European Review for Medical and Pharmacological Sciences 2015; 19: 3006-3011

Evaluation of hand circulation with CardioWaves photoplethysmograph device during Allen test in healthy volunteers

G. TANZILLI, G. TRUSCELLI, F. BARILLÀ, N. COCCO, G. PANNITTERI, A. TANZILLI, S. AL KINDY, E. MANGIERI[1], C. GAUDIO

Department of Heart and Great Vessel "A. Reale", Sapienza University of Rome, Rome, Italy
[1]Electron Solutions Ltd, London, UK

Abstract. – OBJECTIVE: Radial artery occlusion is a potential complication of transradial procedures and its occurrence ranges from 0.8 to 30%. It is virtually always asymptomatic but the functional and sensorial consequences of a long acting hand hypoperfusion could go underestimated. CardioWaves is a novel photoplethysmograh device that allows us to detect the pulse wave amplitude of the blood flowing to the hand. Our objective was to assess in normal subjects the hand blood flow supplied by radial arteries and ulnopalmar arches, respectively, by using CardioWaves device during modified Allen's test (MAT).

PATIENTS AND METHODS: MAT was performed on both hands of 60 normal subjects, age ranging 21 to 66 years, without any cardiovascular factor risk.

RESULTS: Photoplethysmograh and MAT showed a high positive linear correlation (r=0.93). Despite that, MAT tends to give a higher reading by between 1.05 and 1.6 sec. 11 of 120 readings (9%) by CardioWaves showed values of radial/ulnar pulse amplitude ratio more than mean + 1 SD, suggesting a significant decrease in ulnopalmar arterial circulation when radial blood flow supply would ceased.

CONCLUSIONS: The CardioWaves device allows us an accurate reading of the flow because of its independency from respiratory changes. Furthemore, the evaluation of radial and ulnar pulse wave amplitude and the ratio between them would reveal an insufficient blood flow supply by the ulnar artery irrespective of the MAT results. We suggest that their assessment before performing coronary angiography and interventions may reduce potential complication of transradial access.

Key Words:
Modified Allen's test, Photoplethysmograph, Hand circulation, Radial arteries, Ulnopalmar arterial arch.

Introduction

Transradial coronary catheterization is considered safe, feasible, and effective. However, in order to avoid ischemic hand occurrence, percutaneous radial artery cannulation is restricted to patients with normal hand collateral supply by ulnopalmar arterial arches as evaluated by modified Allen's test (MAT). The prevalence of an abnormal MAT in patients undergoing coronary angiography ranges from 6.4% to 27%[i,ii], but the definition of a positive result may be overstated by the proper subjective visual assessment of the test especially when hand blushing is slow to occur. Therefore, in absence of radial artery drive the opening of collateral channels does not necessarily mean the restoration of normal hand perfusion. Thus, the qualitative evaluation of the response may provide a discrete number of false positive or false negative results.

Noteworthy, radial artery occlusion is a potential complication of transradial procedures and its occurrence ranges from 0,8 to 30%[iii-5]. It is virtually always asymptomatic but the functional and sensorial consequences of a long acting hand hypoperfusion could go underestimated. Thus, the quantitative detection of hand perfusion fall during radial compression may be of value in identifying subjects at risk for chronic ischemic signals when radial occlusion would occur after transradial percutaneous approach.

CardioWaves is a novel photoplethysmograh device that allows us to detect the pulse wave amplitude of the blood flowing to the hand. Accordingly, the damping of pulse tracing during radial compression may unmask the insufficient ulnar dependent hand perfusion.

Corresponding Author: Gaetano Tanzilli, MD; e-mail: gaetano.tanzilli@uniroma1.it
Giovanni Truscelli, MD; e-mail: giovanni_truscelli@yahoo.it

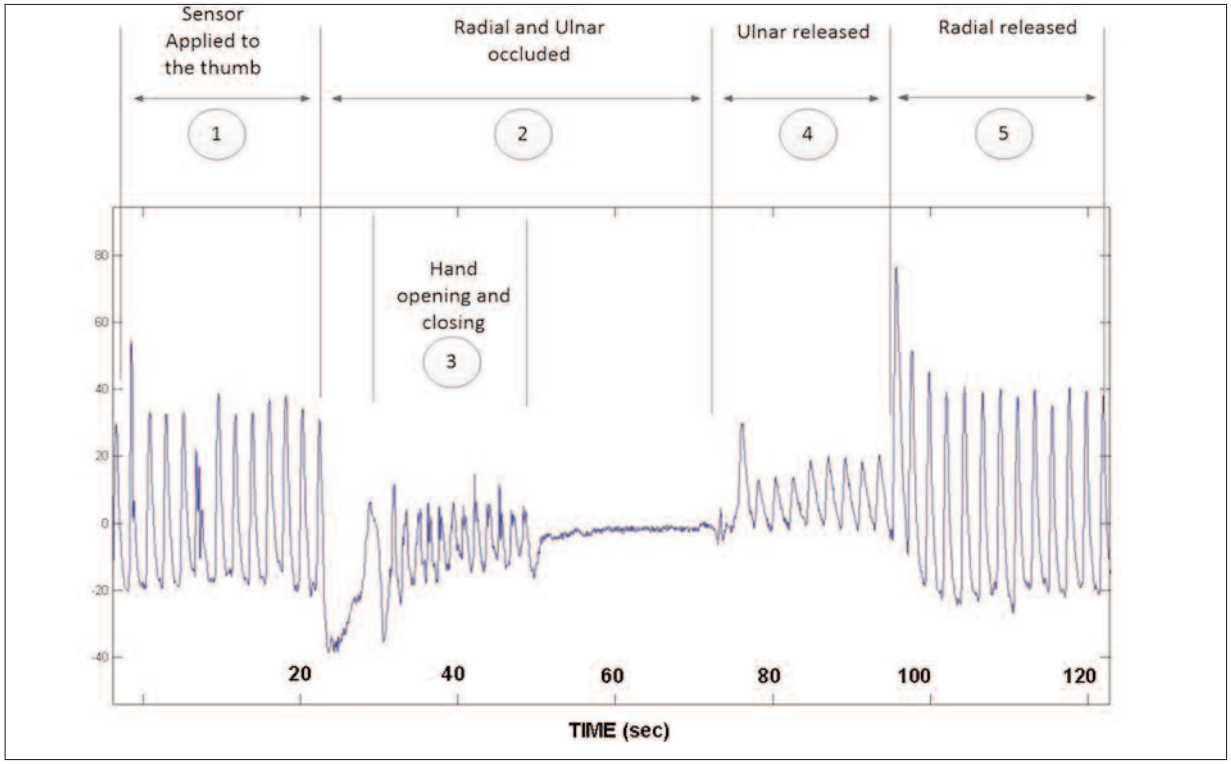

Figure 1. Pulse wave tracing recorded by CardioWaves during MAT.

Our objective was to assess in normal subjects the hand blood flow supplied by radial arteries and ulnopalmar arches, respectively, by using CardioWaves device during MAT.

Patients and Methods

Population

Sixty normal subjects, age ranging from 21 to 66 years, without any history of systemic hypertension, diabetes and atherosclerotic peripheral vascular disease were consecutively enrolled. After obtaining written informed consent, all subjects underwent modified AT of both right and left side, thus providing 120 readings.

Modified AT

After localization and assessment of the radial pulse, the modified AT was performed on both hands, with the patient in supine position, as follows. After vigorous compression of both radial and ulnar arteries, the patient was asked to forcefully clench one hand several times to expel blood from the hand. The hand was then opened, avoiding wrist and fingers hyperextension, before release of the ulnar artery compression. The amount of time to achieve maximal palmar blush was measured after compression release of the ulnar artery with continuing occlusive pressure of the radial artery. The AT responses were defined as normal, intermediate and abnormal if time to maximal blushing was within 5 sec, between 6 and 10 sec, or after 10 sec, respectively.

Plethysmography

Plethysmography was recorded by CardioWaves Photopletysmograph (Electron Solutions Ltd, London, UK) with the clamp sensor applied to the thumb. It allows a very constant accurate reading of the blood flow. One additional feature of the used photoplethysmograh, when compared to other photoplethysmopgrahs and pulse oxymeters, is the repeatability and consistency of the produced waveforms when applied to the same subject. Pulse waves amplitude were recorded before test, during compression of both arteries and immediately after ulnar and radial artery release with the clamp sensor applied to the thumb (Figure 1). The displayed signal was used to measure the time that the blood would take to start pulsing back throughout the hand

vessels. Pulse waveform amplitude was measured on a beat-to-beat basis as the vertical distance between peak and preceding valley trough in the waveform and was expressed as arbitrary units. All tests were repeated after 30 minutes for the assessment of repeatability of measurements.

Statistical Analysis

All data were expressed as mean SD. The paired 2-tailed Student *t* test was used for comparison of values between continuous variable. The chi square test was used to compare categorical variable. The time to maximal hand blushing (sec) measured during MAT and the ulnar stabilise time after release of ulnar compression (sec) measured by CardioWaves were used to compare the results between the two techniques. The linear correlation coefficient between the two methods and linear regression analysis were calculated according to standard approach. Agreement between the data obtained by means of the two techniques was assessed by Bland and Altman method[6]. Individual differences between values of time to maximal hand blushing and ulnar stabilise time were plotted on a graph against the mean values of the two measurements. The mean of the differences, together with the corresponding 95% confidence intervals, was also calculated. Furthermore, linear correlation coefficient and the method of Bland and Altman were also used to define variability between CardioWaves measurements to assess their repeatability. A p value < 0.05 was considered significant.

Results

The parameters measured by CardioWaves plethysmograph are depicted in Table I. The rates of photoplethysmographic readings significantly differed across the three MAT results. An abnormal Allen's test was found in 18/120 (15%) readings and an intermediate response was seen in 25/120 (20%) readings. On the contrary, an abnormal response by Cardio Waves photoplethysmograph was seen in 8/120 (7%) and an intermediate response in 20/120 (17%) readings (chi square 3-92, p<0.05). Overall, the mean time for maximal blushing measured by MAT was 5-7±4-4 sec: it was 5-45±4-4 for the right side and 5-9±4-5 for left side (p=NS). The recovery time of blood flow as determined by CardioWaves was significantly shorter than that evaluated by MAT (p<0.0001). In fact, the mean time for the ulnar stabilise time after release of ulnar compression was 4.3±3.7 sec: it was 4.2±3.6 for the right side and 4.4±3.8 for left side (p=NS).

Variability between CardioWaves measurements was evaluated by repeating photoplethysmograph examination 30 min later. The repeatability study (Figure 2) showed an high correlation between the two readings (r=0.97) with a standard error of estimates 0.14 sec and the 95% confidence interval 0,04 to 0,6 sec. Photoplethysmograh and MAT showed a high positive linear correlation (r=0.93). Despite that, mean difference between MAT and plethysmographic measurements was 1.32 sec, with a standard error of the estimates 0.25 and the 95% confidence interval 1.05 to 1.6 sec (Figure 3). Thus, modified AT tends to give a higher reading by between 1.05 and 1.6 sec.

After the release of radial compression an increase of pulse wave amplitude was measured in all but 4 readings. Mean value between radial vs ulnar pulse amplitude ratio was 2.16 ± 1.54 arbitrary units confirming the main role of radial artery in hand blood flow supply as assessed in normal subjects.

Noteworthy, irrespective of recovery time of hand circulation, 11 out of 120 readings (9%) showed values of radial/ulnar pulse amplitude ratio more than mean + 1 SD, suggesting a significant decrease in hand collateral circulation via the ulnopalmar arteries when radial blood flow supply would ceased.

Table I. Parameters measured by CardioWaves plethysmograph.

	Mean	± SD
Ulnar TIME response after release (sec)	1.9	2.3
Ulnar Stabilise Time (sec)	4.4	3.7
Radial TIME response after release (sec)	0.7	0.4
Radial Stabilise Time (sec)	2.6	1.9
Radial/Ulnar Ratio	2	1.3

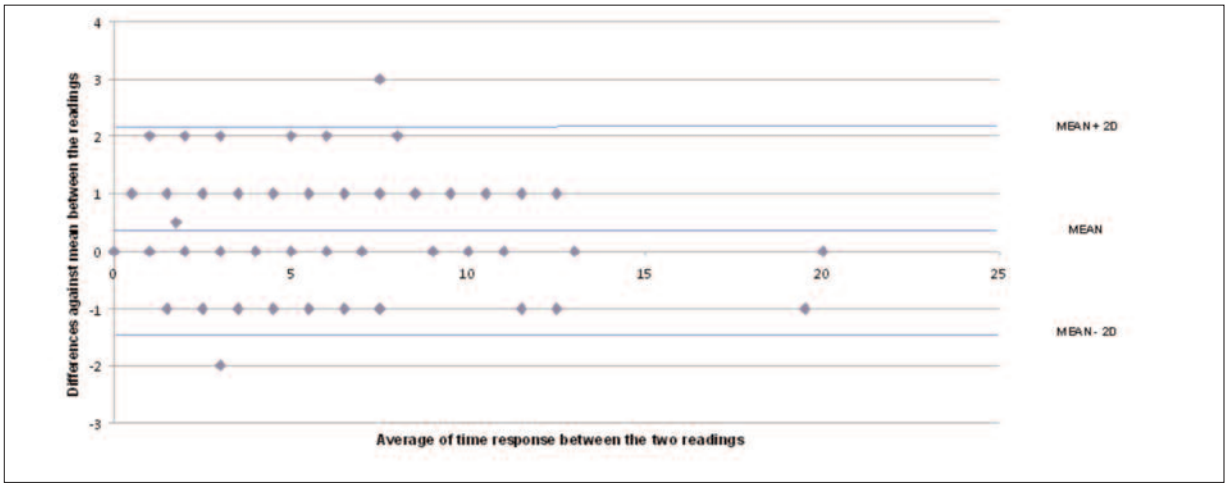

Figure 2. Assessment of measurements repeatability by CardioWaves.

Discussion

This is the first study investigating the safety, feasibility and measurements repeatability of a new plethysmograph in assessing hand circulation across the variety of MAT response in a population of normal subjects. Our results can be summarized as follows.

First, our results confirm the value of plethysmographic readings in reducing observer error in the interpretation of the hand circulatory response thus avoiding many of the pitfalls of the MAT.

Second, CardioWaves plethysmograph works irrespective of respiratory variations as observed in pulse oximetry plethysmographic waveform amplitude.

Third, the reproducibility of waveform tracings as determined by repeatability study allows us to identify ongoing variations in pulse perfusion over the time in the same subjects.

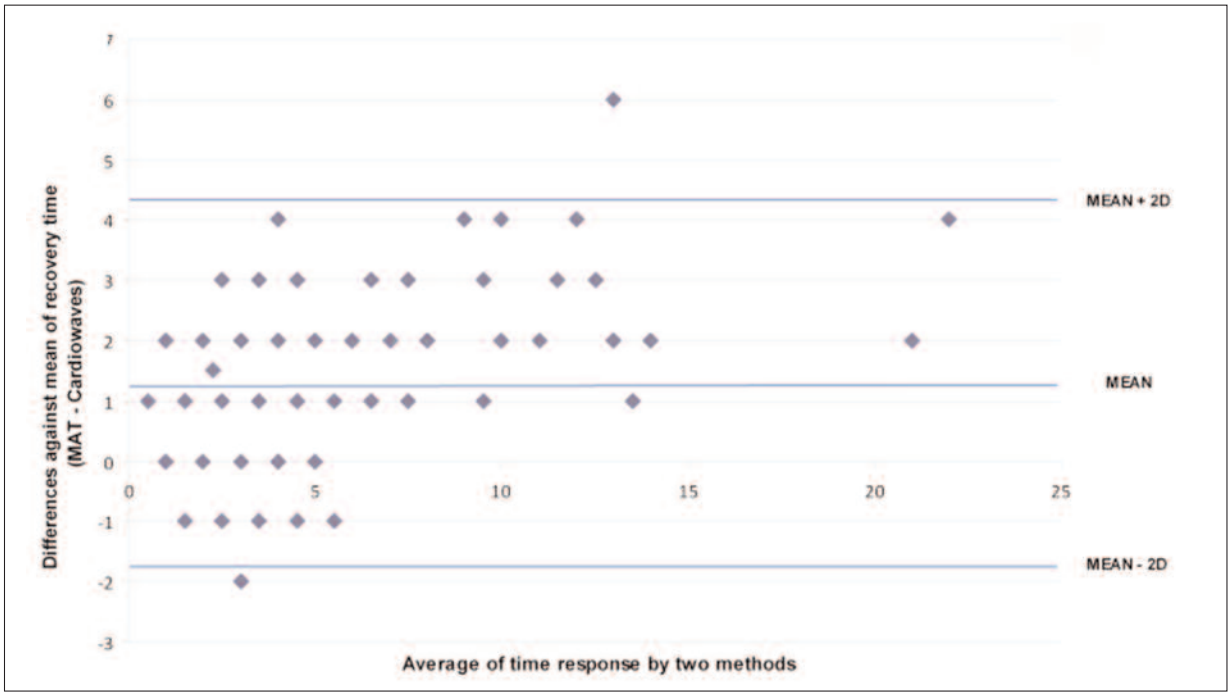

Figure 3. Differences between the recovery time of hand circulation by MAT and CardioWaves against the mean of the measurements by two methods.

So, this could represent a prerequisite for selecting pts who can safely undergo transradial approach. In fact, the percutaneous radial cannulation for coronary angiography and interventions has been associated with consistent radial artery occlusion rate[7-10].

Given the importance of the ulnar artery and interosseous collaterals in maintaining hand perfusion in the event of radial artery occlusion, a reliable method of assessing the ulnar artery supply to the hand before radial artery cannulation is mandatory. The MAT is a simple qualitative test that is used for this purpose. Nevertheless, authors have reported that assessment of the ulnar blood flow is unnecessary, owing to the absence of ischemic complications[11-13] even in patients with abnormal MAT response, thus, indicating that MAT does not provide an adequate assessment of hand collateral flow.

As a consequence, a number of methods have been developed to improve the value of the Allen's test in predicting hand ischemia.

Barbeau et al[14] used plethysmography and pulse oximetry to improve the sensitivity of the MAT.

Based on the morphology of the plethysmography tracing, the response to the test was categorized into 1 of 4 types. Patients with type A and type B responses have uninterrupted arterial filling during radial occlusion. At the opposite, patients with a type D response (1.5% of patients) do not have pulsatile collateral flow and have to be excluded from transradial catheterization. The delayed appearance of a pulsatile tracing in patients with a type C response probably depends on the time required for the recruitment of collaterals. It is conceivable that this pattern of response is more frequent pts with abnormal MAT results. The activation of compensatory recruitable collateral arteries might explain the low rate of ischemic hand complication reported in the literature[10,11,15,16]. However, the lack of published cases of severe hand ischemia does not necessarily mean it does not occur. The chronic hypoperfusion due to the fall of capillary perfusion pressure may result in late claudication or sensory changes with long lasting functional hand impairment. Using this system, the authors report that they have not observed a single case of hand ischemia in more than 7000 patients undergoing transradial procedures at their institution. Despite that, pulse oximeter and plethysmograph provide visual signal of the magnitude of flow that can be recorded without offering a sufficient analysis of the adequacy of flow. In our study, the CardioWaves device allows us to detect the pulse wave amplitude of the blood flowing to the hand and to measure the relative contribution of ulno-palmar circulation during Allen's test. The release of the radial artery resulted in an immediate increase in pulse tracing to the principal artery of the thumb in all but 11 readings, probably depending on changes of both blood volume and perfusion pressure. In a such cases, the higher changes in pulse amplitude provides the evidence that the ulnar dependent blood supply may be inadequate to compensate over time for occlusion of the radial artery. As a consequence, sensorial symptoms of chronic hypoperfusion may appear.

Greenwood et al[12] assessed the relative contribution of collateral palmar circulation during radial artery occlusion. They showed that patients with an abnormal AT had an immediate reduction in blood flow to the principal artery of the thumb by 90%, improving to a 75% reduction after 30 min of arterial occlusion and increased thumb capillary lactate, compared with patients with a normal MAT.

The authors assume that the relative reduction in blood supply has physiological significance, and that the capillary recruitment in hand circulation is unable to maintain over the time an adequate tissue perfusion. This would suggest inadequate thumb perfusion pressure, which could lead to ischemic complications with prolonged occlusion. In this context, they affirm that transradial cardiac catheterization should not be performed in patients with an abnormal Allen's test. Nevertheless, relying on this assumption a discrete number of pts with subjective false positive AT would be denied this approach site.

More recently, Valgimigli et al[11] did not find differences in lactate levels after the procedure and at follow-up in pts with normal, intermediate and abnormal MAT response. Moreover, pulse oximeter plethysmography readings showed an increase of the prevalence of patterns A and B over the time at the expenses of pattern C and D in pts with intermediate and abnormal MAT results.

This observations support the concept that anatomically pre-existing capillary reserve can be functionally recruited during and after transradial percutaneous approach even in patients with delayed response to MAT, thus reducing the risk of severe hand ischemia when radial flow supply would ceased.

Conclusions

Our results confirm the value of plethysmography readings in assessing hand collateral circulation, thus avoiding many of the pitfalls of the MAT. Differently from previous observations, we also evaluated radial and ulnar pulse wave amplitude of the blood flowing to the hand and the ratio between them as representative of the relative amount of hand perfusion supplied by radial artery. Higher values of ratio would reveal an insufficient blood flow supply by the ulnar artery irrespective of the MAT results and could represent a prerequisite for selecting pts who can safely undergo transradial approach.

Therefore, the use of CardioWaves device allows a very constant accurate reading of the blood flow because of its independency from respiratory changes. One additional feature of the used photoplethysmograh, when compared to other photoplethysmograhs and pulse oxymeters, is the repeatability and consistency of the produced waveforms when applied to the same subject(s). The use of CardioWaves device is a very original novelty and we suggest their application before performing coronary angiography to reduce potential complication of transradial access.

Conflict of Interest

The Authors declare that there are no conflicts of interest.

References

1) Barbeau GR, Arsenault F, Dugas L, Simard S, Lariviere M. Evaluation of the ulnopalmar arterial arches with pulse oximetry and plethysmography: comparison with the Allen's test in 1010 patients. Am Heart J 2004; 147: 489-493.
2) Benit E, Vranckx P, Jaspers L, Jackmaert R, Poelmans C, Coninx R. Frequency of a positive modified Allen's test in 1000 consecutive patients undergoing cardiac catheterization. Cathet Cardiovasc Diagn 1996; 38: 352-354.
3) Rao SV, Bernat I, Bertrand OF. Remaining challenges and opportunities for improvement in percutaneous transradial coronary procedures. Eur Heart J 2012; 33: 2521-2528.
4) Stella PR, Keimeneij F, Laarman GJ, Odekerken D, Slagboom T, Van der Wieken R. Incidence and outcome of radial artery occlusion following transradial artery coronary angioplasty. Catheter Cardiovasc Interv 1997; 40: 156-158.
5) Rathore S, Stables RH, Pauriah M, Hakeem A, Mills JD, Palmer ND, Perry RA, Morris JL. Impact of length and hydrophilic coating of the introducer sheath on radial artery spasm during transradial coronary intervention: a randomised study. J Am Coll Cardiol Int 2010; 3: 475-483.
6) Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1986; 1: 307-310.
7) Sanmartin M, Gomez M, Rumoroso JR, Sadaba M, Martinez M, Baz JA, Iniguez A. Interruption of blood flow during compression and radial artery occlusion after transradial catheterization. Catheter Cardiovasc Interv 2007; 70: 185-189.
8) Nagai S, Abe S, Sato T, Hozawa K, Yuki K, Hanashima K, Tomoike H. Ultrasonic assessment of vascular complications in coronary angiography and angioplasty after transradial approach. Am J Cardiol 1999; 83: 180-186.
9) Zankl AR, Andrassy M, Volz C, Ivandic B, Krumsdorf U, Katus HA, Blessing E. Radial artery thrombosis following transradial coronary angiography: incidence and rationale for treatment of symptomatic patients with low-molecular-weight heparins. Clin Res Cardiol 2010; 99: 841-847.
10) Kiemeneij F, Laarman GJ, Odekerken D, Slagboom T, van der Wieken R. A Randomized Comparison of Percutaneous Transluminal Coronary Angioplasty by the Radial, Brachial and Femoral Approaches: the ACCESS study. J Am Coll Cardiol 1997; 29: 1269-1275.
11) Benit E, Vranckx P, Jaspers L, Jackmaert R, Poelmans C, Coninx R. Frequency of a positive modified Allen's test in 1000 consecutive patients undergoing cardiac catheterization. Cathet Cardiovasc Diagn 1996; 38: 352-354.
12) Abu-Omar Y, Mussa S, Anastasiadis K, Steel S, Hands L, Taggart DP. Duplex ultrasonography predicts safety of radial artery harvest in the presence of an abnormal Allen test. Ann Thorac Surg 2004; 77: 116-119.
13) Greenwood MJ, Della-Siega AJ, Fretz EB, Kinloch D, Klinke P, Mildenberger R, Williams MB, Hilton D. Vascular communications of the hand in patients being considered for transradial coronary angiography. Is the Allen's test accurate? J Am Coll Cardiol 2005; 46: 2013-2017.
14) Barbeau GR, Arsenault F, Dugas L, Simard S, Lariviere MM. Evaluation of the ulnopalmar arterial arches with pulse oximetry and plethysmography:comparison with the Allen's test in 1010 patients. Am Heart J 2004; 147: 489-493.
15) Valgimigli M, Campo G, Penzo C, Tebaldi M, Biscaglia S, Ferrari R. Transradial coronary catheterization and intervention across the whole spectrum of Allen test results. J Am Coll Cardiol 2014; 63: 1833-1841.
16) Barbeau GR, Arsenault F, Dugas L, Simard S, Lariviere M. Evaluation of the ulnopalmar arterial arches with pulse oximetry and plethysmography: comparison with the Allen's test in 1010 patients. Am Heart J 2004; 147: 489-493.