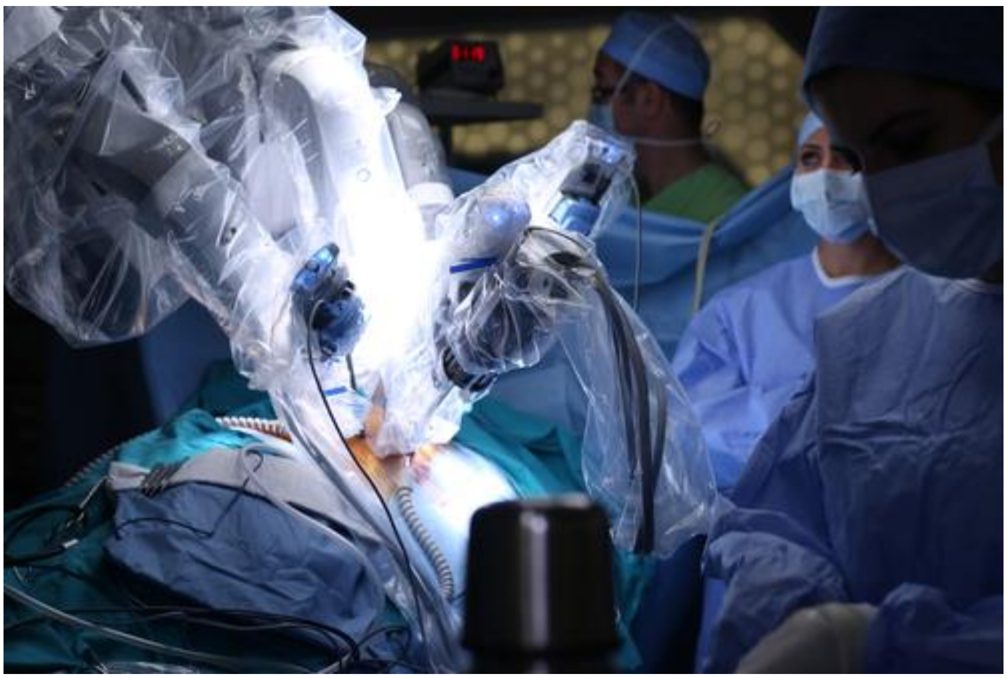
Robotic-Assisted Surgery



By

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This article will discuss the pros and cons of robotic-assisted surgery for various procedures. It will also touch on credentialling issues and the future of robotic-assisted surgery.

How Is Robotic-assisted Surgery Performed?

Robotic-assisted surgery uses a console located away from the bedside where the operating surgeon is seated. The console is connected to a robotic cart that is beside the patient. The console typically contains two binocular lenses that magnify and create a three-dimensional image for the surgeon.[1] A dual-camera endoscope on a robotic arm transmits 3-D images to the surgeon[1]. During the surgery, two handpieces transmit the surgeon's hand movements, allowing manipulation of surgical instruments which are attached to robotic arms.[1,2] A motion filtration system minimizes tremor, and foot pedals control different types of monopolar or bipolar energy used to cut and coagulate during the surgery and also control movement of the different robotic instruments including suction, irrigation and stapler devices needed for the procedure.[2] Some robotic systems have the ability to automatically reposition the robotic arms to keep the instruments in the same relative position in the operating field when the patient’s stretcher is moved to allow better surgical field exposure. This permits a smooth transition when repositioning a patient, as opposed to needing to undock the robotic platform and then reposition the robotic arms.[3]

An assistant, located at the bedside, can retract, remove specimens, suction and deliver equipment as needed.

Some advantages of robotic-assisted surgery for the surgeon include improved dexterity, allowing the surgeon a better ergonomic operating position with lessened muscle fatigue, and the elimination of the need to stand, possibly for hours.[1]

Robotic-assisted Surgery Procedures

The first recorded use of robotics was in a brain biopsy procedure in 1985.[4] Since then, the FDA has cleared or approved robotic-assisted surgery for a broad variety of surgery indications across specialties such as cholecystectomy,[5] thoracic surgery[6], hysterectomy, atrial septal defect closure,[7] mitral valve repair,[8] coronary artery anastomosis during cardiac revascularization,[7] spinal pedicle screw insertion,[9] hip replacement, total knee replacements[10], simple and radical prostatectomy,[11,12] transoral otolaryngology procedures,[13] and bronchoscopic lung biopsy[14]. The FDA removed its clearance for robotic-assisted thyroidectomy in 2011 which will be discussed later.[15]

In 2001, doctors in New York City performed a telerobotic-assisted gallbladder removal on a patient located in France.[4]

Robotic-Assisted Surgery Complications

The reported complication rate due to robotic malfunction is approximately 0.1% to 0.5%. When robotic errors do occur, rates of permanent injury reported range from 4.8% to 46.6% in the medical literature. In 2016 less than 800 complications directly attributable to a robotic operating system were reported to the FDA for the previous 10-year period.[2] However, almost 57% of respondents in an internet survey of urologists had experienced an irrecoverable intraoperative malfunction of the robot while performing a robot-assisted radical prostatectomy. The most common issues reported were malfunctioning of the robotic arms, arm joint problems and camera issues, followed by electrical power issues, instrument malfunction, and a broken console handpiece.[2,16]

Some possible disadvantages of robotic-assisted surgery include increased procedure time, human error in operating the apparatus, mechanical failure, accidental burn injuries, lack of tactile feedback, and nerve palsies due to direct nerve compression or extreme body positioning required for some robotic-assisted surgical procedures.[2] It is uncommon for mechanical failure to result in uncontrolled motion of the arms, due to safety protocols now built into modern robotic-assisted systems that prevent instrument use or restrict motion.*

Experience Required to Gain Technical Proficiency

There is currently no consensus of how many procedures a surgeon would need to perform to gain proficiency in robotic-assisted surgery. While standardized credentialing is gaining attention in the literature, proficiency varies significantly based on the specialty and technical complexity. It has been demonstrated that there is a learning curve when surgeons use these tools.[2,17] A learning curve is the rate of progress in learning a new skill. There are no national standards but it is common practice for hospitals to require certification to perform robotic-assisted surgery. Online and in-person training courses by the manufacturers are typically required, and one reference cited 20 bedside and 50 console procedures for residents and 5 proctored procedures for attendings with 50 tracked procedures as being a common standard.[17] However, an issue that may be problematic is that a hospital's credentialing process relies on the manufacturers of the equipment.[17]

Various studies defining mastery of robotic-assisted colorectal surgery reported that a surgeon needed 15 to 20 cases to overcome the learning curve.[18] However, in one study it was reported that technical competence occurred after 44 cases and expert performance occurred after 75 cases.[19] In another study the initial learning curve was 35 cases but it took 128 cases to reach expert performance.[20]

At one academic center, the failure rate for robotic-assisted mitral valve replacement was 7% for the first 100 cases and fell to 4.5 % in the next 200 cases. The need to convert robotic-assisted to open surgery occurred in 5% to 9.1% during the early part of the learning curve, compared to 0.7% to 1.3% in the later part of the curve.[21,22]

In a study of 3,246 patients who received totally endoscopic coronary artery bypass graft (CABG) surgery, 14% needed a larger incision during the robotic-assisted procedure, which was found to be dependent on where the surgeon was on the learning curve with the equipment.[23]

An appraisal of the robotic-assisted surgery learning curve in the medical literature concluded that there are few guidelines on dealing with the learning curve. The number of cases needed to achieve peak performance varied by type of surgery and the learning curve may have several phases, as surgeons perform more complex cases with growing experience. The literature also lacks a uniform assessment of outcomes and complications that could be used to decide when expertise had been achieved.[24]

A Review of Some Robotic-assisted Procedures

Abdominopelvic Surgery

A systematic review of 50 studies concluded that while robotic-assisted abdominopelvic surgery was safe with slight decreases in complications, it failed to find a significant advantage over traditional open or laparoscopic surgery.[17] In that review, 9% of conventional laparoscopies led to complications requiring further surgical intervention, compared to 8% of robotic-assisted operations. In studies of gastrointestinal surgery, life-threatening complications ranged from 0 to 2 % for robot-assisted surgery, from 0 to 3% for standard laparoscopy and from 1 to 4 % for open surgeries. In up to 8% of robotic-assisted surgeries and up to 12% in standard laparoscopic surgery the surgeon had to convert to an open surgical procedure. Robotic-assisted surgery was found to have increase costs and time duration compared with standard surgery.[17,25] The authors also point out that in the published literature two-thirds of the authors have received honoraria, speaking or consulting fees from the manufacturer. They also stated that the lack of high-quality data supporting robot-assisted surgery over laparoscopy or open surgery has not affected its rapid growth due in part to aggressive marketing by manufacturers, the belief that technology will improve outcomes, and demand from patients, surgeons, and health care systems.[17]

Radical Prostatectomy

Up to 85% of all radical prostatectomies performed in the U.S. are done using robotic-assisted surgery. There are high initial upfront costs of one to two million dollars associated with purchasing a robot. There are also annual maintenance contracts which can cost $150,000 or more per robot, and the cost of disposable instruments which results in much greater direct costs of robotic-assisted prostatectomy compared to open prostatectomy. In the U.S., most hospitals receive little or no additional payment from insurers for robotic-assisted surgery to offset these added costs. Many hospitals have marketed robotic-assisted surgery to patients, possibly as a way to recoup the increased costs of using robot surgical equipment.[26]

A meta-analysis of robotic-assisted versus open radical proctectomy reported that there were significantly less postoperative complications as well as a lower incidence of postoperative urinary incontinence at one year. There was no difference between the two techniques with respect to the amount of blood loss and finding cancer-free margins in the tissue removed. The authors stated that “in the narrow pelvic space, the flexible robotic arm makes the anatomical operation finer than the human hand, and it is easier to preserve the integrity of the nerve.”*[27] (*cavernous nerve)

Another meta-analysis found that robotic-assisted radical prostatectomy was associated with less blood loss and need for blood transfusion, and a shorter length of hospitalization compared to standard surgery. There was no proof of the superiority of either surgical technique with respect to postoperative complications, cancer-free margins of tissue removed, cancer reoccurrence, urinary incontinence or sexual function. Robotic-assisted surgery was found to take more operative time and was more expensive than open surgery.[28]

Radical Cystectomy

A study of robotic-assisted surgery versus open surgery for radical cystectomy (urinary bladder removal) in patients with bladder cancer reported that there were significantly less thromboembolic complications, wound complications, and days spent in the hospital within the first 90 days after surgery with robotic-assisted surgery compared to open surgery. At 18-month follow-up, there was no significant difference in the recurrence of cancer or mortality between the two groups.[29]

Thyroidectomy

In 2011, the FDA withdrew approval of robotic-assisted thyroidectomy surgery and the manufacturer stopped supporting the procedure.[15] This was due to reports that low-volume medical centers with less than five cases per year were found to have a significantly higher complication rate than high-volume centers.[30] While robotic-assisted remote access thyroidectomy is still performed in other countries, it is rarely done in the U.S.[31]

Knee Arthroplasty

A meta-analysis of robotic-assisted vs open total knee arthroplasty reported that there was more precise prosthesis positioning and less blood loss with robotic-assisted surgery. There were no statistically significant differences in the two groups in range of motion and complications after surgery. Several of the included studies found that the surgeons needed some experience with the equipment to perform the procedure optimally.[32]

Hip Arthroplasty

The literature regarding robotic-assisted hip arthroplasty is mixed. A meta-analysis of robotic-assisted total hip arthroplasty compared to open surgery reported that robotic-assisted surgery improved component placement and reduced intraoperative complications. However, robotic-assisted surgery increased the risks of postoperative heterotopic ossification, dislocation, and the need for revision. Robotic-assisted surgery was found to increase surgical time by 20 minutes compared to standard surgery.[33] Another meta-analysis reported similar results.[34] However, a study of over 2,000 patients reported less postoperative dislocations with robotic-assisted surgery.[35] A different meta-analysis reported that robotic-assisted hip arthroplasty had significantly better component placement, less limb length discrepancies and no significant differences in the number of revision surgeries needed or long-term clinical outcomes compared to standard surgery.[36] It is possible the different outcomes might be due to where the surgeons were on the learning curve or which manufacture's device was used. A systematic review reported that the surgeons' learning curve for robotic-assisted total hip arthroplasty was between 12 and 35 cases.[37]

Mitral Valve Replacement

Robotic-assisted mitral valve replacement was first performed in 1998 and received FDA approval in 2002. The 3-D imaging used in robotic-assisted surgery according to one author allows better visualization of the valve area and may obviate the need for a sternotomy.[38] In one study of 759 patients, robotic-assisted surgery took longer than open surgery, and the quality of mitral valve repair was judged to be equivalent for robotic-assisted surgery versus partial and complete sternotomy, and right mini-anterolateral thoracotomy. Neurologic, pulmonary, and renal complications were similar among groups. The robotic-assisted surgery arm had the lowest occurrences of atrial fibrillation, pleural effusion, and shorter hospital stays.[39]

Coronary Revascularization Surgery

A robotic-assisted CABG (coronary bypass graft) is where robotic arms and camera are placed in chest wall incisions and the left internal mammary artery is harvested using the robotic arms. This artery is then grafted onto the blocked coronary artery either through the incisions already in place or hand-sewn in place through a mini-thoracotomy. The procedures can be performed on both the beating heart (off-pump) and the arrested heart (on-pump).[38,40]

In one study of 326 patients receiving totally endoscopic coronary artery bypass graft surgery, 14% needed a larger incision. The need for a larger incision was found to be dependent on where the surgeon was on the learning curve with the equipment.[41]

Pulmonary Lobectomy

Robotic-assisted pulmonary lobectomy for cancer treatment is estimated to be used in about 20% of lobectomies in the U.S.[42] Additional surgical approaches include open lobectomy and video-assisted thoracoscopic surgery (VATS).

A meta-analysis of robotic-assisted lobectomy versus open lobectomy for cancer reported that robotic-assisted lobectomy had lower 30-day mortality rates than open surgery or video-assisted thoracoscopic surgery. Robotic-assisted lobectomy also had less complications and shorter durations of hospitalization than open surgery. In one study in the meta-analysis, blood transfusions requirements were lower with the robotic-assisted approach. Surgical times were found to be longer in the robotic-assisted group.[43]

A systematic review reported that blood loss and length of hospital stay were similar between robotic-assisted lobectomy and video-assisted thoracoscopic surgery. Robotic-assisted lobectomy was superior to thoracotomy and equivalent to video-assisted thoracoscopic surgery for the incidence of persistent air leaks and hospital length-of-stay. There was no difference in survival between robotic-assisted lobectomy and video-assisted thoracoscopic surgery, however, robotic-assisted lobectomy was found to be more costly than video-assisted thoracoscopic surgery. The authors cautioned that large prospective studies were needed to confirm or refute those findings.[44]

Telerobotic Surgery

Benefits of telerobotic-assisted surgery, where a surgeon operates on a patient from another site include providing healthcare to remote areas, allowing top specialists to participate in a patients care,[45] and its use in battlefield hospital units.

Issues include needing rapid data transmission to allow a safe procedure, mechanical failures,[45] and not having personnel at the bedside who can convert robotic-assisted surgery to open surgery which may prove to be problematic in some cases.

Conclusions

Robotic-assisted surgery has created a revolutionary change in surgical procedures. In some areas, such as prostate surgery, there appear to be some significant advantages in using robotic-assisted surgery. However, a large systematic review of abdominopelvic surgery reported that many of the studies failed to find a significant difference in outcomes between robotic-assisted surgery and standard laparoscopic or open surgery.

Advantages of robotic-assisted surgery over open surgery include smaller incisions, in some cases less blood loss, and decreased hospitalization days. Some authors also felt that manipulation of surgical instruments in an anatomically small area might be better with robotic-assisted surgery.

Disadvantages of robotic-assisted surgery include longer operative times, the need for a significant learning curve to gain proficiency, and higher costs. There is also the possible need to change to an open technique, or the possibility of causing an injury during surgery due to mechanical or technical issues. There may be differences in outcomes of robotic-assisted surgery between academic centers and general hospitals.

In the U.S., the FDA revoked approval/clearance for robotic-assisted thyroid surgery. The approval was based on data from academic centers where many procedures were performed. However, when general hospitals doing a lower number of robotic-assisted thyroid procedures were allowed to perform the procedure, outcomes were much worse.

Another issue is that there is currently no consensus on agreed upon credentialling requirements for proficiency in robotic-assisted surgery, although hospitals can set up their own credentialling processes. Using the manufacturer as a necessary part of the credentialling process may potentially be a conflict of interest.

With the significant learning curve required to become proficient with these devices, it is possible not having those standardized guidelines may put some patients at risk for a complication or increased need to convert to an open procedure, especially if the surgeon is at the beginning of the learning curve.

There appears to be some selection bias inherent in the medical literature in studies of robotic-assisted surgery that may affect results. Patients with favorable anatomy, health, and pathology tend to be chosen by surgeons to undergo procedures robotically. Conditions that favor the choice of robotic surgery may also skew outcomes positively. By contrast, hazardous conditions will often require open surgery and may be more frequently associated with poorer outcomes.[46,47]

It is possible that in the future with the addition of artificial intelligence, improved technology, and surgeons who trained on these devices when they were residents that outcomes with robotic-assisted surgery will continue to improve over time.[17,48]

Finally, telerobotic-assisted surgery with the ability of having surgeons able to operate on patients in remote geographic areas or in battlefield hospital units, may improve care to some patients, although communications and mechanical failures, or not having personnel at the bedside who can convert robotic-assisted surgery to open surgery may prove to be problematic in some cases.

Relevant Financial Relationships Statement

Dr. Caplen has disclosed stock ownership in Intuitive Surgical. His relevant financial relationship was mitigated via slide review and the content found to be evidence-based, balanced, and non-promotional.

All other faculty, CME Planning Committee Members, and the CME Office Reviewers have disclosed that they have no relevant financial relationships with ineligible companies that could constitute a conflict of interest concerning this CME activity.

References

[1] Goh EZ, Ali T, Robotic surgery: an evolution in practice, Journal of Surgical Protocols and Research Methodologies, Volume 2022, Issue 1, January 2022. Retrieved from: https://academic.oup.com/jsprm/article/2022/1/snac003/6533488

[2] Kirkpatrick T, LaGrange C. Robotic Surgery: Risks vs. Rewards. Patient Safety Network. February 1, 2016. Retrieved from: https://psnet.ahrq.gov/web-mm/robotic-surgery-risks-vs-rewards#references

[3] Morelli L. et al. Use of a new integrated table motion for the da Vinci Xi in colorectal surgery. Int J Colorectal Dis 31, 1671–1673 (2016). Retrieved from: https://link.springer.com/article/10.1007/s00384-016-2609-3

[4] The History of Robot-Assisted Surgery. The Surgical Clinic. 2017. Retrieved from: https://thesurgicalclinics.com/history-of-robot-assisted-surgery/

[5] George EI, Brand TC, LaPorta A, Marescaux J, Satava RM. Origins of Robotic Surgery: From Skepticism to Standard of Care. JSLS. 2018;22(4):e2018.00039. Retrieved from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6261744/

[6] Prasad SM. Robotic thoracic surgery: an evolution in progress for the treatment of lung cancer. Mo Med. 2012;109(4):307-311. Retrieved from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6179787/

[7] FDA Clearance of da Vinci Surgical System for Intracardiac Surgery Now Encompasses ``ASD'' Closure. Intuitive Surgical. January 30, 2003. Retrieved from: https://isrg.intuitive.com/node/7356/pdf

[8] Intuitive Surgical Receives FDA Clearance for Cardiac Revascularization. Intuitive surgical. July 8, 2004. https://isrg.gcs-web.com/node/7481/pdf

[9] Karthik K, Colegate-Stone T, Dasgupta P, Tavakkolizadeh A, Sinha J. Robotic surgery in trauma and orthopaedics. Bone Joint J. 2015;97-B(3):292-299. Retrieved from: https://boneandjoint.org.uk/article/10.1302/0301-620X.97B3.35107

[10] FDA Clears Zimmer Biomet's Rosa Hip for Robotic Hip Replacement. MDDI. August 19, 2021. Retrieved from: https://www.mddionline.com/robotics/fda-clears-zimmer-biomet-s-rosa-hip-for-robotic-hip-replacement

[11] Munver R et al. Transition from open to robotic-assisted radical prostatectomy: 7 years experience at Hackensack University Medical Center. J Robot Surg. 2007;1(2):155-159. Retrieved from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4247446/

[12] Intuitive receives FDA clearance of da Vinci SP for simple prostatectomy. Intuitive website. April 28, 2023. Retrieved from: https://investor.intuitivesurgical.com/news-releases/news-release-details/intuitive-receives-fda-clearance-da-vinci-sp-simple

[13] Vianini M et al. Experience in Transoral Robotic Surgery in Pediatric Subjects: A Systematic Literature Review. Front Surg. 2021;8:726739. Published 2021 Aug 12. Retrieved from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8387868/

[14] Kelly S. Noah Medical lung biopsy robot exceeds expectations in first-in-human trial. MedTechDIve. Sept. 1, 2023. https://www.medtechdive.com/news/noah-medical-lung-biopsy-robot-first-human-trial/692615/

[15] Rossi L, De Palma A, Fregoli L, et al. Robotic transaxillary thyroidectomy: time to expand indications?. J Robot Surg. 2023;17(4):1777-1785. Retrieved from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10374780/

[16] Dharam K et al. Malfunction of the da Vinci Robotic System During Robot-Assisted Laparoscopic Prostatectomy: An International Survey.Journal of Endourology.Apr 2010.571-575. Retrieved from: https://pubmed.ncbi.nlm.nih.gov/20192613/

[17] Dhanani NH et al. The Evidence Behind Robot-Assisted Abdominopelvic Surgery, A Systematic Review. Annals of Internal Medicine. 2021;174:1110-1117. Retrieved from: https://www.acpjournals.org/doi/pdf/10.7326/M20-7006

[18] Wong SW, Crowe P. Factors affecting the learning curve in robotic colorectal surgery. J Robot Surg. 2022;16(6):1249-1256. Retrieved from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9606100/

[19]Park EJ, et al. Multidimensional analyses of the learning curve of robotic low anterior resection for rectal cancer: 3-phase learning process comparison. Surg Endosc 28:2821–2831.Retrieved from: https://pubmed.ncbi.nlm.nih.gov/24902812/

[20] Sng KK, Hara M, Shin J-W, Yoo B-E, Yang K-S, Kim S-H (2013) The multiphasic learning curve for robot-assisted rectal surgery. Surg Endosc 27:3297–3307. Retrieved from: https://pubmed.ncbi.nlm.nih.gov/23508818/

[21] Toolan C et al. "Robotic mitral valve surgery: a review and tips for safely negotiating the learning curve." Journal of Thoracic Disease [Online], 13.3 (2021): 1971-1981. Web. 28 Dec. 2023. Retrieved from: https://jtd.amegroups.org/article/view/45078/html

[22] Chitwood WR Jr, Rodriguez E, Chu MW, et al. Robotic mitral valve repairs in 300 patients: a single-center experience. J Thorac Cardiovasc Surg 2008;136:436-41. Retrieved from: https://www.jtcvs.org/article/S0022-5223(08)00858-1/fulltext

[23] Schachner T, Bonaros N, Wiedemann D, et al. Predictors, causes, and consequences of conversions in robotically enhanced totally endoscopic coronary artery bypass graft surgery. Ann Thorac Surg. 2011;91(3):647-653. Retrieved from: https://pubmed.ncbi.nlm.nih.gov/21352972/

[24] Pernar LIM et al. An appraisal of the learning curve in robotic general surgery. Surg Endosc. 2017;31(11):4583-4596. Retrieved from: https://pubmed.ncbi.nlm.nih.gov/28411345/

[25] Bakalar N. Are Robotic Surgeries Really Better? The New York Times. Aug. 16, 2021. Retrieved from: https://www.nytimes.com/2021/08/16/well/live/robotic-surgery-benefits.html

[26]. Stitzenberg KB et al. Trends in radical prostatectomy: centralization, robotics, and access to urologic cancer care. Cancer. 2012;118(1):54-62. Retrieved from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3184375/

[27] Wang T, Wang Q, Wang S. A Meta-analysis of Robot Assisted Laparoscopic Radical Prostatectomy Versus Laparoscopic Radical Prostatectomy. Open Med (Wars). 2019;14:485-490. Published 2019 Jun 11. Retrieved from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6572386/

[28] Cao L, Yang Z, Qi L, Chen M. Robot-assisted and laparoscopic vs open radical prostatectomy in clinically localized prostate cancer: perioperative, functional, and oncological outcomes: A Systematic review and meta-analysis. Medicine (Baltimore). 2019;98(22):e15770. Retrieved from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6709105/

[29] Catto JWF, Khetrapal P, Ricciardi F, et al. Effect of Robot-Assisted Radical Cystectomy With Intracorporeal Urinary Diversion vs Open Radical Cystectomy on 90-

Day Morbidity and Mortality Among Patients With Bladder Cancer: A Randomized Clinical Trial. JAMA. 2022;327(21):2092-2103. Retrieved from: https://pubmed.ncbi.nlm.nih.gov/35569079/

[30] Berber E, Bernet V, Fahey TJ 3rd, et al. American Thyroid Association Statement on Remote-Access Thyroid Surgery. Thyroid. 2016;26(3):331-337. Retrieved from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4994052/

[31] Rossi L, De Palma A, Fregoli L, et al. Robotic transaxillary thyroidectomy: time to expand indications?. J Robot Surg. 2023;17(4):1777-1785. Retrieved from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10374780/

[32] Onggo JR, Onggo JD, De Steiger R, Hau R. Robotic-assisted total knee arthroplasty is comparable to conventional total knee arthroplasty: a meta-analysis and systematic review. Arch Orthop Trauma Surg. 2020;140(10):1533-1549. Retrieved from: https://pubmed.ncbi.nlm.nih.gov/32537660/

[33] Kort N, Stirling P, Pilot P, Müller JH. Clinical and surgical outcomes of robot-assisted versus conventional total hip arthroplasty: a systematic overview of meta-analyses. *EFORT Open Rev*. 2021;6(12):1157-1165. Published 2021 Dec 10. Retrieved from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8693228/

[34] Peng-fei H et al. Robotics-assisted versus conventional manual approaches for total hip arthroplasty: A systematic review and meta-analysis of comparative studies. The International Journal of Medical Robotics and Computer Assisted Surgery. June 2019. Volume15, Issue 3. Retrieved from: https://onlinelibrary.wiley.com/doi/full/10.1002/rcs.1990

[35] Shaw JH et al. Comparison of Postoperative Instability and Acetabular Cup Positioning in Robotic-Assisted Versus Traditional Total Hip Arthroplasty. The Journal of Arthroplasty. Volume 37, ISSUE 8, SUPPLEMENT , S881-S889, August 2022. Retrieved from: https://www.arthroplastyjournal.org/article/S0883-5403(22)00113-9/fulltext

[36]Kumar V et al. Does robotic-assisted surgery improve outcomes of total hip arthroplasty compared to manual technique? A systematic review and meta-analysis, Postgraduate Medical Journal, Volume 99, Issue 1171, May 2023, Pages 375–383. Retrieved from: https://academic.oup.com/pmj/article/99/1171/375/7192094

[37] Ng N et al. Robotic arm-assisted versus manual total hip arthroplasty. Bone Joint J. 2021;103-B(6):1009-1020. Retrieved from: https://boneandjoint.org.uk/article/10.1302/0301-620X.103B6.BJJ-2020-1856.R1

[38]Harky A, Hussain SMA. Robotic Cardiac Surgery: The Future Gold Standard or An Unnecessary Extravagance?. Braz J Cardiovasc Surg. 2019;34(4):XII-XIII. Published 2019 Aug 27. Retrieved from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6713378/

[39] Mihaljevic T et al. Robotic repair of posterior mitral valve prolapse versus conventional approaches: Potential realized. Acquired cardiovascular disease. Volume 141, Issue 1, P72-80.e4, January 2011. Retrieved from: https://www.jtcvs.org/article/S0022-5223(10)01051-2/fulltext

[40] Cao C, Harris C, Croce B, Cao C. Robotic coronary artery bypass graft surgery. Ann Cardiothorac Surg. 2016 Nov;5(6):594. Retrieved from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5135554/

[41] Schachner T, Bonaros N, Wiedemann D, et al. Predictors, causes, and consequences of conversions in robotically enhanced totally endoscopic coronary artery bypass graft surgery. Ann Thorac Surg. 2011;91(3):647-653. Retrieved from: https://pubmed.ncbi.nlm.nih.gov/21352972/

[42] Mazzei M, Abbas AE. Why comprehensive adoption of robotic assisted thoracic surgery is ideal for both simple and complex lung resections. J Thorac Dis. 2020;12(2):70-81. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7061192/

[43] O'Sullivan KE, Kreaden US, Hebert AE, Eaton D, Redmond KC. A systematic review and meta-analysis of robotic versus open and video-assisted thoracoscopic surgery approaches for lobectomy. Interact Cardiovasc Thorac Surg. 2019;28(4):526-534. Retrieved from: https://pubmed.ncbi.nlm.nih.gov/30496420/

[44] Agzarian J e tal. The Use of Robotic-Assisted Thoracic Surgery for Lung Resection: A Comprehensive Systematic Review. Semin Thorac Cardiovasc Surg. 2016;28(1):182-192. Retrieved from: https://pubmed.ncbi.nlm.nih.gov/27568159/

[45] Mohan A et al. Telesurgery and Robotics: An Improved and Efficient Era. Cureus. 2021;13(3):e14124. Published 2021 Mar 26. Retrieved from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8075759/

[46] Housman B, Flores RM. Minimally Invasive vs Open Lobectomy for Lung Cancer: Safety Is the Selection Bias. The Annals of Thoracic Surgery. Volume 115, ISSUE 1, P191, January 2023. Retrieved from: https://www.annalsthoracicsurgery.org/article/S0003-4975(22)00188-6/fulltext

[47] Housman B, Flores RM. Minimally Invasive vs Open Lobectomy for Lung Cancer: Safety Is the Selection Bias. Ann Thorac Surg. 2023;115(1):191. Retrieved from: https://pubmed.ncbi.nlm.nih.gov/35176263/

[48] McCartney J. Robotic Surgery Is Here to Stay— and So Are Surgeons. American College of Surgeons. May 10, 2023. Retrieved from: https://www.facs.org/for-medical-professionals/news-publications/news-and-articles/bulletin/2023/may-2023-volume-108-issue-5/robotic-surgery-is-here-to-stay-and-so-are-surgeons/

***** Personal observation of Dr. Housman

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