Robotic surgery has continued to experience explosive growth in several specialties like urology, gynecology and general surgery. However, growth in cardiothoracic surgery has occurred at a slower pace, and rightly so for a variety of reasons that are not the focus of this paper. Consequently, clinical data in the cardiothoracic specialty has grown at a similarly slower pace. As new approaches to surgery gain popularity, there is an increase in analysis of the new approach versus the gold standard, the open approach, and other more established approaches. In the last few years, more clinical publications on robotic cardiac surgery have appeared.

The purpose of this paper is to briefly review the results of a series of single center and multicenter studies on robotic mitral valve repair and to provide insight on trends with minimally invasive (MI) and robotic mitral valve surgery. The search for relevant papers with a series greater than 150 patients yielded a few results. We focused on some leading robotic and minimally invasive pioneers. Some of the robotic valve pioneers have been doing robotic mitral valve repair surgery since 2000. Other high volume robotic valve centers, like the Cleveland Clinic, started in 2006.

The review commences with the study that is the first study of its kind: the Cleveland Clinic's "Robotic Mitral Valve Repair versus Conventional Approaches: Potential Realized. Tomislav Mihaljevic, MD et al compared four different approaches to mitral valve repair using propensity matching. It is the largest comparison to date and is the first from a major institution like the Cleveland Clinic. Additionally, we reviewed studies from East Carolina Univeristy, St. Joseph's Hospital Atlanta, Georgia, Good Samaritan Hospital in Cincinnati, Ohio, and Sacred Heart Medical Center in Spokane, Washington.

Conclusions: Overall, the results for robotic mitral valve repair surgery were equivalent to the conventional approaches in some criteria, superior in others, and inferior in a few. Complexity of repairs was equivalent to open technique. When compared to other approaches, it was clear that the robotic procedures took longer. Length of stay for patients undergoing robotic surgery ranged from 4.2 days[4] to 4.8 days[3]: the shortest length of stay in each study. Cardiopulmonary bypass times ranged from 156-166 minutes. (The detail from the Cleveland Clinic study regarding CPB times was not included in the abstract and as of the printing of this paper had not yet been published.) Mean operative time was listed at 389 minutes in the Cleveland Clinic's study, an hour longer than the reported minimally invasive time. Percent of valves repaired are 99%[5], 96.4%[1], 94.2%[4] and 88%[2].

In spite of the new published results, robotic mitral valve surgery still has some misconceptions most recently discussed at the AATS in Toronto in May 2010. Some cardiac surgeons maintain the belief that robotic mitral valve surgery is reserved for simple repair techniques that feature P2 resection/approximation followed by an annuloplasty with a flexible band. There is a growing body of evidence showing that valve repair methods like the American Correction Technique made famous by Dr. Gerald Lawrie, and other techniques featuring complex neochord placement and/or the use of rigid annuloplasty rings can be performed in a robotic approach with equivalent repair results to conventional approaches. Following in the footsteps of Dr. W. Randolph Chitwood at East Carolina University Heart and Vascular Center, the Cleveland Clinic, Mayo Clinic, Johns Hopkins and other centers routinely perform complex mitral valve repairs.

A growing trend in robotic valve surgery is the increase in multi-valve procedures, most commonly mitral valve repair followed by a tricuspid valve repair. At least one surgical team, Clifton Lewis and John Richardson at St. Vincent's Hospital in Birmingham, Alabama are performing a MI aortic valve replacement followed by robotic mitral valve repair and as required, a MAZE procedure. Dr. Lewis has one of the largest series of robotic multivalve procedures in the US. History has shown the growth of MI valve surgery started initially with simple

repairs and expanded to more complex repairs post-learning curve. Due to improved 3D visualization in high definition, wristed instruments and other advancements, the growth of complex robotic mitral valve surgery has occurred in a shorter time.

Is robotic mitral valve surgery superior to the minimally invasive approach? According to the Cleveland Clinic study, it is equivalent. There are several sites across the country to include ECU, the Cleveland Clinic, the Mayo Clinic, Johns Hopkins and many more that still perform minimally invasive mitral valve repairs with excellent operative times and similar lengths of stay. Undoubtedly, there are those surgeons who have mastered using the robot and feel that they can see the valve better than they ever have before without having to increase the size of the working incision. Other experienced valve surgeons state that having dynamic atrial retraction is the impending paradigm shift in mitral valve repair. Still other surgeons insist that having a 3rd operating "hand" is extremely valuable. But, is having another "hand" to operate, or better vision, or dynamic atrial retraction a reason to invest the resources required to build a successful robotic mitral valve repair program? Surgeons who have mastered the MI approach would state that a robot is not necessary. Additionally, these surgeons have proven that most of the limitations of MI mitral valve repairs can be overcome by practice and perseverance.

On the other hand, robotic surgeons like Doug Murphy truly believe in the value that the robot brings to mitral valve surgery. Dr. Murphy's discussion of having 5 hands working at the same time inside the heart is very compelling. The 5 hands are: 3 robotic instruments, 1 binocular camera, and the instrument held by the physician's assistant. He states that having 5 hands working at the same time in the heart is impossible to do without robotic assistance. In 2008, Tom Mihaljevic stated that "robotic mitral valve surgery is the fastest growing procedure in the history of the Heart and Vascular Center of the Cleveland Clinic." The advancements of robotic technology overcome the limitations commonly identified with MI surgery; counterintuitive motion, 2D vision, non-wristed instrumentation, and static atrial retraction.

Why is the robotic approach still growing? We have to look at the consumer / patient for the answer. We are well into the era of the quickly informed consumer / patient. Consumers demand smaller, faster, better, more features, more power, less energy used, low-calorie, no-calorie, more flavor, less expensive etc.. Consumers demonstrate demand by paying for what they want. Consumer demands are at an all-time high in the medical field. Surgeons want a 128-slice CT scanner to replace the "old" 64-slice scanner; or 3D echo for better pre-op diagnosis and post-op valve evaluation compared to 2D echo. High definition cameras provide better visualization of the anatomy than standard definition cameras. Integrated operating rooms provide faster and better information access, analysis and integration. Patients are now demanding smaller incisions, no incisions, faster return to work, faster return to normal activities, better cosmesis and the list goes on and on. Patients communicate these demands with their patronage, a well-known fact among hospital executives and surgeons.

Are patients willing to trade efficacy for a less invasiveness? Consider the invasiveness over efficacy[2] equation which speaks to the patient's willingness to sacrifice some efficacy in favor of less invasiveness. Recall percutaneous coronary intervention (PCI) versus the undisputed gold standard of surgical coronary revascularization. Neither cardiac surgeons nor cardiologists will argue the efficacy of surgical revascularization over PCI. Patients continue to select a less invasive approach even with the understanding that less invasive could mean less effective. However, the robotic approach does not mean less effective. **Robotic mitral valve repair is equivalent to minimally invasive or open approaches. Also, robotic mitral valve repair is the least invasive approach.** The Cleveland Clinic proved that the patient does not have to sacrifice efficacy for the least invasive approach.

Finally, the Cleveland Clinic's study proved equivalency of this least invasive approach to conventional approaches. Dr. Mihaljevic stated that the technical complexity of the approach resulting in longer operative times was offset by the least invasive method and shorter post-operative stay. An increasing number of patients are seeking less invasive and robotic approaches to heart surgery. Dr. Chitwood has stated that over 50% of the mitral valve patients coming to ECU in Greenville, NC (population ~ 60,000 about half of which are students) are from outside of the state of North Carolina. He, and now several other surgeons, have shown that adding a robotic approach to mitral valve repair has the potential to increase mitral valve repair volume: the primary goal of most mitral valve programs.

Robotic Mitral Valve Repair versus Conventional Approaches: Potential Realized [4]
Tomislav Mihaljevic, Craig Jarrett, A. Marc Gillinov, Sarah Williams, Pierre DeVilliers, Eugene H. Blackstone;
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Objective: Robotic mitral valve (MV) repair provides the least invasive surgical approach for treating myxomatous mitral valve disease, yet there are few data comparing its outcomes to those of conventional approaches. Therefore, we sought to compare outcomes of robotic (ROB) MV repair to those using complete sternotomy (CST), partial sternotomy (PST), and mini-anterolateral thoracotomy (MIN) approaches.
Methods: From 1/2006 to 1/2009, 743 patients with degenerative MV disease and posterior leaflet prolapse underwent primary isolated MV surgery by ROB (n=253), CST (n=113), PST (n=263), or MIN (n=114) approaches. Outcomes were compared on an intent-to-treat basis using a propensity score study design based on 60 preoperative factors to obtain well-matched patient pairs.
Results: Mitral valve repair was achieved in all patients except for one in the CST group. Among matched patients, ROB patients had the longest operative times (median 389 min), 117 min, 107 min, and 60 min longer than CST (P<.0001), PST (P<.0001), and MIN (P<.0001), respectively. There were no in-hospital deaths. Occurrences of STS-defined neurologic, pulmonary, renal, vascular, and infectious complications were similar (P>.07). ROB patients had the shortest postoperative hospital stays (median 4.2 days), 0.9 days, 1.2 days, and 0.8 days shorter than CST (P<.0001), PST (P<.0001), and MIN (P=.001), respectively. Effectiveness of MV repair was similar among groups (P=.4).
Conclusion: Robotic MV repair is as safe and effective as repair using conventional approaches. Technical complexity of the robotic approach, with resulting increase in operative times, is compensated for by lesser invasiveness and shorter postoperative stay.

Cleveland Clinic Results

Approach	N	Mean Op. Time (min.)	Post-op Hosp. Stay (Days)
ROB	253	389	4.2
CST	113	272	5.1
PST	263	282	5.4
MIN	114	329	5.0

Types of Repair [4]	N (%)
Posterior leaflet resection	77 (67.5)
Anterior leaflet resection	15 (13.2)
Chordal Repair (GoreTex® neo-chordae)	26 (22.8)
Anterior leaflet plication	2 (1.7)
Commisurotomy	2 (1.7)
Leaflet pericardial patch	2 (1.7)
Annuloplasty ring	6 (5.3)
Annuloplasty band	107 (93.9)
Atrial ablation	8 (7.0)
Left atrial appendage closure	8 (7.0)
Pericardial patch of ASD	1 (0.8)
Closure of patent foramen ovale	8 (7.0)

Multicenter Studies

	N	CPB (min.)	Aortic Occlusion (min.)	ICU (Days)	Post-op Hosp. Stay (Days)
ROB[1]	186	166	103	1.55	4.4
ROB[2,3]	200	156	119	1	4.8

Types of Repair [1]	N (%)
Isolated annuloplasty	28 (15.0)
Leaflet resection	131 (70.4)
Quadrangular resection	32 (17.2)
Sliding plasty	9 (4.8)
Chordal Repair, Replacement, Transfer or Shortening	31 (16.6)
Mitral Valve repair and concomitant procedures (i.e.,PFO/AA closure, CryoMAZE, ASD)	14 (7.5)

Repair techniques included[3]:
Quadrangular resections
Sliding plasties
Chordal transfers
Chordal shortening
Neochord insertion
Annuloplasties

[1]Murphy D, Smith JM, Siwek L et al.: Multicenter Mitral Valve Study: a Lateral Approach using the daVinci Surgical System; ISMICS 2006, San Francisco
[2]Rodríguez E, et al: Robotic Mitral Surgery At East Carolina University: A 6 Year Experience. Int J Med Robotics Comput Assist Surg
[3]W. Randolph Chitwood, Jr.:Robotics are the Future of Cardiac Surgery...And Always Will Be. Presentation 86th Annual Meeting AATS, Philadelphia 2006
[4]Murphy D, et al.: Lateral Endoscopic Approach to the Mitral Valve Using Robotic Instrumentation; JTCVS 2006.
[5]Robotic Mitral Valve Repair versus Conventional Approaches: Potential Realized [4]
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