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Original Article

Total Arterial Revascularization: Evaluating the Length of the Radial Artery in a Composite Graft Configuration

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Purpose: Reimplanting the radial artery in the left internal thoracic artery as a composite graft allows total arterial revascularization (TAR) without aortic manipulation. The limitation of this strategy is the length of the radial artery required to reach distal right coronary artery (RCA) branches. Our analysis focuses on the feasibility of this strategy.

Methods: A total of 169 patients underwent TAR using the radial artery in a composite grafting configuration. Length of the radial artery, number of sequential anastomoses, heart size, target location, length of the arm, patient height, body surface area, and flow in the composite graft were prospectively collected.

Results: The mean length of the radial artery was 18.02 cm. Patients with a mean length of the radial artery of 15.9 cm needed an extension of the radial artery with another conduit to reach the RCA distal branches. When T-configuration is used, the length of the radial artery should be 0.53 cm per sequential anastomosis to reach the RCA distal branches.

Conclusions: Our study shows that an average length of 18.02 cm of radial artery is needed to reach targets on the RCA distal branches in composite grafting. In T-configuration, we need 0.53 cm more length per anastomosis to achieve TAR.

Keywords: total arterial revascularization, radial artery as composite graft, T-versus Y-configuration, radial artery length

Introduction

Total arterial revascularization (TAR) is associated with long-term freedom from major adverse cardiac and cerebrovascular events, death, and myocardial infarction.[1)] While the left internal thoracic artery (LITA) is the cornerstone in myocardial revascularization, the choice of the second arterial graft depends on various factors including patient risk factors, degree of coronary artery stenosis, complexity of grafting strategy, as well as surgeon's experience. Whereas LITA remains a good alternative, randomized and observational evidence suggests excellent radial artery patency rate making its utilization as class I indication in current guidelines in myocardial revascularization.[2)] The use of the radial artery as a second graft has been shown to decrease long-term major adverse cardiac events as well as higher rate of graft patency at the 5-year follow-up.[3)] Several studies highlight its benefits such as length and diameter as well as its versatility in terms of graft configuration and number of anastomoses that are crucial when planning the grafting strategy.[4,5)] Further, evidence suggests the superiority of sequential anastomotic technique allowing better

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utilization of conduit length, complete revascularization, and better hemodynamics, which may improve graft patency.[6–8] Reimplanting the radial in the LITA as a composite graft in a T- or Y-fashion allows TAR with only two conduits and no aortic manipulation. However, the limitation of this strategy is the length of the radial artery required to reach the right coronary artery (RCA) branches. In our monocenter study, we analyzed patients and operative characteristics that predict the feasibility of the radial artery reaching the RCA territory without complementary graft.

Materials and Methods

This study has been approved by the Ottawa Health Science Network Research Ethics Board (OHSN-REB) (Protocol ID#: 20210226-01H) and a written consent was obtained by participating patients.

In all, 169 patients with advanced coronary disease underwent isolated TAR using the radial artery as a secondary graft in a T- or Y-composite grafting configuration between January 1, 2019 and December 31, 2020 at the Ottawa University Heart Center. The T-composite grafting implies that the radial artery was anastomosed on the top of the left mammary artery in 90° angle in order for the radial artery to align perpendicular to the first coronary target. In contrast, the Y-composite grafting involves anastomosis of the radial artery to the fascia surface of the left mammary artery in a termino-lateral fashion. The decision of the type (Y or T) of the composite anastomosis and its location was made depending on the location of the first anastomosis with the radial artery. If the first targeted coronary artery was a diagonal or a ramus artery, the T-configuration was chosen, for all other scenarios, and a Y-configuration was chosen in order to perform a diamond-shaped anastomosis with the radial artery on the first coronary target to maximize the conduit length.

Only patients with a radial artery harvested endoscopically were included in this analysis. The radial artery was harvested endoscopically using a sealed system, Vasoview Hemopro 2 (Maquet, Getinge Group, Gothenburg, Sweden). The procedure was performed as previously described.[9,10] The radial artery was harvested in a semi-skeletonizated fashion, implying that only accompanying veins were harvested with the artery without its fascia. The length of the radial artery was measured on the table after it was harvested and the length documented accordingly.

Coronary revascularization was performed in an off-pump technique according to the standard that has been described previously and is utilized at the Ottawa University Heart Center.[11,12] LITA was routinely anastomosed to the left anterior descending (LAD), while the radial artery was used as a composite graft to bypass coronary arteries on the left side as well as branches of the RCA. No other supplemental grafts where used. The LITA–radial artery anastomosis was performed as the first step of the grafting procedure in a technique described above. All other anastomoses other than anastomoses to LAD and posterior descending artery (PDA) were performed in a diamond fashion. Distal anastomoses to PDA or posterolateral artery (PLA) were performed in a 90° angle.

In 121 patients, the radial artery in the composite graft configuration off the LITA was used to bypass distal branches of the RCA as the remaining patients did not need revascularization of the RCA territory.

Out of 121 patients, one patient was classified as outlier and excluded from regression analysis based on the analysis of the studentized residuals.

The length of the radial artery, number of sequential anastomoses, heart size (end-diastolic left ventricular diameter [EDLVD]), target location, length of the arm, height of the patient, body surface area (BSA), and flow in the composite graft were prospectively collected and analyzed.

The primary endpoint of the study was to analyze the required length of the radial artery to bypass the branches of the RCA in either a T- or Y-configuration depending on the number of sequential anastomoses and the heart size expressed as EDLVD. We used the length of the radial artery as a dependent variable, whereas the number of sequential anastomoses, mode of configuration, and EDLVD appeared as independent variables in our first analysis.

Furthermore, we fitted a logistic regression to examine which variables have a significant influence on whether the targets can be reached without graft extension or not. The second endpoint of this study was to perform a correlation analysis between the length of the radial artery and anthropomorphic measures such as height, BSA, EDLVD, and the length of the arm differentiated by gender. The final analysis focused on the assessment of the relation between the flow in the radial artery and the number of the performed sequential anastomoses in either a T- or Y-configuration.

Statistical analysis

Statistical analysis was carried out using Statistical Package for Social Sciences (SPSS, version 26; IBM, Armonk, New York, U.S.). As not stated otherwise, data were presented as mean (± standard deviation [SD]). A p-value ≤0.050 was considered statistically significant. For comparison of means, either the Mann–Whiney U test or the Kruskal–Wallis test was employed. Correlation analysis was carried out using the Spearman's rank correlation coefficient. To estimate the influence of graft configuration, number of sequential anastomoses, and EDLVD on graft length required for successful intervention, multiple linear regression models were calculated. Linear regression models were checked for outliers, multicollinearity, and autocorrelation. In addition, we conducted a binominal logistic regression with the endpoint whether a graft extension was necessary.

Results

Consecutive patients with advanced coronary artery disease who underwent total arterial off-pump revascularization using radial artery as a composite graft in a T- or Y-configuration to LITA between January 2019 and December 2020 were included.

All patients underwent endoscopic radial artery harvesting. **Table 1** shows the preoperative data for all patients in our cohort. Out of 169 patients, total of 88.8% (n = 150) were male and 11.2% (n = 19) female with a mean age of 66.2 years (SD: 9.5 years). Off-pump coronary artery bypass grafting was performed on 88.2% of patients. We conducted different regression analyses for patients where radial artery in a composite graft configuration was used to bypass distal branches of the RCA to analyze whether the number of sequential anastomoses, configuration, or heart size has an influence on RA graft length. Y-configuration between LITA and radial artery (RA) was performed in 55.6% (n = 94) of patients, whereas 44.4% (n = 75) received T-configuration between LITA and RA.

Number of sequential anastomoses performed in n = 121 patients was six anastomoses in 0.8% (n = 1) of the patients, five in 5.0% (n = 6), four in 35.5% (n = 43), three in 57.0% (n = 69), two in 0.0% (n = 0), and one in 1.7% (n = 2) (**Supplementary Table 1**; all supplementary files are available online). The heart size was assessed using the left ventricular end-diastolic diameter with the mean heart size of 49.1 mm (SD: 5.9 mm) and mean radial artery length of 18.1 cm (SD: 1.4 cm) (**Fig. 1**). Depending on the (sub)-sample, we found that the RA graft length is positively influenced by the number of sequential anastomoses within the total sample (B = 0.388; p = 0.032) (F[3,115] = 2.704; p = 0.049) and for patients undergoing surgery with T-configuration (B = 0.530; p = 0.047) (F[2,49] = 2.703; p = 0.137) but not in patients undergoing surgery with Y-configuration (B = 0.203; p = 0.453) (F[2,65] = 1.101; p = 0.339). Furthermore, we employed a logistic regression model with reaching the target (yes or no) as a dependent variable. This analysis showed the length of the radial artery being the significant predictor to the endpoint in question. The whole model showed statistical significance (X^2 [6] = 28.024; p <0.001; Nagelkerke R^2 = 0.579), but

Table 1 Baseline and pre-operative patient characteristics

Baseline characteristics (N = 169)	
Sex (female) (n, %)	19 (11.2%)
Sex (male) (n, %)	150 (88.8%)
Smoker (yes) (n, %)	85 (50.3%)
Age (years) (mean ± SD, range)	66.23 ± 9.48 (45–87)
Weight (kg) (mean ± SD, range)	87.31 ± 17.88 (47.2–170.0)
Height (cm) (mean ± SD, range)	172.06 ± 11.38 (70.0–195.6)
BMI (kg/m²) (mean ± SD, range)	29.1 ± 5.45 (16.6–48.9)
BSA (m²) (mean ± SD, range)	2.00 ± 0.19 (1.5–2.6)
Clinical characteristics (N = 169)	
CCS (mean ± SD, range)	2.33 ± 1.08 (0–4)
NYHA (mean ± SD, range)	1.31 ± 0.64 (0–3)
HTN (yes) (n, %)	143 (84.6%)
Diabetes mellitus (non-insulin dependent) (yes) (n, %)	58 (34.3%)
Diabetes mellitus (insulin dependent) (yes) (n, %)	16 (9.5%)
FAM (yes) (n, %)	38 (22.5%)
DLP (yes) (n, %)	141 (83.4%)
Cerebrovascular disease (yes) (n, %)	21 (12.4%)
Peripheral vascular disease (yes) (n, %)	15 (8.9%)
Stroke/transitory ischemic attack (yes) (n, %)	11 (6.5%)
Chronic renal failure (yes) (N, %)	13 (7.7%)

BMI: body mass index; BSA: body surface area; CCS: Canadian Cardiovascular Society stage; DLP: dyslipidemia; FAM: family history; HTN: hypertension; NYHA: New York Heart Association functional stage; SD: standard deviation

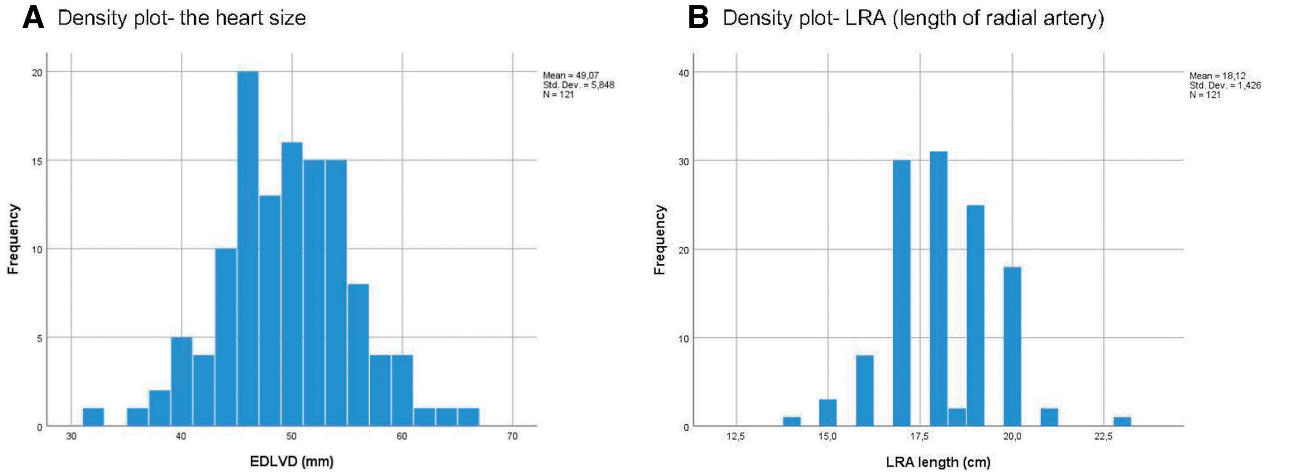

Fig. 1 Density plot: (**A**) heart size and (**B**) LRA. LRA: length of radial artery; EDLVD: end-diastolic left ventricular diameter; Std. Dev.: standard deviation

only length of the radial artery could be identified as a significant predictor if the target can be reached without graft extension (Exp[B] = 0.154; p = 0.005). Other possible predictors did not reach statistical significance. In those 121 patients, no significant correlation was found between RA length and heart size for those 121 patients (Spearman's r = 0.009; p = 0.923).

Further, we analyzed possible correlation in the whole cohort between the length of radial artery and patient's anthropomorphic measures such as height, BSA, and arm length. Correlation analysis of the total sample showed a positive relationship between radial artery length and patient's height (Spearman r = 0.461; p <0.001), BSA (Spearman r = 0.260; p = 0.001), and arm length (Spearman r = 0.519; p <0.001), but no significant correlation was found between radial artery length and heart size (Spearman r = 0.054; p = 0.485) (**Supplementary Table 2**). Separate analysis of male patients only yielded the same significant correlations (radial artery length * height: Spearman r = 0.402; p <0.001; radial artery length * BSA: Spearman r = 0.206; p = 0.011; radial artery length * arm length: Spearman r = 0.617; p <0.001; radial artery length * heart size: Spearman r = 0.018; p = 0.825), but no significant correlations were found in women (**Supplementary Table 3** and **Fig. 2**). In order to examine the influence of the graft configuration and the number of sequential anastomoses on the LRA flow, we performed separate analysis. No significant differences were found for different configurations (T: 85.9 ± 53.8 vs. Y: 85.9 ± 56.8; Mann–Whitney U = 3388.00; p = 0.665). A Kruskal–Wallis test yielded no significant differences regarding LRA flow depending on the number of sequential anastomoses (chi square(5) = 9.104; p = 0.105) (**Supplementary Table 4** and **Fig. 3**).

Finally, our analysis showed that patients with the length of radial artery of 17.1 cm (95% CI upper bound of patients with graft extension) needed an extension of the radial artery with another conduit to reach the RCA distal branches, while the lower 95% CI of the radial artery length of patients who did not need an extension was significantly higher (18.02 cm) (Mann–Whitney U = 81.500.00; p <0.001) (**Supplementary Table 5** and **Fig. 4**). The regression analysis showed that when T- configuration rather than Y-configuration is used, the length of the radial artery should be 0.53 cm per sequential anastomosis to reach the RCA distal branches (p = 0.047) (**Supplementary Table 6**).

Discussion

In the present study, we try to elucidate the technical aspects of the radial artery as a second conduit used in T- or Y- configuration during TAR.

Radial artery is an excellent conduit to be utilized in coronary artery surgery with a higher long-term patency rate as recently shown by Buxton et al. in the Radial Artery Patency and Clinical Outcomes (RAPCO) trial.[13] However, the length of the radial artery is often a limiting factor when planning to revascularize branches of the RCA as a second graft in a T- or Y-configuration.

Hence, comprehensive assessment not only of the graft quality but also of its length in relation to the

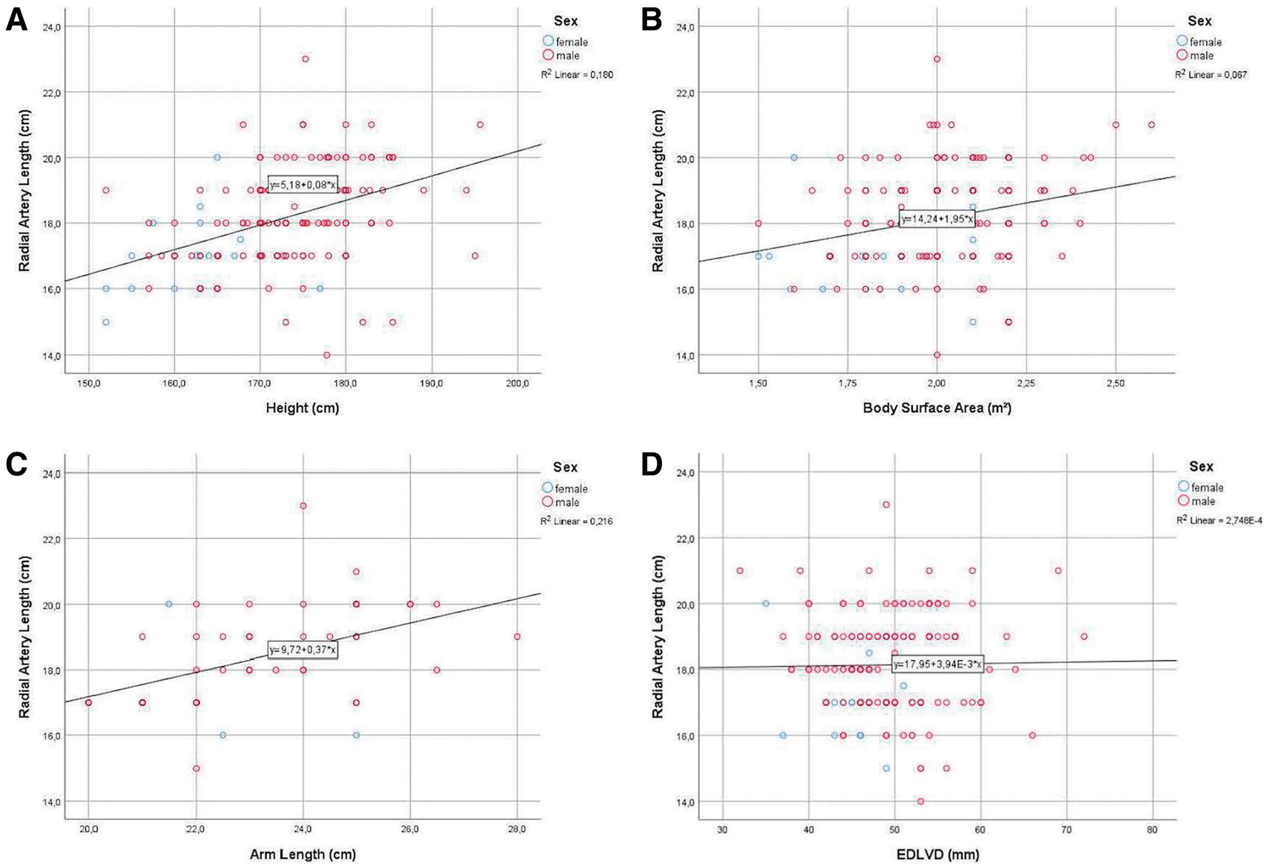

Fig. 2 Correlation plots: (**A**) LRA and height, (**B**) LRA and BSA, (**C**) LRA and arm length, and (**D**) LRA and heart size. LRA: length of radial artery; EDLVD: end-diastolic left ventricular diameter; BSA: body surface area

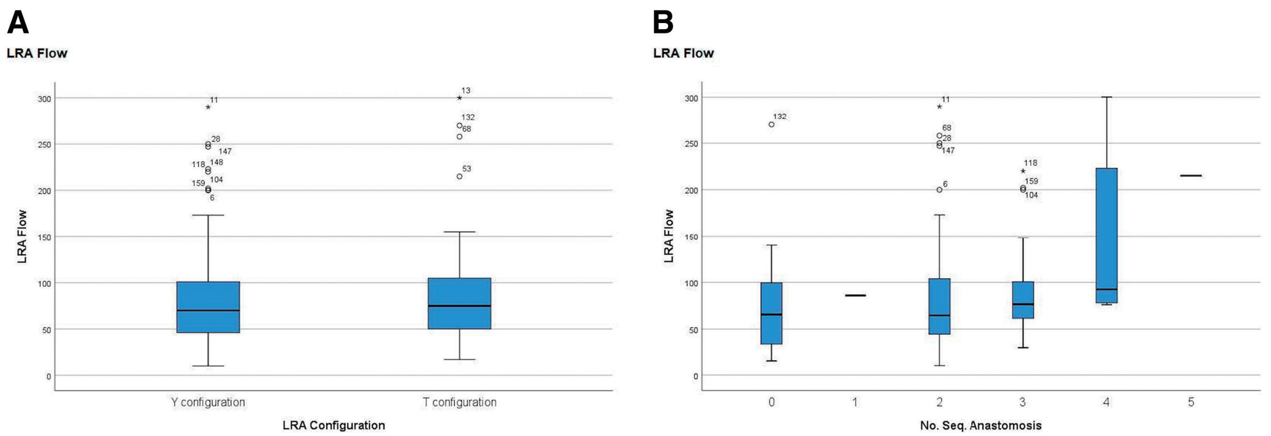

Fig. 3 A Box–Whisker plot showing distribution between (**A**) LRA flow and graft configuration (T vs Y), and (**B**) LRA flow and number of sequential anastomoses. LRA: length of radial artery

accessible targets, heart size, number of sequential anastomoses to be performed, as well as configuration modus is crucial to generate the best possible revascularization strategy, especially in three coronary territory diseases. Strategic assessment of the radial artery may already start by considering anthropomorphic data of the patient. Our data clearly show positive correlation between the length of the radial artery, the height, and the length of the forearm. Additional qualitative measurements remain essential for preoperative assessment of the potential

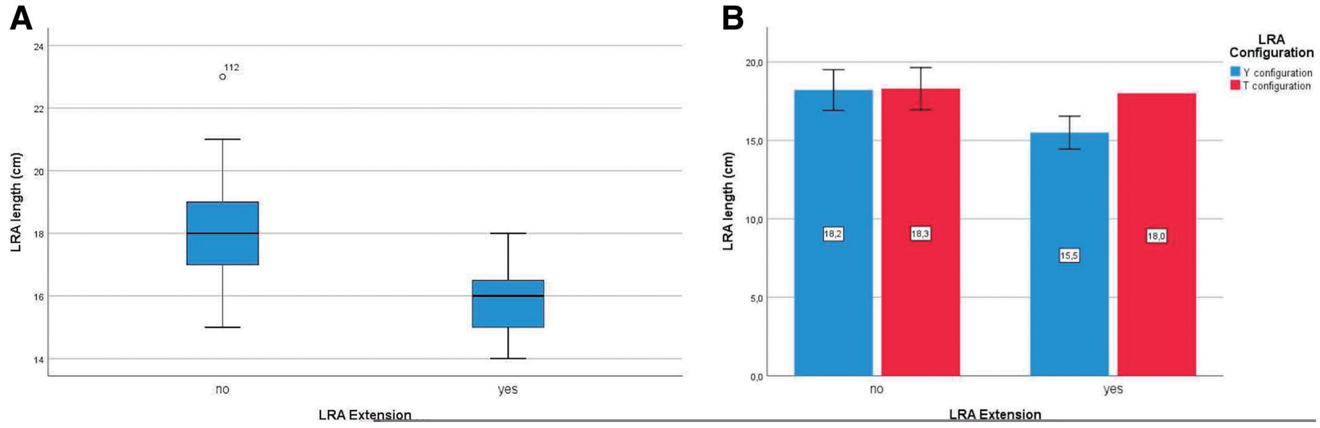

Fig. 4 (**A**) Box–Whisker plot: LRA length and extension and (**B**) bar chart comparing LRA length according to Y- or T- configuration and required extension. LRA: length of radial artery

composite graft such as Allen test and/or echo color Doppler.[14–16] Further evaluation includes the revascularization strategy bearing in mind possible coronary targets, number of sequential anastomoses, and composite graft configuration. While the number of sequential anastomoses and the type of configuration do not affect the flow in the composite graft, these factors have an impact on the required length of the radial artery. Our results highlight that per sequential anastomosis, a longer composite graft is required in a T-configuration as compared to a Y-configuration to anastomose branches of the RCA. Hence, a Y-configuration is preferable to a T-configuration when several sequential anastomoses are planned and branches of the RCA need to be grafted. Further, our results suggest that a length of composite graft of more than 15.9 cm is essential to reach branches of RCA independent of the heart size. Our measurements suggest a length of 18.02 cm in order to reach the coronary targets on the inferior wall. Thus, graft extension remains necessary to avoid composite graft failure due to hyperextension. In conclusion, our study could serve as a guide when planning TAR using radial artery as a composite graft, recommending utilization of a Y-configuration when several sequential anastomoses are required and extension of radial artery to reach branches of the RCA if its length is not sufficient.

Conclusions

Our study shows that an average length of 18.02 cm of radial artery is needed in 95% of the cases to reach targets on the RCA distal branches in the analyzed sample. Further, when using a T-configuration, we need 0.53 cm more length per anastomosis compared to a Y-configuration to achieve TAR. Patient's arm length, height, and BSA are predictors for the radial artery length. Additionally, radial artery length is the only significant predictor of whether the targets will be reached without graft extension. Further, there is a significant correlation between the length of the radial artery and the number of sequential anastomoses in the T-configuration compared to the Y-configuration.

Disclosure Statement

None.

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