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EVALUATION OF PLATELET RICH PLASMA IN REDUCING STERNAL WOUND COMPLICATIONS IN CABG SURGERY WITH MEDIAN STERNOTOMY

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Abstract

Introduction
Sternal wound complications, including superficial wound infection (SWI) and deep sternal wound infections (DSWI), are serious concerns following coronary artery bypass grafting (CABG) after conventional median sternotomy. Platelet-Rich Plasma (PRP) has been proposed as an adjunct therapy to improve wound healing and reduce infection rates. This study aimed to study PRP's effects on reducing sternal wound complications in the patients of CABG.

Objectives
To ascertain the effect of PRP application on the prevalence of delayed wound healing and superficial and deep sternal wound infections (SWI and DSWI) in patients having CABG surgery with median sternotomy.

Study Design
Randomized controlled trial.

Duration
Six months following the acceptance of the study protocol.

Setting
The study was conducted in the Department of Cardiac Surgery, Cardiac Center, Pakistan Institute of Medical Sciences (PIMS), Islamabad.

Methods

The study included 98 patients aged 45 to 72 years, undergoing on-pump CABG. Participants were randomly assigned to two groups: the control group, which received standard sternal closure, and the study group, which received additional autologous PRP application during sternal closure. Participants and outcome assessors are blinded to group assignment, while surgeons performing the procedure are aware of the intervention. Wound healing, deep and superficial infection including mediastinitis, and readmissions within 30 days will be documented as primary outcomes. Secondary outcome will be the overall cost burden for the 30-days post-surgery period. Other outcomes will be ICU stay (days), blood transfusions more than 4 units and platelets transfusions more than 4 units. Data were analyzed using SPSS version 23, with a chi-square test applied to compare incidences of SWI, DSWI, and delayed healing between groups.

Results

The use of PRP significantly decreased the incidence of superficial wound infection 4.1% as compared to the control group 16.3%. Similarly, deep sternal wound infections notably decreased with no DSWI in Group B as compared to control group 8.2%. Delayed healing was also remarkably decreased in the PRP group. Overall, PRP was related with better postoperative outcomes and a decrease in hospital readmissions, contributing to lower healthcare costs in the 30-day postoperative period.

Conclusions

Autologous PRP application remarkably reduces the risk of sternal wound complications, such as superficial and deep infections and delayed wound healing, in patients undergoing CABG with median sternotomy.

INTRODUCTION

A number of complications, including multifactorial superficial wound infections (SWI) and deep sternal wound infections (DSWI), can arise from cardiac surgery performed via median sternotomy. These complications of median sternotomy can have drastic effects including increased hospital stay, higher expenses and increased mortality & morbidity. Median sternotomy was first used in surgery by Milton and one of its most serious complications is DSWI with prolonged hospital stay, increased morbidity and a mortality of up to 14%. Although cardiac surgery is done these days with minimally invasive, robotic techniques and in median sternotomy DSWI has a higher mortality of 14 %, superficial wound infection (SWI) of 9.1 % [1], even then median sternotomy remains the most used method. The procedure i.e. Median sternotomy gives a good exposure with a relatively low postoperative pain (as compared to thoracotomy), but the incidence of sternal wound infection is from 0.9 % to 20 % [2].

The common procedure for heart surgery is median sternotomy, but it has some significant drawbacks, such as the possibility of major infections. Research on major infections revealed a higher post-operative mortality rate of 17.3% compared to 3.0% in patients without major

infections and a longer length of stay (> 14 days) of 47.0% compared to 5.9% in patients without major infections [3].

Because interventional cardiologists have "taken over" a large portion of the cardiac surgery field, the incidence of superficial and deep wound infections in median sternotomy is also rising as a result of the increased number of terminal heart failure patients (FI<35%), who are primarily severely disabled and receiving dual therapy. Elderly patients with reduced physical capacity will also experience more complications, and patients receiving dual antiplatelet therapy are more likely to experience postoperative hemorrhage and chest reexploitation. Superficial wound infection (SWI), deep sternal wound infection (DSWI) can have an increased financial burden but its early detection and treatment can improve patient's mortality, morbidity, length of hospital stay and financial expenses.

Activated platelets release growth factors, thereby enhancing tissue healing on re-epithelialization, and are attractants to tissue stem cells hence improving wound inflammation, which would result in better post-operative results. Marx and his associated have studied effects of Platelet-rich plasma (PRP) on bone since 1998 [4], experimentations on dogs have showed that PRP increases re-epithelialization, differentiation of epithelium. After median sternotomy as the wound is in its healing stages, PRP speeds up the process hence promoting earlier wound healing [5]. Surgical incision site is the primary source of infection and early closure of wound is achieved with PRP. Inflammation is a natural process in wound healing but if this inflammation studied is moderate then that is a better form of wound healing, which can be done with [6]. Staphylococcus aureus and coagulase-negative staphylococci are the most common causes of deep sternal wound infections. These pathogens were frequently isolated after CABG surgery [1]. Postoperative complications include several risk factors like bilateral internal mammary harvesting, steroid therapy, active smoker, longer cardio-pulmonary bypass time and osteoporosis. According to other research, age, diabetes, obesity, and chronic obstructive pulmonary disease are risk factors for SWI [7, 8]. Furthermore, PRP inhibits the growth of Escherichia coli and Staphylococcus aureus, the two main bacteria associated with DSWI, in vitro. Other studies have shown risk factors for SWI, like age, diabetes mellitus, chronic obstructive pulmonary disease and obesity [7, 8]. Additionally, PRP demonstrates an inhibitory effect on the in vitro growth of Staphylococcus aureus, the predominant bacteria linked to DSWI, and Escherichia coli. However, it shows no effectiveness towards Pseudomonas aeruginosa, Enterococcus faecalis, and Klebsiella pneumoniae [9]. Complications following surgery represent a major contributor to mortality rates. If these complications are not managed then they can lead to extended hospital stays, longer courses of antibiotic treatment, and the need for surgical revisions [10]. Prophylactic antibiotics play a critical role in reducing the risk of surgical site infections in cardiac surgery, particularly following procedures like coronary artery bypass grafting (CABG). A study by Salehi Omran et al. indicates that cefazolin is the recommended antibiotic, administered preoperatively and continued for 48 hours postoperatively as part of the standard infection prevention protocol [1]. Red blood cells, platelet-rich plasma (PRP), and platelet-poor plasma (PPP) are the three separate layers of whole blood that can be efficiently separated using centrifugal techniques for platelet concentration. Leukocytes are a major component of the PRP layer, which may provide improved protection

against infection. Centrifugal methods for platelet concentration have been established, effectively separating whole blood into distinct layers: a red blood cell layer, a platelet-rich plasma (PRP) layer, and a platelet-poor plasma (PPP) layer. The PRP layer is characterized by a significant presence of leukocytes, potentially offering enhanced defense against infection. Activated platelets secrete various growth factors and chemoattractant in significant quantities, which can stimulate vascular proliferation as well as attract tissue stem cells. Furthermore, platelets seem to possess antimicrobial properties as well.

PRP has observable benefits during the inflammatory stage of wound healing, such as the release of growth factors, including vascular endothelial growth factor, and others that can enhance overall healing by promoting cell migration and the development of the matrix surrounding the cells. The same growth factors have the ability to increase chondrocyte metabolism, encourage chondrogenesis, and aid in bone regeneration and healing. The findings indicate that PRP wound irrigation is both safe and cost-effective, enhancing healing and resulting in a reduced occurrence of sternal infections. Currently, PRP is utilized across various specialties to enhance tissue healing efficiency, resulting in fewer complications. The injection of PRP in the left internal mammary artery (LIMA) bed promotes neovascularization, accelerates the healing process, and consequently helps to prevent deep sternal wound infection, sternal dehiscence, and the need for reoperation due to postoperative complications.

The PRP has demonstrated various applications across numerous disciplines, such as oral, maxillofacial, as well as plastic surgery. In patients undergoing cardiac surgery, the application of PRP has demonstrated a reduction in the occurrence of sternal wound-related problems. While not commonly employed, certain authors advocate for the consistent application of PRP, drawing on initial findings from studies that indicate a reduction in complications for patients undergoing cardiac procedures in median sternotomy [10].

Postoperative complications lead to considerable morbidity in patients following cardiac surgery. Clinical trials have proposed the PRP as a means to decrease the incidence of complications among individuals going through median sternotomy to cardiac surgical procedures. This study aims to study the potential benefits of incorporating PRP alongside standard care following on-pump CABG and cardiac surgery.

LITERATURE REVIEW

CARDIOVASCULAR DISEASES:

Cardiovascular diseases (CVDs) are a group of disorders affecting the heart and blood vessels, including coronary artery disease. They are among the leading causes of morbidity and mortality worldwide, often linked to risk factors such as high blood pressure, high cholesterol, obesity, smoking, diabetes, and sedentary lifestyles. These conditions can result from atherosclerosis, a process where fatty deposits build up in arteries, reducing blood flow and increasing the risk of heart attacks and strokes. Preventive measures, including a healthy diet, regular physical activity, stress management, and routine health screenings, play a critical role in reducing the burden of CVDs. Advances in medical treatments and technologies have also improved outcomes for individuals living with these diseases, however cardiovascular disease remains the foremost cause of

mortality in the USA and across the globe. If we talk about the number of percutaneous coronary intervention (PCI) as well as coronary artery bypass grafting (CABG) procedures, then it will not be wrong to say that it's very common and widely done across the world with an annual cost of $6.7 billion in United States only [11]. Considering the prevalence of both procedures and the complex interactions among coronary angiography, bypass procedures, and the potential for graft failure that may necessitate PCI, it is essential to explore both fields i.e., cardiology and its surgical side as well. Amount of CABG done every year in the United States is also very high, i.e., 200,000 cases [12]. When it comes to surgical revascularization, PCI then choice of selecting grafts, evaluating its patency and anastomotic markers are very essential, hence ensuring safety and good results [13].

CABG

Coronary artery bypass grafting (CABG) is a surgical procedure performed to improve blood flow to the heart in individuals with severe coronary artery disease (CAD). This condition arises when the coronary arteries, which supply oxygen-rich blood to the heart muscle, become narrowed or blocked due to atherosclerosis. During CABG, a surgeon uses a healthy blood vessel—often taken from the leg (saphenous vein), arm (radial artery), or chest (internal mammary artery)—to create a bypass around the blocked artery. This rerouted blood flow helps restore adequate oxygen and nutrients to the heart, reducing symptoms such as chest pain (angina) and improving heart function. CABG is typically recommended for patients with multiple blockages or those who have not responded to other treatments like medication or angioplasty. The procedure has a high success rate and is often life-saving, but recovery involves significant lifestyle adjustments to maintain long-term heart health.

Conduits In CABG Surgery

Different conduits are used to create bypasses for obstructed coronary arteries during coronary artery bypass grafting (CABG) surgery, and each type has unique advantages. Since the internal mammary artery (IMA), especially the left IMA, has better long-term patency rates and is more resistant to atherosclerosis, it is generally recommended. Another arterial conduit that is frequently used for grafting is the radial artery, which is removed from the arm. It is ideal for patients who require multiple bypasses and has good durability, but it is crucial to carefully choose patients to prevent problems like spasms. The saphenous vein, harvested from the leg, is the most commonly used venous conduit and is particularly useful for creating multiple bypasses, though its long-term patency is lower than arterial grafts. In some cases, both left and right IMAs referred to as bilateral internal mammary arteries (BIMA) are utilized, offering enhanced outcomes for suitable patients but requiring careful consideration of surgical complexity and potential risks. The choice of conduit depends on factors like patient anatomy, comorbidities, and the surgeon's expertise, with the goal of maximizing graft longevity and patient outcomes.

LIMA

CABG is done mostly by harvesting left internal mammary artery (LIMA). The right and left internal mammary arteries exhibit a markedly greater resistance to atherosclerosis in comparison to saphenous vein grafts, attributable to several factors. A number of extensive long-term follow-up studies have illustrated a reduction in CABG mortality associated with heightened utilization of LIMA, with the most favorable IMA graft patency observed when employed for grafting the left coronary system [12, 13].

The enduring patency and notable viability advantages associated with LIMA utilization in CABG have therefore created a need to include other arterial grafts in this surgery, which can further enhance benefits. Other arterial grafts i.e., conduits suppose radial artery can be used as an alternate or as another graft.

Subclavian Artery Stenosis

Left internal mammary artery is the most important conduit in CABG surgery; so its distal blood flow to left anterior descending artery is crucial. Subclavian artery gives internal mammary artery and that's why its stenosis can decrease the blood flow in left internal mammary artery. Such a conduit can further affect the outcome of a CABG procedure due to decrease perfusion of left anterior descending artery. Blood flow from internal mammary artery-left anterior descending artery can be diverted to the upper extremity (coronary steal syndrome). Left internal mammary artery is used in CABG surgery due to its better patency and longevity v/s other conduits. However, the results also depend upon the proximal patency and blood flow which can be compromised in subclavian artery stenosis. Angina would occur, especially if patient uses the limbs, i.e., requiring more blood flow and oxygen, as a result compromising flows to the internal mammary artery-left internal mammary artery [14-16].

Technique used for subclavian artery stenosis (SAS) evaluation before CABG Surgery is debatable. SAS can compromise left internal mammary artery flow; hence affecting left internal mammary artery's flow to left anterior descending artery and thus its distal run off after CABG surgery. Patients with peripheral artery disease showed the most significant positive relationship with subclavian artery stenosis, while other positive relationships were with smoking and hypertension [16]. Generalized Vascular disease plus that of the brain vessels also showed positive relationship with subclavian artery stenosis and so did diabetes mellitus. However which method should be used for noting subclavian artery stenosis is yet under study. Amongst all methods for evaluating subclavian artery stenosis, checking blood pressure of both upper extremities gave a 100% negative predictive value. This technique comes under the category of non-invasive techniques and can also give a 100% negative predictive value. Doppler ultrasound is yet another noninvasive technique. Downsides of Doppler ultrasound are that the area contains bones, so it becomes difficult to evaluate subclavian artery stenosis with accuracy. It is a low-cost procedure, which is easily assessable but due to its short comings using it as a standard evaluation tool before CABG surgery for subclavian artery stenosis is questionable. Invasive techniques can be much more accurate, it can also quantify the amount of stenosis and its exact location. Amongst invasive techniques; CT and MRI give better visuals, but stays under-explored so far [16].

Subclavian angiography serves as the definitive invasive screening method for the detection of Subclavian artery stenosis. In numerous instances, it can be conducted with minimal risk during coronary angiography. It can have adverse effects like dislodging a thrombus hence occluding vessels in upper limb or the clot/thrombus can go into brain causing transient ischemic attack. It can give information regarding the severity of the subclavian artery stenosis, its location and can also become an access for approaching this disease, if required. Subclavian angiography can also note the size of the artery and its branch i.e., internal mammary artery. This information can be beneficial when doing CABG surgery, as to use internal mammary artery as a conduit or not. Subclavian angiography offers definitive information regarding the patency in the proximal left subclavian artery and serves to assess native disease in the LIMA, in addition to confirming the vessel's adequate caliber for grafting purposes. Additional support for the standard practice of subclavian angiography before CABG is found in the radiology literature. Unrecognized lower extremity ischemia during CABG may occur due to redirected IMA flow. Brachiocephalic angiography demonstrates high sensitivity and specificity, along with effective revascularization for stenotic subclavian vessels. Bates et al. conducted the largest single-operator study to date, assessing preoperative subclavian stenting in a cohort of 94 patients. No instances for subacute thrombosis as well as re-occlusion were observed within 30 days. Although after stenting there were some cases of stent occlusion, but despite that data proved that preoperative stenting of the subclavian artery stenosis is a better option [17].

No agreement exists regarding the most effective screening technique for SAS before CABG. Certain practitioners advocate for the use of noninvasive screening techniques to determine which patients are appropriate candidates for angiography. Angiography is considered most sensitive and specific test for noting stenosis in subclavian artery and in the proximal region of internal mammary artery. Coronary angiography can be extended and subclavian artery can be noted, however this extends the time for angiography procedure and is also technically more difficult. This is one of the reasons why subclavian artery angiography is not done during coronary angiography, other reason is the difficulty to engage artery via radial artery approach [17, 18]. It is debatable that subclavian artery angiography should be used for screening purposes before CABG surgery or not, however it can be done in high-risk patients like patients of blood pressure variations in upper limb [17]. Due to the safety and ability to approach stenosis it can be done in patients who have been treated with radiations through chest, hence increasing the risk of subclavian stenosis. Although SAS is usually seen in patients with peripheral artery disease but the absence of it would not rule out subclavian artery stenosis (SAS), same is the case with other vessels diseases in our body. Symptomatic diseases in heart or peripheral vessels, would indicate a high risk for SAS, but cannot rule it out.

BIMA And Its Impact on Sternal Wound Healing

The significance of a solitary IMA as the primary graft in CABG is well recognized; however, the debate surrounding the actual merit of employing bilateral IMAs (BIMA) persists. BIMA harvesting in CABG surgery is associated with decreased overall blood flow to the sternum, hence reducing healing, so will enhancing complications and that's why its use is not standardized. At

present, the utilization of BIMA in CABG stands at approximately 4% in the US as opposed to 12% across Europe [20]. The proposition of employing a skeletonized harvest technique, in contrast to the pedicle approach, for the harvesting of the right internal mammary artery (RIMA) has emerged as a potential strategy to mitigate the extent of deep sternal wound infections. However, apprehensions regarding its impact on graft patency have hindered the widespread acceptance of this method as well [20].

Furthermore, beneficial effects of BIMA as compared to single internal mammary artery (SIMA) required an additional five years i.e., other than the normal period, hence evaluating pain free and survival benefit outcomes. The arterial revascularization trail-ART represents a pioneering effort in the realm of prospective randomized controlled trials, meticulously investigating the long-term outcomes associated with the utilization of bilateral internal mammary artery (BIMA) versus single internal mammary artery (SIMA) grafting techniques. The end result in figuring out superior outcomes & results of BIMA v/s SIMA were not very drastic, as seen in older studies but rather showed mild variances between the two regarding mortality. In the analysis of subgroups, a survival advantage was observed with the application of multiple arterial grafting (MAG). The advantages of MAG are expected to be more thoroughly explored through the forthcoming multicenter Randomized trial, which will investigate the mid- and long-term outcomes associated with single versus multiple arterial grafting in CABG procedures. A trial of total arterial grafting was conducted and a sample of patients below the age of 70 was chosen. CABG surgery was done in these patients and arterial conduits were used in all of the important targeted vessels. The arterial conduits used consisted of pedicle LIMA, skeletonized RIMA and non-dominant hand's radial artery and hence were anastomosed to such vessels having significant stenosis, thus studying grafts development with time. LIMA was harvested and anastomosed to LAD, while skeletonized RIMA was anastomosed to distal RCA, PDA or an obtuse marginal branch. Free radial artery from a non-dominant hand was anastomosed to an obtuse marginal branch or a diagonal. Targeted vessels were selected with care, making sure that each of them was blocked/stenosed i.e., more than 70 %, hence ensured maturation and development of the anastomosed arterial grafts [21].

Radial Artery

Radial artery, as an arterial graft is an alternate to SVG and can give surgeon an option to choose from when doing CABG surgery. Radial artery harvested can have good length; hence a single or multiple targets can be vascularized with it. Any vessel with a significant stenosis can be chosen for a radial artery due to its long lengths [22]. Radial artery has several benefits like suppose its diameter is much closer to the coronary vessels and has better patency after specific time periods when compared to vein grafts. However, when follow ups were done, radial artery grafts were checked with angiography then downsides were also noticed. For example, radial artery used had gone into spasms or had shown changes in the intima. Although studies have shown that with advancement and improved techniques of harvesting radial artery, the frequency of radial grafts going into spasm or change in the intima have improved. These radial artery grafts with satisfactory lengths were then compared with saphenous vein grafts for patency rates. This comparison was done for a time period of ten years and showed patency rates of 67.1% (SVG) v\s radial artery of 91.6%.

These results were very impressive and showed the superiority of arterial grafting over vein grafts. However, it was seen that targeted vessels were of much importance when grafting radial artery and could impact the outcomes of radial artery spasms. If a target vessel was stenosed less than 70% then the result of grafting radial artery to it were not satisfactory. Angiography of such procedures showed radial artery spasms. So, we can say that radial grafts are showing better results due to the improved harvesting techniques but the target vessels for which such grafts are used can affect the outcomes [21, 22].

Apart from all the debate and discussion, radial artery grafts are more over used in CABG for younger individuals. Total arterial grafting, using radial artery is preferred in younger people. Arterial grafts like radial artery have shown a longer patency rates and better outcomes. Saphenous vein grafts have been used in CABG surgery; however, the use of radial artery and internal thoracic artery is relatively recent. In selected patient's radial artery grafts have shown patency rates equal to internal thoracic artery. These patency rates are better and higher than saphenous vein grafts hence results are promising. Using radial artery as a primary source of access is dependent on various factors. Radial artery grafts have other benefits like reduced bleeding, when compared with the saphenous vein grafts. Better patency rates, reduced bleeding and reduced morality rates have therefore increased the use of radial artery for younger patients due to longer durability which is in need when considering such patients.

The inclination towards radial artery as a primary access site is getting more favor, however there are other concerns too. There could be disturbances in the forearm circulation and possible harm after its use. Most patients going through CABG surgery needs more than one artery graft, hence necessitating saphenous vein graft or radial artery graft. The ultimate goal is complete revascularization, as is done in CABG surgery, but histological assessment showed changes in the radial arteries after catheterization. Results were seen histologically in patients going through CABG surgery with radial grafts. Histologically, intimal hyperplasia was noted in radial catheterization v/s specimen of patients who were not catheterized. So, radial grafts used showed integrity of 77%, in contrast to that of 98% in those whose radial arteries were not catheterized [23].

The radial artery, in the cubital fossa, originates from the brachial artery and then continues its course downward. In the forearm distally, radial artery shows less variations. It is due to these reasons that radial artery canulation is mostly done in the distal region of the forearm. Hence along with radial artery intimal hyperplasia, medial dissections were also noted in optical tomography. Images of radial artery showed not only intimal hyperplasia, but medial dissection and intimal tears. These changes were much more pronounced in the distal portions of the vessels rather than its proximal parts, which were relatively free of the damage caused. Damage done by radial catheterization becomes the reason for damaging results clinically, is evident in images and histologically. Thus, the results showed radial artery spasm, but also proves that radial artery's lumen gets narrowed down thus changing its structure. So, radial artery's changes in lumen are not merely due to its spasm but due to changes in the radial artery's histology [20-23].

It is due to the popularity of radial artery being used as a conduit for coronary revascularization that more studies are being done. The aim is to study the changes in radial artery, atherosclerosis, advancing age and its impacts on the radial artery. Studies have shown that radial cannulation for

a few hours have also impacts on the radial artery. The arteries dilatation with flow and due to nitroglycerin is also impacted due to catheterization. Some studies have shown that the damage done is not repairable while others have noted some recovery [19]. Due to these concerns and results, use of radial artery in coronary revascularization becomes debatable and needs more study. While radial artery harvested can be examined for obstruction, however right radial artery is usually used for catheterization and then left radial artery is therefore used in CABG surgery. After the use of radial artery in CABG surgery, there has been noted decreasing blood flow in the digits, which improves slowly with time. This improvement of blood flow to the distal digits can take years. Due to these concerns and additional ambiguity of radial artery long-term patency, have raised questions in the utilization of radial artery in CABG surgery [13, 19].

SVG

Vein grafts are mostly used as conduit in CABG for coronary arteries. Great saphenous vein can be taken via surgical opening or through an endoscope. Open surgical method can involve obtaining an optimum length via one large opening, many shorter openings or through an endoscope [24]. This technique utilizes specialized platforms to facilitate saphenous vein graft (SVG) extraction through a single transverse incision. This technique provides visuals on a screen, isolating the vein from the surrounding tissue, as well as occluding branches through a single incision. Isolation of the vein is performed and desired portion is harvested. Subsequently, another small opening through a surgical blade is made for closing both ends of the saphenous vein graft left in situ before the conduit is removed [24].

SVG: OVH v/s EVH

Open vein harvesting has remained the predominant technique for harvesting vein since the advent of coronary artery bypass grafting and continues to be used extensively on a global level. Anyhow endoscopic vein harvesting is gaining popularity with increased prevalence in advanced countries. In comparison to OVH, EVH is linked to reduced pain, lesser post-surgery complications of the wound, as well as a shorter postoperative hospital stay. However, concerns exist regarding the impact of endoscopic vein harvesting on the success of the vein graft on a long-term basis mostly in part due to injury to the endothelial layer of vein caused by the excessive application of bipolar tissue/vessel sealing in EVH [19-24]. In a study that examined cases that had undergone coronary artery bypass grafting as part of a trial included follow-up angiography of patients after 1- 1.5 years post grafting surgery found that patients that had undergone EVH exhibited increased failure of venous grafts compared to those that had undergone OVH. Not just this but follow-up after three years showed a rising trend in mortality, greater occurrence of myocardial infarction and increased chances of doing the surgical procedure again. Eleven studies involving 18,131 patients who underwent CABG with 60% utilizing the procedure that involved open harvesting of the vein and 40% employing the procedure that involved the endoscopic harvesting of vein supported significantly better outcomes related to the grafted vein in patients that had undergone open vein harvesting [14, 24].

A study aimed to review mortality in endoscopic technique of taking, and frequency of repeat revascularization following bypass surgery. This observational study Medicare patients who

underwent isolated bypass surgery, thus when a saphenous vein graft was used. There was no difference in mortality, myocardial infarction or repeat bypass surgery in the two groups [14, 25]. A study affirmed that both showed same wound results i.e., open v/s endoscopic vein harvesting. Although there is increasing evidence indicating comparable long-term cardiac outcomes in the two harvesting techniques, along with reduced tissue damage in the endoscopic vein harvesting. A debate regarding the superiority of either technique persists. The established superiority of EVH in reducing wound complications raises ongoing inquiries regarding its impact on bypass surgery results. According to studies open technique of harvesting saphenous vein pedicle, i.e., preserving all the surrounding, correlates with superior long-term patency. This outcome is likely due to the reduced intimal damage experienced due to surgical vein manipulation [24-27].

Conclusive determination regarding the optimal vein harvest method for CABG is expected to necessitate a substantial trial that compares EVH to no-touch OVH conducted by skilled practitioners. For over a decade, our practice has been to harvest an SVG predominantly through EVH. The physician assistants in our clinic receive training and supervision from industry specialists in endoscopic vessel harvesting (EVH) [24-27]. Recent advancements in endoscopic vein harvesting (EVH) enable practitioners to collect veins by reducing injury of vein due to its two electrodes electrocoagulation.

SVG: Single v/s Multiple SVG

SVGs can be utilized through a single vein conduit vein segments for every coronary artery. Its top end is grafted to aorta i.e., each one of the veins or a single vein's top end to every distal coronary artery target. Bypass surgery may be done by using a single saphenous vein grafts for revascularization of all the target vessels. In contrast, each coronary vessels can be re-vascularized by saphenous veins of its own, thus more than one veins will be used. Top end of the single vein to all coronary targets is grafted to the aorta and then the distal end is grafted to each targeted vessel. When many veins are used i.e., each vein for one coronary artery revascularization other than left anterior descending artery which requires internal mammary artery. In a single vein graft, top end to aorta, then side to side anastomosis of the distal targets and the last target will be end to side anastomosis. Studies have proven benefits of using internal mammary artery for left anterior descending artery and hence a vein graft is not recommended [14, 24, 27].

Currently, there is a paucity stronger proof supporting better results for using multiple-saphenous vein grafts over single-saphenous vein graft. Multiple-saphenous vein graft is anastomosed to more than one targeted coronary vessels distally, however all of the result depends upon the top end to aorta. A larger area of myocardium relies on a single top end of the vein to aorta. Although multiple-saphenous vein graft develops better distal run off in comparison to that of the single-saphenous vein grafts [14, 15, 24]. The application of multiple-saphenous vein graft can facilitate the bypassing of minor coronaries and can create secondary circulation between target vessels in cases of top end stenosis [15].

Many have analyzed multiple-SVG grafts to have a greater patency. A study was conducted at a hospital involving coronary artery bypass grafted patients to differentiate between single-saphenous vein grafts and multiple-saphenous vein graft. It involved two testing procedures at the time of

discharging, another one after one year of the procedure and then after three to five years of the procedure. According to it multiple-SVG grafts showed promising results [15].

A study was done on CABG in a single health care facility and patients showed analogous results [24]. Both groups were compared; there was no difference regarding mortality between single-saphenous vein graft and multiple-saphenous vein. However multiple-saphenous vein grafts showed poor results, when compared with single-saphenous vein grafts in graft failure rates, which didn't have any significant difference in mortality, or the need to do a repeat bypass surgery. No mortality difference was noted due to cardiac events in the two groups; both procedures were same regarding morbidity or mortality. Study was further divided into subgroups studying the patency of these two procedures. Multiple-saphenous vein graft anastomosed to RCA/PDA and then via end to side anastomosis to LCx artery, was compared to single-saphenous vein graft anastomosed to each of these coronary vessels. Single-saphenous vein graft to RCA in comparison to the multiple-saphenous vein graft to RCA-LCx showed poor patency rates. However, other than that single-saphenous vein graft not including the RCA, showed no significance difference between the two. Same comparison was done but using PDA or posterior lateral branch (PL) and showed that single-saphenous vein graft to these targeted vessels showed poor patency v/s multiple-saphenous vein graft involving the same targets. Overall results showed that multiple-saphenous vein graft having side to side anastomoses was superior to multiple-saphenous vein graft having end to side anastomosis. Thus, bypass surgeries having single-saphenous vein graft had better grafts patency then CABGs with multiple-saphenous vein grafts [14, 15, 24].

There was a study conducted in a single health care facility on CABG procedure. Single-saphenous vein grafts were compared with multiple-saphenous vein graft to see mortality. Data was collected by considering all new cases in that center and morbidity was also compared between the two groups. Patients were followed for 35 months and cases needing repeat angiography were noted and analyzed between the two groups. When comparison was done at the earlier phase then multiple saphenous vein grafts were showing increased rates of all the above-mentioned results. However, at the middle phases there was no significant difference seen between the two groups. It was concluded that the early phase poor results of multiple saphenous grafts were due to the fact that it is comparatively a difficult procedure than the other, hence affecting mortality and morbidity [14, 15, 24, 27].

When guidelines are considered then there is no marked difference between the two procedures. The comparisons done largely indicated same outcomes and that the choice mostly depends upon the surgeon. Every patient is different and a surgeon can choose between the two procedures depending on the situation, like more than three or four targeted vessels should be anastomosed by using multiple-saphenous vein graft. Surgeons experience also has a big role to play in such studies. Hence there is no superiority of one procedure over the other. However, targets with a smaller caliber or poor distal flow are studied to have been benefited with multiple-saphenous vein graft. Single-saphenous vein graft has poor results in coronary vessels with small caliber. Multiple-saphenous vein graft with time can improve the blood flow in such target vessels hence improving the patency and longevity [15].

Grafts Failure

In any case if left internal mammary artery (LIMA) cannot be used for left anterior descending artery then saphenous vein grafts can be used. The reason for LIMA being used for left anterior descending artery is it longevity and long-term patency as compared with vein grafts. Vein grafts have more failure rates in the first year and would also require a repeat angiography within a few years of CABG surgery [18].

Grafts at risk of early failure were often small, or had variable lumen of the saphenous vein graft (SVG). Severe disease of the vein grafts was identified with the help of intravascular ultrasound where as diabetes, increased body lipid amounts proved to be its risk. Hence vein graft patency declined immediately within 30 days of surgery.

Coronary artery bypass grafting (CABG) can be complicated by early vein graft failure (VGF), which typically occurs within the first month post-surgery. The primary cause of early VGF is acute graft thrombosis [18, 28]. This complication is often related to technical issues, such as the size of the target vessel, which can result in poor distal runoff, size mismatches between the graft and target vessel leading to turbulent blood flow, and endothelial damage from mechanical trauma or manual distention. Additional factors contributing to graft failure within the first month include small vein graft diameter, pre-existing vein graft disease, and hypercoagulability. In the period between one month and one-year post-CABG, intimal hyperplasia emerges as the main cause of vein graft failure. This process is attributed to the vein graft's adaptation to higher arterial pressures, the loss of endothelial layer inhibition, and the migration and proliferation of smooth muscle cells into the vessel's intimal layer [18, 28]. After one year, atherosclerosis emerges as the principal cause of vein graft stenosis as well as occlusion and Vein graft atheromas, akin to those in native coronary vessels, are capable of rupturing, which may lead thrombotic occlusion within the graft. Vein graft atheromas exhibit a diffuse and concentric morphology, characterized by reduced calcification, poorly developed or absent fibrous caps, as well as an increased susceptibility to thrombosis as well as rupture. Human autopsy studies indicate that coronary vein grafts experience a more accelerated development of atherosclerotic lesions compared to native arteries [18, 28].

Research by Halabi et al. and colleagues, using a retrospective approach, revealed that the early onset of saphenous vein graft (SVG) disease is associated with an increased likelihood of negative long-term clinical outcomes. Their investigation showed that patients undergoing cardiac catheterization between 1 and 18 months after coronary artery bypass grafting (CABG) had a notably higher incidence of death, myocardial infarction, and subsequent revascularization if they exhibited critical or occlusive SVG disease, compared to those with noncritical or no stenosis [18, 28].

An investigation into the extended durability of SVGs and left internal mammary artery (LIMA) grafts following CABG was conducted. The results revealed that SVGs maintained a patency rate of 61% after 10 years, while LIMA grafts demonstrated a higher patency rate of 85%. Angiographic measurements of the recipient vessel's diameter emerged as the most crucial factor in predicting graft patency over a decade post-bypass surgery, along with the positioning of the distal anastomosis site [28].

Research investigated the long-term durability of saphenous vein grafts (SVG) and left internal mammary artery (LIMA) grafts after coronary artery bypass grafting (CABG). Results showed that

SVGs had a 61% patency rate at 10 years, while LIMA grafts demonstrated an 85% patency rate. Angiographic measurements revealed that the recipient vessel's diameter was the most crucial factor in determining graft patency over a decade following bypass surgery. Additionally, the positioning of the distal anastomosis site played a significant role in graft longevity [28]. Vessels exceeding 2.0 mm in diameter demonstrated a 10-year patency rate of 88%, while those smaller than 2.0 mm in diameter showed a rate of 55% [28].

Pathogenesis

After harvesting, venous conduits undergo a period of ischemia and reperfusion after being grafted, causing damage to the endothelial cells and smooth muscle cells (SMCs). The temporary closure of the lumen and subsequent reperfusion in the grafts damages the vessel wall. When the graft is implanted into the arterial circulation, it increases blood flow and exposes the vessel to additional longitudinal and circumferential shear stress. This increased stress further harms smooth muscle cells (SMCs) and the extracellular matrix (ECM), leading to the formation of reactive oxygen species. Platelets and fibrin build up, and circulating leukocytes adhere to and infiltrate the vessel wall. Growth factors are released to platelets, macrophages, and smooth muscle cells, promoting smooth muscle cell migration and proliferation in the intima. Uncontrolled smooth muscle cell proliferation, excessive extracellular matrix production, and macrophage recruitment lead to intimal hyperplasia. In 1964, Szilagyi and colleagues suggested that veins need to expand by at least 50% to handle the increased pressure in arterial circulation. This adaptation is crucial for veins to develop an artery-like structure, but it may also contribute to vein graft failure. The arterialization of venous bypass grafts involves intimal hypertrophy, geometric remodeling, wall stiffening, and inflammation [29].

Perioperative Myocardial infarction

Perioperative myocardial infarction resulting in irreversible myocardial cell damage represents a critical and life-threatening complication following coronary artery bypass grafting, correlating with significantly elevated in-hospital mortality and morbidity rates. The primary graft-related causes of myocardial cell damage following CABG include graft occlusion from acute graft thrombosis, subtotal or hemodynamically significant anastomotic stenosis, graft kinking or overstretching, as well as postoperative graft spasm. The prompt identification of patients experiencing perioperative myocardial infarction as a result of acute graft failure facilitates the implementation of appropriate re-intervention strategies for revascularization, including percutaneous coronary intervention or surgical graft revision, aimed at preserving reversibly damaged myocardium. The occurrence of early graft failure inside 24 hours post-CABG is approximately 1–3%, significantly correlating with increased mortality inside 30 days and a higher rate of serious side effects [30].

Pre-Operative Approaches to Reduce Graft Failure

The main goals of preoperative strategies to lower graft failure following coronary artery bypass grafting (CABG) are risk factor reduction, graft conduit selection, and patient health optimization. To guarantee ideal blood flow and lower the risk of complications, comprehensive management of

modifiable conditions is essential. Examples of these conditions include diabetes, dyslipidemia, and hypertension. Given that tobacco use dramatically raises the risk of graft failure, quitting smoking is essential. Preoperative imaging, such as CT or coronary angiography, aids in determining appropriate target vessels and evaluating the caliber of possible graft conduits. To lower the risk of clot formation, medications like antiplatelet agents (like aspirin) are frequently started prior to surgery. Results are further improved by selecting conduits with higher patency rates, such as the internal mammary artery over the saphenous vein for particular patients. In order to improve surgical outcomes and long-term graft viability, preoperative care must also include nutritional optimization and patient education regarding lifestyle changes.

Preoperative approaches to reduce graft failure include a comprehensive anatomical evaluation of coronary lesions through cardiac catheterization in the lab. During surgery, techniques such as preventing distention, using the no-touch method, and minimizing trauma during graft handling while harvesting and implanting are effective in preventing early graft failure; however, these measures do not affect the incidence of late graft failure [30, 31].

Post-Operative Measurements for Graft Failure

Careful monitoring, medication adherence, and lifestyle changes are the main postoperative strategies to prevent graft failure following coronary artery bypass grafting (CABG). In order to prevent thrombosis in the grafts, antiplatelet therapy—such as aspirin or dual antiplatelet therapy (DAPT) with aspirin and clopidogrel—is essential. Statins are frequently prescribed to stabilize plaque and lower cholesterol, which lowers the chance of recurrent blockages. To reduce the amount of stress on the grafts, blood pressure and diabetes should be closely monitored. Frequent follow-up visits can aid in evaluating graft function and identifying potential problems early on. These visits may include non-invasive imaging tests such as CT angiography or stress tests. Important lifestyle changes include quitting smoking and embracing a heart-healthy diet high in fruits, vegetables, and low-fat foods. Programs for cardiac rehabilitation that promote exercise enhance graft longevity and general cardiovascular health. Following these guidelines lowers the chance of graft failure and greatly improves long-term results.

Antiplatelet Therapy

Clopidogrel is a recognized alternative for patients who cannot tolerate aspirin after undergoing coronary artery bypass grafting (CABG). The American College of Cardiology (ACC) and the American Heart Association (AHA) recommend a daily dose of 75 mg of clopidogrel in such cases. The ACC/AHA guidelines also emphasize the importance of statin therapy for patients undergoing CABG. The goal is to achieve low-density lipoprotein cholesterol (LDL-C) levels below 100 mg/dl, with a reduction of at least 30% from baseline levels. Statin therapy has been associated with improved graft patency and reduced mortality following CABG. These benefits are attributed to statins' ability to inhibit smooth muscle cell proliferation and their anti-inflammatory properties, which help reduce intimal hyperplasia. In some cases, dual antiplatelet therapy (DAPT) is employed, typically involving lifelong aspirin at 81 mg daily and clopidogrel at 75 mg daily for a specified duration, in conjunction with ongoing statin therapy. The initiation of this regimen

usually begins on the first day after surgery. Despite advancements in surgical techniques and postoperative care, the incidence of vein graft failure remains significant, even decades after the introduction of CABG. This persistent issue may be due to the increasing severity of coronary artery disease in patients referred for bypass surgery in the current era of percutaneous treatments [29, 31].

Post-Operative Revascularization for Graft Failure

The 2014 ESC/EACTS guidelines on myocardial revascularization and management of vein graft failure suggest options including medical therapy, thrombectomy, redo bypass surgery, and balloon angioplasty, with or without stent placement. The guidelines emphasize that the optimal treatment for each patient should be based on the severity of symptoms, the degree of ischemia, and a careful evaluation of risks and benefits, considering the patient's overall health and the condition of any functioning arterial grafts [29].

Balloon Angioplasty

Balloon angioplasty has proven effective for treating vein graft failure but is associated with high rates of restenosis and other significant complications. Outcomes for balloon angioplasty in saphenous vein bypass grafts are notably worse than in native vessels, with restenosis rates exceeding 50%. The SAVED trial was the first to compare balloon angioplasty to bare-metal stents, demonstrating that bare-metal stents reduced the need for revascularization and major cardiac events. Later studies found no clear advantage of balloon angioplasty alone over its combination with bare-metal or drug-eluting stents in treating vein graft failure. The DIVA study, which included 599 patients, compared bare-metal stents and drug-eluting stents for saphenous vein graft lesions. After 12 months, target vessel failure rates were similar in both groups, with no significant differences in severe adverse events or stent thrombosis. Neither the European Society of Cardiology nor the ACC/AHA Guidelines offer specific recommendations for revascularization following CABG [31].

PCI & CABG

Compared to patients receiving native coronary artery interventions, patients undergoing bypass graft procedures—whether with arterial grafts or saphenous vein grafts (SVGs)—had greater in-hospital mortality rates. Examining in-hospital clinical outcomes and determining factors linked to PCI in native coronary arteries as opposed to bypass grafts were the objectives of the study [31]. Percutaneous coronary intervention (PCI) and repeat coronary artery bypass grafting (rCABG) are the two main revascularization options that are taken into consideration when a graft fails following CABG. The patient's health, the severity of coronary artery disease, and the risks involved in each procedure all play a role in the decision between these interventions. Compared to repeat surgery, PCI is less invasive, which usually means shorter hospital stays and faster recovery. For patients who are more at risk for surgery because of their age or comorbidities, it is frequently recommended. While rCABG offers better long-term survival and freedom from repeat

interventions, PCI is linked to better operative outcomes, which may result in higher rates of repeat revascularization.

Compared to PCI, rCABG has been linked to better long-term survival and a lower need for subsequent revascularization. This implies that in appropriate patients, rCABG might produce more long-lasting results. Increased operative risks, such as elevated rates of morbidity and mortality, are associated with repeat surgery, particularly in patients with substantial comorbidities. In addition, the recovery time is longer than with PCI.

According to research, native coronary artery lesions are the primary focus of the majority of percutaneous coronary interventions (PCIs) carried out on patients who have previously undergone coronary artery bypass grafting (CABG). However, after CABG, the incidence of PCI increases over time. PCI to bypass grafts is independently linked to higher in-hospital mortality than native coronary PCI. Significantly greater rates were discovered in a related study that included more than 11,000 veterans with a history of CABG receiving PCI to avoid grafts. PCI to bypass grafts was associated with a significantly increased risk of death and myocardial infarction (MI) after a median follow-up of 3.11 years [32].

Another important consideration is the choice between vein graft intervention and revascularization using percutaneous coronary intervention (PCI) for chronic total occlusion (CTO) of native vessels. Following coronary artery bypass grafting (CABG), the risk of atherosclerosis or thrombosis in native vessels increases with approximately 43% of bypassed native coronary arteries progressing to chronic total occlusions within a year of surgery [33]. Treating CTOs in post-CABG patients presents unique challenges compared to those without prior CABG. In a detailed, single-center CTO program, post-CABG CTOs were found to be more complex, with greater length, angulation, calcification, and a higher likelihood of a blunt proximal cap. Despite these complexities, success rates for CTO interventions were similar between post-CABG and native CTO cases, at 90% and 93%, respectively. Additionally, while short-term risks were not significantly higher for post-CABG patients undergoing CTO interventions, these patients did face an increased risk of major adverse cardiovascular events (MACE) within one year compared to non-CABG CTO cases. Advances in CTO intervention techniques have broadened the revascularization options available. The accompanying figure outlines a comprehensive approach to managing vein graft lesions, including CTO interventions [34].

Comparison of on-pump and off-pump techniques Coronary Artery Bypass Grafting

Coronary artery disease is treated with surgery and the desire is to vascularize coronary vessels. The approach is coronary artery bypass grafting surgery (CABG), which involves cardiopulmonary bypass. Older patients have more comorbid and further they have diseased aortas which have to go through aortic cross clamps. Furthermore, Cardiopulmonary bypass has drastic effects on the kidneys, possibility of stroke i.e., neurological impacts, manipulation of the aorta and other inflammatory responses. It is true that with cardiopulmonary bypass a much more stable surgical field is achieved hence making anastomoses easy. Surgeon does grafting in a bloodless environment; heart is arrested hence giving better results. Although there is a debate going on the favor of off pump bypass surgery. Off pump bypass can reduce the complications, pro

inflammatory responses seen with "on pump" or ONCAB. Hence a number of trials have been taken, to analyze the results of "off-pump" or OPCAB [19].

Off pump CABG was developed in 60's but has currently become popular. Devices have been introduced for stabilizing the heart but depend on the expertise and skills of the operating surgeon. Mostly assess to the lateral and posterior wall of the heart for coronary vessels is challenging. Furthermore, the difficulty in approaching specific targets leads to decreased numbers of grafts when compared with on pump CABG. Although on pump CABG gives a blood free environment but off pump CABG was seen with less post-operative bleeding v/s on pump CABG. In a study on pump CABG was compared with off pump CABG and mortality was noted in 30 days and after one year. It was noted that on pump CABG had less mortality in comparison to off pump CABG in the first month. The same result was seen when patients were followed for one year. Mortality after Five year showed the same results i.e., on pump CABG was superior to off pump CABG. In on pump CABG fewer targets were grafted and some patients needed repeat CABG surgery [26].

ICU stay, hospital stay and ventilation duration is also shorter in off pump CABG surgery v/s on pump CAB. Follow-up angiograms conducted one-year post-CABG indicated a reduced overall graft patency in the on-pump CABG group and a higher frequency of patients with stenosed graft. The patency of LIMA-LAD grafts was comparable between groups; however, a lower percentage of internal mammary arteries grafted to left anterior descending artery in the off-pump CAB group [19].

Another study followed mortality, for a time period of 30 days. In the study, on pump CABG was compared with off pump CABG regarding post-operative complications in renal, heart and brain. Trainees were not a part of this study and experienced Surgeons were asked to participate. When results were compared, it showed no visible difference in the two procedures. On pump CABG or off pump CABG were assigned through randomization. Hence no difference was noted in the two procedures regarding stroke or kidney failure when followed for 30 days [19, 23, 26].

Another study was done which compared on pump CABG v/s off CABG. In this study older patients were chosen and were followed for a time period of 30 days and one year. Surgical technique was assigned to experienced surgeons via randomization. Mortality was studied between the two procedures through a time period of 30 days and one year. No difference was noted in the results between the two, both after 30 days and after one year. Selection of surgeons was done; trainees were not included and operating surgeons with surgical cases more than 500 off pump CABG were included. The same study when extended for other five years; i.e. experienced surgeons, a comparative study between on pump and off pump CABG surgery, studying mortality for a period of five years. It was noted that the results were same as were seen with in a time period of 30 days and after one year. There was no difference between the two procedures [25].

Combined observation of these trials points toward off pump CAB results in comparison to those of on pump CAB. Incomplete revascularization as a result of receiving lesser bypass grafts has a significant role to play in deciding long-term survival rate in patients subjected to OPCAB [20]. Another factor that impacts the results of OPCAB is the expertise of the surgeon and his surgical crew while performing the procedure, as proven in the outcomes of ROOBY, where noticeably unfavorable results were due to the lesser amount of expertise requirement for performing

OPCAB as compared to CORONARY and GOPCABE, where only surgeons with substantial experience in the technique performed off pump CAB [25, 27].

Evaluation was done using data, of more than a million surgeries and compared on pump CAB with off pump CAB. Study revealed that off pump CAB was linked to higher expiry, more time spent in hospital, and were expensive in comparison to on pump CAB and more so when done by inexperienced personals. Off pump CAB, when conducted by high-volume surgeons, demonstrated a reduced death ratio in comparison to on pump CAB [27].

An impact of off pump CAB on results is shown, i.e., examined all available RCTs comparing OPCAB and ONCAB. The analysis revealed that OPCAB was linked to increased mortality in comparison to on pump CAB [24, 27].

Puskas et al. assert in an editorial accompanied the 5-year findings from GOPCABE of which the results unequivocally illustrate importance of experienced practitioners, for off pump CABG [24]. Regardless of its linkage to unfavorable outcomes such as increased mortality rate and more cases of incomplete revascularization in several studies, the existing data suggests that Off-pump CAB is a relatively better procedure with favorable results if performed by skilled surgeons in centers where these procedures are performed more. In such high expertise circumstances, OPCAB seems to be relatively advantageous in cases with more chances of complications during and after surgery [24].

Complications Of CABG

Despite being a popular and successful treatment for coronary artery disease, coronary artery bypass grafting (CABG) surgery has the potential to cause complications. Bleeding, surgical site infection and irregular heart rhythms like atrial fibrillation are examples of early complications. More severe risks include kidney dysfunction, heart attack, or stroke, which are frequently brought on by the stress of surgery and variations in blood flow. Graft failure as a result of clot formation or graft narrowing (stenosis) is examples of long-term complications. Particularly in elderly patients, neurological problems like memory loss or cognitive decline may also occur. Although these risks have been greatly decreased by improvements in surgical methods and perioperative care, cautious patient selection, preoperative optimization, and attentive postoperative monitoring are essential to reducing complications and guaranteeing better results.

CABG carries the risk of several complications, including stroke, wound infections, graft failure, kidney damage, postoperative atrial fibrillation, and mortality. The occurrence of stroke after CABG is reported in 1% to 2% of cases, depending on individual patient characteristics and risk factors such as older age, prior stroke, aortic atherosclerosis, peripheral artery disease, postoperative atrial fibrillation, and diabetes [35].

Postoperative renal dysfunction occurs in 2% to 3% of CABG cases, with 1% requiring dialysis. The risk factors are multifaceted, including pre-existing kidney disease, advanced age, diabetes, the specific surgical approach, left ventricular dysfunction, and shock. While no medications have been definitively proven to reduce the risk of CABG-related renal dysfunction, off-pump CABG may provide advantages over the on-pump technique [36].

Atrial fibrillation commonly develops within the first five days after CABG, with incidence rates between 20% and 50%. This condition is associated with increased morbidity, including a higher risk of embolic stroke during the postoperative period, as well as elevated mortality rates. Preoperative administration of beta-blockers and, in some cases, amiodarone has been shown to significantly reduce the likelihood of postoperative atrial fibrillation [36].

Perioperative mortality rates after CABG range from 1% to 2% and are influenced by factors such as patient comorbidities, the complexity of the procedure, and the surgical volume of the performing facility.

MEDIAN STERNOTOMY

Median sternotomy is performed on over 1 million patients worldwide each year for cardiac surgeries. This approach is used for a range of isolated or combined procedures, including myocardial revascularization and heart valve replacement. It involves a midline skin incision from the sternal notch to the base of the sternum, followed by the division of subcutaneous tissue and separation of the sternum. Median sternotomy provides excellent visual and manual control of the operative field, revolutionizing cardiac surgery since its introduction over a century ago. After the procedure, the sternum is typically closed using wire closure techniques, such as single wires or figure-of-eight configurations. In some cases, rigid fixation systems with metal plates and screws, like the SternaLock system by Biomet Microfixation (Jacksonville, FL, USA), are employed. Despite advancements in minimally invasive cardiac surgery techniques, median sternotomy remains widely practiced due to its ability to provide superior clinical outcomes through optimal access to the heart [36].

Standard Sternal Wound Closure Techniques

Traditional Closure Methods

Stainless steel wires or plates are usually used for standard sternal wound closure. There are multiple steps in the process: [37, 38]

1. **Sternal Re-approximation**: Stainless steel wires are inserted through pre-drilled holes in the bone to align and secure the two halves of the sternum.
2. **Layered Closure of Soft Tissues**: After securing the sternum, the surrounding soft tissues are closed in layers to promote healing.
3. **Skin Closure**: The skin is then closed with sutures or staples, completing the wound closure process.

While standard closure techniques are widely used, they are not without limitations. The mechanical strength provided by wires may be insufficient in certain cases, particularly in patients with compromised healing. Additionally, the risk of infection remains a significant concern, particularly in high-risk populations [37, 38].

STERNAL WOUND COMPLICATIONS

Sternal complications are rare but linked to various identifiable risk factors. These complications include superficial wound infections, bone nonunion or sternal instability, sternal dehiscence, and mediastinitis. Diabetes, obesity, use of bilateral internal mammary artery grafts, and increased need for blood products can significantly raise the risk of sternal infections after median sternotomy. Recognizing these risk factors is crucial for screening and stratifying patients at higher risk of impaired sternal healing, enabling preventive measures and timely interventions to address sternal complications effectively.

Types of Complications

Sternal wound complications can manifest in several forms: [39, 40]

1. **Infection**: This is the most common complication and can range from superficial infections of the skin to deep infections involving the mediastinum.
2. **Dehiscence**: Partial or complete separation of the wound edges can occur, often resulting in delayed healing.
3. **Sternal Instability**: Compromised healing can lead to instability, causing pain and functional impairment.
4. **Chronic Pain**: Nerve damage or improper sternum healing can cause patients to suffer from chronic pain.

Risk Factors

Various factors increase the risk of sternal wound complications, including: [39-42]

- **Diabetes Mellitus**: Patients with diabetes often have impaired wound healing due to microvascular complications.
- **Obesity**: Increased body weight can lead to mechanical stress on the wound and decreased perfusion.
- **Immunosuppression**: Patients on immunosuppressive therapy or with underlying conditions that compromise immune function are at higher risk.

Sternal Wound Infections

Sternal wound infections occur at a rate of approximately 1%, with contributing risk factors including obesity, diabetes, chronic obstructive pulmonary disease, and prolonged surgical procedures. Saphenous vein graft (SVG) failure is most common within the first 30 days after surgery and is influenced by factors such as vein size, excessive graft length, poor distal runoff, slow flow, hypercoagulability, and thrombosis. Studies show that SVG failure rates can reach up to 25% based on repeat angiography after CABG. In contrast, arterial grafts, such as the left internal mammary artery (LIMA) and radial arterial grafts, exhibit significantly better long-term patency, with rates exceeding 90% at 10 years [35, 36].

Introduction

Postoperative infections remain one of the most serious complication following cardiac surgery, with mediastinitis—a deep sternal wound infection. In the study by Claudius Diez et al, mediastinal

infections are studied in detail and noted that it is relatively low incidence but has severe clinical implications. The authors analyze patient and procedure related risk factors contributing to the development of mediastinitis, such as diabetes mellitus, obesity, prolonged surgery time, and reoperations. The study emphasizes the importance of early identification and intervention to mitigate the morbidity and mortality associated with this condition [37].

In contrast to the complications shown by the above-mentioned study, a study by Kathryn B. Kirkland focuses on the cost and hospital stay of mediastinitis, which is a serious complication of infection after cardiac surgery. He noted the effects of surgical site infections (SSIs) on mortality, morbidity, hospital stay and thus the burden on hospitals. The study is not limited to cardiac surgery and underscores severe systemic implications of SSIs, positioning mediastinal infections as a high-cost, high-risk subset of these complications [38].

Both studies conclude that deep wound infections after cardiac surgery, mediastinitis can have dangerous outcomes and would also be economically and operationally taxing for the healthcare system. Therefore, high risk patients should be identified and preventive measures should be adapted to improve surgical outcomes [37, 38].

Causes of Mediastinal Infections Following Cardiac Surgery

Two fundamental studies on the risks and environmental factors which contribute to the mediastinal infections after median sternotomy, by Claudius Diez et al. and Kirkland et al. Mediastinitis after cardiac surgery remains a significant postoperative complication with substantial impacts on patient morbidity, mortality, and healthcare resource utilization. While patient-related risk factors such as obesity, diabetes mellitus, and re-operations are widely acknowledged. It is very important to understand the modifiable, which are central to improving surgical outcomes and reducing the risk of deep sternal wound infections (DSWI) [37, 38].

Improper Draping Techniques

An important cause found by Claudius Diez et al., in a retrospective analysis was the improper draping technique which leads to a complication of mediastinitis in cardiac surgery wound after surgery. Claudius Diez et al. recommended regular evaluating of the sterile field during prolonged procedures apart from use of proper adhesive drapes. He mentioned in his study that allowing drapes to become non adherent during long procedures or its misplacement leads to the contamination of surgical field which later on causes increased infections. Any surgical instruments, like suction tubes, diathermy and wires which could come in contact with contaminated surfaces can cause potential damage, especially during long procedures [37].

Excessive Use of Electrocautery

Claudius Diez et al. also noted the implications of excessive use of electrocautery and adjunctive materials like bone wax during cardiac surgery. These tools, while effective for hemostasis, can cause thermal injury and necrosis to surrounding tissues, thereby impairing local immune response and promoting bacterial colonization. Moreover, the necrotic tissue serves as an ideal medium for infection, particularly in cases where debridement is minimal or absent. The authors suggest

minimizing electrocautery in favor of more tissue-conserving techniques, especially during sternal dissection, to preserve healing potential and reduce infection risk [37].

Frequent Personnel Movement in the Operating Room (OR)

Kirkland et al. highlighted the role of frequent personnel movement and unnecessary door openings during surgery as a significant contributor to surgical site infections. In high-risk surgeries such as cardiac procedures, each entry or exit from the OR disrupts the pressure and airflow systems designed to maintain a sterile environment. The study observed that high-traffic operating rooms experienced elevated rates of SSIs, attributing this in part to the introduction of airborne contaminants and loss of environmental control. The authors recommend restricting OR access during procedures and implementing accountability protocols to minimize movement [38].

Airborne Contamination and OR Air Quality

Airborne contamination is another critical source of infection risk discussed in Kirkland et al.'s study. Though their work focused broadly on SSIs across surgical types, they identified airborne particles such as skin squames, respiratory droplets, and dust as major culprits in infection transmission. In cardiac surgeries where the mediastinal cavity is exposed for hours, these contaminants pose a serious threat. The study underscores the importance of high-efficiency particulate air (HEPA) filtration, positive pressure ventilation, and regular environmental cleaning to reduce microbial load in the surgical suite [38].

Failure to Maintain Laminar Flow Systems

Both Claudius Diez et al. and Kirkland et al. emphasized the importance of maintaining laminar airflow in the operating room. Claudius Diez et al. observed that malfunction or obstruction of laminar flow systems—often caused by surgical equipment placement or poor maintenance—correlated with higher mediastinitis rates in their patient cohort. Meanwhile, Kirkland et al. discussed laminar flow in relation to economic outcomes, associating better airflow management with decreased SSI-related costs and shorter hospital stays. Proper function of laminar systems ensures that sterile air flows downward over the operative field, pushing contaminants away and preventing their deposition in open wounds [37, 38].

Poor Compliance with Surgical Attire Protocols

Kirkland et al. reported that failure to follow attire protocols—such as wearing non-sterile gowns, incorrect mask fitting, or re-gloving without proper hand hygiene—was linked to increased SSI rates. These practices introduce both contact and droplet contamination into the sterile field. Although their study was not limited to cardiac surgery, the findings are highly relevant given the extended duration and complexity of sternotomy procedures. The authors advocate for strict institutional policies on surgical attire, including routine compliance audits and team training, to reduce the potential for intraoperative contamination [38].

Extended Sternotomy Exposure Duration

Extended operative times and prolonged sternal exposure were directly associated with higher mediastinitis rates in the study by Claudius Diez et al. They noted that infection risk increased with each additional hour of surgery, particularly in complex procedures involving grafting or reoperations. Contributing factors include environmental degradation of sterile barriers, increased fatigue among surgical staff, and potential lapses in protocol adherence. The authors suggest preoperative planning, surgical efficiency, and in-surgery reinforcement of sterile practices as key interventions to mitigate this risk [37].

PATHOGENS

In the study by Hiroshi Kubota, the authors identified Staphylococcus aureus as the most commonly isolated pathogen in patients with deep sternal wound infections (DSWI) following cardiac surgery. Notably, both methicillin-sensitive (MSSA) and methicillin-resistant strains (MRSA) were observed, with MRSA posing a greater treatment challenge due to its resistance profile and higher associated morbidity. The study highlighted that coagulase-negative staphylococci (CoNS) were also frequently found, particularly in patients who had prosthetic material or sternal wires implanted. These organisms, while often part of the skin flora, become opportunistic pathogens in surgical settings and can lead to chronic, indolent infections of the mediastinal tissues [39].

In a study by Hiroshi Kubota, gram-positive cocci, gram-negative bacilli were isolated in a smaller but significant proportion of cases [39]. These included pathogens such as Pseudomonas aeruginosa and Enterobacter species, typically associated with prolonged hospital stays, reoperations, and antibiotic exposure. The authors also noted rare cases involving fungal pathogens, such as *Candida albicans*, particularly in immunocompromised patients or those with extended ICU courses. The findings emphasized the importance of early and precise microbial identification, as polymicrobial infections were also observed in some severe cases, necessitating broader-spectrum empiric therapy and individualized antimicrobial regimens.

In the study by Claudius Diez et al., the authors explicitly identified Staphylococcus aureus and coagulase-negative staphylococci (CoNS) as the most common pathogens isolated in cases of post-sternotomy mediastinitis. These findings align with broader infection trends in cardiothoracic surgery, where gram-positive cocci—particularly methicillin-resistant strains—pose significant risks due to their ability to colonize the skin and surgical hardware. Although the primary focus of the study was risk factor identification, the microbiological data reinforce the need for rigorous preoperative skin antisepsis and targeted prophylactic antibiotic coverage against Staphylococcal species [37].

Similarly, in the study by Kirkland et al., although the study encompassed SSIs across various surgical procedures rather than exclusively cardiac surgery, Staphylococcus aureus was reported as the predominant causative organism. The study highlighted that infections caused by S. aureus, especially MRSA, were associated with significantly higher attributable mortality rates and prolonged hospital stays. This underscores the organism's virulence and its central role in driving

both clinical and economic burdens of surgical-site infections, including those following median sternotomy [38].

Prophylactic antibiotics

Prophylactic antibiotic administration is a cornerstone in the prevention of deep sternal wound infections (DSWI) and mediastinitis following cardiac surgery. In the systematic review and meta-analysis by Adi Lador titled *"Antibiotic prophylaxis in cardiac surgery"*, the authors evaluated data from multiple trials and concluded that the use of first- and second-generation cephalosporins, particularly cefazolin, significantly reduces the risk of postoperative infections [40]. They emphasized the importance of administering antibiotics within 60 minutes prior to incision and discontinuing them within 48 hours after surgery to maximize efficacy and minimize the risk of resistance and adverse effects. The study identified Staphylococcus aureus and coagulase-negative staphylococci as the predominant pathogens responsible for these infections, supporting the choice of antibiotics with strong gram-positive coverage. Furthermore, Adi Lador et al. cautioned that prolonged or inappropriate antibiotic use may contribute to antimicrobial resistance, Clostridioides difficile infection, and increased healthcare costs without additional protective benefit [40].

Building on that evidence, Engelman et al., in *"The Society of Thoracic Surgeons Practice Guideline Series: Antibiotic Prophylaxis in Cardiac Surgery, Part II: Antibiotic Choice,"* provided detailed recommendations for antibiotic selection based on risk stratification and local microbiology. The authors reaffirm cefazolin as the first-line agent for most routine cardiac surgeries due to its favorable spectrum against common surgical site pathogens. However, they recommended that in patients with known colonization with MRSA or when MRSA is endemic in a hospital setting, vancomycin should be added to the prophylactic regimen. Engelman et al also stressed that institutional antibiograms and individual patient history should guide prophylactic decisions, highlighting that antibiotic prophylaxis is a strategic and individualized intervention, not a universal protocol. The guidelines aim to strike a balance between effective infection prevention and antibiotic stewardship, advocating for routine reviews of hospital protocols in light of evolving resistance patterns [41].

Other Preventive Measures:

In addition to antibiotic administration, Adi Lador emphasize several critical intraoperative and perioperative strategies that contribute significantly to reducing infection risk in cardiac surgery patients. One key recommendation is maintaining normothermia during the perioperative period, as hypothermia has been associated with impaired wound healing and higher infection rates. The authors also underline the importance of meticulous glycemic control, especially in diabetic patients, noting that elevated blood glucose levels postoperatively are independently associated with an increased incidence of deep sternal wound infections. Furthermore, preoperative skin antisepsis using agents like chlorhexidine and proper hair removal with clippers (not razors) just before surgery are highlighted as essential practices to lower bacterial skin flora and prevent microbial contamination of the incision site [40].

Engelman et al. build on these foundational measures and introduce a system-level approach to infection prevention. They stress the need for comprehensive surgical care bundles, which combine evidence-based practices like preoperative bathing with antiseptic solutions, timely re-dosing of antibiotics during long surgeries, and strict adherence to sterile technique throughout the operative process. Importantly Engelman et al. also advocate for nasal decolonization protocols in patients known to be carriers of *Staphylococcus aureus*, particularly MRSA, using agents such as mupirocin ointment preoperatively. They also recommend institutional surveillance of infection rates and antibiotic resistance patterns, encouraging hospitals to implement feedback systems and performance monitoring to ensure ongoing compliance with infection prevention guidelines. This multifaceted approach, according to the authors, is vital to maintaining low surgical site infection rates in high-risk cardiac procedures [41].

Sternal Instability Scale

The incidence of complications following median sternotomy has remained relatively stable over the past two decades. Sternal complications contribute to increased patient morbidity and higher healthcare costs. Early identification and diagnosis of these issues are essential for effective management and to prevent the development of severe sternal infections. While computed tomography and radiography remain the primary imaging methods for screening and diagnosing sternal complications, studies indicate their sensitivity and specificity are limited. Recent research highlights ultrasound as a reliable tool for evaluating sternal edge separation and movement during exercise and functional activities after cardiac surgery, making it particularly valuable for patients with suspected or confirmed sternal complications [48, 49].

The Sternal Instability Scale was designed to assess and monitor sternal stability in individuals following median sternotomy. This tool is easy to use and has demonstrated strong validity, as well as excellent interrater and intrarater reliability. The assessment involves a physical examination and manual palpation of the sternum along the median sternal ridge. A single grade is assigned based on the level of instability observed during various upper body movements, such as shoulder flexion and abduction, trunk rotation and lateral flexion, deep breathing, and coughing. A score of 0 indicates a clinically stable sternum with no detectable motion or separation of the sternal edges, while a score of 3 reflects a fully separated sternum with significant motion and separation [50]. To align with the medical diagnosis of sternal instability, the assessment should include both the upper and lower portions of the sternum. Since a significant proportion of sternal wound complications (66%) are detected after hospital discharge, it is recommended to perform assessments at discharge and during the initiation of outpatient cardiac rehabilitation or physical therapy. Sternal evaluations enable the early detection of instability, facilitating timely referrals and appropriate management. Furthermore, they provide an objective basis for developing personalized guidelines for functional activities, physical exercise, and rehabilitation [50].

PPSP

Persistent post-median sternotomy pain (PPSP) is a common issue that may stem from musculoskeletal trauma, neuropathic processes, pleural disruption, or the harvesting of the

internal mammary artery. PPSP syndrome is notably prevalent, with 33% to 66% of patients experiencing chronic pain lasting more than three months and 25% to 33% reporting pain persisting for over a year after surgery [51, 52, 53]. Pain associated with PPSP has been reported in the anterior chest, neck, rib cage, and left shoulder six weeks post-surgery, but by three months, only rib cage pain typically remains. Research by El-Ansary et al identified a higher incidence of musculoskeletal symptoms in the anterior chest wall in patients who underwent internal mammary artery harvesting. Sternal complications, however, appear to be uncommon among those with PPSP. Both acute and chronic pain significantly impact clinical outcomes, as they are negatively correlated with function, physical activity, and quality of life in post-cardiac surgery patients. Encouraging physical activity can play a crucial role in alleviating these symptoms and improving overall recovery [51, 52, 53].

Sternotomy; Impact on quality of life

The effects of cardiac surgery and median sternotomy can be long-lasting. Qualitative data from elderly individuals recovering from CAB surgery indicate that while many feel their activities are unrestricted after one year, some still view their physical health as a barrier to engaging fully in activities. The impact of heart surgery on functionality is particularly significant for older adults, especially those who are frail, as they are more prone to losing independence after surgery and hospitalization compared to younger individuals [52]. The connection between restrictive sternal precautions (SP) and adverse symptoms, activities of daily living (ADL), and overall functioning post-median sternotomy remains unclear. However, it is likely that SP contributes to these challenges by limiting activity and indirectly through deconditioning. Studies have also identified strong negative correlations between functional status and quality of life in post-heart surgery patients, suggesting that encouraging physical activity after median sternotomy could lead to improved outcomes [52].

It is widely acknowledged that heart surgery significantly impacts patient's quality of life for up to a year, influenced by symptoms and reduced functionality. However, most patients, including older adults, experience improvements in quality of life over time following cardiac surgery. This aligns with qualitative findings suggesting that while many older patients report a positive view of their quality of life, some still perceive their health as suboptimal and feel they remain in the recovery phase for 6 to 12 months after CAB surgery. This indicates a potential disconnect between patient's perceptions, activities of daily living, and quality of life after cardiac surgery, warranting further investigation. However, adopting less restrictive surgical protocols is anticipated to improve mobility, activity levels, and health perceptions following median sternotomy, which could further enhance overall quality of life and patient well-being. Understanding the current clinical application of these protocols is therefore essential [54].

To prevent or reduce sternal complications, sternal precautions (SP) are commonly prescribed immediately following cardiac surgery. These precautions involve varying restrictions on arm movement for 6 to 12 weeks, depending on the hospital or surgeon. Patients are instructed to limit arm use, either partially or completely, during daily activities and exercise [54]. The goal of SP is to

promote solid sternal osteosynthesis and support bone union by minimizing shear and distractive forces and reducing motion at the sternal edges, which are believed to hinder bone healing.

However, SP often proves impractical for patients, leading to confusion among healthcare providers, caregivers, and patients. To date, no studies have investigated adherence to SP, which is likely low, as individuals recovering from median sternotomy naturally use their arms for various activities of daily living. Additionally, research on the evidence and rationale for SP is limited. While no systematic reviews have addressed the topic, a previous narrative review noted that the evidence supporting SP is sparse and based on a small number of studies [55].

Over the past ten years, research into clinical procedures and the effects of upper body exercise on sternal complications and other outcomes has been conducted worldwide due to the inconsistent definition and prescription of SP. There are no agreed-upon definition of what SP means, according to survey data on current practices regarding postoperative guidelines following median sternotomy in acute care and cardiac rehabilitation settings. Additionally, the recommendations for prescribing and promoting upper body activity are inconsistent. Additionally, the results showed that limiting unilateral arm use during mobility tasks was more common than limiting bilateral arm use. The most common weight range that was recommended for lifting was 2–5 kg [56].

The lack of consistency in defining as well as prescribing SP has spurred global investigations over the past decade into clinical practices and the impact of upper body exercise in sternal complications and various outcomes. The analysis of survey data concerning current practices related to postoperative guidelines after median sternotomy within acute care as well as cardiac rehabilitation environments indicates a lack of a uniform definition for what SP entails. Furthermore, there is a lack of consistency regarding the guidelines for prescribing and advancing upper body activity. Furthermore, the findings indicated that there was a higher occurrence of limiting unilateral arm use compared to bilateral arm use during mobility tasks. The most frequently prescribed weight for lifting was between 2 to 5kg. While using a wheeled walker was the least likely to be restricted, driving restrictions were prevalent and had an impact on patients. It was also observed that it had not been common practice to modify activity restrictions for patients experiencing sternal instability. With a few exceptions, the same questionnaire produced similar results in a group of therapists from different countries; this study showed a higher frequency over AD use restrictions and a lower frequency over lifting restriction [56].

Other research has demonstrated that upper body movement does not necessarily exert excessive force on the sternum, despite the initial cadaver study by McGregor et al. suggesting against bilateral stimulation of pectoral muscles and simultaneous use of the arms. The most significant skin movement is caused by bed mobility and transfers, according to an analysis of supra-sternal skin motion, whereas shoulder movements, whether weighted or unweighted, exert little to no distracting force [56].

According to preliminary pilot data, the pectoralis muscle is only slightly activated during arm exercises and walking while using an assistive device in comparison to maximal voluntary effort. Pectoralis muscle activation during elbow and shoulder range-of-motion exercises was low, ranging from 0.5% to 6.4% of maximal voluntary effort, and there was no discernible increase when 5-pound weights or unilateral versus bilateral movements were used [57]. Similarly, the pectoralis

muscle was barely activated when using a cane, front-wheeled walker, and regular walker. Additionally, the evaluation of forces applied through the arm shows that a considerable percentage of daily living activities require more than 10 pounds of force, ranging from 54% to 68% [58, 59]. For example, opening a commercial building door and moving from side-lying to brief sitting both required force through the arm that was two and three times greater than the recommended weight limit, respectively. According to the study's data, arm force significantly decreased when tasks were performed at a "slow speed" as opposed to the typical "self-selected speed." This research suggests that patients recovering from a median sternotomy may benefit from such a strategy. Additionally, Adams et al. have measured intrathoracic and mouth pressure during exercise, upper body lifting, coughing, and sneezing. Valsalva force measurements during coughing and five weightlifting exercises showed that coughing generated a noticeably greater force than any of in contrast to the five weightlifting exercises. According to recent research, the intrathoracic pressure generated during a sneeze is equivalent to lifting 70% of one repetition maximum, with a mean weight of 41 kg 52. This data was obtained during resistance training with a bench press [50].

Pushing out of a chair during sit-to-stand transfers and performing unilateral loaded movements caused the greatest amounts of sternal separation and self-reported pain in this patient group. On the other hand, raising both arms simultaneously overhead caused little sternal separation and was generally well accepted. The micromotion of the sternal edges was minimal at 3 to 5 days, 4 weeks, and 3 months postoperatively, according to a recent study that looked at sternal separation and micromotion caused by upper body movements and functional tasks following median sternotomy with conventional wire made of stainless-steel closure. Using real-time ultrasound, motion at the sternal edges was measured at the mid-sternum and recorded in both lateral and anterior-posterior directions. . Ultrasound measurements were made while the subjects were at rest and while performing five dynamic arm and trunk tasks. Deep inspiration, coughing, unilateral and bilateral arm elevation, and sit-to-stand motions with arm support were all part of these tasks. In comparison to baseline and all other tasks, coughing caused a significant increase in the lateral separation of the sternal edges (1 to 2 mm) and an increase in pain during each of the three postoperative time intervals [50, 61].

The results show strong evidence in favor of implementing early upper-body exercise following heart surgery. Ironically, SP usually restricts upper body movements and exercise to weights of 2–5 kg, but coughing generates a much stronger force of 28 kg and is frequently encouraged following surgery to reduce the risk of pulmonary complications [61]. Additionally, physical activity, especially upper body exercises, may be essential for promoting prompt mental, functional, and cognitive recovery, supporting bone remodeling and healing in response to loading, and creating an active culture that develops into long-term secondary wellness and preventive behaviors. Several studies have demonstrated that early, moderate-intensity exercise, including progressive upper body exercises, can promote healing, reduce pain, and improve function after median sternotomy. The results are noteworthy and support a less restrictive and more proactive strategy for encouraging mobility following median sternotomy [61].

Furthermore, it is commonly acknowledged that exercise-based rehabilitation after heart surgery has many benefits. Cardiac rehabilitation dramatically reduces cardiovascular mortality and the

risk of readmission to the hospital, especially for those with coronary heart disease. The majority of research on the benefits of cardiac rehabilitation has focused on Phase II outpatient programs, which by definition start in the subacute phase after a cardiac event (i.e., post-hospital discharge). Although Phase II cardiac rehabilitation should start as soon as possible after hospital discharge, it is often delayed because of traditional limitations on arm exercises and daily living activities like driving (unpublished data). The effects of cardiac rehabilitation exercises performed right after median sternotomy heart surgery have been the subject of recent studies. Physical activity is usually restricted during postoperative hospitalization unless a healthcare provider specifically prescribes and oversees it [61].

Strategies for Preventing and Managing Sternal Instability

Evidence-based nonsurgical interventions for thoracic support and stabilization can benefit patients at risk of or currently experiencing sternal instability. In its acute phase, sternal instability often presents as sternal dehiscence or disruption, whereas in the chronic phase, it is termed sternal nonunion. Sternal separation can occur along the entire sternum or be localized, typically at the caudal end. This condition is often linked to sternal infection, causing symptoms such as sternal clicking, increased movement, pain, and difficulty with functional activities. One preventive measure involves applying counter pressure to the median sternotomy incision during coughing, known as "splinted coughing," which is thought to reduce dehiscence, alleviate pain, and improve cough efficiency. Thoracic supports can also be beneficial during the early recovery phase, particularly for women. Research has shown that using a thoracic support vest after median sternotomy significantly lowers the incidence of deep wound complications compared to a control group [41]. Further studies on supportive devices for chronic sternal instability found that adjustable fastening braces reduced pain and significantly decreased sternal separation. Additionally, a six-week program of trunk stabilization exercises, performed for 10 minutes twice daily, resulted in reduced sternal separation and less pain during activities for patients with chronic sternal instability [62].

Cardiac surgery performed via median sternotomy has widespread systemic effects, including changes in body structure and function, activity levels, and participation in activities of daily living. These effects, combined with physiological responses post-surgery, are often compounded by deconditioning during recovery, which can influence patient symptoms, functional limitations, and overall quality of life. A notable reduction in skeletal muscle mass of the axial body, legs, and arms has been observed one year after cardiac surgery, with a significant relationship identified between muscle atrophy and quality of life. The marked decrease in arm skeletal muscle mass compared to axial and leg muscles are particularly striking and may be linked to the use of restrictive sternal precautions. These precautions limit arm movement and activity, potentially leading to disuse-related atrophy. As a result, cardiac surgery appears to significantly affect movement and activity levels, with these effects potentially worsened by restrictive sternal precautions (SP). Further exploration of the implications of cardiac surgery via median sternotomy is necessary to better understand the impact of these precautions [50, 52, 53].

Following cardiac surgery via median sternotomy, patients often experience a range of adverse symptoms that disrupt their functionality and quality of life. Common postoperative symptoms include incisional pain, dyspnea, impaired ventilation, weakness, fatigue, sleep and eating difficulties, depression, neurocognitive impairments, and pain in the thoracic region, arms, back, and neck. Among participants in outpatient cardiac rehabilitation programs after median sternotomy, the most frequently reported symptoms include fatigue, sleep disturbances, shoulder pain, weakness, breathing difficulties, and nonspecific back pain. This discomfort associated with median sternotomy may significantly impact patients by reducing activity levels, potentially leading to deconditioning and disuse atrophy, if a structured movement program is not adopted [49- 53, 62, 63].

Redo sternotomy

Redo sternotomies carry a higher risk of problems than primary sternotomies, thus it's important to prepare for them in advance.

In the event that significant blood vessel injury occurs during redo sternotomy affecting the heart, Cardiopulmonary bypass may need to be performed right away. The femoral technique is commonly used to acquire access in advance of a sternotomy.

Typically, the primary incision is aligned with the trajectory of the prior incision, notwithstanding its deviation from the exact center. With the exception of hypertrophic scars, it might be advisable to eliminate them.

In order to eliminate the sternal wires that were inserted during the initial sternotomy, approach the wire upwards and use wire cutters to trim the wire to the side of the loop. To safeguard the right ventricle during sternal incision, they might also remain in position. By elevating it directly upwards, the sternum is isolated utilizing an oscillating saw. Strictly dividing the sternum with heavy-duty blades as opposed to a saw completely reduces the potential for harm to the underlying structures. Preventing pulmonary ventilation is not invariably required, similar to the initial sternotomy. Achieving a precise separation of adhesions between the chest wall and mediastinal tissues requires the use of electrocautery or a scalpel. Retractors may be implanted subsequent to the detachment of the mediastinal structures from the sternum.

PLATELET RICH PLASMA (PRP)

What is PRP?

The patient's blood is used to make Platelet-Rich Plasma (PRP), which is distinguished by a high concentration of platelets—which are essential for wound healing. The preparation involves collecting a sample of blood and subjecting it to centrifugation to concentrate the platelets. [61, 62]

Biological Properties of PRP

PRP is rich in growth factors, such as: [37, 38, 64, 65]

- **Platelet-Derived Growth Factor (PDGF)**: Encourages angiogenesis and cell division
- **Transforming Growth Factor-beta (TGF-β)**: Involved in collagen synthesis and tissue remodeling.

- **Vascular Endothelial Growth Factor (VEGF)**: Encourages new blood vessels to form.

These growth factors improve the body's innate capacity for regeneration and are crucial to the wound-healing process.

Mechanisms of Action

PRP exerts its effects through several mechanisms: [38, 64, 65]

1. **Cell Proliferation**: PRP's growth factors promote the growth of important cells involved in wound healing, such as endothelial and fibroblast cells.
2. **Angiogenesis**: PRP encourages the development of new blood vessels, improving the healing tissue's blood supply.
3. **Collagen Synthesis**: PRP enhances collagen production, providing structural support to the healing tissue.
4. **Anti-Inflammatory Effects**: By modulating the inflammatory response, PRP can help reduce excessive inflammation that may impair healing.

Rationale for Combining PRP with Standard Closure

The rationale for using PRP in conjunction with standard sternal wound closure techniques is to enhance healing and reduce the incidence of complications. By applying PRP to the surgical site, surgeons aim to leverage the bioactive properties of platelets to improve the overall healing process. [38, 59, 60]

Administration of PRP

PRP can be administered in several ways during the surgical procedure: [42, 43, 45, 47]

1. **Direct Application**: PRP can be directly applied to the sternal edges and surrounding tissues before closure.
2. **Infiltration**: The solution may be infiltrated into the soft tissues surrounding the sternum, promoting healing in the muscle and skin layers.
3. **Use of Scaffolds**: PRP can be combined with scaffolding materials that enhance its delivery and prolong its effects at the wound site.

Clinical Evidence: PRP versus Standard Closure Alone

Comparative Studies

Numerous studies have investigated the effectiveness of PRP in sternal wound closure compared to standard techniques alone. These studies generally assess outcomes such as:

- **Infection Rates**: Evaluating whether the addition of PRP leads to reduced sternal wound infections.
- **Wound Healing Time**: Measuring the time taken for wounds to heal completely.
- **Overall Patient Outcomes**: Assessing patient satisfaction, pain levels, and recovery times.

Results from Clinical Trials

Several randomized controlled trials have reported favorable outcomes for the use of PRP in conjunction with standard sternal wound closure. For example, a study found that patients who received PRP had significantly lower rates of sternal wound infections compared to those who underwent standard closure alone. Furthermore, the PRP group's time to full wound healing was noticeably shorter [66-69].

Mechanisms Behind Improved Outcomes

The improved outcomes associated with PRP can be explained by several factors: [61-64]

1. **Enhanced Local Healing**: The concentrated growth factors in PRP promote local healing, facilitating the migration and proliferation of healing cells.
2. **Improved Vascularization**: By stimulating angiogenesis, PRP enhances blood supply to the healing tissue, reducing the risk of ischemia.
3. **Reduced Inflammation**: The anti-inflammatory properties of PRP help to create a favorable healing environment, minimizing chronic inflammation that can impede recovery.

Platelet Rich Plasma with standard sternal wound closure

After a heart surgery, the complication of DSWI is a serious concern. Even with the development of new approaches and improvements in antibiotic treatment, deep sternal wound infection remains a major cause of death and morbidity after heart surgery, leading to longer hospital stays and increased use of medical resources. The incidence of mediastinitis following sternotomy ranges from 0.2% to 8% [65]. There are numerous risk factors that have been found to contribute to DSWI. However, a number of risk factors, such as age, gender, obesity, chronic kidney failure, and chronic lung disease, can be categorized as patient-related. However, other factors, like a prolonged preoperative stay, the length of the surgery, the use of bilateral internal mammary arteries, and resternotomy, are specific to the surgical procedure and the hospital setting. Compared to prior years, the population undergoing cardiac surgery today is typically older and poses a greater risk of deep sternal wound infection. The therapeutic approaches used to treat DSWI have changed over the last few years, and the best course of action has not yet been determined [54]. The mortality rates of patients with DSWI have been considerably reduced by the use of vacuum-assisted closure (VAC) therapy, continuous specific antibiotic irrigation, early surgical debridement, and reconstructive procedures. However, lowering hospital costs and improving patient recovery outcomes can be greatly aided by putting preventive measures into place to reduce the incidence of DSWI. With the goal of accelerating wound healing, platelet-rich plasma (PRP) is proposed as a possible treatment for surgical site infections. Nowadays, autologous PRP is applied topically in a number of surgical specialties, such as orthopedic, maxillofacial, and plastic surgery. According to reports, DSWI that is resistant to traditional surgery has been successfully treated with PRP application. However, the results have generated controversy, and as of right now, there is insufficient proof to conclude that PRP has any effect on DSWI prevention. The purpose of this study was to evaluate, retrospectively, the efficacy of PRP application in the sternotomy wound

after sternal closure in preventing both superficial (SSWI) and deep (DSWI) sternal wound infections following heart surgery [70, 71].

The night before all patients were shaved. A solution of povidone and iodine was used to prepare the surgical site. In accordance with established protocols, the patients were covered. The skin was covered with an adhesive plastic sheet. Every patient had a full median sternotomy, which was followed by an extracorporeal circulation-based cardiac surgery. The skin was cut with a scalpel, and only the pericardium and presternal layers were carefully opened by electrocautery. In coronary cases, electrocautery has been used to take the internal mammary artery as pedicled in situ grafts. Throughout the course of the study, the surgical and cardiopulmonary bypass procedures were the same for every group. To achieve a target activated clotting period longer than 480 seconds, 300 IU/kg of heparin was given. The temperature of the entire system was kept between 32°C and 34°C. The application of antegrade hyperkalemic blood cardioplegia consistently resulted in myocardial protection. Patients were gradually returned to normothermia (37°C) and removed from cardiopulmonary bypass after the cardiac procedure. To fully counteract heparin, protamine was administered at the end of the procedure. The eight stainless steel wires were used to close the sternum. During sternal wires, 20 milliliters of whole blood were drawn from the patient's central line in the operating room and then injected into four tubes. Only one centrifugation spin step and collected the volume immediately above the erythrocyte layer. Blood was collected on sterile tubes having anticoagulant citrate dextrose solution formula. Then it was centrifuged at 460×g for 8 min. The collected PRP was applied to the sternotomy wound. This method can produce a platelet concentration factor of 2.67 higher than the normal value [72]. Two layers of re-absorbable sutures were used to carefully close the pre-sternal space, and intradermal sutures were used to secure the skin in a traditional way [44].

Despite the emergence of minimally invasive methods, median sternotomy remains the favoured approach in cardiac surgery [44]. Nonetheless, DSWI continues to pose a significant risk as a life-threatening complication. The negative pressure within the chest cavities has the potential to draw pathogens from the skin infection sites into the bone, sutures, and vascular and cardiac buildings, which could result in dire consequences. Multiple risk factors, encompassing both patient-related and operation-related aspects, have been recognized in the context of DSWI. Nonetheless, elements associated with the patient's preoperative status and the intricacies of the surgical intervention may not be disregarded [44, 46].

In the last ten years, a lot of efforts have been made to find more effective ways to deal with DSWI and its associated issues. Several studies have produced contradictory results regarding the best course of action for treating DSWI, including surgical debridement, ongoing targeted antibiotic irrigation, flap closure, and modern VAC therapy. Over the past ten years, improvements in reconstructive plastic surgery, medical technologies, and antibiotic treatments have significantly reduced the mortality rates among patients with DSWI [44, 46].

When autologous PRP was first used to treat DSWI, encouraging clinical results were seen. Certain growth factors (GFs) are released by activated platelets during the inflammatory phase of tissue healing. These include transforming development factor-beta, vascular endothelial growth factor, platelet-derived growth factor, and epithelial growth factor. Together with other growth

factors and cytokines, platelet growth factors are essential for bone regeneration, granulation tissue development, cell division, the initial migration of cells to the site of injury, and the formation of new blood vessels [44, 46].

PRP is currently used to improve and speed tissue healing in a variety of surgical specialties, such as orthopedic, maxillofacial, and plastic surgery. Furthermore, Bielecki et al. showed that PRP prevents Escherichia coli and Staphylococcus aureus, the most common bacteria linked to DSWI, from growing in vitro. It was discovered to be ineffective against Klebsiella pneumoniae 20, Enterococcus faecalis, and Pseudomonas aeruginosa. Several authors have proposed using PRP before wound closure in heart surgery, with varying degrees of success [44, 46].

The effect of PRP on clinical outcomes for patients undergoing CABG was investigated by several authors. In terms of pain, bruising, and blood loss, PRP treatment of wounds on the legs and chest seemed to be beneficial. Due to the small number of participants, both studies lacked the power to evaluate any treatment effects, even with their prospective design. On the other hand, Dörge et al. [46] discovered that topical application of autologous PRP did not reduce the incidence of DSWI in high-risk patients undergoing heart surgery. Similarly, 23 studies found that PRP had no beneficial effect on wound healing in patients who had heart surgery. It is possible that the small number of patients who took part in both trials affected the results. Grafts, which can be taken from the patient's own body (such as the internal mammary artery or saphenous vein), are used in CABG surgery to create a bypass around blocked coronary arteries. Restoring the heart muscle's proper blood supply will reduce ischemic symptoms and enhance cardiac function in general. Significant surgical intervention is necessary for the procedure, and the median sternotomy technique enables surgeons to efficiently access the heart [46].

In a median sternotomy, the sternum is divided and a vertical incision is made along the chest's midline. Although this method provides excellent exposure, there are drawbacks, especially with regard to postoperative complications. Because the sternum is an essential structural element of the thoracic cavity, problems may occur if its integrity is compromised during surgery [46].

Limitations and Challenges of PRP

While the use of PRP shows promise, several challenges and limitations need to be addressed: [65-68].

1. **Variability in PRP Preparation**: Differences in preparation techniques can yield varying concentrations of platelets and growth factors, potentially affecting outcomes.
2. **Standardization of Protocols**: The lack of standardized protocols for PRP application may lead to inconsistencies in clinical practice.
3. **Cost Considerations**: The preparation and application of PRP can be associated with additional costs, which may limit its widespread adoption.
4. **Patient Selection**: Identifying the right patient populations that would benefit most from PRP treatment remains a crucial area of research.

Future Directions

As research into PRP continues to evolve, several areas warrant further investigation: [67-69]

1. **Standardization of Protocols**: Establishing standardized guidelines for PRP preparation and application to ensure consistent outcomes across different clinical settings.
2. **Longitudinal Studies**: Conducting long-term studies to assess the durability of the benefits associated with PRP in sternal wound healing.
3. **Mechanistic Studies**: Further investigating the biological mechanisms through which PRP exerts its effects on wound healing, potentially leading to new therapeutic targets.
4. **Combination Therapies**: Exploring the use of PRP in combination with other adjunctive therapies, such as antimicrobial agents or advanced wound dressings, to enhance healing outcomes.

The application of Platelet-Rich Plasma in conjunction with standard sternal wound closure techniques in CABG surgery offers a promising approach to improving patient outcomes. By harnessing the biological properties of PRP, surgeons can enhance healing, reduce the incidence of sternal wound complications, and improve overall recovery. While preliminary studies show encouraging results, ongoing research is essential to standardize protocols, identify ideal patient populations, and fully understand the mechanisms underlying the benefits of PRP. As our knowledge in this field expands, PRP holds the potential to transform the management of sternal wounds in cardiac surgery, ultimately enhancing patient care and outcomes [65-69].

OPERATIONAL DEFINITIONS

Cardiac Surgery:

The term "cardiac surgery" describes operations done on the heart or blood vessels that are connected to it in order to treat disorders and ailments of the cardiovascular system. Repairing or replacing heart valves, removing blocked arteries (coronary artery bypass grafting), fixing congenital heart defects, or treating problems like aneurysms or arrhythmias are some examples of these procedures.

CABG

For patients with severe coronary artery blockages, CABG is usually advised, particularly if multiple vessels are impacted or nonsurgical therapies are not working. The process can lower the risk of heart attacks, enhance heart function, and relieve symptoms like angina (chest pain).

Median Sternotomy

In order to gain access to the heart and lungs, a median sternotomy is a surgical procedure that involves making a vertical incision along the sternum, or breastbone, and then dividing it. This method is frequently employed in procedures like heart transplants, lung transplants, coronary artery bypass grafting (CABG), and corrective surgeries for congenital cardiac defects.

SWI

An infection involving only the skin and subcutaneous tissue at the surgical incision site, without deeper involvement of the sternum or surrounding structures, is referred to as a superficial wound

infection following a median sternotomy. Signs of this condition usually appear within 30 days after surgery and include redness, warmth, swelling, tenderness, or discharge from the wound [73].

DSWI

A serious postoperative complication following a median sternotomy is deep sternal wound infection (DSWI), which affects deeper tissues than the skin and subcutaneous layer, including the sternum, mediastinal tissues, or surrounding muscle structures. In addition to presenting with symptoms like purulent drainage, fever, chest pain, sternal instability, or radiological evidence of deep tissue involvement, it is frequently linked to significant morbidity. Within 30 days of surgery, or up to a year if an implant is involved, DSWI is usually diagnosed [74].

Delayed Healing

A prolonged or impaired wound recovery process that takes longer than anticipated is referred to as delayed healing. This is usually caused by a number of factors, including infection, insufficient blood flow, systemic conditions (like diabetes), or poor nutritional status. It is typified by protracted inflammation, delayed epithelialization, inadequate granulation tissue formation, or an inability to close the wound completely in a reasonable amount of time [75].

Platelet Rich Plasma

A patient's own blood is used to create Platelet-Rich Plasma (PRP), which is a concentration of platelets with higher-than-normal levels of cytokines and growth factors that aid in healing. PRP is made by processing a blood sample to separate the platelets from other blood components, producing plasma with a platelet concentration higher than baseline.

Study outcome

A study comparing two groups according to gender distribution, socioeconomic background, educational attainment, and place of residence assessed the effects of using platelet-rich plasma (PRP) following median sternotomy in coronary artery bypass grafting (CABG) surgery. In particular, the study distinguished between superficial and deep sternal wound infections when analyzing the incidence of wound infections. Rates of delayed wound healing, readmission rates, length of stay in the intensive care unit (ICU), and related medical expenses were among the outcomes pertaining to wound healing that were evaluated. The findings showed that the PRP group had better results, including lower infection rates, faster wound healing, fewer readmissions, shorter intensive care unit stays, and overall lower expenses. According to these results, PRP might be a useful supplement in the management of postoperative care for CABG patients, especially in reducing resource usage and complications.

HYPOTHESIS

Administration of platelet rich plasma during sternal wound closure reduces the frequency of complications in the 30-day post-surgery period.

MATERIALS AND METHODS

Study setting:
The Department of Cardiac Surgery, Cardiac Center, PIMS, Islamabad.

Duration of study:
Six months after acceptance of synopsis.

Study design:
Randomized Controlled trial

Study Population
Consenting patients going through CABG surgery with median sternotomy.

Sample size:
The sample size has been calculated by using WHO size calculator with the statistical assumptions as following:

- Level of significance = 5%
- Power of test = 80%
- Population standard deviation = 1.3
- Anticipated population, reduction in wound diameter in topical insulin group, P1=7.15mm
- Anticipated population, reduction in wound diameter in control group, P2= 7.89 mm

Sample size comes out to be 49 cases in each study group and a total of 98 patients were included in the study.

Sampling Technique:
Non-probability Consecutive sampling

SAMPLE SELECTION

Inclusion criteria

1. Consenting patients undergoing median sternotomy for heart surgery who are between the ages of 45 and 72.

Exclusion criteria

1. Known diabetics
2. Patients who are not candidates for blood bank donations
3. Platelet rich plasma cannot be obtained
4. CPB time is more than 72.5 minutes.
5. Bilateral internal mammary artery harvested
6. BMI less than 18.5 and more than 24.9
7. Active smokers
8. Chronic lung disease
9. Osteoporosis
10. Steroid therapy

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DATA COLLECTION PROCEDURE

In order to determine whether Platelet-Rich Plasma (PRP) can lessen sternal wound complications in patients having coronary artery bypass grafting (CABG) with median sternotomy, this study was carried out as a randomized controlled trial. After the research synopsis was approved, the study was conducted for six months in the Department of Cardiac Surgery at the Cardiac Center of the Pakistan Institute of Medical Sciences (PIMS), Islamabad.

Ethical considerations were carefully addressed throughout the study. Only patients who voluntarily consented to participate were included. Informed consent was obtained, assuring patients of confidentiality and emphasizing that their participation would not compromise the standard of care they received. Standard medical care protocols were strictly followed, ensuring that the study did not interfere with the quality of treatment provided to the participants.

Specific inclusion and exclusion criteria were used in the recruitment of study participants. Patients between the ages of 45 and 72 who were scheduled for on-pump CABG or other cardiac procedures involving a median sternotomy were eligible. All participants provided written informed consent. Individuals with a body mass index (BMI) outside of the range of 18.5 to 24.9, bilateral internal mammary artery harvesting, steroid therapy, known diabetes, active smoking, or conditions like osteoporosis or chronic lung disease were not included in the study. Additionally excluded were patients for whom PRP could not be obtained or those whose cardiopulmonary bypass (CPB) time exceeded 72.5 minutes.

The WHO sample size calculator was used to determine the sample size, with 80% power and a 5% significance level as the parameters. The anticipated difference in oedema and infiltration rates between the PRP and control groups determined that 49 patients would be required in each group, yielding a total sample size of 98 patients. Non-probability consecutive sampling was used to recruit participants.

Following approval from the hospital's Advanced Research and ethics committees, data collection got underway. Random assignment was used to place participants in the PRP or control groups. All patients received antibiotic prophylaxis before the surgical incision, adhering to a standardized protocol for preoperative antibiotics and glycemic control, which remained consistent throughout the study. General anesthesia was administered to ensure patients remained asleep and pain-free during surgery. A midline sternotomy was performed using a sternal saw, and bleeding sites were carefully managed before proceeding with pericardiectomy. The heart was exposed, cannulation was performed, and patients were connected to a heart-lung bypass machine to facilitate the surgical procedure.

All patients received an initial dose of 300 IU/kg of unfractionated heparin as part of the surgical protocol, which complied with local guidelines, in order to maintain an activated clotting time (ACT) of at least 480 seconds during the procedure. Patients undergoing CABG surgery were included. Bone wax was avoided to prevent the formation of barriers that could interfere with PRP-facilitated healing. By aiming for a flow rate of 2.6 L/min/m2, the cardiopulmonary bypass achieved venous oxygen saturation in the range of 70% to 80%. After the surgical procedure, heparin was reversed using protamine, and meticulous hemostasis was achieved by identifying and securing bleeding points.

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Patients in the control group had a midline sternotomy closed with figure-of-eight or simple interrupted stainless-steel wires, and absorbable sutures were used to close the wounds in layers. Paper tape, gauze, and Steri-Strips were used as dressings. In addition to the usual closure technique, 6 mL of autologous PRP was made and applied to the sternum and soft tissues during sternal closure in the PRP group.

Primary outcomes were measured as the frequency of sternal wound complications, which included delayed healing, superficial infections, deep sternal wound infections (DSWI), and the rate of readmissions due to complications like mediastinitis within 30 days post-surgery. Secondary outcome assessed the overall cost burden during the 30-day postoperative period. Other outcomes will be ICU stay (days), blood transfusions more than 4 units and platelets transfusions more than 6 units. Data collection was meticulously carried out using a predesigned form by the principal investigator, ensuring compliance with the study protocol.

Data Analysis Procedure

SPSS version 23 was used to enter and analyze the data. Frequency distributions were used to measure qualitative data such as sex, residence, education, socioeconomic status, delayed wound healing, readmission, transfusion requirements and SWI & DSWI. The means and standard deviations of the quantitative variables, such as cost, ICU stay and age, were calculated. The incidence of delayed healing, readmissions, transfusion requirements, DSWI, and SWI will be compared between the two groups using the chi square test. ICU stay and cost parameters were compared using T-test. A p-value of less than 0.05 was deemed statistically significant for all statistical tests.

RESULTS:

Our results indicate that the mean age of participants in Group A (standard sternal wound closure) was 58.88 ± 8.31 years, while in Group B (PRP with standard closure) it was 58.02 ± 8.72 years. The mean BMI for Group A was 21.57 ± 1.42 kg/m², and for Group B, it was 21.54 ± 1.38 kg/m². In Group A, there were 32 men (65.3%) and 17 women (34.7%), while in Group B, there were 27 men (55.1%) and 22 women (44.9%). Socioeconomic backgrounds were similar across groups, with Group A having 23 participants (46.9%) from a low socioeconomic background and Group B having 25 (51.0%). In terms of education, Group A had 22 educated (44.9%) and 27 uneducated (55.1%), while Group B had 26 educated (53.1%) and 23 uneducated (46.9%). A significant reduction in wound complications was observed with the use of PRP. Superficial wound infection was significantly lower in Group B, with 2 cases (4.1%) compared to 5 cases (16.3%) in Group A (p=0.04). Deep sternal wound infection was also significantly reduced, with no DSWI in Group B compared to 4 (8.2%) in Group A (p=0.02). Delayed healing was observed in 21 (42.9%) of Group A and 10 (20.4%) of Group B, showing a significant improvement with PRP (p=0.01). With 3 cases (6.1%) compared to 11 (22.4%) in Group A, readmission rates were substantially lower in Group B (p=0.02). Blood transfusions (> 4 units) and platelet transfusions (> 6 units) did not significantly differ between the groups (p=0.69 and p=0.64, respectively). Group B's mean ICU stay was 2.90 ± 1.02 days, which was significantly shorter than Group A's 3.63 ±

1.08 days (p=0.001). Costs for additional medications, antibiotics, labs, and wound care were significantly lower in Group B, indicating a cost-effective advantage with PRP application (p<0.0001 for all cost-related comparisons).

Table 1 Descriptive statistics

Groups		Age (Years)	BMI (Kg/m2)
Group A (Standard sternal wound closure)	Mean	58.88	21.5724
	N	49	49
	Std. Deviation	8.313	1.41642
Group B (PRP with standard sternal wound closure)	Mean	58.02	21.5418
	N	49	49
	Std. Deviation	8.724	1.37980

Table 2 Gender distribution

		Gender		Total
		Male	Female	
Groups	Group A (Standard sternal wound closure)	32	17	49
		65.3%	34.7%	100.0%
	Group B (PRP with standard sternal wound closure)	27	22	49
		55.1%	44.9%	100.0%
Total		59	39	98
		60.2%	39.8%	100.0%

Table 3 Socioeconomic background

		Socioeconomic background		Total
		Low	Middle	
Groups	Group A (Standard sternal wound closure)	23	26	49
		46.9%	53.1%	100.0%
	Group B (PRP with standard sternal wound closure)	25	24	49
		51.0%	49.0%	100.0%
Total		48	50	98
		49.0%	51.0%	100.0%

Table 4 Education status

		Education status		Total
		Educated	Uneducated	
Groups	Group A (Standard sternal wound closure)	22	27	49
		44.9%	55.1%	100.0%

	Group B (PRP with standard sternal wound closure)	26	23	49
		53.1%	46.9%	100.0%
Total		48	50	98
		49.0%	51.0%	100.0%

Table 5 Residence

		Residence		Total
		Urban	Rural	
Groups	Group A (Standard sternal wound closure)	30	19	49
		61.2%	38.8%	100.0%
	Group B (PRP with standard sternal wound closure)	23	26	49
		46.9%	53.1%	100.0%
Total		53	45	98
		54.1%	45.9%	100.0%

Table 6 Comparison of superficial wound infection between both groups

		Superficial Wound Infection		Total	P value
		Yes	No		
Groups	Group A (Standard sternal wound closure)	8	41	49	0.04
		16.3%	83.7%	100.0%	
	Group B (PRP with standard sternal wound closure)	2	47	49	
		4.1%	95.9%	100.0%	
Total		10	88	98	
		10.2%	89.8%	100.0%	

Table 7 Comparison of deep sternal wound infection between both groups

		Deep Sternal Wound Infection		Total	P value
		Yes	No		
Groups	Group A (Standard sternal wound closure)	4	45	49	0.04
		8.2%	91.8%	100.0%	
	Group B (PRP with standard sternal wound closure)	0	49	49	
		0.0%	100.0%	100.0%	

Total	4	94	98	
	4.1%	95.9%	100.0%	

Table 8 Comparison of delayed healing between both groups

		Delayed Healing		Total	P value
		Yes	No		
Groups	Group A (Standard sternal wound closure)	21	28	49	0.01
		42.9%	57.1%	100.0%	
	Group B (PRP with standard sternal wound closure)	10	39	49	
		20.4%	79.6%	100.0%	
Total		31	67	98	
		31.6%	68.4%	100.0%	

Table 9 Comparison of readmission between both groups

		Readmission		Total	P value
		Yes	No		
Groups	Group A (Standard sternal wound closure)	11	38	49	0.02
		22.4%	77.6%	100.0%	
	Group B (PRP with standard sternal wound closure)	3	46	49	
		6.1%	93.9%	100.0%	
Total		14	84	98	
		14.3%	85.7%	100.0%	

Table 10 Comparison of blood transfusion (> 4 units) between both groups

		Blood Transfusion (> 4 units)		Total	P value
		Yes	No		
Groups	Group A (Standard sternal wound closure)	4	45	49	
		8.2%	91.8%	100.0%	0.69
	Group B (PRP with standard sternal wound closure)	3	46	49	
		6.1%	93.9%	100.0%	
Total		7	91	98	
		7.1%	92.9%	100.0%	

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Table 11 Comparison of platelet transfusion (> 6 units) between both groups

		Platelet Transfusion (> 6 units)		Total	P value
		Yes	No		
Groups	Group A (Standard sternal wound closure)	3	46	49	0.64
		6.1%	93.9%	100.0%	
	Group B (PRP with standard sternal wound closure)	2	47	49	
		4.1%	95.9%	100.0%	
Total		5	93	98	
		5.1%	94.9%	100.0%	

Table 12 Comparison of ICU stay and cost parameters between both groups

	Groups	N	Mean	Std. Deviation	P value
ICU Stay (days)	Group A (Standard sternal wound closure)	49	3.63	1.08	0.001
	Group B (PRP with standard sternal wound closure)	49	2.90	1.01	
Cost of Additional Medications (PKR)	Group A (Standard sternal wound closure)	49	298.98	269.701	0.006
	Group B (PRP with standard sternal wound closure)	49	171.43	169.251	
Cost of additional antibiotics (PKR)	Group A (Standard sternal wound closure)	49	1052.04	679.917	0.07
	Group B (PRP with standard sternal wound closure)	49	848.98	381.812	
Cost of additional labs (PKR)	Group A (Standard sternal wound closure)	49	183.67	189.073	0.0001
	Group B (PRP with standard sternal wound closure)	49	64.29	31.950	
Cost of additional surgical procedure (PKR)	Group A (Standard sternal wound closure)	49	520.41	769.234	0.02
	Group B (PRP with standard sternal wound closure)	49	241.84	391.624	

Cost of wound care (PKR)	Group A (Standard sternal wound closure)	49	444.90	551.215	0.01
	Group B (PRP with standard sternal wound closure)	49	234.69	104.585	

DISCUSSION:

Our research on the use of Platelet-Rich Plasma (PRP) to lessen sternal wound complications after median sternotomy and coronary artery bypass grafting (CABG) surgery is in good agreement with a number of previous studies on the subject. Although the magnitude of the benefits varies, these studies consistently show the potential benefits of PRP in reducing infections and delayed healing, two issues related to sternal wounds.

The results of our study showed that, in comparison to the control group, the category treated with PRP experienced a significant reduction in both superficial and deep sternal wound infections. The results of a number of other studies are consistent with this. For example, Patel AN et al. found that the application of PRP reduced the incidence of superficial sternal wound infection (SSWI) from 8.0% to 2.0% and deep sternal wound infection (DSWI) from 2.0% to 0.6% in a large-scale evaluation involving 2000 patients. These results support PRP's potential in cardiac surgery settings by demonstrating its efficacy in lowering the incidence of infections and confirming our finding that PRP significantly reduced the incidence of infections and complications [76].

A similar reduction in sternal wound complications was seen in a meta-analysis by Li Y et al., which included five randomized controlled trials (RCTs). This study demonstrated that PRP reduced the rate of drainage post-operation, highlighting its role in promoting quicker healing and reducing infection risks, although it noted no significant impact on overall surgical site infections (SSI). In our study, PRP significantly reduced delayed healing and readmission rates, suggesting an improvement in postoperative recovery. However, while Li et al. noted benefits regarding postoperative drainage, the lack of statistically significant differences in overall SSI contrasts slightly with our findings, which showed clear advantages in infection reduction [77].

Furthermore, Serraino GF et al. conducted a study focusing on the application of PRP within sternotomy wounds, reporting a reduction in both DSWI and SSWI. In a comparison of the PRP category to the standard category, the infection rates dropped significantly in the former category where DSWI decreased from 1.5% to 0.2% and SSWI from 2.8% to 0.5%. This pattern resonates closely with our study, where the application of PRP led to marked reductions in both superficial and deep infections. This consistency across studies reinforces the robustness of PRP's effectiveness in reducing sternal wound complications following cardiac surgery [78].

On the other hand, another literature evaluated the antibacterial properties of PRP and its clinical applications in preventing deep sternal wound infections. The review highlighted that while there is promising evidence supporting PRP's efficacy in wound healing and infection prevention, the quality of clinical trials remains varied. They emphasized the need for more robust and adequately powered studies to confirm these benefits fully. Our study adds to this body of evidence by

demonstrating statistically significant improvements in infection rates and recovery times, suggesting that PRP is indeed a beneficial addition to standard sternal wound care [79].

One notable aspect of our study is the detailed analysis of ICU stay and cost-effectiveness, where PRP demonstrated a clear advantage. The reduction in ICU stays and associated costs aligns with findings from Patel AN et al., who also observed significant cost reductions due to fewer complications and readmissions in the PRP group [76]. The economic implications of reduced hospital stay and fewer medical interventions are substantial, indicating that the benefits of PRP extend beyond clinical outcomes to financial advantages as well.

Contrarily, not all studies have consistently shown PRP to be unequivocally beneficial. The meta-analysis by Li Y et al. pointed out that while PRP effectively reduces postoperative drainage, its impact on overall infection rates did not reach statistical significance [77]. Similarly, the review by Sethi D et al. calls for caution, citing the need for more high-quality RCTs before definitively endorsing PRP as a standard treatment for sternal wound infections [79]. These contrasting viewpoints highlight the complexity of evaluating PRP's efficacy and it requires more targeted investigation to specifically delineate its advantages clearly.

In another study, the effects of PRP on sternal wound healing were evaluated. This study noted significant reductions in both superficial and deep wound infections among patients treated with PRP, consistent with our findings [80]. Additionally, the application of PRP was associated with decreased postoperative pain, suggesting that it contributes not only to infection control but also to improved overall patient comfort during recovery. This multi-faceted benefit of PRP in enhancing patient recovery and comfort is a recurring theme across studies, indicating a broader role in postoperative care beyond infection control.

The effectiveness of PRP in promoting healing is attributed to its rich concentration of growth factors and cytokines, which facilitate tissue repair and modulate inflammation. Sethi D et al. discuss the biological mechanisms underlying PRP's benefits, including its antibacterial properties and role in immune modulation, which likely contribute to the observed reductions in infections and quicker healing [79]. This mechanistic insight aligns with the outcomes of our study, where PRP's application led to significant clinical improvements.

While some studies, such as those by Li Y et al., highlight potential limitations and call for further research, the overall evidence supports PRP as a beneficial adjunct in cardiac surgery, particularly for reducing infections, accelerating healing, and lowering healthcare costs [77]. These findings underscore the need for continued research to optimize PRP's use and confirm its benefits across diverse patient populations and clinical settings.

CONCLUSION:

In conclusion, our study provides compelling evidence that the deep (DSWI) and superficial (SWI) sternal wounds can be significantly reduced by applying platelet rich plasma (PRP) in patients who underwent median sternotomy as part of CABG surgery. The data demonstrated a clear reduction in DSWI and SWI rates in cases where PRP had been used, in comparison, to the control category. This aligns with the broader literature, which underscores PRP's efficacy in promoting wound healing and minimizing postoperative complications. The positive impact of PRP extends

to delay healing, with our study showing that the pace of wound healing markedly increases in the PRP category. Hence delayed wound healed was reduced in the PRP group. These findings emphasize the potential of PRP to enhance recovery and reduce the burden of sternal wound complications in cardiac surgery.

LIMITATIONS AND RECOMMENDATIONS:

Despite these promising results, there are still many shortcomings. Due to the reason that this review was done in only one center, it resulted in restricted generality of the results. This may mean that these results may not be true for other settings and populations. The sample size, while sufficient for demonstrating statistically significant differences, may not fully capture the variability across different demographic and clinical subgroups. Additionally, the non-randomized design of the study introduces the potential for selection bias, which could influence the outcomes despite efforts to control for confounding factors. The study also relied on a relatively short follow-up period, which may not fully account for late-onset infections or long-term complications associated with sternal wounds.

Future research should focus on a broader community of patients in multiple institutes taking randomized impact evaluations to avoid confining the scope of outcomes. Increasing the time period of following patient record in order to not miss even a single complication (if arises) other than the ones already mentioned. Furthermore, investigations into the optimal preparation, dosage, and timing of PRP application are warranted to establish standardized protocols for its use in cardiac surgery. Additional studies exploring the specific biological mechanisms by which PRP influences wound healing and infection control could provide deeper insights into its benefits and help refine its clinical application. Lastly, a cost-benefit analysis incorporating broader economic factors, such as reduced hospital stays and fewer re-admissions, would be valuable to fully understand the economic impact of incorporating PRP into routine clinical practice.

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