TITLE: Robotic Surgery versus Open-chest Surgery for Internal Mammary Artery Harvesting and Mitral Valve Surgery: Clinical Effectiveness

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CONTEXT AND POLICY ISSUES

Surgical robots, such as the da Vinci Surgical System (Intuitive Surgical), can be used for remote manipulation of surgical tools in a variety of endoscopic procedures, including urological surgery (e.g., radical prostatectomy), gynecological surgery and, increasingly, thoracic surgery. In thoracic surgery, the use of surgical robotics offers a minimally-invasive alternative to the conventional median sternotomy, which involves increased trauma with the cracking of the sternum and can lead to chronic complications and undesired cosmetic results.

Two cardiac interventions where robotic-assistance is potentially useful are mitral valve repair, to fix narrowing or leakage of the mitral valve, and coronary artery bypass grafting. Coronary artery bypass grafting typically involves grafts taken from multiple sources, though survival benefit is thought to derive mainly from harvesting the internal mammary artery and grafting it onto the left anterior descending artery. Grafting the internal mammary artery to the left anterior descending artery allows for use of minimally invasive techniques, without requiring full sternotomy.

The initial costs and maintenance costs of a surgical robot can be high, and the cost per procedure exceeds that of conventional techniques, but the added clinical value to robotically-assisted cardiac procedures, and whether any benefits outweigh the additional costs, remain unclear.

This report examines the existing evidence of the clinical effectiveness of robotic surgery compared to open-chest surgery for coronary artery bypass surgery involving internal mammary artery harvesting and mitral valve repair.

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RESEARCH QUESTIONS

1. What is the comparative clinical effectiveness of robotic surgery versus open-chest surgery in adult patients undergoing internal mammary artery harvesting?

2. What is the comparative clinical effectiveness of robotic surgery versus open-chest surgery in adult patients undergoing mitral valve surgery?

KEY MESSAGE

For coronary artery bypass graft and mitral valve repair, robot-assisted surgical procedures take longer than open-chest techniques but result in faster recovery times and fewer complications.

METHODS

A limited literature search was conducted on key health technology assessment resources, including Medline, Embase (via OVID), PubMed, The Cochrane Library (Issue 1, 2011), University of York Centre for Reviews and Dissemination (CRD) databases, ECRI (Health Devices Gold), EuroScan, international health technology agencies, and a focused Internet search. The search was limited to English language articles published between January 1st, 2001 and January 14th, 2011. Filters were applied to limit the retrieval to health technology assessments, systematic reviews, meta-analyses, randomized controlled trials, and non-randomized studies.

SUMMARY OF FINDINGS

One health technology assessment (HTA) and one systematic review assessing the efficacy of robot-assisted surgery were identified. Two non-randomized studies were identified comparing robot-assisted surgery to conventional techniques for mitral valve repair and two were identified comparing the two approaches for coronary artery bypass graft surgery. One additional relevant HTA and three additional non-randomized studies were identified but were included in the other HTA or systematic review and are not summarized in this report.

Health technology assessments

In 2009, the Belgian Health Care Knowledge Centre published an HTA reviewing the efficacy and safety of robot-assisted surgery. A systematic literature search for the evidence on the effectiveness of robot-assisted surgery in humans, compared to conventional interventions, was undertaken focussing on health technology assessments, systematic reviews, clinical trials, and prospective studies. The search included articles published between 2002 and April 2008, with an additional update in October 2008 and a supplemental hand search during the final stages of the report. Other study inclusion and exclusion criteria were not defined. The search strategy resulted in 234 studies for inclusion, including 18 HTAs, systematic reviews or horizon scans. Included studies were not limited to cardiac interventions. The included studies reported on a variety of outcome measures including amount of blood loss, transfusions needed, complication rates (during and after surgery), procedure time and length of hospital stay. Depending on the indication, robot-assisted surgery was compared to open surgery or minimally invasive techniques.
Review of the literature indicated that robot-assisted coronary artery bypass surgery has had some positive results but long-term safety and efficacy has not yet been established. One included HTA suggested that there was insufficient data to conclude whether robot-assisted coronary artery bypass provides comparable outcomes to conventional open bypass surgery or to other minimally invasive revascularization techniques. Another HTA concluded that robot-assisted coronary artery bypass on an arrested heart was sufficiently safe and efficacious, and compared well with other minimally invasive or conventional techniques. No systematic reviews were identified for mitral valve surgery. Comparative studies suggest that robot-assisted endoscopic mitral valve surgery can be performed safely with similar results to conventional methods, while allowing patients to avoid a sternotomy, and resulting in fewer transfusions and shorter hospital stays. However, short follow-up durations mean that long term durability of robotically-repaired mitral valves is uncertain.

The authors conclude that in the case of coronary artery bypass grafts, robot-assisted surgery is promising but is highly operator dependent and should be restricted to experienced surgical teams. In the case of mitral valve surgery, robot-assisted techniques seem safe and efficacious compared to conventional techniques. The assessment is limited by the lack of clear inclusion and exclusion criteria. Additionally, the included studies were not described in detail, so assessing the quality of the available evidence and the specifics of the data is not possible.

**Systematic reviews and meta-analyses**

In 2009, the Australian Safety and Efficacy Register of New Interventional Procedures-Surgical (ASERNIP-S) agency\(^6\) published a rapid systematic review to evaluate the safety and efficacy of robot-assisted surgery compared to conventional techniques for urological, cardiac and gynaecological interventions. Studies published between January 1, 2004 and February 20, 2009 were eligible for inclusion if they were systematic reviews, randomized controlled trials or non-randomized comparative studies which reported on the use of robotic-assisted surgery compared with conventional surgical approaches. To be eligible for inclusion, studies had to be done with adult (over 18 years old) human patients. Only studies published in English were considered. Efficacy outcomes included length of hospital stay, procedure time, blood loss, need for transfusion, and conversion rates. In the case of cardiac procedures, 478 potentially relevant citations were identified, of which four non-randomized comparative studies were eligible for inclusion. All four studies (\(n = 155\) for robot-assisted surgery versus \(n = 528\) for other techniques) examined the use of the da Vinci Surgical System for mitral valve repair. Studies were assessed based on quality of evidence. Three included studies were graded III-3, indicating comparative studies with historical controls. One study was graded III-2, indicating comparative studies with concurrent controls, case-control studies, or cohort studies.

Two included studies reported on procedure time. One reported that robot-assisted operating times were longer compared to open mitral valve repair (241 minutes versus 188 minutes, \(P = 0.002\)). The other compared robot-assisted mitral valve surgery to video-assisted endoscopic repair and reported no significant difference in procedure length (283.2 minutes versus 261 minutes, \(P = \text{not reported}\)). One study examined estimated blood loss during the procedure and found no statistically significant difference between robot-assisted and conventional open surgery (477.2 mL versus 566.2 mL). All included studies reported on length of hospital stay. Two studies reported shorter hospital stays with robot-assisted procedures (7.1 days versus 10.6 days, \(P = 0.039\) and 7 days versus 9 days, \(P = 0.05\)), while the other two also reported shorter stays when the da Vinci system was used (6.6 days versus 7.9 days and 4.8 days versus 6.5 days) but did not report on statistical significance. Three studies reported on
transfusion rates. One reported no statistically significant difference in transfusion rate between robot-assisted and open mitral valve repair, another only reported transfusion rates only for conventional open surgery, and the third reported a higher transfusion rate in patients undergoing video-assisted endoscopic surgery compared to robot-assisted but did not report on statistical significance. The fourth study did not examine transfusion rates but did report the use of fewer units of packed red blood cells among patients undergoing the robot-assisted procedure (2.8 units versus 5 units, P = 0.04). Three included studies reported re-operation rates and claimed a lower rate of re-operation with robot-assisted procedures, though none of the studies mentioned statistical significance. All four studies reported mortality and complication rates during mitral valve repair. Two studies reported higher complication rates with the da Vinci Surgical System, while two studies reported lower rates. None of the studies included statistical analysis. Overall, complication rates were 9%, 4.4% and 27.3% for robot-assisted, video-assisted and open mitral valve repair, respectively, while mortality rates were 1.3%, 2.3% and 1.6%.

The authors conclude that operation times with the da Vinci Surgical System are longer but generally result in shorter overall hospital stays. Blood loss and need for transfusion were not significantly different between robot-assisted and open mitral valve repair. Mortality rates for robot-assisted, video-assisted and open procedures were generally low and complications were more frequent with open repair procedures compared to other techniques. Some key patient-related outcomes were not reported such as post-operative pain and quality of life measures, and there was insufficient follow-up data to determine long-term outcomes. All included studies were non-randomized comparative studies, which are considered lower quality evidence due to inherent potential for bias.

Non-randomized studies

Coronary Artery Bypass Graft

In an abstract presented at the 2010 World Congress of Cardiology, Sutter et al. reported the results of a prospective single-centre four-year study comparing mini-incision, non-rib spreading, robot-assisted coronary artery bypass graft to the traditional approach of sternotomy. Between May 2005 and April 2009, 394 patients underwent robot-assisted coronary artery bypass graft surgery. Six patients underwent conversion to sternotomy during the procedure. During the same time, 1,100 patients underwent coronary artery bypass graft by traditional sternotomy. From this group, a matched cohort (based on age, sex, BMI and disease features) was randomly selected.

Robot-assisted procedures took longer than the traditional approach (3.3 ± 8 hours versus 4.6 ± 1.2 hours, P < 0.001) but resulted in shorter overall hospital stays (6 ± 6 days versus 7.3 ± 7.8 days, P < 0.01). There was no statistical difference in post-operative mortality or stroke between the two groups. Patients undergoing the robot-assisted procedure had lower transfusion rates both intra-operatively (8.2% versus 16.6%, P < 0.01) and post-operatively (15.2% versus 36.7%, P < 0.001) and a lower rate of post-surgical renal failure (1% versus 3.5%, P < 0.05). The authors conclude that despite a longer operating time, the shorter hospital stay and lower complication rate offsets many disadvantages of traditional sternotomy. However, the lack of randomization introduces the risk of bias, and it is not evident who performed the surgeries or whether differences in surgical experience were accounted for in the analysis. The surgeries performed were not well described, so it is not clear if grafts were done with the internal mammary artery or other vessels.
In 2008, Potson et al.\textsuperscript{3} performed an observational study of patients undergoing coronary artery bypass graft surgery. This study included 100 consecutive patients undergoing minimally invasive coronary artery bypass graft with internal mammary artery harvesting using a da Vinci Surgical System. Patients were excluded if they suffered from severe pulmonary and vascular disease, decompensated heart failure, significant arrhythmia, or were allergic to radiographic contrast material. Hemodynamically unstable patients and those who could not be provided with complete revascularization were also excluded. Patients undergoing robot-assisted surgery were compared to a control group of 100 patients undergoing off-pump coronary artery bypass graft using internal mammary artery and saphenous veins by median sternotomy. These control patients were selected from a cohort of 307 patients and matched to cases based on risk factors for outcomes of surgical revascularization. All patients underwent their respective surgical intervention between January 2005 and June 2007. There were no significant differences in group demographics.

Patients operated on using the da Vinci system had longer procedure times (5.8 ± 2.1 hours versus 4.1 ± 0.9 hours, \(P < 0.001\)) but shorter ICU stays (21.9 ± 9.3 hours versus 50.6 ± 27.3 hours, \(P < 0.001\)) and shorter overall hospital length of stay (3.77 ± 1.51 days versus 6.38 ± 2.23 days, \(P < 0.001\)). Patients receiving robot-assisted surgery also experienced shorter intubation times (4.80 ± 6.35 hours versus 12.24 ± 6.24 hours, \(P < 0.001\)), less intraoperative blood loss (547 ± 366 mL versus 1230 ± 945, \(P = 0.001\)) and required fewer units of transfused packed red blood cells (0.16 ± 0.37 units versus 1.37 ± 1.35 units, \(P < 0.001\)) compared to patients undergoing median sternotomy. Conventional surgery resulted in a higher rate of major post-operative complications within 30 days of intervention, including myocardial infarction, reoperation due to bleeding, stroke, or 30-day mortality (aggregate complication rate 37% versus 12%, \(P = 0.031\)). One year post-surgery, patients undergoing median sternotomy had higher rates of major adverse cardiac and cerebrovascular events, including myocardial infarction, stroke, graft failure, and cardiac-related deaths (26% versus 4%, hazard ratio [HR] 3.9, 95% confidence interval [CI] 1.4 to 7.6, \(P = 0.008\)). Robot-assisted patients also returned to work or normal activities in a shorter amount of time post-surgery (44.2 ± 33.1 days versus 93.0 ± 42.5 days, \(P = 0.016\)).

The authors conclude that in exchange for a longer procedure time and higher intraoperative costs compared to median sternotomy for coronary artery bypass graft, robot-assisted surgery results in shorter hospital stays, reduced risk of major complication, and improved quality of life immediately following surgery through the first year post-surgery. The lack of randomization does increase the risk of bias, though attempts were made to minimize this by enrolling consecutive rather than selected patients and having all interventions performed by a single surgeon. However, because blinding to treatment is not possible, there is the risk of bias in making decisions directly related to outcomes such as length of hospital stay, intubation time, or use of blood products.

**Mitral Valve Repair**

In 2010, Kam et al.\textsuperscript{4} published a retroactive review of all mitral valve repair surgeries performed within the Epworth HealthCare network over a three year period (June 2005 to June 2008). Patients were eligible for inclusion if they were over 18 years old, and had an elective mitral valve repair for degenerative mitral valve disease. Outcome measures included operation times, residual mitral regurgitation severity, length of ICU stay, and total length of hospital stay. All robotically-assisted surgeries were performed using the da Vinci Surgical System.
A total of 147 patients were included in the study. Of these, 107 underwent robotically-assisted mitral valve repair. The remaining 40 patients received conventional mitral valve surgery. All robot-assisted surgeries were performed by the same surgeon, while conventional repair was done by 11 different surgeons. There were no statistically significant differences in patient demographics between the groups, though the group receiving robotically-assisted repair had a higher proportion of severe mitral regurgitation (94.2% versus 82.5%, $P = 0.029$). Robot-assisted surgeries took longer overall (239 min versus 202 min, mean relative difference 1.18, $P < 0.001$, 95% CI 1.11 to 1.27), and had longer cardio-pulmonary bypass times (126 min versus 94 min, mean relative difference 1.35, $P < 0.001$, 95% CI 1.23 to 1.48) and longer aortic cross-clamp times (95 min versus 73 min, mean relative difference 1.30, $P < 0.001$, 95% CI 1.17 to 1.44).

Post operatively, there was no statistically significant difference in rates of regurgitation. Ventilation time did not differ between the two groups (6.17 hours [robot] versus 6.61 hours [conventional], $P = 0.412$). Patients receiving robot-assisted surgery had shorter stays in the ICU (37 hours versus 45 hours, mean relative difference 0.81, $P = 0.002$, 95% CI 0.71 to 0.92) and shorter overall hospital stays (6.47 days versus 8.76 days, mean relative difference 0.74, $P < 0.01$, 95% CI 0.68 to 0.80). There were no intra-operative deaths in either group. Two patients in the robot-assisted group experienced post-operative bleeding requiring re-operation. No patients undergoing conventional surgery experienced post-operative bleeding. Inconsistent discharge form completion prevented the analysis of other complications.

The authors conclude that mitral valve repair performed with robotic-assistance results in longer procedure times with a comparable success rate, and significantly reduces recovery times. Because the study was a retrospective review of patient cases, there was no randomization of subjects and there may have been unknown reasons why patients were selected to receive one form of surgery over another. While surgical success can be measured by post-operative mitral regurgitation rates, the number of repair procedures that were converted to replacement during surgery is unknown. The study is further limited by lack of reporting on complication rates for the two interventions. Finally, though the study excluded the first year of the robotic surgery program to minimize learning curve bias, all robot-assisted surgeries were performed by a single surgeon while conventional surgery was performed by 11 different surgeons. Differences in surgical skill or experience were not accounted for in the analysis.

In an abstract presented at the 2009 meeting for the International Society for Minimally Invasive Cardiothoracic Surgery, Bhamidipati et al. reported the results of a review of mitral valve repair procedures conducted at a single institution between August 2004 and April 2008. During that period, 22 patients underwent median sternotomy for mitral valve repair with no concomitant procedures. Fifty patients were scheduled for robot-assisted mitral valve repair, with seven undergoing conversion (six sternotomy, one port-access) and two outliers were excluded from the analysis.

Compared to patients undergoing median sternotomy ($n = 22$), patients receiving robot-assisted surgery ($n = 41$) had shorter operation times ($266.68 \pm 39.21$ minutes versus $306.27 \pm 75.89$ minutes, $P = 0.008$) and shorter overall hospital stays ($5 \pm 2$ days versus $7.36 \pm 4.07$ days, $P = 0.003$). There was no statistically significant difference in ventilation time between the robot-assisted and median sternotomy patients ($21.06 \pm 35.08$ hours versus $18.59 \pm 8.89$ hours, $P$ not reported). Mild post-operative regurgitation was observed more often in patients undergoing median sternotomy (23% versus 2%, $P = 0.024$). Patients undergoing median sternotomy also required more blood transfusions (41% versus 29%) and a higher rate of post-operative atrial
fibrillation (41% versus 27%). Statistical significance of these differences was not reported. There were no 30-day mortalities in either group.

Overall, the authors conclude that robot-assisted mitral valve repair results in shorter operation times and hospital stays with fewer complications. Long term follow-up was not done. Lack of randomization could introduce the risk of bias, and the two outliers and reasons for exclusion were not well described which may affect the reported results. The study was also limited by the sample size.

Limitations

Available evidence for the clinical effectiveness of robot-assisted procedures for mitral valve repair or coronary artery bypass graft comes mainly from non-randomized studies with small populations. These types of studies are considered a lower standard of evidence compared to systematic reviews of randomized controlled trials or well-designed single RCTs, due to the inherent risk of bias. Lack of randomization means there may be inherent differences in patients selected for a particular intervention type that could bias results. Small study populations also limit the statistical power of the included studies.

Most of the included studies did not include long-term follow-up of patients after surgery, so there is limited data on the long term risks or benefits of robot-assisted cardiac surgery, or the durability of repairs done with this technique.

While some studies tried to minimize bias due to training time with the da Vinci Surgical System, in most cases it was unclear whether differences in surgical personnel or experience with the procedures might affect reported observations.

Finally, it is impossible to blind with respect to robot-assisted endoscopic or open-chest surgery, and there is some inherent risk of bias when making decisions related to patient outcomes.

CONCLUSIONS AND IMPLICATIONS FOR DECISION OR POLICY MAKING:

One health technology assessment and two non-randomized studies that compared robot-assisted coronary artery bypass graft surgery to an open-chest approach were identified. Procedures performed with the da Vinci Surgical System took longer on average but resulted in lower transfusion rates, fewer complications, and shorter overall hospital stays. Results from the one HTA suggest that robot-assisted coronary artery bypass surgery is promising but should be limited to experienced surgical teams.

One HTA, one systematic review, and two non-randomized studies were identified that compared robot-assisted versus open-chest surgery for mitral valve repair. The included studies found that robot-assisted procedures took longer on average, with the exception of one study that reported shorter operating time with the da Vinci Surgical System. In all cases, the use of surgical robotics resulted in shorter overall hospital stays and fewer transfusions. Patients receiving robotically-assisted surgeries had lower rates of post-operative complications.

There were no statistically significant differences in post-surgery mortality between robot-assisted and open-chest surgeries for either coronary artery bypass graft or mitral valve repair. Data on long term clinical benefits was limited.
REFERENCES:


