INNOVATIONS OF INTERNAL MAMMARY ARTERY HARVEST

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ABSTRACT

The effects of internal mammary artery (IMA) harvest by harmonic scalpel under conventional open, thorascopic, and robotic coronary artery bypass have not been sufficiently evaluated. The study materials were based on literature retrieval of pertinent articles published between 1998 and 2018. In total 20 articles describing IMA harvest for 2,661 patients was accomplished by the harmonic scalpel in open, video-assisted or robotic CABG procedures (termed as the innovative group), while IMA harvest by electrocautery and (or) argon beam coagulator were taken as the control group. It revealed that IMA harvest by harmonic scalpel was associated with less thermal injury with potentially better preservation of the endothelial cells, satisfactory intraoperative IMA flow, and promising postoperative IMA patency. Apart from the harvest-related merits, the innovative techniques had other advantages in terms of clinical outcomes, such as lower postoperative mortality and complications. Nevertheless, concerning the disadvantages of thorascopic and robotic IMA harvesting, such as longer harvest time, prolonged operative time, and increased hospitalization expenses, they could be used in selected and non-emergent pateints with coronary artery disease.

Keywords: *Coronary artery bypass grafting, internal mammary artery, surgical instruments, robotics, video-assisted surgery.*

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Introduction

The internal mammary artery (IMA) is a preferred conduit for coronary artery bypass grafting (CABG) due to its better long-term patency for both single and multiple anastomoses than other alternative arterial or venous grafts[1]. In 1981, Björk et al.[2] reported that the early and late IMA graft patency rates were 95% and 91%, respectively. They found, at late follow-up, 16 grafts were occluded, due to technical problems (6/16, 37.5%), inadequate graft size (5/16, 31.3%), extensive disease of the recipient coronary artery (4/16, 25%), and overestimated proximal coronary obstruction (1/16, 6.3%). Huddleston et al.[3] stated the determinants for long-term IMA graft patency could be the choice of the conduit (left vs. right IMA), the choice of the coronary artery recipient (left anterior descending coronary artery vs. other coronary arteries), and post-bypass blood flow >35 mL/min. However, they concluded that the harvest technique did not influence the long-term patency of IMA grafts. It is well-known that the long-term patency of the IMA in CABG is superior to that of other grafts. Similarly, clinical observations revealed that the long-term patency of the left IMA is superior to that of the right IMA[4], and that of the in situ to the free IMA[5]. It has been recognized that the endothelial function is a standard of successful vascular grafts[6]. Accordingly, semiskeletonization[7] and skeletonization of the IMAs[8] have been advocated in order to preserve the endothelial function of the IMAs, and these were eventually proved to be the effective and safe harvesting techniques. Most recently, the PEAK PlasmaBlade, a monopolar electrosurgical device powered by pulsed radiofrequency energy was used for IMA harvest, and the histological results demonstrated significantly less endothelial damage of IMAs[9]. The harmonic scalpel is a surgical instrument used to simultaneously cut and cauterize tissues, which ensures advanced hemostasis, stronger larger vessel sealing, and less tissue damage[10].

The harmonic Scalpel was firstly applied for IMA harvest in CABG in as early as 1994[11]. Subsequently, thoracoscopic ultrasonic scalpel technique was taken into use for minimally invasive coronary artery bypass. A new modification with an angled shaft allows the mobility of the instrument in the narrow space of the surgical field[11]. In recently years, robotic CABG was invented as a safe and feasible method for the treatment of coronary artery disease in highly selected patients, and compatible long-term outcomes have been achieved in comparison to conventional CABG[12, 13].

However, the effects of IMA harvest by harmonic scalpel under conventional open, thorascopic, and robotic CABG have not been sufficiently evaluated. This article aims to assess the harmonic scalpel IMA harvest under these conditions and to compare the advantages and disadvantages of these innovative techniques.

Methods

The Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) statement guidelines were followed in this meta-analysis. Publications were systematically searched in the PubMed, Highwire Press, and the Cochrane Library databases from January 1998 to December 2018. The MeSH terms and keywords used to identify articles included “internal mammary artery”, “Harmonic scalpel”, “harvest technique”, “coronary artery bypass grafting”, “off-pump coronary artery bypass”, “minimally invasive direct coronary artery bypass”, “thoracoscopic”, “video-assisted thoracoscopic”, “da Vinci robot”, and “robot-assisted cardiac surgery using the da Vinci surgical system”. The screening of the bibliographic references helped in completing the literature retrieval. Sixty articles were found related to the topic and keywords in the literature search; and 20 articles, which met the inclusion and exclusion criteria during preliminary assessment, were included in this review. The exclusion criteria were: electrocautery as a harvest device (n=18), lack of patient information (n=7), radial artery harvest (n=4), animal experiment (n=3), irrelevant to graft vessel harvest (n=3), pleural integrity during IMA harvest (n=2), application papaverine for IMA harvest (n=2), and harvest complications (n=1).

The data independently extracted from each study were the study population, demographics, surgical procedures, apparatus for IMA harvest, harvest time, intraoperative IMA graft flow, injury to IMAs, IMA patency rate, and patients’ outcomes.

The measurement data were expressed in mean±standard deviation with range and median values and were compared by independent sample t-test. The categorical variables were compared by Fisher exact test. $P<0.05$ was considered statistically significant.

Results

In total 20 articles[11, 14-32] were recruited into this study, with 19 original articles[11, 14-27, 29-32] and 1 case report[28]. The 20 studies included 2,661 patients, in whom IMA harvest was accomplished by the innovative techniques (Table 1). The gender of 478 (18.0%) patients was unspecified. Of the remaining 2,183 (82.0%) patients, 1,662 (76.1%) were male and 521 (23.9%) were female patients. The CABG techniques performed in these patients were mostly conventional CABG procedures (Table 2).

In 6 (30%) studies, one or two control groups were set-up with 514 patients (478 patients received CABG and 36 received off-pump coronary artery bypass). An electrocautery IMA harvest was as a control in all 6 studies[16, 21-23, 25, 26] and an argon beam coagulator IMA harvest as a control in one of them[16]. The control groups had 382 patients with 269 (70.4%) male and 113 (29.6%) female patients. There was no difference in patient age between the innovative and the control groups (61.7±6.5 vs. 64.0±3.0, $p=0.273$). In 8 reports[11, 14, 17, 22, 25, 26, 30, 32], the number of IMAs was reported. As a result, a total of 2,888 IMAs were harvested in 2,055 patients with a mean of 1.4 IMAs per patient. In 4 (50%) of these reports[11, 17, 22, 30], the sides of 2,409 harvested IMAs were reported for 2,327 patients: 1,522 (63.2%) left IMAs and 887 (36.8%) right IMAs ($\chi^2=334.77$, $P<0.001$). The harvest time was 40.2±23.4 (range, 8-112; median, 32) min (n=29) for patients in whom IMA was harvested by the innovative techniques. Time of IMA harvest by the harmonic scalpel was much shorter than by the thoracoscopic or robotic approaches but longer than the controls; however, no significant difference was noted between harvest times by the thoracoscopic and by the robotic technique (Figure 1).

Harvest technique	Study, n (%)	Patient, n (%)
Harmonic scalpel[14, 16, 17, 19, 22, 23, 26, 27]	8 (40)	1893 (71.1)
Thoracoscopic + harmonic scalpel[11, 15, 24, 25, 31, 32]	6 (30)	242 (9.1)
Robotic (+ EndoWrist spatula cautery)[18, 20, 28-30]	5 (25)	409 (15.4)
Robotic [automated endoscopic system for optimal positioning (AESOP)] + harmonic scalpel[21]	1 (5)	50 (1.9)
Robotic (Zeus robotic telesurgical system + harmonic scalpel)[21, 31]	2 (10)	67 (2.5)
Total	20 (100)*	2661 (100)

Table 1: Harvest technique of the Study Groups.
**In 2 studies, 2 harvest techniques were used.*

Coronary artery bypass technique	Study, n (%)	Patient, n (%)
Coronary artery bypass grafting[14, 16, 17, 19, 22, 23, 25, 26, 27, 28, 31]	11 (55)	1604 (60.3)
Off-pump coronary artery bypass[17, 20, 22]	3 (15)	439 (16.5)
Minimally invasive direct coronary artery bypass[18, 20, 24, 32]	4 (20)	160 (6.0)
Robot[15, 29]	2 (10)	27 (1.0)
Automated endoscopic system for optimal positioning (AESOP)[21, 30]	2 (10)	358 (13.5)
Zeus[21]	1 (5)	50 (1.9)
Unspecified[11]	1 (5)	23 (0.9)

Table 2: Coronary artery bypass techniques of the study groups.

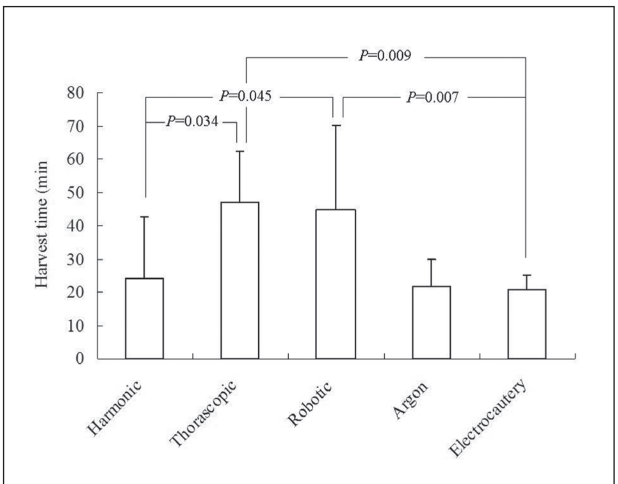

Figure 1: Time of internal mammary artery harvest by harmonic scalpel was much shorter than by thoracoscopic or robotic approaches but longer than the controls; however, no significant difference was noted between harvest times by thoracoscopic and by robotic technique.

Hemostatic clip use was reported in 4 reports on IMA harvest by the harmonic scalpel[14, 16, 19, 22]. The number of the hemostatic clips was 1.9±1.2 (range, 0-5.5; median, 1.4) per patient. In 6 (30%) reports[11, 14, 15, 19, 20, 25], postoperative IMA graft patency was detected angiographically for 636 grafts with a patency rate of 97.6%-100%. The average patency rate of the IMAs, the left IMAs and the right IMAs were 99.7% (634/636), 99.6% (284/285), and 100% (129/129), respectively. The intraoperative IMA flow detected by echocardiography was much higher in the Innovation Group than in the control but lack of significant difference (Figure 2).

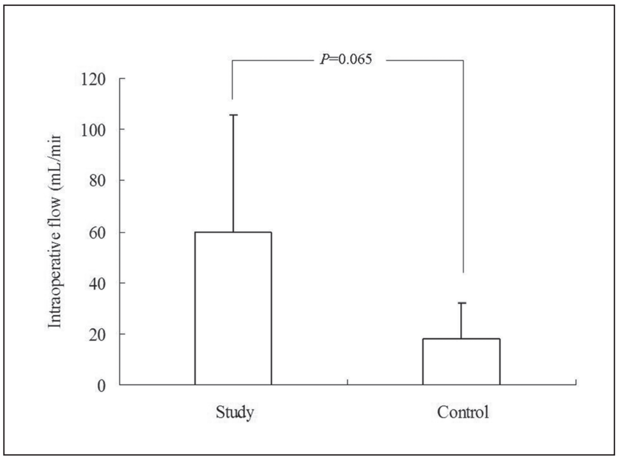

Figure 2: The intraoperative internal mammary artery flow detected by echocardiography was much higher in the Innovation Groups than in the control but lack of significant difference.

There were 12 patients in the Innovation Group who had to convert to sternotomy to complete IMA harvest. The prevalence of other postoperative adverse events including IMA injury, reoperation for bleeding, reoperation for failed grafts, deep sternal infection, sternal dehiscence, perioperative myocardial infarction, left phrenic palsy, acute renal failure, and mortality did not differ from that of the Control Groups (Table 3).

Discussion

Electrocautery is commonly applied in IMA harvest, while several improvements have been made for the apparatus of IMA harvest aiming at enhancing the graft patency, the most important of which is the harmonic scalpel. Brose et al.[16] found the three devices they used for IMA harvest (harmonic scalpel, argon beam coagulator, and electrocautery) did not bring about the endothelial cell loss of the IMAs. In spite of a few of pathological changes, such as parietal thrombus, periadventital bleeding, ruptured intima and arterial wall edema, occurred, no intergroup difference was noted. Moreover, among the three groups, only was a case of intramural bleeding found in the argon group.

Adverse event	Study (n=2661)	Control (n=514)	χ^2	P value
Conversion to sternotomy to complete IMA harvest	12 (0.5)[31]	--	--	--
IMA injury	10 (0.4)[21, 22]	1 (0.2)[22]	0.41	1.000
Reoperation for bleeding	77 (2.9)[14, 17, 22, 26]	10 (1.9)[26, 22]	1.45	0.300
Reoperation for failed grafts	7 (0.3)[22]	0 (0)	1.36	0.607
Deep sternal infection	20 (0.8)[22, 26]	7 (1.4)[22, 26]	1.90	0.186
Sternal dehiscence	1 (0.04)[27]	1 (0.2)[27]	1.69	0.298
Perioperative myocardial infarction	18 (0.7)[19, 22]	2 (0.4)[22]	0.57	0.759
Left phrenic palsy	1 (0.04)[32]	0 (0)	0.19	1.000
Acute renal failure	1 (0.04)[14]	0 (0)	0.19	1.000
Mortality	12 (0.5)[17, 19, 26]	2 (0.4)[26]	0.04	1.000

Table 3: A comparison of adverse events between the study and control group patients, n (%).
IMA: internal mammary artery.

Thoracoscopic IMA harvesting allows a complete dissection of either the left or right IMA from the first rib to the sixth intercostal space under clear magnified views that are even superior to those of the open approach. Dissection of the IMA inferior to the proposed thoracotomy site is also considerably easier with thoracoscopic techniques than with presently available thoracotomy retractors designed to directly expose the IMA[15].

Robotic systems have facilitated the endoscopic coronary surgery[24]. Robotic video assistance has improved the IMA harvest especially for the patients requiring bilateral IMA harvest. It improves the visualization of the IMAs and ensures a more precise dissection by providing a tremor-free image. Robotic video-assisted IMA harvest should become faster with time after the learning curve. The surgical robot aids IMA harvesting, and the automated endoscopic system for optimal positioning (AESOP) can position a thoracoscope under the verbal commands of the surgeon. The AESOP approximates the form and function of a human arm and provides the surgeon with direct control of the thoracoscope[15]. The use of the Zeus robotic arms has facilitated complete robotic harvesting of the IMA[24]. By video-assisted thoracoscopy, quality of IMA harvest could be equal to that by the open mini-thoracotomy approach, and the IMA harvest was with minimal trauma[24]. This method can be applied safely for bilateral IMA harvest without the need of changing the position of the robot arm, therefore reducing the risk of infection due to maneuver of the nonsterile part of the robot arm[28]. The IMA harvest time by harmonic scalpel under direct vision was ususally longer than by conventional electrocautery[16], but much shorter than by thoracoscopic IMA harvest with a harmonic scalpel[15]. As reported by Brose et al.[16], the IMA harvest time by harmonic scalpel was longer than by argon beam coagulator and by electrocautery (Figure 3). On the contrary, Balcı et al.[14] reported an opposite result that they took shorter time for IMA harvest by using a harmonic scalpel[14].

Some authors reported IMA injury during the maneuver of IMA harvest[21], while others depicted that no thermic damage of the IMA by the harmonic scalpel was observed[25, 26]. Meanwhile, less hemostatic clips were needed during IMA harvest by the harmonic scalpel (Figure 4)[16].

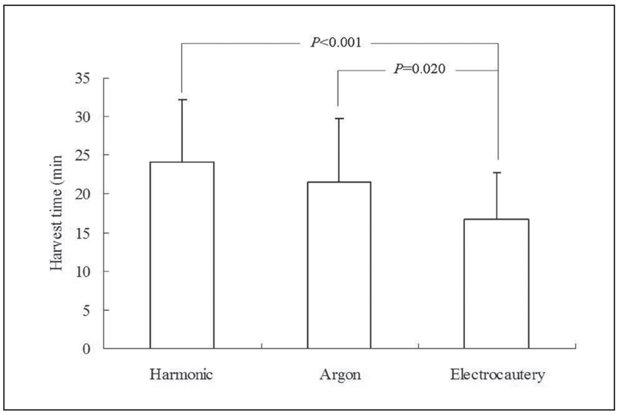

Figure 3: Internal mammary artery harvest time was longer than by argon beam coagulator and by electrocautery as reported by Brose et al.[16].

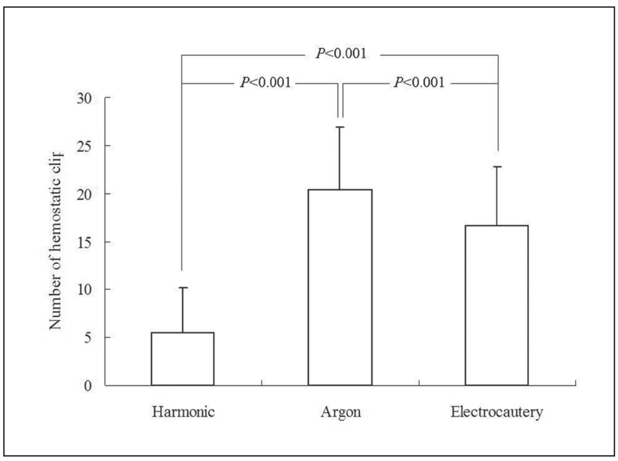

Figure 4: Less hemostatic clips were needed for internal mammary artery harvest by harmonic scalpel[16].

Innovation	Advantage	Disadvantage	Compatibility
Harmonic scalpel	• Minimal smoke[24, 25, 32] • Less thermal injury[11, 14, 19, 24, 25, 26, 32] No muscle stimulation[11, 24] • Less common spasm associated with ima harvesting[19] • Shorter time for harvesting[14] • Less hemostatic clip[14, 16, 22] • No endothelial damage[14, 23] • Increased availability of bilateral IMAs[19] • Less instrument transfer as compared to clipping[24] • Facilitating division of the transversus thoracis muscles[11] • Dissection of the tissue, coagulation & division of the vessels can be accomplished using only the harmonic scalpel[25] • Each branch was well sealed[25] • Less bleeding[14] • No/decreased incidence of sternal wound infection[17, 19, 27] • No mediastinitis[27] • Left phrenic palsy did not occur[25]	• Prolonged harvest time[16]	• No histological difference[16] • No sig diff bleeding points in comparison to control[16] • No difference in reoperation for bleeding, early reoperation for failed grafts, deep sternal infection, and perioperative infarction[22] • Wound infection[26] • Sternal dehiscence was observed in one patient in each group[27] • Left and right sternal perfusion was found to be similar on the postoperative test[27]
Thoracoscopic	• No conversions to a standard approach[15, 24] • No reoperations for bleeding[15] • Complete dissection of IMA from its origin to sixth intercostal space[24] • Avoids possibility of insufficient length or kinking of IMA[24] • Avoids forceful coastal retraction[24] • Excellent views of the ima and its anatomic relation with adjacent structures and it allows dissection of the pedicle with sufficient length for anastomosis[11, 24]	• Requirement of training and experience in endoscopic surgery and instruments[24] • Technique contraindicated in patients unable to support single-lung ventilation (e.g., low pulmonary reserve)[24] • Obesity, superior mediastinal masses, cardiomegaly, or extremely narrow intercostal space may cause difficult harvesting[24]	
Robotic	• Cosmetic advantage[20] • A minor injury to the distal left IMA[21] • No hemorrhage[21] • A more precise dissection[28] • Providing a tremor-free image[28] • Reduced need for lens cleaning[28] • Reduced operating time[28] • No intraoperative conversion[18] • Minimized postoperative wound pain[20] • Shorter length of stay in-hospital[21] • No procedural mortality[18] • No wound infection[18, 21]	• Requirement of greater opening of the left pleural cavity, which may cause pleural adhesions[20] • Longer harvest time[21] • An increased cost[20] • 12 (12%) conversion to sternotomy to complete the IMA harvest[31]	

Table 4: Advantages, disadvantage s and compatibilities of innovated internal mammary artery harvest in comparison to the control.
IMA: internal mammary artery.

Satisfactory intraoperative IMA flow has described[25], but the quantitative results were heterogeneous, as it was reported to be in a very wide range of 14-126 mL/min[15], and Higami et al.[19] reported their very high average value of IMA flow as 122.2±44.8 mL/min in the left IMA and 137.6±51.7 mL/min in the right IMA[19]. As a result, the mean IMA flow of the innovation group patients with a harmonic scalpel IMA harvest was much higher than that of the control group as shown in this report. It was fortunate that the patency rate of IMA harvested by the innovative techniques was promising as verified by postoperative angiography. Apart from the harvest-related merits, the innovative techniques were also associated with other advantages in terms of clinical outcomes, such as lower postoperative mortality and fewer complications. The advantages and disadvantages of the innovative techniques were shown in Table 4. The above results supported that the innovative techniques were effective and safe. Nevertheless, concerning the disadvantages of thorascopic and robotic IMA harvest, such as longer harvest time, prolonged operative time, and increased hospitalization expenses, the clinical application of the latter two techniques can be limited.

In conclusion, harmonic, thorascopic, and robotic IMA harvesting may minimize the IMA damage, ensure minimal damage to IMA, and obtain satisfactory graft flow and patency rate in the long run, and are associated with good clinical outcomes, and therefore are effective and safe harvest techniques. As for the major drawback of longer harvest time and increased cost, they could be used in selected and non-emergent patients with coronary artery disease for CABG.

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