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REVIEW ARTICLE

DECADES OF CARDIOVASCULAR SURGERY: A REVIEW

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Abstract

There has been a drastic advancement in cardiovascular surgery for the past 6 decades. Repair of valvular stenosis and regurgitation was made possible with the introduction of bioprostheses and mechanical valves. The use of variety of circulatory assist devices that include the intraaortic balloon pump, ventricular assist device and total artificial heart has greatly alleviated patient suffering in our clinics. In conducting this review, the early historical perspective of cardiovascular surgery was unveiled followed by a review of recent advances in surgical approaches to coronary artery disease, acquired valvular heart disease, and myocardial preservation. Recent devices for mechanical circulatory assistance as well as the hope of xenotransplantation were also discussed. Other advances in cardiovascular surgery involving biomolecular therapy and tissue engineering which may allow for replacement of dysfunctional tissues or to improve organ function with an assembly that contains specific populations of living cells were also enumerated.

INTRODUCTION

Cardiovascular surgery is surgery on the heart or great vessels performed by cardiac surgeons. It is done to treat complications of ischemic heart diseases (for example, coronary artery bypass grafting), correct congenital heart disease, or treat valvular heart disease from various causes including endocarditis, rheumatic heart disease and atherosclerosis. It also includes heart transplantation (Anon, 2012). Cardiac surgery has kept pace with the general trend of advancement in technology in all aspect of human endeavour. We have moved from the once pessimistic view that 'any surgeon who touches the heart would be scorned by his colleagues' to not just open heart surgery, but to minimally invasive coronary and valvular heart surgeries. In carrying out this review, attempts were made to unveil the historical perspective of the earlier cardiovascular procedures and also to evaluate some of the recent surgical advances in the management of heart diseases such as coronary artery disease, acquired valvular heart disease, congenital cardiac disease, as well as in myocardial preservation and cardiac transplantation (Richenbacher, 1989).

Historical perspective

Within the past few decades, cardiovascular surgery has undergone dramatic advancements. Before these advancements, any surgical attempt on the heart was seen as not only misguided, but unethical (Keown, 1963). In 1891 however, Henry C. Dalton in St. Louis repaired a pericardial wound in a human being. Similar success was achieved by Daniel Hale Williams in Chicago, in 1893 (Weisse, 2011). In 1906, Ludwig Rehn of Frankfurt compiled a summary of 124 cases of cardiac-wound repair that had been performed in Europe during the 1890s and thereafter. The survival rate of 40% was remarkable for that period (Weisse, 2011).

Later, the introduction of cardiopulmonary bypass, off-pump coronary artery bypass, minimally invasive direct coronary artery bypass surgery, total endoscopic coronary artery bypass, transmyocardial revascularization and cardioplegic arrest ushered in the true era of cardiovascular surgery. Bioprostheses and mechanical valves as well as techniques for valve reconstruction permitted routine repair or replacement of stenotic and regurgitant native valves

(Richenbacher, 1989). Progress in mechanical and electrical engineering also led to the development of pocket watch-sized, physiologically responsive pacemakers as well as a variety of circulatory assist devices which include the intra-aortic balloon pump, ventricular assist device and total artificial heart. The synthesis of cardiotonic and vasoactive drugs and advancements in anesthetic management, postoperative monitoring and nursing care greatly facilitated perioperative patient management (Richenbacher, 1989).The performance of serious extracardiac procedures began with the ligation of a persistent patent ductus arteriosus by Robert E. Gross in 1938 (Kaemmerer, *et al*., 2004). During the 1940s came Clarence Crafoord's repair of aortic coarctation and the Blalock-Taussig procedure for relieving the effects of hypoxia and polycythemia in the cyanotic congenital condition called tetralogy of Fallot (Harris *et al.*, 1964). Russell C. Brock in England relieved pulmonic stenosis in 3 patients who had tetralogy of Fallot, reducing the right-to-left intra-cardiac shunting. Another noteworthy extra-cardiac procedure involved Charles Hufnagel's ball-and-cage device, which was inserted into the descending aorta in patients with severe aortic regurgitation. Regurgitation was reportedly reduced by as much as 70%. This device was a precursor of mechanical valves that were developed after cardiopulmonary bypass (CPB) was introduced. Yet another important procedure that gained acceptance during the first half of the 20th century was pericardiectomy for patients with constrictive pericarditis. The first direct surgical repair of a common, chronic structural abnormality of the heart was mitral commissurotomy for mitral stenosis. Surgical management of atherosclerotic coronary artery disease began in the mid 1950s with the introduction of coronary endarterectomy by Bailey and Longmire (Baily *et al.*, 1957; Longmire, *et al*., 1958) and their co-workers. These procedures were performed on the beating heart without cardiopulmonary bypass. In 1961, Goetz *et al*. performed a non-suture anastomosis over a tantalum ring between the right internal mammary artery and the right coronary artery. The first reversed saphenous vein bypass graft was performed by Garrett in 1964 (Reul *et al.*, 1972). It is worthy to note that the greatest handicap of most of these early coronary artery bypass surgeries was the development of myocardial infarction and hyperthermia (Hultgren, *et al*, 1971).

Recent Advances in Cardiovascular Surgeries

With the advancement in cardiopulmonary bypass surgery as a form of extracorporeal circulation, surgical outcomes became better and more successful. Cardiopulmonary bypass (CPB) is a technique that temporarily takes over the function of the heart and lungs during surgery, maintaining the circulation of blood and the oxygen content of the body (Stoney, 2009). Cardiopulmonary bypass consists of two main functional units, the pump and the oxygenator which removes oxygen-deprived blood from a patient's body and replaces it with oxygen-rich blood through a series of tubes (hoses). The CPB pump itself is often referred to as a heart-lung machine or "the pump"(Wikipedia 2014). Cardiopulmonary bypass is commonly used in heart surgery because of the difficulty of operating on the beating heart (Stoney, 2009). Operations requiring the opening of the chambers of the heart such as in valvular repairs or replacement, atrial or ventricular septal defect surgeries require the use of CPB to support the circulation during that period (Stoney, 2009). The machine nourishes the blood cells and allows them to continue cellular respiration even through surgery. Cardiopulmonary bypass can be used for the induction of total body hypothermia, a state in which the body can be maintained for up to 45 minutes without perfusion (blood flow). If blood flow is stopped at normal body temperature, permanent brain damage normally occurs in three to four minutes — death may follow shortly afterward. Similarly, CPB can be used to rewarm individuals suffering from hypothermia (McCullough and Arora, 2004). Cardiopulmonary bypass mechanically circulates and oxygenates blood for the body while bypassing the heart and lungs. It uses a heart-lung machine to maintain perfusion to other body organs and tissues while the surgeon works in a bloodless surgical field. The surgeon places a cannula in right atrium, vena cava, or femoral vein to withdraw blood from the body. The cannula is connected to tubing filled with isotonic crystalloid solution. Venous blood that is removed from the body by the cannula is filtered, cooled or warmed, oxygenated, and then returned to the body. The cannula used to return oxygenated blood is usually inserted in the ascending aorta, but it may be inserted in the femoral artery. The patient is administered heparin to prevent clotting, and protamine sulfate is given after to reverse effects of heparin. During the procedure, hypothermia is maintained; body temperature is usually kept at 28 °C to 32 °C. The blood is cooled during CPB and returned to the body. The cooled blood slows the body's basal metabolic rate, decreasing its demand for oxygen. Cooled blood usually has a higher viscosity, but the crystalloid solution used to prime the bypass tubing dilutes the blood. Cardiopulmonary bypass is used in the following cardiovascular surgeries: Cardiac valve repair and/or replacement (aortic valve, mitral valve, tricuspid valve, pulmonic valve),Repair of large septal defects (atrial septal defect, ventricular septal defect, atrioventricular septal defect),Repair and/or palliation of congenital heart defects (Tetralogy of Fallot, transposition of the great vessels),Transplantation (heart transplantation, lung transplantation, heart–lung transplantation),Repair of some large aneurysms (aortic aneurysms, cerebral aneurysms),Pulmonary thromboendarterectomy and Pulmonary thrombectomy (Wikipedia 2014). The first heart-lung machine for total body perfusion was developed in 1926 by Sergei Brukhonenko. Dr. Clarence Dennis led the team that conducted the first known operation involving open cardiotomy with temporary mechanical takeover of both heart and lung functions on April 5, 1951 at the University of Minnesota Hospital. The patient

however, did not survive due to an unexpected complex congenital heart defect. Dr. Russell M. Nelson, performed the first open heart surgery in Utah. The first successful open heart procedure on a human utilizing the heart lung machine was however performed by John Gibbon on May 6, 1953 at Thomas Jefferson University Hospital in Philadelphia. He repaired an atrial septal defect in an 18-year-old woman (Cohn, 2003). Using a modification of the Gibbon apparatus, John Kirklin at the Mayo Clinic performed the first series of such procedures. Although the series was small (8 patients) and the mortality rate was high by current standards (50%), the attempt was favorably viewed, and it encouraged surgeons to persist in similar efforts. In spite of the advancements and the successes achieved with CPB, it was however associated with a number of complications such as; post perfusion syndrome also known as "pumphead" (Jensen, *et al* 2006), hemolysis, capillary leak syndrome, clotting of blood in the circuit which can block the circuit (particularly the oxygenator) or send a clot into the patient, air embolism and leakage – a patient can rapidly exsanguinate (lose blood perfusion of tissues) if a line becomes disconnected (Jensen, *et al* 2006). To avoid clotting of blood, CPB should be used for at most 6 hours (Anon, 2008). For longer procedures, extracorporeal membrane oxygenation or ventricular assist device (VAD) circuit was advocated (Anon, 2008).

Off-pump coronary artery bypass

Because of the complications inherent on CPB**,** Dr Atsushi Amano developed the Off-pump coronary artery bypass or "beating heart" surgery (Anon, 2012). This was a form of coronary artery bypass graft (CABG) surgery performed without cardiopulmonary bypass (heart-lung machine) as a treatment for coronary heart disease (Hillis *et al.*, 2011). During most bypass surgeries, the heart is stopped and a heart-lung machine takes over the work of the heart and lungs. When a cardiac surgeon chooses to perform the CABG procedure off-pump, also known as OPCAB (Off-pump Coronary Artery Bypass), the heart is still beating while the graft attachments are made to bypass a blockage. This takes care of the post-operative cognitive decline known as post perfusion syndrome that is inherent in cardiopulmonary bypass. In recent times, researches have however shown no long-term difference between on and off pump coronary artery bypass (Anon, 2013).In some cases, fats may collect, break and form a blockage in the walls of the artery during CABG procedures. This debris can result in clots, or "emboli", that may interrupt the flow of blood to the brain, causing neurological damage or even stroke *(*Hillis *et al,* 2011*)*. Data analysis from OPCAB surgery patients shows a significant reduction in the release of this debris with correspondingly lower stroke rates (Wikipedia, 2014). The fatty emboli which cause brain damage are generated when the aorta is manipulated, and although these are reduced in most off-pump coronary bypass surgeries they are not eliminated because the aorta is still used as a site for the attachment of some of the grafts (Hillis *et al,* 2011). A growing number of OPCAB surgeons, however have resorted to what is known as "anaortic" coronary bypass surgery, by taking all their grafts from sites other than the aorta; example, the internal mammary arteries (Ross, 2012).This results in a very low risk of stroke, actually less than occurs during percutaneous coronary intervention (Misfeld, *et al.,* 2011) In addition to off-pump surgery being associated with the clinical benefits of a reduced risk of stroke or memory problems, patients also typically have a faster recovery and shorter hospital stay, fewer blood transfusions, and fewer unwanted inflammatory/immune response issues (Wikipedia, 2014). Recently, advancement in surgical management of coronary heart diseases has led to the development of minimally invasive direct coronary artery bypass surgery. Minimally Invasive Direct Coronary Artery Bypass (MIDCAB) is a surgical treatment for coronary heart disease that is less invasive than the coronary artery bypass surgery (CABG). In MIDCAB, surgical access to the heart is via a smaller incision (Texas Heart Institute, 2005). Minimally Invasive Direct Coronary Artery Bypass is sometimes referred to as "keyhole" heart surgery because the operation is analogous to operating through a keyhole (Wikipedia, 2014). Minimally Invasive Direct Coronary Artery Bypass is a form of off-pump coronary artery bypass surgery (OPCAB), performed "off-pump" - without the use of cardiopulmonary bypass (the heart-lung machine). Minimally Invasive Direct Coronary Artery Bypass differs from OPCAB in the type of incision used for the surgery. With traditional CABG and OPCAB, a median sternotomy (dividing the breastbone) provides access to the heart (Texas Heart Institute, 2005), but with MIDCAB, the surgeon enters the chest cavity through a mini-thoracotomy (a 2-to-3 inch incision between the ribs) (Wikipedia, 2014). Minimally Invasive Direct Coronary Artery Bypass has been adapted for the treatment of multi-vessel diseases. Patients with multi-vessel coronary disease that desire a minimally invasive approach may be treated by hybrid bypass which combines coronary bypass (using the MIDCAB approach) and coronary stenting (Wikipedia, 2014).

Another landmark in management of coronary heart disease was the use of totally endoscopic coronary artery bypass surgery. Totally Endoscopic Coronary Artery Bypass Surgery (TECAB) is an entirely endoscopic robotic surgery used to treat coronary heart disease, developed in the very late 1990s. It is an advanced form of minimally Invasive Coronary Artery Bypass Surgery, which allows bypass surgery to be conducted off-pump without opening the ribcage. The technique involves three or four small holes in the chest cavity through which two robotic arms and one camera are inserted (Kappert *et al.*, 2010). Totally Endoscopic Coronary Artery Bypass surgery uses the da Vinci tele-robotic Stereoscopic 3-D Imaging system. The system consists of a robotic "slave" system at the bedside. The robot relays its information to an external surgical control unit, where a cardiac surgeon has a three-dimensional view of the

chest cavity, and twin-controllers for the robotic arms. The procedure frequently involves grafting of the internal mammary artery to the diseased coronary artery, and therefore does not require external harvesting of blood vessels (Mishra *et al.*, 2006).

Ventricular Assist Device (VAD)

The ventricular assist device (VAD) is an electromechanical circulatory device that is used to partially or completely replace the function of a failing heart. Ventricular assist devices are employed in patients with postcardiotomy cardiogenic shock and as a bridge to cardiac transplantation (Richenbacher, *et al.*, 1987). Ventricular assist devices are designed to assist either the right (RVAD) or left (LVAD) ventricle, or both at once (BiVAD). The type that is used depends primarily on the underlying heart disease and the pulmonary arterial resistance that determines the load on the right ventricle (Birks, *et al*., 2006; Anon, 2006). In the last few years, VADs have improved significantly in terms of providing survival and quality of life among recipients (Osak, *et al*., 2008).The pumps used in VADs can be divided into two main categories – pulsatile pumps, that mimic the natural pulsing action of the heart, and continuous flow pumps (Schulman *et al*., 2007). In 1988, Dr. William F. Bernhard conducted the first successful long-term implantation of an artificial left ventricular assist device (LVAD). The early VADs emulated the heart by using a "pulsatile" action where blood is alternately sucked into the pump from the left ventricle then forced out into the aorta. More recent work has concentrated on continuous flow pumps, which can be roughly categorized as either centrifugal pumps or axial flow impeller driven pumps. These pumps have the advantage of greater simplicity resulting in smaller size and greater reliability. These devices are referred to as second generation VADs. A side effect is that the user will not have a pulse, or that the pulse intensity will be seriously reduced. Peter Houghton was the longest surviving recipient of a VAD for permanent use. He received an experimental Jarvik 2000 LVAD in June 2000. Since then, he completed a 91-mile charity walk, published two books, lectured widely, hiked in the Swiss Alps and the American West, flew in an ultra-light aircraft, and traveled extensively around the world. He died of acute renal failure in 2007 at the age of 69 (Anon, 2007; Anon, 2009). In July 2009 in England, surgeons removed a donor heart that had been implanted in a toddler next to her native heart, after her native heart had recovered. This technique suggests that mechanical assist device, such as an LVAD, can take some or all the work away from the native heart and allow it time to heal (Maugh, 2009). In July 2009, 18-month follow-up results from the HeartMate II Clinical Trial concluded that continuous-flow LVAD provides effective hemodynamic support for at least 18 months in patients awaiting transplantation, with improved functional status and quality of life (Pagani *et al*., 2009). In spite of the enormous benefits inherent in the use of LVAD, it is however not free from some complications. Early postoperative bleeding complications are a major cause of morbidity and reoperation in LVAD patients (Schaffer *et al*., 2010) Bleeding is the most common postoperative early complication after implantation or explantation of LVADs, necessitating reoperation in up to 60% of recipients (Goldstein and Beauford, 2003) The implications of massive blood transfusions are great and include infection, pulmonary insufficiency, increased costs, right heart failure, allosensitization, and viral transmission, some of which can prove fatal or preclude transplantation (Goldstein and Beauford, 2003). Because the devices generally result in blood flowing over a non-biologic surface, predisposing the blood to clotting, there is need for anticoagulation measures. One device, the HeartMate XVE, is designed with a biologic surface derived from fibrin and does not require long term anticoagulation (except aspirin); however, this biologic surface may also predispose the patient to infection through selective reduction of certain types of leukocytes (Samuels, *et al*., 2008).

Transmyocardial revascularization

Most people with coronary artery disease are treated with angioplasty and stenting or coronary_bypass surgery and medications to improve blood flow to the heart muscle (Texas Heart Institute, 2014). The objective of each of these approaches is to increase blood flow through the coronary arteries to the heart. When these treatment options are exhausted, the patient is left with no viable surgical alternative other than, in limited cases, heart transplantation (Texas Heart Institute, 2014). Without a viable surgical alternative, the patient is generally managed with drug therapy, often with significant lifestyle limitations. Transmyocardial laser revascularization (TMR) is a newer treatment aimed at improving blood flow to areas of the heart that were not treated by angioplasty or surgery. Transmyocardial laser revascularization (TMR) is a procedure used to treat inoperable heart disease in patients with persistent angina that isn't relieved by any other method (Texas Heart Institute, 2014). When performing TMR a qualified cardiac surgeon delivers a precise laser therapy (either with a Holmium:YAG laser or CO2), directly to the target area(s) of the heart muscle. When performed as a primary therapy, it is done through a small incision between the ribs (thoracotomy) with the patient under general_anesthesia. Transmyocardial laser revascularization (TMR) can also be performed as a secondary procedure in patients that have ischemic heart disease with areas of the heart that cannot be bypassed. The precise laser therapy is delivered to create small channels into the heart chamber (Texas Heart Institute, 2005). During a typical procedure, approximately 10 –50 channels are made in each targeted region of the heart muscle. The channels in the heart muscle seal over almost immediately with little blood loss while the new channels allow fresh blood to perfuse the heart wall immediately.

Other advances in cardiovascular surgery involves; Biomolecular Therapy and Tissue Engineering which may allow for replacement of dysfunctional tissues or to improve organ function with an assembly that contains specific populations of living cells, such as (1) engineering of vein grafts that are resistant to atherosclerosis or restenosis; (2) gene therapy for coronary arteries to prevent restenosis after angioplasty or surgical endarterectomy; (3) genetic manipulation of vessels in an attempt to prevent lipid accumulation and progression of atherosclerosis; (4) the delivery of growth factors or genetic material into the coronary system or myocardium to promote therapeutic angiogenesis; and (5) the total bioengineering of blood vessels using cell seeding techniques and a biodegradable scaffold .

Conclusion

Against the backdrop of the enormous advancements in cardiovascular surgery, the number of patients with end-stage heart failure that is unresponsive to medical therapy is increasing. Approximately 5 million persons in the United States are currently affected, and half a million additional cases are diagnosed each year (Go *et al.*, 2013). Current surgical research involves the continuing evaluation of different left and right ventricular assist devices and the development of improved designs (Fang, 2009). Although the potential use of total artificial hearts has diminished in comparative priority, future models may overcome the deficiencies of their precursors. As the struggle to improve upon the mechanics of existing cardiac-support devices continues, new possibilities are being explored regarding transplantation in the treatment of end-stage heart failure. The shortage of human donor hearts has focused investigative attention on xenotransplantation research, which has quietly progressed in several laboratories over the past 2 decades. By genetically altering donor organs—for example, from the pig, so that transplanted porcine organs do not elicit a rejection response in a human recipient, surgeons might one day achieve cardiac transplantation from pigs to human beings (Zhu *et al.*, 2007). In our aging population, calcific aortic stenosis is a major health concern (Cribier, *et al*., 2002). It has been estimated that, in the U.S., between 2% and 4% of individuals aged 65 years or older will develop this disease. This number climbs to approximately 8% in persons 85 years and older. Many of these patients have coexisting aortic abnormalities, renal insufficiency, multi-organ dysfunction, or extensive vascular disease that precludes traditional valve replacement with the use of CPB. Percutaneous transcatheter aortic valve implantation, introduced by Cribier and colleagues and pursued by others, offers new hope for these patients (Cribier, *et al.*, 2002). In conventional valve replacement, the search continues for an ideal prosthetic valve, one that incorporates the longevity of a mechanical prosthesis and the safety of a bioprosthesis without the need for anticoagulation.

Competing interests

The authors declare that they have no competing interests.

References

Anon (2006) First VentrAssist Heart Recovery Featured on National TV. ventracor.com,

Anon (2007) Patient Sets World Record for Living with Heart Assist Device. texasheart.org, 6 July 2007.

Anon (2008) Man survives 16 days without a heart United Press International.

Anon (2009) "The First Lifetime-Use Patient". Jarvik Heart. Retrieved 4 August 2009.

Anon (2012). Cardiac Surgery, www. /en.wikipedia.org/w/index.php?title=Cardiac surgery

Anon, 2003 Postperfusion syndrome. "http://en.wikipedia.org/w/index.php?title=Off-pump_coronary_artery_bypass&oldid=630343382".

Bailey CP, May A., Lem mon WM. (1957) Survival after coronary endarterectomy in man. JAMA :164:611-6.

Birks, E. J.; Tansley, P. D.; Hardy, J.; George, R. S.; Bowles, C. T.; Burke, M.; Banner, N. R.; Khaghani, A.; Yacoub, M. H. (2006). "Left Ventricular Assist Device and Drug Therapy for the Reversal of Heart Failure". *New England Journal of Medicine* **355** (18): 1873–1884.

Cohn LH (May 2003). "Fifty years of open-heart surgery". *Circulation***107** (17): 2168–70.

Cribier A, Eltchaninoff H, Bash A, Borenstein N, Tron C, Bauer F, et al. Percutaneous transcatheter implantation of an aortic valve prosthesis for calcific aortic stenosis: first human case description. Circulation2002;106(24):3006–8

Fang JC. Rise of the machines–left ventricular assist devices as permanent therapy for advanced heart failure. NEngl J Med 2009;361(23):2282–5.

Go, AS, Mozaffarian,D, Roger, VL, Benjamin, EJ,Berry, JD et al., (2013) Heart Disease and Stroke Statistics-2013 update: areort from the American Heart Association. *Circulation* 127:e6-e245

Goetz RH, Rohman M. Hailer JD. Dee R. Rosenak SS (1961). Internal mammary-coronary artery anastomosis. J Thorac Cardlovasc Surg:41:378-86.

Goldstein, D.J.; Beauford, R.B (2003) "Left ventricular assist devices and bleeding: adding insult to injury". *Ann Torac Surg* **75**: S42–7.

Harris,AM; Segel, N and Bishop, JM (1964) Blalock-Taussig Anastomosis for Tetralogy of Fallot: A ten to fifteen year follow-up. *British Heart Journal* 26 (**2**)266-273

Hillis,LD, Smith, PK,Aderson,JL, Bittl, JA,Bridge, CR, Byrne,JG,Cigarroa,JE et al., (2011) 2011-ACCF/AHA Guidline for C oronary Artery Bypass Graft Surgery

Jansen, B, Hughes,P, Rasmussen,L, Pedersen, P, Steinbruchel, D (2006) Cognitive outcome in elderly high-risk patients after off-pump versus conventional coronary artery bypass grafting: a randomized trial. Circulation **113** (24) 2790-5

Kaemmerer,H; Meisner,H; Hess,J and Perloff,JK (2004) Surgical treatment of Patent ductus Arteriosus: a new historical perspective. American Journal of Cardiologists; 1:94 (9)1153-4

Kappert U, Schneider J, Cichon R, *et al.* (2000). "Closed chest totally endoscopic coronary artery bypass surgery: fantasy or reality?". *Curr Cardiol Rep* **2**(6): 558–63.

Keown, KK. (1963)History. In Adriani J, ed. Anaesthesia for Surgery of the heart. Springfield, IL; Charles C. Thomas.

Longmire WP Jr, Cannon JA. Kattus AA. Direct-wsion coronary endarterectomy for angina pectoris. N Engl J Med 195%259:993-Y.

Maugh, Thomas (14 July 2009). "Transplant shows heart's reparative capabilities". *Los Angeles Times*. Retrieved 15 September 2009

McCullough, L.; Arora, S. (Dec 2004). "Diagnosis and treatment of hypothermia.". *Am Fam Physician* **70** (12): 2325–32.

Misfeld, Martin; Brereton JL; et al (August 2011). "Neurological complications after off-pump coronary artery grafting with and without aortic manipulation".*J. Thorac. Cardiovasc. Surg.* **142** (2): e11–e17.

Mishra YK, Wasir H, Sharma KK, Mehta Y, Trehan N (December 2006). "Totally endoscopic coronary artery bypass surgery". *Asian Cardiovasc Thorac Ann* **14** (6): 447–51.

Osaki, S; Edwards, V, Johnson, et al (August 2008). "Improved survival in patients with ventricular assist device therapy: the University of Wisconsin experience", *European Journal of Cardio-Thoracic Surgery* **34** (2): 281–288.

Pagani, F. D.; Miller, L. W.; Russell, S. D.; Aaronson, K. D.; John, R.; Boyle, A. J.; Conte, J. V.; Bogaev, R. C.; MacGillivray, T. E.; Naka, Y.; Mancini, D.; Massey, H. T.; Chen, L.; Klodell, C. T.; Aranda, J. M.; Moazami,

N.; Ewald, G. A.; Farrar, D. J.; Frazier, O. H.; Heartmate Ii, I. (2009). "Extended Mechanical Circulatory Support with a Continuous-Flow Rotary Left Ventricular Assist Device", *Journal of the American College of Cardiology* **54** (4): 312–321.

Richenbacher, W.R. (1989) Current Status of Cardiac Surgery: A 40 Year Review, Journal of American College of Cardiologists; 14:534-44

Richenbacher, WE; Pae WE Jr. Rosenberg G, Pennock JL, Pierce WS. (1987), Experimental and clinical experience with the Pennsylvania State University pneumatic ventricular assist device and total artificial heart, *Eur Rev Biomed Tech*;9:31-4.

Ross, Donald (Summer 2012). "Anaortic Coronary Bypass Surgery". *Seminars in Thoracic and Cardiovascular Surgery* **24** (2): 90–92

Samuels, L. E.; Kohout, J.; Casanova-Ghosh, E.; Hagan, K.; Garwood, P.; Ferdinand, F.; Goldman, S. M. (2008). "Argatroban as a Primary or Secondary Postoperative Anticoagulant in Patients Implanted with Ventricular Assist Devices". *The Annals of Thoracic Surgery* **85** (5): 1651–1655.

Schaffer, Justin M.; Arnaoutakis, George J.; Allen, Jeremiah G.; Weiss, Eric S.; Patel, Nishant D.; Russell, Stuart D.; Shah, Ashish S.; Conte, John V. (2010) "Bleeding Complications and Blood Product Utilization With Left Ventricular Assist Device Implantation". *The Annals of Thoracic Surgery* **91** (3): 740–749.

Schulman, A. R.; Martens, T. P.; Christos, P. J.; Russo, M. J.; Comas, G. M.; Cheema, F. H.; Naseem, T. M.; Wang, R.; Idrissi, K. A.; Bailey, S. H.; Naka, Y. (2007). "Comparisons of infection complications between continuous flow and pulsatile flow left ventricular assist devices". *The Journal of Thoracic and Cardiovascular Surgery* **133** (3): 841–842.

Stoney, WS (2009) Evolution of Cardiopulmonary Bypass. *Circulation*, 119:2844-2853

Texas Heart Institute (2014)Transmyocardial Laser Revascularization. Surgical of Association of Texas www.texasheart.org/HIC/Topics/Proced/tmlrs.cfm

Weisse, A.B. (2011) 'Cardiac Surgery: Century of progress' *Texas Heart Institute Journal* **38**: 486-490

Wikipedia,(2014)"http://en.wikipedia.org/w/index.php?title=Minimally_invasive_direct_coronary_artery_bypass_surgery&oldid=434850633

. Zhu X, Dor FJ, Cooper DK. 2007Pig-to-non-human primate heart transplantation: immunologic progress over 20 years. J Heart Lung Transplant; 26(3):210–8.