Vol. 6.2: 45-55

URJ

THE UNIVERSITY OF CENTRAL FLORIDA
UNDERGRADUATE RESEARCH JOURNAL

Published
April 30, 2013

A Practicality Analysis Pertaining to Minimally Invasive Robot-Assisted Urologic Surgery

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ABSTRACT: Minimally invasive robot-assisted surgery is a technological development that has changed the field of medicine in the past decade. The introduction of the da Vinci® by Intuitive Surgical Inc. has opened up many interesting options in several different fields. Specifically, the field of urology has seen increased utilization of the robotic technique due to the precision allowed by the technology. Although many perioperative and postoperative benefits have been documented within the literature pertaining to robotic surgery, some surgeons contend that the extra cost associated with the procedures is not practical. To this point the extra cost has not been prohibitive, as the number of robot-assisted procedures has continued to increase in the years since FDA approval. In this study, we employed an analysis of three of the more commonly performed da Vinci® robotic urology procedures (prostatectomy, pyeloplasty, and nephrectomy) to assess the practicality of the robotic techniques as compared to the more established methods of laparoscopic or open urologic surgery. The study results displayed that robotic integration is more practical for all three of the surgeries reviewed. Factors that influenced the results were the tendencies of robot-assisted procedures to have similar outcomes to laparoscopic or open procedures while allowing for less estimated blood loss and a shorter length of hospital stay. This paper discusses the results from the practicality evaluation as well as how these findings should be interpreted.

KEYWORDS: robotic surgery; da Vinci® robot; robotic urology; prostatectomy; pyeloplasty; nephrectomy; cystectomy

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INTRODUCTION

Modern urologic surgery traces back to 1947 when Millin described the first retropubic approach to radical prostatectomy.[1] Although surgeons continued to improve on their outcomes, it was not until 1991 that Clayman first described and utilized techniques needed to perform the first laparoscopic nephrectomy.[2] With newfound hope for patients, an opportunity arose for further advancement of minimally invasive surgery with the advent of surgical robots in the late 1990s. The traditional challenges of urologic surgery appear to offer an apt avenue for displaying the benefits of minimally invasive robot-assisted surgery. Since the introduction of robot-assisted surgery, surgeons have wondered whether there was a place for such revolutionary methods. For some time, robotic surgery was seen as a gimmick and an unrealistic option for the masses. However, the introduction of the da Vinci® surgical system has helped to gain acceptance for robotic surgery within the last ten years, allowing for a variety of procedures to be performed using minimally invasive techniques. The current viewpoint has shifted, as leaders in the medical field have incorporated robotic surgery into their repertoire, and have found it to be a viable and sometimes more successful option than traditional laparoscopy.

Using robots for medical or surgical purposes is a relatively recent development, with the first known application of a surgical robotic device, Programmable Universal Manipulation Arm (PUMA), used in 1985 to orientate a needle for a radiologically guided brain biopsy.[3] As of 2010, more than 800 U.S. hospitals and 2500 surgeons have acquired and incorporated at least one robot into their surgical techniques.[4] The field of surgical robotics has seen numerous technological developments in its brief history in medicine, including the development of several different revolutionary machines, most notably the da Vinci® by Intuitive Surgical Inc. The da Vinci® is a high definition and three-dimensional tremor-eliminating system with the ability to decrease the learning curve of a new surgeon.[5] It is currently in widespread use in several different subspecialties, such as urology, cardiothoracic surgery, and gynecology. There are a number of docu- mented peri-operative advantages generally observed with surgeries performed with the da Vinci®, including decreased blood loss, decreased pain, and shorter hospitalizations. Frequently observed disadvantages of the da Vinci® system include the costs associated with the initial purchase ($1.6 million) and the annual maintenance, which totals over $100,000 per year.[6] Another major concern is the loss of the surgeon's tactile sensation, an issue to which surgeons with more experience on the robotic platform have been able to adapt.[7-9] Overall, the da Vinci's® versatility has allowed for further exploration into the field of Minimally Invasive Surgery and could expand surgical treatment methods beyond what was once conceivable.[10]

THE DA VINCI® SURGICAL SYSTEM

The da Vinci® is currently the most commonly used robotic surgical system used in urology. Over 1,450 academic and community hospital sites have installed the system since its approval, and growth has come in excess of 25% annually.[11] The system's uses extend to various procedures within different medical fields, including urology, gynecology, otolaryngology, and cardiothoracics. The S-model system is separated into three general components: the surgeon's console, the patient side cart and the 3-D Vision System. The surgeon's console, located several feet from the patient, controls four electro-mechanical arms as well as a video endoscope. Inside the surgeon's console, a magnified three-dimensional image is displayed on the visual display system. The surgeon uses controls that relay motion to the robotic arms, which manage the specific instruments and video endoscope operating at the patient side cart. Intuitive Surgical has developed Endowrist technology, which allows the surgeon to use seven degrees of freedom, while extending the traditional angle of rotation allowed by the human arm and wrist. Many supporters of the da Vinci® believe that this added dexterity provided by Endowrist® technology is the device's greatest advantage, which allows easier and more precise suturing.[12] The da Vinci® is considered to be a single quadrant system allowing for work to be performed on only one quadrant of the body at a time. However, the patient side cart is mobile and able to move freely when the system is not set to operate, allowing for numerous possible angles and locations for surgical entry. The da Vinci® has been redesigned several times since its creation, and will most likely be developed further as surgeons continue to incorporate the technology.

PURPOSE

Considering the dynamic climate of the United States healthcare market, return on investment is increasingly important for hospitals and healthcare professionals. Successful outcomes have become progressively more

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difficult to define, and the issue of medical procedures and their inherent practicality seems to have been clouded somewhere along the line. The recent introduction of robotic surgery, especially within the field of urology, has generated much debate regarding the cost versus benefit of these newfound techniques. Considering the costs associated with the da Vinci®, we found it essential to add to the discourse a preliminary practicality analysis for three separate robotic urology procedures. The purpose of this paper is to assess the practicality of performing three distinct urologic procedures--radical prostatectomy, pyeloplasty, and partial nephrectomy--using the da Vinci® surgical system. Our goals are to determine if the robotic approach is a more practical method of surgery for each procedure when compared to the current "gold standard" method of traditional laparoscopy and to give recommendations to the field based on the results.

STUDY DESIGN

We employed a retrospective analysis of three of the more commonly performed da Vinci® robotic urology procedures to assess the practicality of these newly established robotic techniques as compared to the more established methods of laparoscopic urologic surgery. We will assess each of the three surgical procedures--radical prostatectomy, pyeloplasty, and partial nephrectomy--with an experimental assessment tool to determine if the da Vinci® robotic technique is a practical approach to urologic surgery when compared to the standard methods of treatment. We will then conclude with a statement on the practical use of each procedure as they pertain to our assessment.

LITERATURE SEARCH STRATEGY

We screened appropriate literature from provided abstracts. The search strategy for relevant literature included the following: Ovid Medline (1950 to present), CINAHL (1982 to present), PsycInfo (1806 to present), All EBM Reviews, Ovid Healthstar (1966 to present), ERIC, PubMed, and Google Scholar (2011-2012). Further, we conducted ancestry and gray literature searches to ensure full capture of relevant research. The gray literature searches were confined to conferences and dissertation research concerning the daVinci® procedure. All databases except for PubMed, Google Scholar, and ERIC use OVID Gateway. PubMed and Google Scholar use their own searching catalogs while ERIC employs EBSCOhost. Keyword search phrases included: robotic surgery, da Vinci® robot, robotic urology, prostatectomy, pyeloplasty, nephrectomy, video assisted laparoscopic/robotic/robot-assisted. This process yielded a total of 717 search results displaying relevant information (Table 1). Of these 717 results, over half were immediately screened out due to failure to meet some or all of our primary criteria, which included the following characteristics: study design, operative time, length of hospital stay, cost, and estimated blood loss. After initial screening, the results were reviewed further. Observational and comparative studies were utilized when compiling the data; however, only sufficiently large samples were considered. Finally, the information was further narrowed down to large meta-analyses and comprehensive literature reviews. Comparative meta-analyses were included in the study whenever possible and therefore compose the bulk of the results. Case series reporting exclusively on robotic methods or laparoscopic/open methods were included if no other substantial comparative literature existed within the search results. In total, nine articles containing analyses from 91 separate studies were used to construct our results.

MEASUREMENTS/INSTRUMENTATION

An original research based, mathematical tool was used by the team to assess practicality. This exploratory assessment tool consisted of the following criteria: quantitative patient costs, estimated peri-operative blood loss (EBL), operative duration, and length of hospital stay. Qualitative data, such as the opinions of experienced surgeons within the field, were included in the manuscript, but did not contribute to the practicality scores within the tables. For each of the three procedures, both the da Vinci® robotic technique as well as the gold standard technique were scored in the four aforementioned categories. Each procedure was selected because of the diverse challenges they present, which allowed for a more comprehensive analysis. Patient costs, estimated peri-operative blood loss, operative duration, and length of hospital stay were selected to determine the practicality of each method due to their regular occurrence in the literature related to urologic surgery outcomes. Additionally, these criteria are common to the three procedures that were evaluated, whereas other outcome variables within the literature may only be relevant to procedures involving cancer surgery or reconstruction.

Each of the four criteria has previously been cited throughout the literature involving surgery outcomes and are thus of importance to this study. Poorly controlled surgical blood loss can contribute to increases in postoperative mortality, major morbidity, and length of hospital stay.[13] Additionally, excess surgery duration is frequently cited as a major risk factor for postoperative complications.[14] While length of hospital stay may not be independent from perioperative blood loss, operative duration, and cost, it is of great importance to overall surgical success because reduced hospital stay has been shown to result in significant cost savings without increasing morbidity.[15] Within this pilot scoring tool, each of the four categories within the data set are scored with a value between 1-5 (Table 2). A lower assigned number value correlates with a more practical value. For example, a score of 1 represents the most desirable value in each criterion category, whereas a score of 5 represents a larger and less optimal value. Within the category of estimated blood loss (EBL), a 1 corresponds to less than 150 mL and a 5 corresponds to more than 300 mL of blood. Operative duration is analyzed in the same way, with a score of 1 representing a brief procedure shorter than 120 minutes and a score of 5 representing a procedure over 210 minutes. Additionally, length of hospital stay was analyzed, using less than one day as the ideal value of 1 and a stay longer than 2.6 days as the least desirable outcome. Cost was the final quantitative criterion analyzed. A cost of $5,500 or less corresponds to a score of 1, whereas a score of 5 is assessed to a procedure costing over $10,000. (Table 2 describes the intervals in which the data have been divided.) A final mean practicality score will be calculated in Table 3 by taking an average of each of the four category scores. If the calculated mean practicality score is less than the more traditional laparoscopic method, it will be considered more practical. It is important to note that the mean scores are meant to be utilized as a within comparison between two identical procedure types performed using two different techniques. The 5-point score standardization scale located in Tables 2 and 4 has strictly been utilized for greater ease of understanding. Therefore, the mean practicality score of one type of procedure bears no relevance to the mean practicality score of another. This study does not compare practicality between two different types of procedures. All specific numerical statistics pertaining to observed perioperative and postoperative outcomes can be located in Table 3, while mean practicality results can be located in Table 4.

RESULTS

Robot-Assisted Radical Prostatectomy (RARP)

Robot-assisted radical prostatectomy (RARP) is a procedure used to remove the prostate gland and the seminal vesicle, most often performed to treat localized prostate cancer.[16] Robot-assisted prostatectomy is easily the most common robotic procedure performed today; it has experienced exponential growth in the years following its approval by the Food and Drug Administration (FDA) in 2000.[16] Between 2003 and 2004 the number of surgeries increased threefold, and statistics indicate that robot-assisted prostatectomy is gaining popularity throughout the United States.[17] Although robot-assisted prostatectomy is gaining popularity, some practitioners remain skeptical, mainly due to the limited long-term research currently available. However, robotic prostatectomy is widely associated with several peri-operative and post-operative benefits, including decreased blood loss, decreased post-operative pain, and shorter hospitalizations when compared with retropubic or traditional laparoscopic prostatectomy.[18-22] While Ficarra's 2009 meta-analysis shows similar blood loss between the two techniques,[22] a 2005 study shows that RARP displayed far less EBL when compared to traditional laparoscopy (206 vs 299 ml).[19] It also seems that midterm recovery is a benefit of robot-assisted prostatectomy. Comparisons with traditional laparoscopic radical prostatectomy (LRP) surgeries showed that while patients from both methods regained their continence in the long-term, those who underwent robotic prostatectomy were more likely to do so within the first six months (68-96% compared to 43-80%).[22] Additionally, a comprehensive study by Patel et al displayed increased trifecta (continence, potency, and prostate specific antigen) outcome rates at six weeks, three, six, twelve and eighteen months after RARP (42.8%, 65.3%, 80.3%, 86% and 91% respectively).[23] Another benefit of the da Vinci® surgical system is that it appears to minimize the learning curve for new surgeons due to the added dexterity, which is so vital within the pelvis.[12]

Currently, most of the disadvantages associated with robot-assisted prostatectomy seem to be monetary. To this point, LRP continues to be more affordable than RARP by around $1200, mostly due to the initial purchase of the equipment.[21, 24, 25] While the initial purchase and maintenance costs of a da Vinci® surgical system are quite high, they do not seem to be prohibitive given the increase in the amount of robot-assisted prostatectomy procedures being performed at many locations. An additional factor that must be evaluated is total operative time. While robot-assisted prostatectomy initially seems to have a longer total operative time in the early phase, operative duration decreases with experience.[26] Several recent studies have found RARP to have a shorter average duration.[22, 27] Due to the growth and popularity of robot-assisted prostatectomy, some experienced surgeons at high-volume centers are now able to complete the procedure within 90 minutes.[22] Long-term oncologic outcomes are limited, but the existing literature seems encouraging. A 2011 study evaluating 3625 patients over eight years concluded that RARP offers effective long-term biochemical control.[28] Currently, with cost being one of the only barriers, it seems that the frequency of RARP will continue to rise in the future due to the procedure's successes.

Robot-Assisted Pyeloplasty

Pyeloplasty has become the standard surgical treatment for ureteropelvic junction obstruction (UJO) to allow urinary flow from the renal pelvis into the ureter.[12] The first robot-assisted pyeloplasty was performed on a swine model by Sung and co-authors using the Zeus® surgical system in 1999. The team concluded that robot-assisted laparoscopic pyeloplasty is a feasible and effective procedure that may enhance surgical dexterity and precision.[29] With the increasing use of the da Vinci® surgical system, the frequency of robot-assisted pyeloplasty has continued to grow. It appears that both laparoscopic pyeloplasty and robotic pyeloplasty have similar outcomes in terms of their success rates. As of 2006, Bhayani and co-authors concluded that robot-assisted pyeloplasty had no distinct advantage when compared with traditional laparoscopic pyeloplasty performed by an experienced surgeon.[30] However, since then the robotic method has continued to improve, and results point to several common advantages in decreasing mean estimated blood loss (50 vs. 158 ml) and mean hospital stay (1.54 vs. 1.98 days).[31-33] In addition, a comprehensive comparison of two large-scale literature reviews found that robot-assisted pyeloplasty has shorter operating time (194 vs 224 mins) when compared to the laparoscopic method.[31, 33] The enhanced suturing ability often associated with the robotic platform is ideal for the efficient reconstruction needed for the procedure. Those with advanced robotic laparoscopy skills have completed the procedure in as few as 60 minutes.[34] Further benefits of robot-assisted pyeloplasty include the potential to reduce technical challenges of laparoscopic pyeloplasty, which is considered a challenging procedure even for most skilled laparoscopic surgeons.[35] Although evaluation of costs shows that robot-assisted pyeloplasty can be more costly ($10,635 vs $9,065) than laparoscopic or open methods,[33] the procedure will likely continue to gain in popularity due to these documented advantages.

Robot-Assisted Partial Nephrectomy (RAPN)

Nephrectomy is the surgical removal of all or part of the kidney, which is often performed in patients with renal cell carcinoma.[36] The application of robotics to partial nephrectomy is a recent technique in the field, with the first robot-assisted partial nephrectomy performed by Gettman in 2004.[37] Currently robot-assisted partial nephrectomy (RAPN) is a viable option for patients who desire a minimally invasive option for the performance of nephron-sparing surgery.[38] Most of the benefits of RAPN, such as less EBL and shorter hospital stay, [36, 39] can be attributed to enhanced suturing dexterity when compared to laparoscopic techniques.[40] Moreover, RAPN is associated with a shorter total operative time [36, 41] as well as a decreased learning curve.[42, 43] Benway suggests RAPN is a safe and viable alternative to laparoscopic partial nephrectomy, "<that it> may provide maximal renal nerve preservation," [43] which is vital in the sympathetic regulation of the nephron and renin-angiotensin system.[44] Much like what is seen in both RARP and robot-assisted pyeloplasty, the cost of RAPN is greater than that of Laparoscopic methods by roughly $1,500 per surgery.[39] An additional limitation related to the cost of RAPN is the need for a bedside assistant, a factor that presents further challenges in robot integration. Similar to many robot-assisted procedures, the long-term oncologic effects of RAPN have yet to be seen. It requires further exploration since the first recorded procedure was performed in 2004. As surgeons' experience increases, patients will experience the benefits of RAPN, and the use of robotics for partial nephrectomy should continue to grow.

RESULTS ANALYSIS

The results indicate that robotic integration is more practical for each of the three surgeries reviewed in this research project. Factors that influenced the results were the propensity of robot-assisted procedures to produce similar outcomes to laparoscopic procedures while allowing for less blood loss and a shorter length of hospital stay. Laparoscopic and open procedures scored

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better in categories such as cost, while operative duration was highly dependent on the individual procedure. Additionally, while the cost of surgery is higher in the robotic cohort, the decreased hospital stay occasionally brings the patient's expenses within the range of more traditional surgical methods. Although not included in the numerical practicality analysis, the literature review revealed several opinions on the practicality of the robotic technique when used on the three urologic procedures assessed in this study. Most surgeons found that the increased dexterity allowed by the da Vinci® provided for easier suturing within the abdominopelvic cavity. Additionally, several analyses of these specific robotic procedures noted a decreased learning curve for new surgeons, [5, 12, 43] as well as a tendency for operative time to decrease with surgeon experience.[26]

CONCLUSION

Through this retrospective analysis it is clear that robotic surgery in urology bears many advantages. Whether through hybrid integration or full robotic procedures, there will be uses for robot-assisted surgery in the coming years. With that said, we must be careful not to take a broad view of the subject. There can be no general conclusion to the effectiveness of robot-assisted surgery as a whole, nor can there be a general conclusion to its effectiveness within urology, but rather each procedure must be evaluated individually.

The original assessment tool used in this article specifically shows how the strengths of each technique benefit the field in a different way. By using this tool, practicality can be assessed for each procedure rather than grouping the techniques as a whole. Although the results show that there is a difference in the mean practicality score (Table 4), more examination is needed. Our exploratory research tool should be modified to allow for more distinct comparative evaluations of robotic and laparoscopic techniques. Even then, long-term effects such as durability and oncologic outcomes must be assessed before a final conclusion is reached for each procedure. At this time we can only tentatively recommend the robotic techniques for each of the three procedures. For now, it is safe to conclude that minimally invasive robot-assisted surgery is a practical technique for all three urologic procedures, but must be further examined to determine if it is significantly more practical.

LIMITATIONS

The original assessment tool has not yet undergone any formal tests for validity and reliability and is exploratory in nature. We hope to use this current study's results to develop an assessment tool for further research, which would allow for more complete statistical analyses. Although we feel that this practicality assessment tool is in its infancy, we believe that the strength of this study lies in the large number of studies (91) that were incorporated through the review of the meta-analyses and comparative studies used to compile the data for our tables.

FUTURE DIRECTIONS

The da Vinci®'s greatest strength is its versatility, a fact displayed by its use in many different medical specialties. Although well known for its utilization in urology and gynecology, the da Vinci® robot sparked tremendous advancements in other fields, such as cardiothoracic surgery. One of the crowning accomplishments of the da Vinci® system is that it allows the performing of coronary artery bypass grafting (CABG) surgery on a closed chest with a beating heart,[45] a feat considered inconceivable only a few years ago. Further advancements for the future of robotic surgery include the utilization of remote telesurgery in which the surgeon and patient can be thousands of miles apart. Although current application of such technology is not yet mainstream, the first telesurgery procedure was performed in 2001, on a patient in France via a surgeon in New York.[46] Possibly the most futuristic yet controversial technology is that of automated computer surgery.[10] Such robots could provide the possibility of "error free" surgery and would further solidify a niche for robotic surgery. While such ideas seem futuristic, they are within reach given current technologies. The future of robotic surgery seems promising, with fields such as urology continuing to develop and improve the technology and techniques. While it is unlikely that robotic surgery will ever completely replace open surgery or even traditional laparoscopy, it is likely that the technique will see increased utilization as patients seek the most minimally invasive and technologically advanced methods. Overall, we have just scratched the surface of robotic surgery and in the future, these techniques should provide the chance for incredible innovation within the field of medicine.

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Table 1: Literature Search Strategy

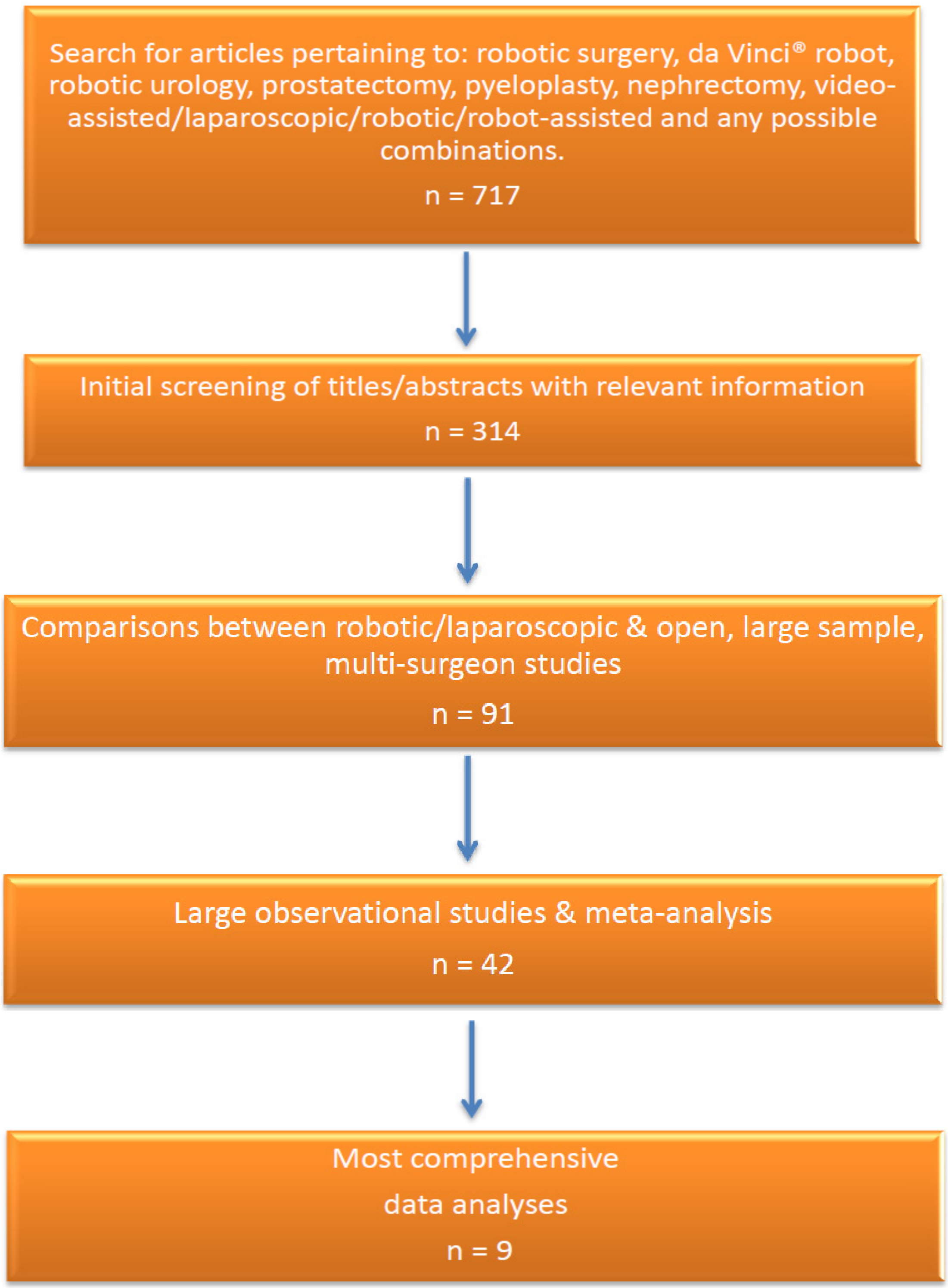

Table 2: Quantitative Data Key

EBL					
score	1	2	3	4	5
mL	<150	151-200	201-250	251-300	>300

Operative Duration					
score	1	2	3	4	5
minutes	<120	121-150	151-180	181-210	>210

Hospital Stay					
score	1	2	3	4	5
days	<1.0	1.1-1.6	1.6-2.1	2.1-2.6	>2.6

Cost					
score	1	2	3	4	5
US $	<5,500	5,501-7000	7,001-8,500	8,501-10,000	>10,000

Table 3: Numerical Data Collection

Radical Prostatectomy				
Method	Peri-operative (EBL)	Operative Duration	Hospital Stay	Cost
Robotic Radical Protatectomy	329.75 ml [22]	207.5 mins [22]	1.56 days [24]	$6752 [25]
Laparoscopic Radical Prostatectomy	350.5 ml [22]	224.75 mins [22]	1.76 days [24]	$5687 [25]

Pyeloplasty				
Method	Perioperative (EBL)	Operative Duration	Hospital Stay	Cost
Robot-assisted Pyeloplasty	50 ml [31]	194 min [31]	1.54 days [33]	$10,635 [39]
Laparoscopic Pyeloplasty	158 ml [32]	224 min [33]	1.98 days [33]	$10,311 [39]

Partial Nephrectomy				
Method	Peri-operative (EBL)	Operative Duration	Hospital Stay	Cost
RAPN	162 ml [36]	191 min [36]	2.6 days [39]	$11,962 [39]
Laparoscopic Nephrectomy	250 ml [41]	210 min [41]	3.2 days [39]	$10,311 [39]

Table 4: Scaled Scoring

Radical Prostatectomy					
Method	Peri-operative (EBL)	Operative Duration	Hospital Stay	Cost	Mean Practicality Score
Robot-Assisted	5	4	2	2	3.25
Laparoscopic	5	5	3	2	3.75

Pyeloplasty					
Method	Peri-operative (EBL)	Operative Duration	Hospital Stay	Cost	Mean Practicality Score
Robot-assisted	1	4	2	5	3
Laparoscopic	2	5	3	4	3.5

Partial Nephrectomy					
Method	Peri-operative (EBL)	Operative Duration	Hospital Stay	Cost	Mean Practicality Score
Robot-Assisted	2	4	5	4	3.75
Laparoscopic	3	4	5	5	4.25

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