Assessment of Cardiovascular Risk Markers from Ultrasound Images: System Reproducibility

E Bianchini[1], A Corciu[1], L Venneri[1], F Faita[1],
C Giannarelli[2], V Gemignani[1], M Demi[1,3]

[1]CNR Institute of Clinical Physiology, Pisa, Italy
[2]Department of Internal Medicine, University of Pisa, Pisa, Italy
[3]Esaote SpA, Florence, Italy

Abstract

In this work the reproducibility of a system for the automatic assessment of carotid intima-media thickness and stiffness from ultrasound image sequences is evaluated. Sequences of the right/left common carotid arteries of 10 healthy volunteers were analyzed repeatedly in order to evaluate the reproducibility between observers and sessions; data were presented as the coefficients of variation. Results regarding the inter-observer and intra-observer intra-session variabilities were comparable. Intra-observer intersession variability was similar to those previously mentioned for the parameters which were derived directly from the B-mode image analysis, but larger for the others. The variability of the data obtained with the system is comparable to that reported in literature for other techniques used for the evaluation of the mechanical properties of large arteries. Thus, the reproducibility of our device, its low-cost and flexibility make it suitable for large population studies.

1. Introduction

The identification of cardiovascular diseases at an early stage is extremely important to prevent fatal events. For this reason, besides general cardiovascular risk factors, such as hypertension, diabetes, and smoking, more objective indicators based on the measurement of physiological parameters have been adopted. The mechanical properties of large arteries are among these. In particular, the increase of the Carotid Intima-Media Thickness (IMT) and the increase of arterial stiffness are thought to play a crucial role in the development of cardiovascular diseases. IMT, which is defined as the distance between the leading edge of the lumen-intima interface and the leading edge of the media-adventitia interface can be assessed by ultrasonography [1]. Indices of local arterial stiffness [2] can be evaluated by measuring the diameter change during the heart cycle (stroke change in diameter or distension) from ultrasound data in conjunction with the local pulse pressure.

A system for the automatic assessment of the aforementioned parameters from ultrasound images was developed in our lab and, in this work, its reproducibility on the carotid artery was evaluated.

2. Methods

The system

The device, which was introduced in [3], is able to evaluate the instantaneous diameter of the artery by using a contour tracking technique applied to B-mode ultrasound image sequences of a longitudinal section of the vessel. Moreover, the IMT can be measured simultaneously.

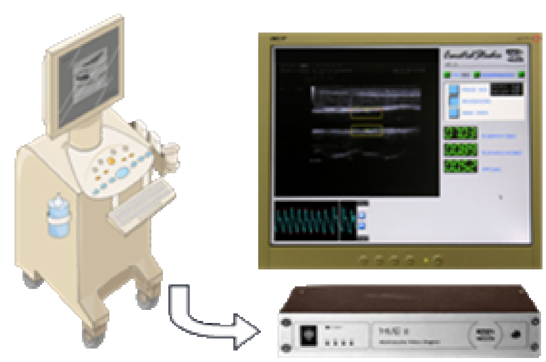

Figure 1. The system

The method is based on a new algorithm [4, 5] which is particularly appropriate for ultrasound images because it is robust to the speckle noise which is typical of ecographic signals and it is suitable for real-time implementation. The algorithm was implemented on a

Variability	Observer	Session	Measurements on each subject
Intraobserver intrasession	1	1	3 right carotid artery 3 left carotid artery
Interobserver intrasession	1	1	3 right carotid artery 3 left carotid artery
Interobserver intrasession	2	1	3 right carotid artery 3 left carotid artery
Intraobserver intersession	1	1	3 right carotid artery 3 left carotid artery
Intraobserver intersession	1	2	3 right carotid artery 3 left carotid artery

Table 1. Study protocol

stand-alone video processing system which is able to acquire the analog video signal from any ultrasound equipment and shows the results on a graphical user interface in real-time (Figure 1). When an acquisition is carried out, the mean of the distension values and the mean of the diastolic diameter values of the last 8 seconds of the examination are evaluated. Moreover, the mean value of the far wall intima-media thickness measurements is also computed.

Study design

Longitudinal scans of the right and left carotid arteries of 10 young healthy volunteers, 5 males and 5 females, were acquired and analysed repeatedly in two different sessions, 7 days apart. During the examination the subjects were supine, at rest, and in a quiet air conditioned room. During each session, the blood pressure of the arm was recorded at the left brachial artery using a Dinamap XL device.

The intima-media thickness (IMT), the diastolic diameter (Dd), the stroke change in diameter (ΔD), the cross-sectional compliance coefficient (CC) and the cross-sectional distensibility coefficient (DC) were calculated on each ultrasound image sequence by using our device. In particular, the cross sectional compliance and distensibility coefficients were computed as:

$$CC = \Delta A / PP; \;\; DC = CC/A_d$$

where ΔA represents the stroke change in lumen area, Ad the diastolic lumen area and PP the brachial pulse pressure, respectively. ΔA and Ad were evaluated from the diameter values, assuming the cross-section of the artery to be circular.

Session 1

During the first session two operators (observer 1 and 2) were involved in order to obtain the intra-observer and inter-observer intra-session variability; both of them acquired three image sequences of each vessel and analyzed them by using our system.

Session 2

During the second session, which was held 7 days later, operator 1 repeated the analysis in order to evaluate the intra-observer intersession variability. In this case also three image sequences of each vessel were acquired and then analyzed by using our system.

The study protocol is described in Table 1. The probe was removed and repositioned after each acquisition. Moreover, the blood pressure of the arm was recorded once per session, at the end of the scans.

Data analysis

The variability was presented as the coefficient of variation (CV), which is defined as the ratio of the standard deviation to the mean of the measurements; values were expressed as a percentage.

The intra-observer intra-session variability was computed as the mean +/- standard deviation of the CVs between the three measurements performed by operator 1 on each vessel during the first session.

With regard to the inter-observer intra-session analysis, the variability was evaluated as the mean +/- standard deviation of the CVs between pairs of corresponding measurements obtained on each vessel during session 1 (one was performed by observer 1 and the other by observer 2, respectively).

Finally, intra-observer intersession variability was computed as the mean +/- standard deviation of the CVs between pairs of corresponding measurements which were performed by operator 1 during the different sessions on each vessel.

3. Results

The results regarding the repeated measurements are

Variability	IMT	D_d	ΔD	CC	DC
intraobserver intrasession	7%±6%	2%±1%	11%±7%	11%±7%	13%±8%
interobserver intrasession	8%±8%	3%±2%	11%±10%	12%±11%	13%±12%
intraobserver intersession	6%±6%	3%±2%	12%±10%	16%±11%	17%±12%

Table 2. Mean coefficients of variation of the measurements

shown in Table 2. The variability of PP between the two sessions was 7%±7%.

4. Discussion and conclusions

In recent years, great attention has been placed on the assessment of the carotid intima-media thickness and stiffness. In fact, vessel wall properties of large arteries are thought to play a crucial role in the development of cardiovascular diseases and they can be assessed by analyzing image sequences obtained with ultrasounds, that is with a non-invasive technique. Initially, the analysis was performed manually, then automatic systems were introduced to reduce the variability of the measurements and to make them less time consuming. In this work, the reproducibility of a device for the automatic assessment of the carotid IMT and stiffness was evaluated. In fact, it is very important to test the robustness of systems like the device we propose, which could be used in clinical applications or epidemiological studies.

Results regarding the inter-observer and intra-observer intra-session variabilities were comparable. Intra-observer intersession variability was similar to those previously mentioned for IMT, Dd, and ΔD, but larger for CC and DC; this is due to the fact that the evaluation of the local stiffness parameters is influenced by the PP measurement that presented a variation on its own, whereas IMT, Dd and ΔD were derived directly from the B-mode image analysis alone. We have to point out that in this study, pressure was acquired in the brachial artery and not in the carotid artery, which was the vessel under investigation. Furthermore, the PP measurements were not performed simultaneously with the acquisition of the B-mode images. This temporal delay could have caused random variations due to the lack of alignment between the measure of the pressure stimulus and that of the corresponding distension.

Moreover, it must be said that the results regarding IMT and diameter here reported are worse than those regarding the technical reproducibility of the device, which was evaluated in previous works [6, 7], by estimating the variability on the same image sequences. It does however include important aspects of this type of examination with regard to the technical difficulty of ultrasound imaging and the variation in the physiological condition of the subjects. It is also important to underline that the examinations carried out in this study were performed as in clinical practice, that is without using time consuming expedients to improve their quality; in some works present in literature a baseline image of the analyzed vessel was exploited as a guide to match the repeated images to the baseline image, whereas in other studies the mean value of several acquisitions was computed to improve the robustness of the results .

However, the reproducibility of the device is comparable to that reported in literature for other techniques used for the assessment of the wall properties of large arteries [8, 9, 10, 11, 12, 13]. Furthermore, the coefficients of variation evaluated here are comparable to those presented, in previous years, for highly precise but more expensive and complex ultrasound RF based systems [14].

Finally, it is also important to underline that our device can be easily integrated in medical labs since it can be used with any ultrasound equipment.

In conclusion, the robustness of the system analyzed in this paper is not influenced by the observers' skill for those parameters which directly derive from the B-mode image analysis. Moreover, the results obtained in this work are comparable to those reported in literature for other techniques used for the assessment of the wall properties of large arteries. Hence, the reproducibility of our device as well as its low-cost and flexibility make it suitable for large population studies.

Acknowledgements

This work was supported by a grant from Esaote SpA and by the Institute of Clinical Physiology.

References

[1] Touboul PJ, Hennerici MG, Meairs S, Adams H, Amarenco P, Bornstein N, Csiba L, Desvarieux M, Ebrahim S, Fatar M, Hernandez R, Jaff M, Kownator S, Prati P, Rundek T, Sitzer M, Schminke U, Tardif JC, Taylor A, Vicaut E, Woo KS, Zannad F, Zureik M. Mannheim carotid intima-media thickness consensus (2004-2006). An update on behalf of the Advisory Board

of the 3rd and 4th Watching the Risk Symposium, 13th and 15th European Stroke Conferences, Mannheim, Germany, 2004, and Brussels*, Belgium, 2006.* Cerebrovasc Dis. 2007; 23(1): 75-80.
[2] Laurent S, Cockcroft J, Van Bortel L, Boutouyrie P,, Giannattasio C, Hayoz D, Pannier B, Vlachopoulos C, Wilkinson I, Struijker-Boudier H on behalf of the European Network for Non-invasive Investigation of Large Arteries. Expert consensus document on arterial stiffness: methodological issues and clinical applications. European Heart Journal 2006; 27:2588-2605.
[3] Bianchini E**,** Giannarelli C, Faita F, Raimo K, Gemignani V, Ghiadoni L, Demi M. Assessment of local arterial stiffness from ultrasound images. Proceedings of the 34th Annual Conference of Computers in Cardiology 2007; Vol. 34: 761-764.
[4] Demi M, Paterni M, Benassi A. The first absolute central moment in low level image processing. Computer Vision and Image Understanding 2000 Oct; 80(1):57-87.
[5] Faita F, Gemignani V, Giannoni M, Benassi A, Demi M. The first absolute moment as an edge-detector in cardiovascular imaging: a comparison with two well known edge-detectors. Proceedings of the 31th Annual Conference of Computers in Cardiology 2004; Vol. 31: 561-564.
[6] Gemignani V, Faita F, Ghiadoni L, Poggianti E, Demi M. A system for real-time measurement of the brachial artery diameter in B-mode ultrasound images. IEEE Transaction on Medical Imaging 2007; 26: 393-404
[7] Faita F, Gemignani V, Bianchini E, Giannarelli C, Ghiadoni L, Demi M. Detection of artery interfaces: a real-time system and its clinical applications. SPIE International Symposium Medical Imaging, 2008; 1-10.
[8] Kanters S D, Algra A, Van Leeuwen M S, Banga J D. Reproducibility of in vivo carotid intima-media thickness measurements: a review. Stroke 1997 March; 28 (3): 665-671.
[9] Selzer R H, Mack W J, Lee P L, Kwong-Fu H, Hodis H N. Improved common carotid elasticity and intima-media thickness measurements from computer analysis of sequential ultrasound frames. Atherosclerosis 2001; 154:185-193.
[10] Kanters S D J M, Elgersma O E H, Banga J D, Van Leeuwen M S , Algra A. Reproducibility of measurements of intima-media thickness and distensibility in the common carotid artery. European Journal of Vascular and Endovascular Surgery 1998; 16:28-35.
[11] Gamble G, Zorn J, Sanders G, MacMahon S, Sharpe N. Estimation of arterial stiffness, compliance, and distensibility from M-mode ultrasound measurements of the common carotid artery. Stroke 1994 January; 25 (1): 11-26.
[12] Woodman R J, Kingwell B A, Beilin L J, Hamilton S E, Dart A M, Watts G F. Assessment of central and peripheral arterial stiffness. American Journal of Hypertension 2005; 18:249-260.
[13] Millasseau S C, Stewart A D, Patel S J, Redwood S R, Chowienczyk P J. Evaluation of carotid-femoral pulse wave velocity: influence of timing algorithm and heart rate. Hypertension 2005; 45: 222-226.
[14] Kool M J F, Van Merode T, Reneman R S, Hoeks A P G, Struyker Boudier H A J, Van Bortel L M A B. Evaluation of reproducibility of a vessel wall movement detector system for assessment of large artery properties. Cardiovascular Research 1994 May; 28(5):610-614.

Address for correspondence:

Elisabetta Bianchini
Institute of Clinical Physiology
Via Moruzzi, 1
56124 Pisa, Italy

betta@ifc.cnr.it