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Peripheral arterial response during haemodialysis – is two-dimensional speckle-tracking a useful arterial reactivity assessment tool?

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Abstract

Aim: 2D speckle tracking is a method used in myocardial strain assessment. However, several studies have confirmed the suitability of its application in the assessment of arterial strain (a marker of arterial stiffness). The aims of our study were to evaluate whether 2D speckle tracking can assess the changes in carotid and femoral strain caused by fluid loss during haemodialysis, and to determine the direction and amount of these changes. **Material and methods:** We examined the distal common carotid and proximal femoral arteries in 74 haemodialysed patients (28 women and 46 men) before and after their haemodialysis sessions. EchoPac software was used to analyse the recorded ultrasound examinations. Circumferential strain values were acquired for further analysis. **Results:** We found a decrease in carotid circumferential strain values after haemodialysis sessions ($5.916 \pm 2.632\%$ before haemodialysis and $4.909 \pm 2.409\%$ after haemodialysis, $p = 0.000022$). The amount of fluid lost during haemodialysis sessions correlated (correlation coefficient of 0.434, $p = 0.000222$) with the decrease of carotid circumferential strain. The correlation coefficients were slightly higher (0.445 , $p = 0.000146$) when a ratio of fluid loss volume to the BMI was used. No statistically significant changes were found in femoral circumferential strain. **Conclusions:** Our findings suggest that arterial response to body fluid loss may be assessed by 2D speckle tracking. This method enabled us to measure carotid circumferential strain changes caused by fluid volume contraction during haemodialysis sessions. We found an important decrease in the carotid circumferential strain values after the procedure. The amount of this decrease correlated significantly with the decrease in the volume of fluid lost during the haemodialysis session.

Introduction

Arterial stiffness is an important and widely accepted parameter in cardiovascular diseases (CVD). It influences several factors including hypertension⁽¹⁾, coronary artery disease⁽²⁾, kidney failure⁽³⁾, heart failure⁽⁴⁾, atrial fibrillation⁽⁵⁾, stroke⁽²⁾, white matter injury⁽⁶⁾, cognitive dysfunction⁽⁶⁾, and dementia⁽⁶⁾. In end-stage renal disease (ESRD) patients, increased arterial stiffness measured by pulse wave velocity (PWV) is a strong and independent predictor of CVD mortality⁽⁷⁾, which is 10–30 times higher in dialysed patients than in the general population and accounts

for more than half of deaths in patients with ESRD⁽⁸⁾. It is important to note that in addition to standard risk factors such as age⁽⁹⁾, atherosclerosis⁽¹⁰⁾, hypertension⁽¹¹⁾, type 2 diabetes⁽¹²⁾ and smoking⁽¹³⁾ chronic kidney disease has also been proven to increase arterial stiffness^(8,14).

Strain describes a change of a dimension (deformation) of a body due to the application of stress expressed as a percentage or fraction^(15,16). The strain measurement of anatomic structures can be performed by two-dimensional speckle-tracking (2DST). The method is relatively simple, angle independent (contrary to Doppler tissue imaging),

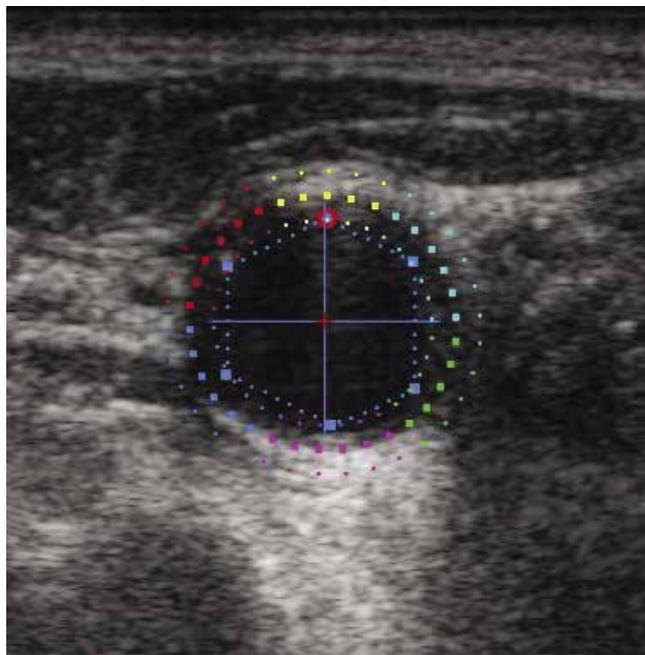


Fig. 1. The vessel outline ROI (with each segment marked by a different colour) is created by the programme on the basis of manually placed points (marked in blue)

and non-invasive. It uses an image-processing technique based on the analysis of blocks of 20–40 pixels⁽¹⁷⁾. The pixel blocks contain similar patterns (“speckles”) over consecutive frames, which enables the programme to track them using the sum of absolute differences (SAD) algorithm⁽¹⁷⁾. The initial purpose of the technique was myocardial strain assessment^(18,19). However, it has been proven that it can be useful in vascular examinations in the assessment of arterial strain – a measure of local arterial stiffness^(20–22).

Patients undergoing haemodialysis (HD) lose considerable amounts of body fluid over short periods during their HD sessions. Therefore, examining HD patients before and after the same HD session would provide data on the effects of blood volume changes on the arterial vessels, which cannot be obtained in any other group of patients. The aim of our study was to determine whether 2DST can assess the changes in arterial strain caused by fluid loss during haemodialysis. In addition, we wanted to determine the relationship between the strain of the carotid and femoral arteries and the blood volume changes due to the HD sessions. To our best knowledge, our study was the first to examine arterial strain using 2DST in patients undergoing HD.

Materials and methods

Study population

We examined a total of 74 (28 women and 46 men) clinically stable, non-smoking, adult patients undergoing chronic HD.

The exclusion criteria were: a history of major CV complications within the preceding 3 months (unstable heart failure, clinically significant arrhythmia including atrial fibrillation), wounds or dressings of the examined neck and groin areas, active infection on the day of the examination, and central catheters placed in the jugular vein.

The study protocol was approved by the ethics committee (decision no. KE/719/20).

All patients gave informed consent before the examination.

Image acquisition

We examined the distal common carotid and proximal femoral arteries in each patient before and after their HD sessions. Before the examination, the patients were asked to rest at least 15 minutes in the supine position. During the image acquisition, the patients were instructed to refrain from swallowing, and to hold breath. As soon as it was possible (10 minutes at the latest), the patients were examined in the same positions after the end of the HD session.

We performed all the examinations using GE Vivid I ultrasound machine with a linear probe 8L RS in short-axis view, with a frequency of 10 Mhz in the “carotid” preset, at an average of 43.7 frames per second. The tracking quality was assessed and revised, as needed, during the examination. For each image acquisition, a concurrent ECG was recorded. For the purpose of analysis, at least two consecutive cardiac cycles were stored in the cine-loop format.

A total of 8 recorded sequences of dilation and contraction were analysed per patient (two sequences for each artery before and after the HD session). EchoPac software was used for the analysis. We used the settings for the analysis of the left ventricle at the level of the mitral valve (SAX-MV) and the small animal protocol was automatically set. The wall outline was generated on the basis of 6 manually set points and divided into 6 segments (Fig. 1). EchoPac analysed each of them individually. In each sequence, we verified the ROI movement and its compliance with the vessel’s wall movement. The reference point was set at the end contraction frame of the vessel. Afterwards, for each record, the programme generated several graphs for strain, strain rate and displacement with the drift compensation option enabled (Fig. 2 and Fig. 3).

In echocardiography, the deformation of the cardiac wall can be measured in all three dimensions – by radial, circumferential, and longitudinal strain^{15,23}. In our analysis, we used circumferential strain (CS), as it is more suitable for describing the distension of the closed shape of the vessel’s outline because it measured deformation tangential to the vessel outline. The radial strain would express deformation in the perpendicular direction (Fig. 4).

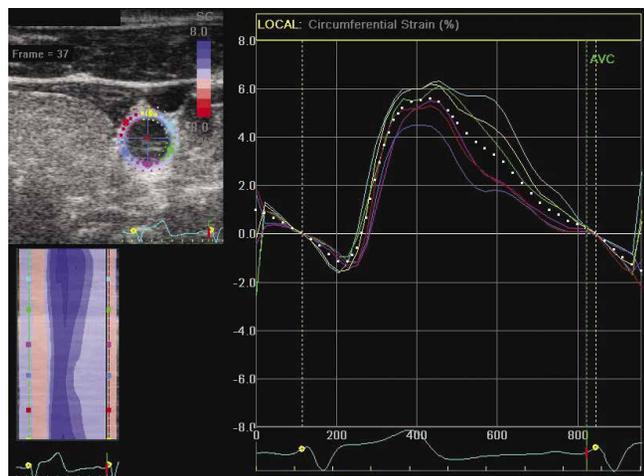


Fig. 2. Carotid circumferential strain graphs before the HD session. Each segment of the vessel's circumference is marked in a different colour, and the dotted graph indicates values for the whole circumference

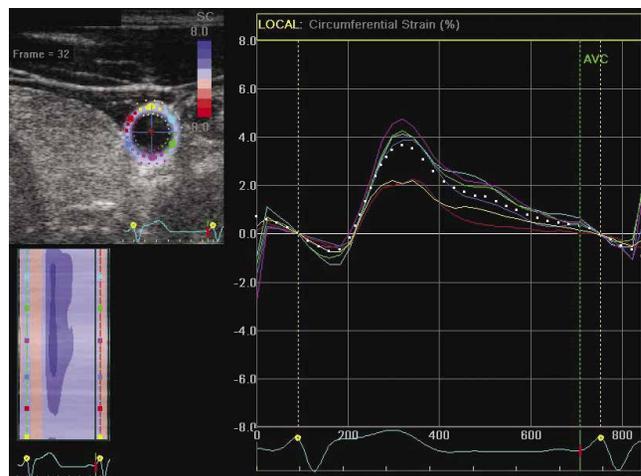
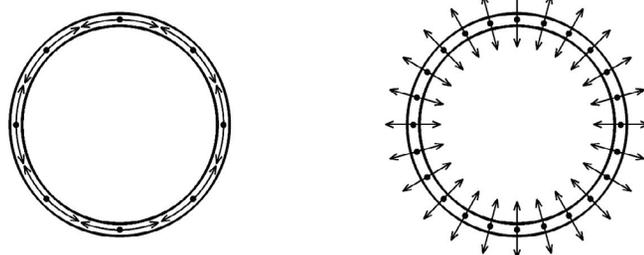


Fig. 3. Carotid circumferential strain graphs of the same patient after the HD session. There is a visible decrease in CS values after the HD session



Circumferential strain

Radial strain

Fig. 4. Strain describes a change of dimension (deformation) of a body due to the application of stress expressed as a percentage or fraction. In echocardiography, the deformation of the cardiac wall can be measured in all three dimensions – by radial, circumferential, and longitudinal strain. In our case, the circumferential strain was a measure of the deformation of a ROI tangential to the vessel outline, and radial strain would express deformation in the perpendicular direction

Circumferential strain values for the circumference of the whole vessel and each of its segments were acquired.

Haemodialysis

The Patients were haemodialysed for 4 to 5 hours, three times a week, with low-flux synthetic, polysulphone membrane dialysers (F series, Fresenius Medical Care AG, Bad Homburg, Germany). The blood flow was set to 200–380 ml/min, and dialysate flow was set to 500–800 ml/min with dialysate calcium concentrations of 1.25 mmol/l or 1.5 mmol/l. Heparin was used as an anticoagulant in patient-tailored doses.

Each patient was weighed before and after the HD session. The changes in the body mass were recognised as water lost during HD. We calculated the BMI regarding body mass after HD as the mass in kilograms divided by the square of height in metres (kg/m²).

Calculations and statistical analysis

A mean of CS values from two analysed sequences was used for the statistical calculations. We correlated the CS values with the fluid contraction volume and with the ratio of lost fluid volume to the BMI.

The statistical analysis was performed using Statistica 13.1. Shapiro-Wilk test was used to evaluate data distribution normality. The carotid and femoral strain values were not normally distributed, and the Wilcoxon test was performed to compare those values before and after HD. The differences in CS were calculated by subtracting the mean values after HD from the mean values before the procedure. The distributions of those differences, and the values of the volume of fluid lost during the HD session were normal. The ratios of the lost fluid volume to the BMI values were also normally distributed. Therefore, Pearson's correlation coefficients were used for the determination of the relationship between those parameters.

The results were considered statistically significant when the *p*-value was less than 0.05.

Results

Out of 74 patients, 6 patients were excluded. In 4 of them, poor visualisation of the carotid artery due to poor echo window, no visible outlines of the arteries, as well as numerous artifacts in the image, rendered the analysis impossible. In 2 of the excluded patients, the analysis could not be performed because of the significant movement of the whole vessel during systole. Ultimately, a total of 68 patients were found eligible: 40 men and 28 women in the age range of 24–91 years and the mean age of 60 ± 15.36 (mean ± SD) years.

The patients lost on average 2.163 ± 1.165 litres of water during their HD sessions. The mean BMI was 24.18 ± 4.064.

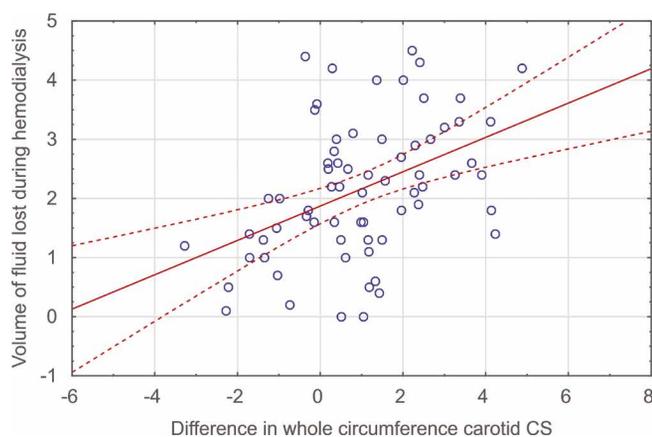


Fig. 5. Correlation between the difference in whole circumference carotid CS and volume of fluid lost during haemodialysis. The fluid volume is measured in litres. The difference in whole circumference carotid CS is a subtraction of circumferential strain before and after haemodialysis (both are measured as percentages)

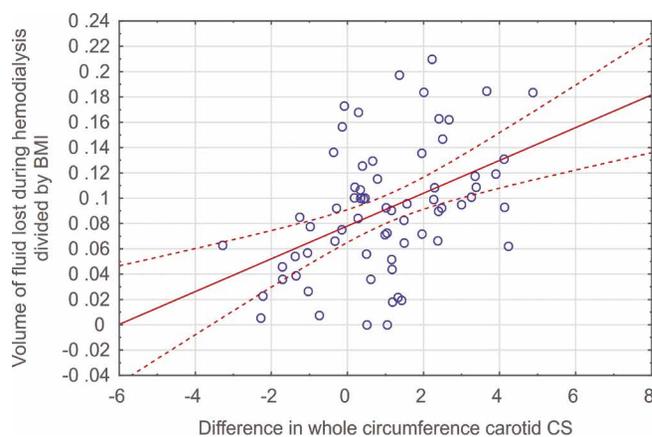


Fig. 6. Correlation between the difference in whole circumference carotid CS and volume of fluid lost during haemodialysis divided by the BMI calculated from dry body mass. The fluid volume is measured in litres. The difference in whole circumference carotid CS is a subtraction of circumferential strain before and after haemodialysis (both are measured as percentages)

The mean whole circumference carotid CS before HD was $5.916 \pm 2.632\%$. After HD, the mean CS value decreased to $4.909 \pm 2.409\%$. The difference between the carotid CS values before and after HD was $1.007 \pm 1.739\%$ and was statistically significant ($p < 0.001$). The amount of CS decrease for the whole carotid artery circumference correlated with the volume of fluid lost during the HD session ($r = 0.434$, $p < 0.001$) (Fig. 5). We also examined the correlation between whole circumference CS change and the ratio of fluid loss volume to the BMI (Fig. 6). In this case, the correlation coefficients were slightly higher ($r = 0.445$, $p < 0.001$). There was no statistically significant difference between the mean whole circumference femoral strain before and after HD ($1.613 \pm 1.606\%$ vs $1.521 \pm 1.63\%$). Femoral CS changes did not correlate with the fluid contraction during the HD session ($r = 0.0153$, $p = 0.902$) or the fluid loss volume to the BMI ratio ($r = 0.0382$, $p = 0.757$).

Discussion

Arterial strain can be influenced by many factors, and it is known to decrease with age^(22,24). It has to be noted that the patients examined in our study are not healthy (even though some of them were under the age of 35), nor formed a homogeneous group. Most of them were burdened with multiple medical conditions (apart from end-stage renal disease) which affect arterial stiffness. What is more, chronic dialysis treatment itself contributes to arterial stiffening⁽²⁵⁾. Therefore, it is necessary to enlarge the study group to analyse the results in terms of the causes and factors affecting arterial strain, such as age or the time the patients have been undergoing HD sessions.

The mean carotid CS values in our study were higher than those reported by Park *et al.* ($3.99 \pm 1.82\%$) and Su-A Kim *et al.* ($2.81 \pm 0.91\%$ in healthy patients and $2.29 \pm 0.84\%$ in patients with coronary artery disease)^(21,26). This may be due to the specifics of our study group or differences in the

selected analysis protocol – even though the researchers in both studies used EchoPac software, the settings selected in the programme were not described in the mentioned studies. However, in a study comparing the carotid CS values in healthy subjects and diabetic patients, the mean results were similar to those obtained in our study (5.48% in healthy and 4.29% in diabetic patients)⁽²⁰⁾.

In addition to examining local arterial stiffness in HD patients, our work also allowed us to observe the arterial reaction to body fluid loss. The present study confirmed a decrease in carotid CS for the whole circumference after HD. The finding was contrary to our expectations. We assumed that after HD the CS values would be higher because of blood volume contraction and the resultant lower diastolic artery filling. The opposite result is probably due to compensatory mechanisms such as plasma refilling from the interstitial space, vasoconstriction, and increased arterial tone⁽²⁷⁾. Furthermore, fluid volume contraction during HD causes a decrease in end-diastolic volume by 21.5% and in stroke volume by 20.2%⁽²⁸⁾. Finally, the dilatation of carotids by ejected blood is smaller. The decrease in carotid artery CS values correlated with the amount of fluid lost. There was a small statistically insignificant decrease in femoral artery CS after HD. The described phenomenon is likely due to several factors. Differences in stroke volume can be more easily appreciated in the most proximal arteries such as carotids. It is also important to highlight that in the peripheral vessels the blood flow becomes less pulsatile⁽²⁹⁾. The smaller changes observed in the femoral arteries may also be due to the presence of atherosclerotic lesions in the peripheral vessels.

Our observations and further studies in this field may be useful in the assessment of overhydration, dehydration and the adaptability of the cardiovascular system to hypo- and hypervolaemia in HD patients. The degree of CS change likely depends on the degree of arterial stiffness. The loss of arterial flexibility most probably impairs the patient's ability to adapt to blood volume contraction, and increases

the risk of hypotension and cardiovascular events. The results of previous studies seem to confirm that claim, as an increased arterial stiffness has been found to be associated with orthostatic hypotension and a smaller increase in mean arterial pressure on standing from the supine position^(30–32). Therefore, 2dST examination may be helpful with identifying patients at risk of dialysis hypotension. Moreover, the method could potentially be beneficial in patients with hypovolaemia caused by other factors such as bleeding, shock or hypoproteinaemia caused by transudate.

Conclusions

Our findings suggest that the arterial response to body fluid loss may be assessed by 2DST. This method enabled us to measure carotid CS changes caused by fluid volume contraction during the HD session. We detected an important decrease in the carotid CS values after the procedure. The amount of decrease correlated significantly with the decrease in the volume of fluid lost during the HD session. However, no statistically significant changes in femoral CS were found.

Limitations

The main drawbacks of the study were related to the ultrasound method. For the results to be credible, both

ultrasound examinations (i.e. before and after HD) had to be performed in the same patient position, in exactly the same body areas. Although the spots were marked with a drawn outline of the ultrasound probe, there was still a need for image verification before its acquisition due to possible minor angle differences. It is very important to consider that the probe pressure on the patient's body during the ultrasound image acquisition may cause a change in the shape of the vessel. Compared to the veins, the arteries are less compressible, but the probe pressure can still lead to differences in the dilation and contraction of the examined artery. This is a bigger concern for the measurement of individual segments than the entire circumference of the vessel, as reduced dilation of more compressed segments can be compensated by overdilation of the less affected ones.

Another aspect to be taken into account is that we had to rely on the approximation that the body mass change was equal to the amount of fluid loss, while some patients were allowed to drink during the HD session.

Conflict of interest

The authors do not report any financial or personal connections with other persons or organizations, which might negatively affect the contents of this publication and/or claim authorship rights to this publication.

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