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The ideal intercostal space for internal mammary vessel exposure during total rib-sparing microvascular breast reconstruction: A critical evaluation[☆]

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Abstract *Background:* Total rib-preserving free flap breast reconstruction (RP-FFBR) using internal mammary vessel (IMV) recipients usually involves vessel exposure in the second or third intercostal spaces (ICS). Although the third one is more commonly used, no direct comparisons between the two have hitherto been performed.
Objectives: To compare the in-vivo topography and vascular anatomy of second and third ICSs in patients undergoing FFBR using the rib-preservation technique of IMV exposure.
Methods: An analysis of prospectively collected data on intercostal space distance (ISD), number and arrangement of IMVs, location of venous confluence, and vessel exposure time was conducted on a single surgeon's consecutive RP-FFBRs.
Results: A total of 296 RP-FFBRs were performed in 246 consecutive patients. The second, third, or both second and third spaces were utilized in 282, 28, and 22 cases, respectively. The ISDs were 20.6 mm ± 3.52 for the second ICS and 14.0 mm ± 4.35 for the third ICS (p<0.0001,

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CI = 5.17-7.97, *t*-test). The second versus third ICS vein content was as follows: single 81.4% vs. 74%, dual 18.6% vs. 26%, and confluence 3.7% vs. 13%. The second ICS single vein was medial to the artery in 92.6%. The third ICS single vein was medial to the artery in 88.2%
Vessel exposure times for second (47.2 mins ± 26.7) and third (46.5 mins ± 31.4) spaces were similar ($p = 0.93$). The overall intraoperative anastomotic revision rate was 9.1%, and the post-operative flap re-exploration rate was 4.0%, with 99.7% overall flap success.
Discussion and conclusion: Preferential use of the second ICS is supported by its more predictable vascular anatomy, a broader space for performing the microanastomoses and a higher frequency of a single postconfluence (and thus larger) vein facilitating the microsurgery.

Introduction

Total rib-preserving free flap breast reconstruction (RP-FFBR) using internal mammary vessel (IMV) recipients is now well established.[1,2] It involves vessel exposure in the third[3,4] or the second intercostal space (ICS).[5-9] However, the third ICS is more commonly used, as CT angiographic and cadaveric studies have suggested that the a higher second space may be more difficult to access.[4,10,11] Currently, there is no consensus as to the better site and no direct comparisons have hitherto been performed.

Objectives

The primary aim of the study was to compare the in vivo topography and pertinent vascular anatomy of the second and third ICSs in a single surgeon's patients undergoing FFBR using the total rib-preservation technique of IMV exposure. The secondary objective was to attempt to determine the superior site for microvascular anastomosis. The third goal of the study was to analyze the vessel exposure times of different grades of surgeons as a proxy for the ease or difficulty with which the technique can be learned and thus adopted into existing microsurgical practices.

Methods

A retrospective review of 255 consecutive patients who underwent rib-preserving FFBR by a single operator (CMM) over a nine-year period was undertaken. It analyzed prospectively collected data on intercostal space distance (ISD), number and arrangement of internal mammary arteries and veins, location of venous confluence, and time taken for vessel exposure by the attending surgeon and residents. Comparative statistical tests (*student's t* and Fishers' exact) were two-sided and set the significance level at 0.05.

Patients were identified from the senior author's log book and the departmental free flap register. Flap and anastomotic details were obtained from these prospectively collected databases and cross referenced with paper and electronic patient records. Only patients operated on by the senior surgeon were studied in order to eliminate interoperator variability. In addition, the senior author (CMM) performed all his reconstructions using the rib-preserving technique of IMV dissection.[5,7,8] The data were tabulated and stored on an excel spread sheet, and statistical tests were performed using JSTAT software.

Results

General

A total of 310 rib-sparing FFBRs were performed in 255 consecutive patients (median age = 50 years, range = 28-72). There were 258 immediate, 37 delayed, 11 salvage, and 3 combined delayed/immediate reconstructions. Forty-five patients underwent bilateral reconstructions (90 flaps), whilst 169 were unilateral cases (169 flaps). The remaining 51 flaps were bipedicled free flap unilateral reconstructions. The flap type distribution was 266 DIEP, 34 SIEA, 2 IGAP, 2 PAP, and 6 muscle-sparing free TRAM flaps.

Comparative intercostal space topography

The spaces utilized for the microvascular anastomoses were second space only (266 cases), third space only (6 cases), and both second and third spaces (24 cases). Therefore, a total of 290 s spaces and 30 third spaces were available for direct comparison. The first ICS was accessed inadvertently in 2 cases, and these were excluded from analysis. The ICS distances (mean ± SD) were 20.6 mm ± 3.59 for the second and 14.0 mm ± 4.20 for the third ICSs ($p < 0.0001$, CI = 5.16-8.44, *student's t*-test)

In the entire series, the spaces available for left-right comparison were 182 on the left and 141 on the right (a total of 323 spaces). There was no statistical difference between the right and left second ICS distances ($p = 0.46$ [CI = −1.56-1.43 whether in the same patient ($n = 45$ bilateral reconstructions) or between patients (Figure 1).

Vessel anatomy

The second ICS contained a single vein in 81%, two veins in 19%, and the confluence in 4.7% cases (Figure 2). In contrast, the third ICS contained a single vein in only 68% but two veins in 32% and the confluence in 16% ($p = 0.66$, χ 2 test). When a single vein was noted in the second ICS (226 cases), it was found medial to the artery in 92% cases. When there were two veins in the second ICS ($n = 53$ cases),

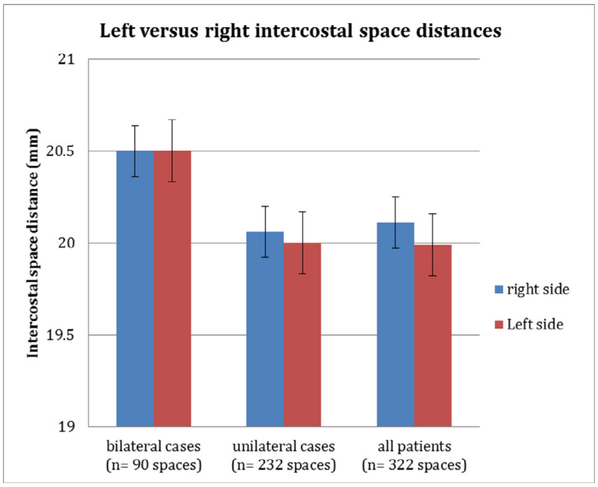


Figure 1 Comparison of the left and right intercostal space distances in patients undergoing rib-preserving FFBR. There is no difference between left and right spaces. The three cases with incomplete information on the interspace distance were not included.

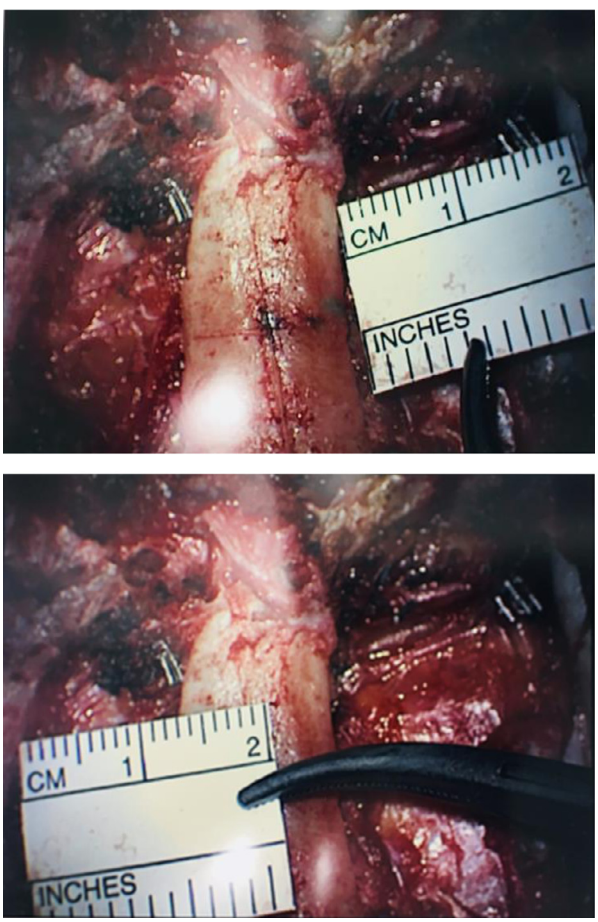
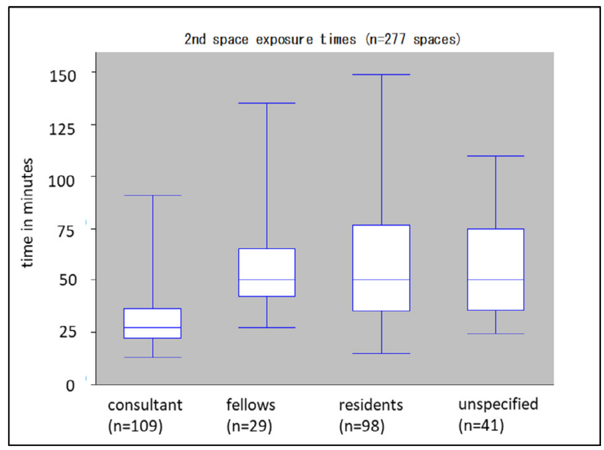


Figure 2 Intraoperative photograph showing exposed second and third intercostal spaces with the internal mammary vessels between the second and third costal cartilages (second space) and between third and fourth costal cartilages (third space).

Table 1 Median vessel exposure times according to the grade of surgeon.

Grade of surgeon	Second space (minutes)	Third space (minutes)	*P* value (M-W-*U* test)
Consultant (attending)	27	25	0.7535
Fellows (postresidency)	50	46	0.6389
Registrars (residents)	50	41	0.1571
All surgeons	40	41	0.5847



Figures 3 Bar chart showing second space vessel exposure times depending on the grade of surgeon ($n=277$ spaces). [The grade of trainee surgeon exposing the vessels was not specified in the operating notes in 41 cases].

the medial vein was larger and thus used for the microvascular anastomosis in 83% of cases.

Vessel exposure times

The median IMV exposure times were 40 min for the second ICS and 41 min for the third ICS ($p=0.5847$, Mann-Whitney U test). These, however, varied greatly depending on the experience of the surgeon with the senior author taking much less time (median 27 min) than the rotating fellows/residents (median of 50 min) (Table 1 and Figures 3 and 4). The exposure times based on the surgeon are summarized in Table 1 and graphically illustrated in Figures 3 and 4. The exposure times were not recorded in 3 cases for the third space and 29 cases for the second space. Residents and fellows performed over half of the vessel dissections (Figures 3 and 4), and the average number of cases per resident or fellow was four. Despite this, their median exposure time was on average 47 min (range 12 to 149) (Table 1). The time taken for IM vessel dissection plateaued off after about 7 cases as illustrated by one resident who performed 25 consecutive cases with a median time of only 22 min (Figure 5).

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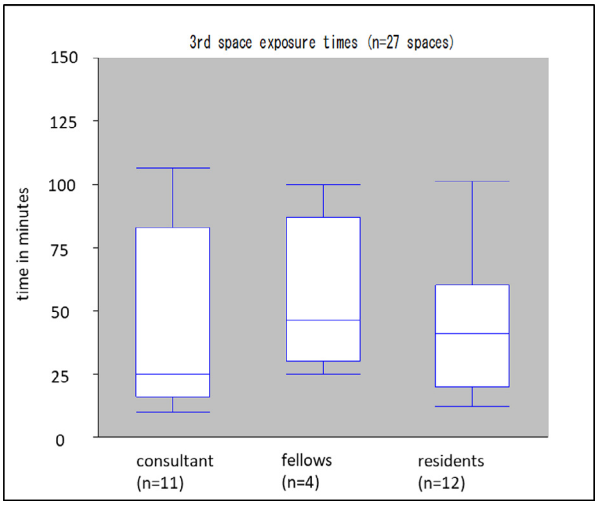

Figure 4 Bar chart showing third space vessel exposure times depending on the grade of surgeon ($n = 27$ spaces as the exposure times had not been recorded in 3 cases).

Flap outcomes

Of the 310 flaps, 309 were transferred successfully (0.3% flap failure rate), with an intraoperative anastomotic revision rate of 9.3% (28 cases) and a postoperative flap re-exploration rate of 4.2% (13 cases). The reasons for the free flap re-exploration and the intraoperative microanastomotic rates are shown in Figure 6 and Tables 2 and 3.

Discussion

Our study has shown that the second ICS is significantly wider than the third ICS, which is a major advantage when performing microvascular anastomoses. In addition, the second ICS is more likely to contain a single vein, which almost always lies medial to the artery. This single vein is cranial to the venous confluence, which is only seen in the second ICS in a minority of cases (4.7%). Therefore, the vein in the second space is predominantly postconfluence and thus of a larger caliber than its third space tributaries. These findings support the preferential use of the second over the third ICS during the total rib-preserving technique of microvascular breast reconstruction contrary to the recommendations of others who still predominantly use the third ICS.[3,4] In Darcy et al's series of 463 patients, they used the wider of the third or fourth spaces, predominantly the third.[10] Our intraoperative findings are supported by the evaluation of the IMVs using magnetic resonance imaging by Tuinder et al.[12] They identified a significantly broader second versus third ICS, containing both a larger vein and artery compared with the third space. Additionally, the Melbourne group found that the confluence of the internal mammary vein had predominantly occurred by the third rib, suggesting a single larger vessel was present cranial to it in the second ICS.[13] Although we found no difference in the spaces on the left versus the right, it has been postulated that the rib-sparing technique in the second space is particularly beneficial on the left side where the internal mammary veins have been found to be comparatively larger than that of the right side.[14] The use of the second space is, however, not universally accepted as a first-choice space.

The disadvantages of using the second space that have been postulated include the possible need to extend the mastectomy pocket superiorly as it is difficult to access it particularly during an immediate reconstruction,[4,10] high flap inset, and potential for excessive medial fullness. However, this has not been our experience. Indeed, Yang et al. found the rib-sparing technique to be a manageable and safe approach even with nipple-sparing mastectomies that have a larger distance from the mastectomy wound to the sternal edge. This potential problem can easily be overcome by the use of appropriate tissue retraction, and in extreme circumstances, resection of a small section of adjacent costal cartilages could facilitate adequate access, although in our series we did not find this necessary. We did, however, find that on three occasions (about 1%) we

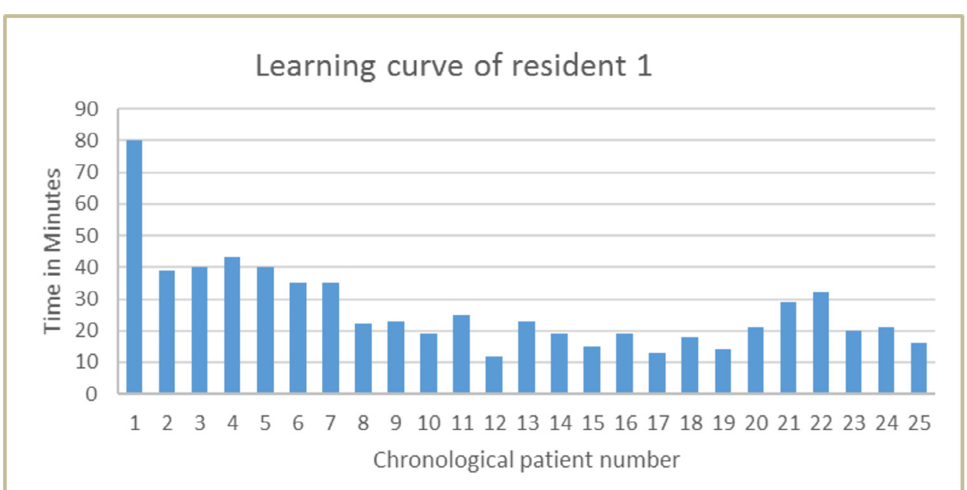

Figure 5 Learning curve of resident 1 - internal mammary vessel exposure times of a single resident who performed 25 consecutive cases. She was able to perform this technique in about 20 min after a very short learning curve of only a few patients.

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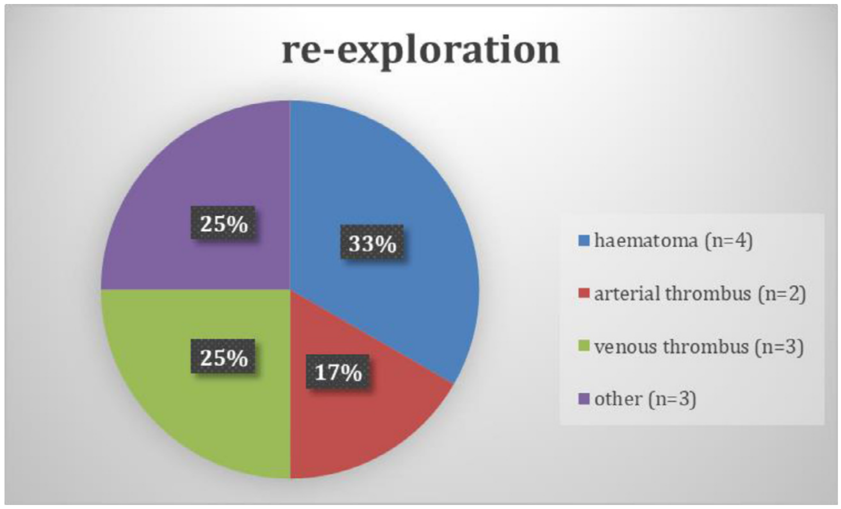

Figure 6 Pie chart showing reasons for the postoperative free flap re-exploration.

Table 2 Individual outcomes of the free flap re-explorations.

Indication for re-exploration	Intraoperative findings	Flap outcome	Timing postop
Hematoma	Hematoma	Success	Days 7
Venous engorgement/hematoma	Hematoma	Success	32 h
Mottled flap skin paddle	Hematoma	Success	24 h
Venous engorgement/hematoma	Venous thrombus, insufficiency	Success	12 h
Venous engorgement	Other	Success	20 h
Hematoma	Hematoma	Success	24 h
Ischemia (no audible doppler)	Arterial thrombus	Success	24 h
Venous engorgement	Venous thrombus, small hematoma	Success	days 14 and 18
Ischemia	Arterial thrombus	Failure	20 min
Venous engorgement/hematoma	Other	Success	12 h
Venous engorgement	Other	Success	days 7 and 8
Venous engorgement	Venous thrombus	Success	20 h

Table 3 Reasons for intraoperative microanastomotic revisions (on-table redo anastomoses).

Indication	Number of flaps
Artery ($n = 10$)	
Vessel discrepancy	3
Flow problems	4
Intimal damage	2
Unacceptable bleeding	2
Vein ($n = 13$)	
Vessel discrepancy	2
Flap engorgement	3*
Unacceptable bleeding	5
Vessel kinked	1
Vessel damage	2

* Two of these needed vein grafts to optimize/re-establish flow.

had to nibble back the third or the second rib because of intraoperative constraints (no flow in artery because of silicone-induced perivascular fibrosis and two cases of bleeding under the second costal cartilage). This shows the versatility of the technique. It has also been suggested that rib preservation exposure is more difficult and thus might take longer to perform. This, however, is not borne out by our study because the exposure times for the second and third spaces were almost identical. The exposure times for the two spaces clearly depended on the experience of the dissecting surgeon.

One of the secondary objectives of the study was to analyze the vessel exposure times of different grades of surgeons with the purpose of attempting to determine the ease or difficulty with which the technique can be learned and thus adopted into an existing microsurgical practice. It demonstrated that the exposure time decreases with experience (resident to fellow to attending). Our study also showed that total rib preservation IMV exposure, especially in the second ICS, is easy to learn, and the time taken for it plateaued off after about seven cases as illustrated by one resident who performed 25 consecutive cases with a median time of only 22 min (Figure 5).

In addition to exposure times that are comparable for the second and third spaces, our study has demonstrated that the vascular anatomy of the second space was more predictable than that of the third space and, therefore, does not need preoperative delineation using CTA or MRA.

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This is an important conclusion from our study as some authors have recently suggested that CT angiography of the IMVs should be performed to facilitate microvascular breast reconstruction.[11] We consider CTA of the IMVs unnecessary given the consistency and reproducibility of vascular anatomy and topography of this region, and this was true irrespective of whether it was on the left or the right. We believe that routine CTA should be avoided because of high radiation dose, possible contrast toxicity/allergic reactions,[15] and cost and the unlikelihood that it will change management. The contralateral carcinogenic risks of chest imaging are amplified in this already "susceptible" cancer population.[13] Therefore, CT angiography of the IMVs should be reserved for highly selected cases only.

Our paper also draws attention to intraoperative anastomotic redo surgery in a large microvascular series, a subject not addressed in many papers. Indeed, very few papers discuss the intraoperative flap problems, but this subject is important as it highlights factors that may lengthen operative time and thus contribute to morbidity. It also indirectly demonstrates efficacy of this vessel exposure type and its adequacy for microvascular anastomoses because of the relatively low number of intraoperative complications encountered.

Identified weaknesses of this paper include a discrepancy in numbers between the second and third IC spaces for comparison. A randomized study can potentially address this deficit, but it may be difficult to justify its cost and duration before statistical significance can be reached. Second, our study did not directly measure the diameters of the IMVs in the two spaces, which would have provided the ideal comparison. However, in anatomy, a given vein generally becomes larger as it goes from distal to proximal in the body and postconfluence versus preconfluence. Therefore, internal mammary veins in the second space would be expected to possess wider diameters than those in the third space. Similarly, a given artery is wider proximally (second space) than it is distally postbifurcation (third space). Nevertheless, despite the lack of direct vessel diameter measurements, the study gave us information when both the second and third spaces were simultaneously exposed about which vein was larger, as visually determined by the operating surgeons. When there were two veins present and thus a choice between the lateral and medial IM vein tributaries in the second space, the larger vein was selected for the anastomoses to facilitate the microsurgery. Third, it was also not possible to compare ischemia times for the second and third spaces because the exposures were done for slightly different reasons, but the exposed spaces provided an opportunity to study the pertinent anatomy. Although this study is from one operator and has given valuable information, a larger series from multiple centers would add more evidence to ICS selection. The vessel exposures are, however, valid for extrapolation to a larger series as they were done by different grades of surgeons. Whilst this study is retrospective, it analyzed data that were prospectively collected for the specific purpose of studying the ICS topography and vascular anatomy pertinent to microvascular breast reconstruction. Despite the aforementioned short comings of the present study, it has clearly shown the advantages of using the second space for microvascular anastomoses in FFBR in a relatively large consecutive series. Notable amongst these is the greater space available for performing the microsurgery compared to the third space, larger vein, and more predictable anatomy.

Conclusion

Total rib-preservation exposure of the IMVs is an effective technique for microvascular breast reconstruction. We recommend the second ICS for this purpose because of its wider ICS and larger caliber single vein. Our series has also further supported the rib preservation technique as safe in microsurgery as shown by our low intraoperative anastomotic revision rate and free flap failure rate.

Conflict of Interest

N/A.

Funding

N/A.

References

1. Nahabadien M. The internal mammary artery and vein as recipient vessels for microvascular breast reconstruction. *Ann Plast Surg* 2012;**68**:537-8.
2. Yang SJ, Eom JS, Lee TJ, Ahn SH, Son BH. Recipient vessel selection in immediate breast reconstruction with free abdominal tissue transfer after nipple-sparing mastectomy. *Arch Plast Surg* 2012;**39**:216-21.
3. Parrett BM, Caterson SA, Tobias AM, Lee BT. The rib-sparing technique for internal mammary vessel exposure in microsurgical breast reconstruction. *Ann Plast Surg* 2008;**60**:241-3.
4. Sacks JM, Chang DW. Rib-sparing internal mammary vessel harvest for microvascular breast reconstruction in 100 consecutive cases. *Plast Reconstr Surg* 2009;**123**:1403-7.
5. Malata CM, Moses M, Mickute Z, Di Candia M. Tips for successful microvascular abdominal flap breast reconstruction utilizing the "total rib preservation" technique for internal mammary vessel exposure. *Ann Plast Surg* 2011;**66**:36-42.
6. Kim H, Lim SY, Pyon JK, et al. Rib-sparing and internal mammary artery-preserving microsurgical breast reconstruction with the free DIEP flap. *Plast Reconstr Surg* 2013;**131**:327e-334e.
7. Khoo A, Rosich-Medina A, Woodham A, Jessop ZM, Di Candia M, Malata CM. The relationship between the intercostal distance, patient height and 12 outcome in microsurgical breast reconstruction using the second interspace rib-sparing internal mammary vessel exposure. *Microsurgery* 2014;**34**:448-53.
8. Rosich-Medina A, Bouloumpasis S, Di Candia M, Malata CM. Total 'rib'- preservation technique of internal mammary vessel exposure for free flap breast reconstruction: a 5-year prospective cohort study and instructional video. *Ann Med Surg* 2015;**4**:293-300.
9. Ball J, Huang M, Oni G, Di Candia M, Malata C. Advantages of internal mammary vessel exposure in the 2nd intercostal space during total ribpreserving microvascular free flap breast reconstruction. *Abstract presented at joint meeting of the British association of plastic, reconstructive and aesthetic plastic surgeons and the Finnish association of plastic surgeons*. Helsinki, Finland; 17th June 2017.

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10. Darcy C, Smit JM, Audolfsson T, Acosta R. Surgical technique: the intercostal space approach to the internal mammary vessels in 463 microvascular breast reconstructions. *J Plast Reconstr Aesthet Surg* 2011;**64**:58-62.
11. Cook JA, Tholpady SS, Momeni A, Chu MW. Predictors of internal mammary vessel diameter: a computed tomographic angiography-assisted anatomic analysis. *J Plast Reconstr Aesthet Surg* 2016;**69**:1340-8.
12. Tuinder S, Dikmans R, Schipper RJ, et al. Anatomic evaluation of the internal mammary vessels based on magnetic resonance imaging (MRI). *J Plast Reconstr Aesthet Surg* 2012;**65**:1363-7.
13. Rozen WM, Alonso-Burgos A, Murray AC, Whitaker IS. Is there a need for preoperative imaging of the internal mammary recipient site for autologous breast reconstruction? *Ann Plast Surg* 2013;**70**:111-15.
14. Chang EI. My first 100 consecutive microvascular free flaps: pearls and lessons learned in first year of practice. *Plast Reconstr Surg Glob Open* 2013;**1**:e27.
15. Marcus R, Ruff C, Burgstahler C, et al. Recent scientific evidence and technical developments in cardiovascular computed tomography. *Rev Esp Cardiol (Engl Ed)* 2016;**69**:509-14.

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