Revaskularizacija miokarda z uporabo zadnjih medrebrnih arterij kot presadkov z vidika anatomskih variacij

Myocardial revascularization using the posterior intercostal arteries as grafts: anatomical variation aspect

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Izvleček

Namen: *Zadnje medrebrne arterije (PIA) predstavljajo alternativno obliko presadkov zaradi ugodnih histoloških, morfoloških in anatomskih značilnosti. Raziskali smo anatomske variacije izvora in poteka leve pete in desne sedme PIA, saj so bile te arterije dokazano najprimernejše za in situ presaditve koronarnih arterij. Namen raziskave je bil ugotoviti, ali lahko variacije vplivajo in omejijo postopek revaskularizacije miokarda, če se PIA uporabi kot presadke.*

Metode: *Raziskava je bila opravljena na 44 kadavrih, balzamiranih po Thielovi metodi. PIA so bile prikazane od izvora do srednje aksilarne linije. Zabeležili smo izvore in potek PIA, izvedli meritve dolžine skupnih debel, razdalje do rebrnega kota in premerov arterij na izvoru, na mestu razcepitve skupnega debla in v nivoju rebrnega kota. Stopnjo zmanjšanja premera arterij smo izračunali.*

Rezultati: *Anatomske variacije izvora leve pete PIA smo našli v 25 %.*

Abstract

Purpose: *The posterior intercostal arteries (PIAs) present potential alternative graft sites because of their histological, morphological, and anatomical features. We investigated the anatomical variations of the origin and course of the left fifth and right seventh PIAs, since these arteries have been demonstrated as the most suitable for in situ grafting of the coronary arteries. The aim of this study was to determine whether variations of the PIAs as grafts could influence or limit myocardial revascularization.*

Methods: *PIAs from the origin to the mid–axillary line were dissected from 44 cadavers embalmed via Thiel's method. The origin and course of the arteries was documented. The lengths of the common trunks, the distances to the costal angle levels, and the diameters of the arteries at the origin, at the point of division from the common trunk, and at the costal angle level were measured to calculate the diameter reduction rate.*

Nobenih variacij nismo zasledili pri desni sedmi PIA. Dolžina skupnega debla vpliva na dolžino pridobljenega žilnega peclja. Premeri arterij so bili odvisni od oblike izvora iz aorte, zato bi se naj PIA uporabilo pred nivojem rebrnega kota, da se zagotovi ustrezen premer presadka.

Zaključek: *Podatki naše raziskave kažejo, da je v primeru uporabe PIA za CABG priporočeno upoštevati potencialne anatomske variacije PIA, ki lahko poleg tehničnih problemov pri pridobivanju PIA povzročijo tudi hemodinamske spremembe v pretoku krvi.*

Results: *Anatomical variations of the left fifth PIA were found in 25% of the cadavers. No variations were found in the right seventh PIAs. The length of the common trunk influences the length of the obtained pedicle. The PIA diameter is dependent on the origin from the aorta. The target PIA should be harvested before the costal angle level to assure a proper diameter of the conduit.*

Conclusion: *Potential anatomical variations of the PIA must be considered when harvesting a vessel for CABG to avoid technical problems in PIA harvesting and hemodynamic changes.*

INTRODUCTION

Myocardial revascularization in case of obstruction of the coronary circulation or severe angina is achieved by surgical anastomosis of an appropriate vessel with a coronary artery in a procedure known as coronary artery bypass grafting (CABG) (1). In standard graf-ting procedures, the left internal thoracic artery (ITA) is routinely grafted to the left anterior descending (LAD) artery with additional grafting of the greater or lesser saphenous vein to other damaged coronary arteries (2). If standard conduits are unsuitable, the radial artery, right gastroepiploic artery, inferior epigastric artery, splenic artery subscapular artery, inferior mesenteric artery, descending branch of the lateral circumflex femoral artery, or ulnar artery can be also used for CABG (3–11). The posterior intercostal arteries (PIAs) also meet the necessary criteria for myocardial revascularization due to favorable histologic structures and locations in the thoracic cavity (12,13). Histologically, the PIAs have a relatively thin intima and media, the latter being elastic or elastomuscular and, therefore, resistant to intimal thickening, ischemia, and atherosclerosis, which ensures long–term patency of the graft (14,15). Anatomically, the PIAs, which directly branch from the aorta, are considered medium–sized arteries with sufficient blood flow for CABG (1,12–14,16). The anatomical positions of the PIAs, being in close proximity to the heart, also indicate the theoretical use of the PIAs as *in situ* grafts for transplantation of the entire coronary arterial system, in addition to use as free grafts, because the PIAs reach all of the major coronary artery territories (12–14). The collateral circulation among the PIAs is so excessive that ischemia to just one intercostal space is rare. Harvesting of a PIA can be performed without any impact to the perfused organs or limitation in the number of available arteries because all are easily dispensable and readily available (13).

Due to the histological, morphological, and anatomical features of the PIAs, these vessels have been investigated as potential alternative conduits in CABG. The left fifth and right seventh PIAs have been confirmed as the most suitable for *in situ* grafting of the coronary arteries (12). The left fifth PIA travels through the inferior route and is thus the most suitable for grafting to the LAD and lateral circumflex artery, while the right seventh PIA, which travels through the inferior route, is most suitable for grafting to the right coronary artery (12).

The aim of this study was to assess the anatomical variations and morphometric characteristics of the left fifth and right seventh PIAs that might impact the use of these vessels as grafts for myocardial revascularization.

MATERIAL AND METHODS

PIAs injected with red ink–colored latex solution were dissected from 44 human cadavers that were embalmed according to the methods described by Thiel (17,18). The only selection criterion for choosing a cadaver was no previous cardiothoracic surgical procedure. The chest wall was opened with the ribs cut at the mid–axillary line. The lungs and heart remained intact. Fine preparation of the parietal pleura and intercostal muscles was performed to visualize the origin of the PIA from the thoracic aorta and to follow the course of the PIA to the adjacent intercostal space. The anatomical variations of the origin and courses of the left fifth and right seventh PIAs were documented. The length of the common trunks and the distance of the arteries from the origin to the costal angle level were precisely measured. The outer diameters of the arteries at the origin, at the division of the common trunk into single arteries, and at the costal angle were measured using a caliper (mm). The costal angle was used as a landmark to determine the influence of the length of the artery from the origin on its diameter, since before this point, the artery is divided into one of its bigger branches, the collateral branch.

Statistical analysis

Results were analyzed by descriptive statistics using SPSS ver. 18.0 statistical software (IBM–SPSS Inc., Chicago, IL, USA). All data are presented as the mean ± standard deviation (SD).

Ethical standards

All donors of their remains for the scientific and teaching purposes to the Institute of Anatomy submitted written consent prior to donation. The study protocol was approved by The National Medical Ethics Committee of the Republic of Slovenia, University Institute of Clinical Neurophysiology, Medical Centre Ljubljana, and was performed in accordance with the ethical standards ascribed in the 1964 Declaration of Helsinki.

RESULTS

Anatomical variations in PIA origins

All investigated PIAs originated from the thoracic aorta. Common trunks originating from the aorta and involving the left fifth PIA were present in 25% (11/44) of cadavers and were as follows: common trunk of the fourth and the fifth PIAs (n = 5), common trunk of the fifth and the sixth PIAs (n = 5), and common trunk of the fourth, fifth, and sixth PIAs (n = 1). The lengths of the common trunks and distances to the costal angles are shown in Table 1. The most common trunks of the left fourth and fifth PIAs and the left fifth and sixth PIAs were divided into single arteries in the second third of the course of the PIA from its origin to the level of the costal angle. If the PIA originated from the thoracic aorta as a single artery, the average length of the left fifth PIA from its origin to the costal angle was 9.3 cm (range, 7.0–11.5 cm), whereas the average length of the right seventh

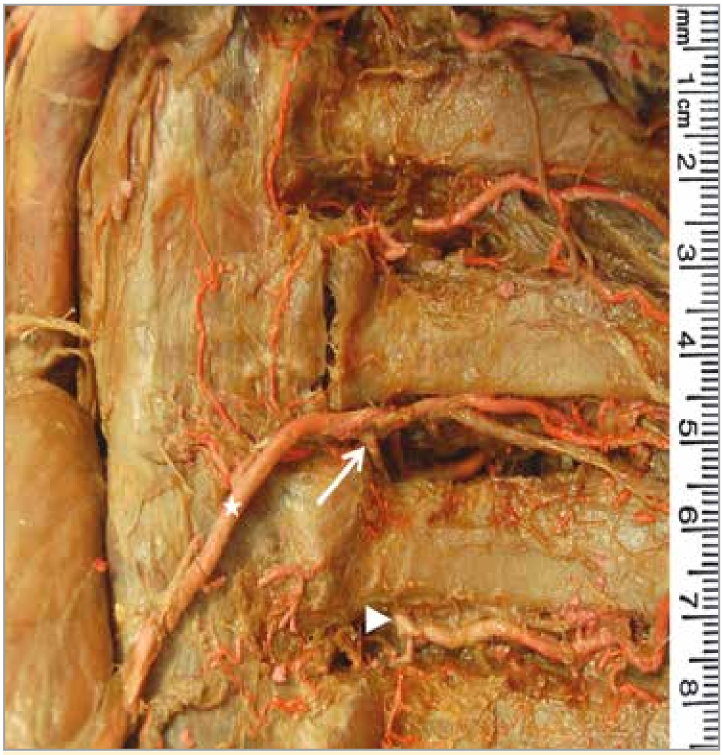

Figure 1.: The left fifth PIA as the thoracic vertebral artery. The arrow shows the point of branching of the left fifth PIA from the common trunk with the left fourth PIA (asterix). The left fifth PIA then descends dorsally to the fifth rib into the fifth intercostal space (arrow head).

Table 1. *Common trunks of the left PIA*

**The left fourth PIA divided from the common trunk at a distance of 3.2 cm from the thoracic aorta, and the fifth and sixth PIA at a distance of 5.1 cm from the origin.*

Left PIA	Common trunk length (cm)	Mean common trunk length (cm) ± SD	Length to the costal angle (cm)	Mean length to the costal angle (cm) ± SD
4+5	5.8	4.04 ± 1.52	9.0	8.6 ± 0.8
4+5	1.7		8.0	
4+5	4.8		7.5	
4+5	3.8		9.0	
4+5	4.1		9.5	
5+6	4.2	3.76 ± 1.33	10.0	10.4 ± 1.3
5+6	5.8		12.0	
5+6	3.1		9.5	
5+6	2.3		11.5	
5+6	3.4		9.0	
4+5+6	3.2 (5.1*)	/	10.0	/

PIA to the costal angle was 11.7 cm (range, 9.0–14 cm). None of the common trunks involved the right seventh PIA with the sixth or eighth PIA.

Anatomical variation in the PIA course

An anatomical variation involving the left fifth PIA, which is known as the thoracic vertebral artery, was observed in one case (Figure 1). The left fifth together with the fourth PIA arose from the aorta and formed a common trunk, which was 5.8 cm in length. After division of the neighboring arteries, the fifth PIA coursed downward dorsally to the fifth rib into the fifth intercostal space. No other anatomical variation of the right seventh PIA was found.

Vessel diameters

The diameters of the PIAs are summarized in Table 2. The average outer diameters of the left fifth and right seventh PIAs were 1.9 ± 0.4 mm at the origin and 1.4 ± 0.3 mm (left fifth PIA) and 1.6 ± 0.3 mm (right seventh PIA) at the costal angle level. After the common trunks divided into single arteries, there were no differences in the diameters of the individual arteries at the origin. Diameters at the costal angle were independent of those at the origin.

The reduction in the diameter from the origin to the costal angle was calculated on the basis of the above–measured values, which varied from a maximum of 44% for the left fifth PIA (mean, 26.3%) and maximum of 45% for the right seventh PIA (mean, 15.7%). The maximum reduction rate in the occurrence of a common trunk was increased to 58% because of the difference in diameters at the origin and the costal angle, as compared to individual arteries.

DISCUSSION

The anatomical criteria of using arterial conduits include simple accessibility, a proper length to reach the targeted arteries, a suitable caliber, and compatible histological structures to the coronary vessels (19). Since the ITA is most often used for CABG, all other potentially appropriate arteries must be compatable with the majority of its characteristics. Difficult accessibility is the major drawback of a particular PIA be-

Table 2. *Mean outer diameters of the PIA at different levels*

*ϕ1 – outer diameter at the origin from the thoracic aorta; ϕ1a – outer diameter of the left fifth PIA after division from the common trunk; ϕ2 – outer diameter at the costal angle level; *absolute value*

PIA	Mean outer diameter (mm) ± SD		
	ϕ1	ϕ1a	ϕ2
5 (left)	1.9 ± 0.4	/	1.4 ± 0.3
7 (right)	1.9 ± 0.4	/	1.6 ± 0.3
4+5	2.3 ± 0.4	1.8 ± 0.5	1.3 ± 0.3
5+6	2.2 ± 0.3	1.9 ± 0.1	1.3 ± 0.2
4+5+6	2.6*	2.2*	1.6*

cause of its location in the posterior mediastinum of the thoracic cavity. However, the close relationship of the PIAs to the heart renders these arteries favorable for *in situ* grafting. Dandolu et al. reported that harvesting of the intercostal pedicles is technically easier and more convenient via median sternotomy than thoracotomy in clinical application (13).

Studies of the intercostal flap have allowed a detailed anatomical classification of the aortic intercostal arteries into four segments according to the relationship to adjacent bones (vertebral and costal groove segments) and muscles (intermuscular and rectus segments) for plastic and reconstructive surgery (20). Although there are many reports on the use of the intercostal arteries for myocardial revascularization before coronary artery bypass surgery, reports on the use of the PIA in CABG remain limited to few experimental animal and cadaveric studies on proper harvesting techniques and approaches to revascularize and anastomotize the intercostal arteries with a particular coronary artery (12–13, 21–22).

To the best of our knowledge, the main concern with the use of a PIA as graft for bypass surgery is the lack of previous reports on anatomical variations of the PIA origin from the thoracic aorta and possible effects on arterial diameter and blood flow. Anatomical variations of the course could also limit the potential use of a particular PIA as an *in situ* graft when creating a pedicle. Results of a study that mapped the variability of the descending branch of the lateral circumflex femoral artery as a conduit for CABG concluded that even moderate morphological variations were not possible in 27% of potential vessels, as demonstrated by computed tomography angiography (19).

If common trunk variation is considered to affect the target PIA, the data of this study indicate that according to the length of the common trunk before its division, which mostly occurs in the second third of its course to the costal angle level, we can anticipate that this variation might be problematic when harvesting an appropriate PIA pedicle of an appropriate length to reach the target coronary artery. However, variations in the origin and course could have some impact on the hemodynamic process, potentially causing turbulence, especially at the site of division of the common trunk, which may increase the risk of a cardiovascular event. A PIA with a low frequency of common trunks would be more appropriate for CABG because the reduction in the origin diameter will also increase the risk of medullar ischemia when harvesting a PIA beyond the fifth pair. On the other hand, anatomical variability of the PIA, such as the dorsal course, can potentialy cause technical problems when harvesting the artery.

The origin of the aorta determines the size of the diameter at the costal angle level independent of whether the PIA originates from the aorta as a single branch or forms a common trunk with a neighboring artery. The diameter of the left fifth PIA supports previous histomorphometric studies of the lumen diameter at the origin (1.4 ± 0.3 mm), in consideration of the average thickness of the intima (54 ± 38 µm) and media (205 ± 38 µm) (14), lumen diameter at the origin (1.75 ± 0.35 mm), and the total thickness of the intima and media (246 ± 35 µm) (23).

The reduction rate of the diameters at the costal angle level determined in this study shows that in case of harvesting an appropriate PIA, the main limitation to the use of an artery for revascularization is that the diameter is incompatible with the diameter of the target coronary artery, especially in consideration of the possibility of vasospasm (23). The PIA should, therefore, be harvested before the costal angle level to assure a proper diameter of the conduit.

CONCLUSIONS

Although the use of a PIA for revascularization of the myocardium has been thoroughly investigated for potential grafting, no study has addressed the basic anatomical variations of common arteries in regard to the vessel origin and course that could influence its harvesting as an *in situ* or free graft. In addition, it remains uncertain whether these variations might have any hemodynamic consequences on myocardial perfusion, thus further research is warranted.
Based on the information obtained from the present study, we conclude that the anatomical variations at the origin and course of the PIA, despite all already known chatacteristics, must be taken into consideration when chosing of an appropriate artery for myocardial revascularization.

Conflict of interest

The authors declare that they have no conflict of interest.

REFERENCES

1. Moore KL, Dalley AF (2006) Clinically Oriented Anatomy. 5th edn. Lippincott Williams & Wilkins, Baltimore, Philadelphia.
2. Hillis LD, Smith PK, Anderson JL, Bittl JA, Bridges CR, Byrne JG et al. (2011) 2011 ACCF/AHA Guidelines for Coronary Artery Bypass Graft Surgery: Areport of the Americal College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines. Circulation 124:e652–e735.
3. Carpentier A, Guermonprez JZ, Deloche A, Frechette C, Dubost C (1973) The aorto-to-coronary radial artery bypass graft: a technique avoiding pathological changes in grafts. Ann Thorac Surg 16:111–21.
4. Pym J, Brown PM, Charrette EJP, Parker JO, West RO (1987) Gastroepiploic–coronary anastomosis: a viable alternative bypass graft. J Thorac Cardiovasc Surg 94:256–9.
5. Puig LB, Ciongolli W, Cividanes GVL, Dontos A, Kopel L, Bittencourt D et al. (1990) Inferior epigastric artery as a free graft for myocardial revascularization. J Thorac Cardiovasc Surg 99:251–5
6. Buche M, Schoevaerdts JC, Louagie Y, Schroeder E, Marchandise M, Chenu P et al. (1992) Use of the inferior epigastric artery for coronary bypass. J Thorac Cardiovasc Surg 103:665–70.
7. Edwards WS, Lewis CE, Blakeley WR, Napolitano L (1973) Coronary artery bypass with internal mammary and splenic artery grafts. Ann Thorac Surg 15:35–9.
8. Mills NL, Dupin CL, Everson CT, Leger CL (1993) The subscapular artery: an alternative conduit for coronary bypass. J Card Surg 8:66–71.

9. Shatapathy P, Aggarwal BK, Punne J (1997) Inferior mesenteric artery as a free arterial conduit for myocardial revascularization. J Thorac Cardiovasc Surg 113:210–1.
10. Tatsumi TO, Tanaka Y, Kondoh K, Minohara S, Sawada Y, Tsuchida T et al. (1996) Descending branch of lateral femoral circumflex artery as a free graft for myocardial revascularization: a case report. J Thorac Cardiovasc Surg 112:546–7.
11. Buxton BF, Chan AT, Dixit AS, Eizenberg N, Marshall RD, Raman JS (1998) Ulnar artery as a coronary bypass graft. Ann Thorac Surg 65:1020–4.
12. John LC, Chan CL, Anderson DR (1995) Potential use of the intercostal artery as an in situ graft: a cadaveric study. Ann Thorac Surg 59:190–5.
13. Dandolu BR, Furukawa S, Valluvan J (1998) Intercostal artery as a pedicled graft for myocardial revascularization: an animal experimental study. J Invest Surg 11:373–9.
14. van Son J, Smedts F, Korving J, Guyt A, de Kok LB (1993) Intercostal artery: histomorphometric study to assess its suitability as a coronary bypass graft. Ann Thorac Surg 56:1078–81.
15. Reddy S, Kumar P, Prasad K (2011) Histomorphometric and sympathetic innervation of the human posterior intercostal artery and its clinical importance. Folia Morphol 70:161–7.
16. John LC (2006) The intercostal artery: an "ideal" arterial graft awaiting clinical application. In: He GW (ed) Arterial grafting for coronary artery bypass surgery, 2nd edn. Springer–Verlag, Berlin, Heidelberg, pp 238–40.
17. Thiel W (1992) The preservation of the whole corpse with natural color. Ann Anat 174:185–95.
18. Thiel W (1992) An arterial substance for subsequent injection during the preservation of the whole corpse. Ann Anat 174:197–200.
19. Loskot P. Tonar Z, Baxa J, Valenta J (2016) The descending branch of the lateral circumflex femoral artery as an alternative conduit for coronary artery bypass grafting: experience from an anatomical, radiological and histological study. Clin Anat 29:779–88.
20. Kerrigan CL, Daniel RK (1979) The intercostal flap: an anatomical and hemodynamic approach. Ann Plast Surg 2:411–21.
21. Juzbašić DM (1946) Beitrag zur Technik der Operation des Pantzerherzens. Schweiz Med Wochenschr 12:256–7.
22. Pearce CW, Hyman AL, Brewer P, Smith PE, Creech O Jr (1966) Myocardial revascularization: implantation of intercostal artery. J Thorac Cardiovasc Surg 52:809–12.
23. Ünlü Y, Keleş P, Keleş S, Yeşilyurt H, Koçak H, Diyarbakirli S (2003) An evaluation of histomorphometric properties of coronary arteries, saphenous vein, and various arterial conduits for coronary artery bypass grafting. Surg Today 33:725–30.