On the consistency of flow rate color Doppler assessment for the internal jugular vein

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Abstract

Color Doppler methodology to assess the vessel blood flow rate is based on the time averaged velocity of the blood measured in the longitudinal plane and the cross sectional area measurement taken either in the longitudinal plane, by assuming circular cross sectional area, or in the transversal plane. The measurement option in longitudinal plane is based on the assumption of circular cross sectional area, while the transversal one needs to evaluate both time-averaged velocity and cross sectional area in the same vessel point. A precise and validated assessment methodology is still lacking. Four healthy volunteers underwent internal jugular vein colour Doppler scanning. The cross sectional area was assessed by means of B-mode imaging in the transversal plane all along the vessel cervical course. During this assessment, cross sectional area, major and minor axis of the vessel were measured and recorded. The distance between the internal jugular vein wall and the skin surface were measured together with the intra-luminal diameter and statistically correlated with the cross sectional area data. The internal jugular vein cross sectional area measured on the transversal plane were significantly different from the cross sectional area calculated using the assumption of circular shape. The intra-luminal distance showed high correlation with the measured cross sectional area. The proper anatomical point in the cross sectional area transversal measurement can be identified by using the internal jugular vein intra-luminal distance as landmark.

Introduction

Venous flow rate is a main measure scientifically recognized for the clinical practice.[1-7] It is a derived value coming from the product of time-averaged velocity (TAV) and the cross sectional area (CSA), thus measurable by color Doppler (CD).

Nowadays, the available CD software can calculate the flow value only along longitudinal (L) plane. Such value is obtained by contouring the Doppler spectrum wave and by calculating the CSA, which is in turn obtained by the measurement of the vessel intra-luminal diameter. The assumption for the flow rate assessment is that the point where such diameter is measured has to be precisely positioned in the same anatomical site of the TAV sample volume. Moreover, a circular vessel shape must be assumed for this kind of CSA calculation.

This last assumption guarantees that the above-described method can be considered reliable for the arterial evaluation thanks to the circular shape. On the contrary, both venous diameter and shape undergo extreme variations linked to trans-mural pressure and compliance features, together with surrounding muscles extrinsic compressions,[8,9] and thus suggesting the need for a more reliable methodology for the venous flow assessment.

Nevertheless, many scientific investigations concerning venous flow rate still refer to a CSA that is obtained by assuming that the vein is a perfect cylinder. Such inaccuracy can determine a considerable loss in the significance of venous flow assessment.

Nowadays, the only available methodology to overcome this issue is to assess the TAV along the L plane, while measuring the CSA along the transverse plane (T).[1-4,6,10] Of course this method includes a high risk of reliability loss since the TAV and CSA assessment sites could not remain the same when moving from L to T scanning plane. Aim of the present study is to evaluate different ways of CSA measurement and to identify a consistent methodology to assess the flow rate, so as to avoid the significance loss risk when moving from L to T scanning.

Materials and Methods

The internal jugular vein geometry model

We designed a geometry model of the internal jugular vein (IJV), so as to identify anatomical landmarks aimed to find corresponding sites between T and L evaluations.

IJV anatomic feature can be schematized by considering the ellipse minor (b) and major (a) axis for its shape and the distance from the skin for its location.

In L ultrasound images the IJV walls are both visible. We named *Lh* the distance between the vessel inner linings and *Ld* the distance between the skin and the superior wall inner lining (Figure 1). In T images, the whole CSA contour is easily traceable. If we consider the ultrasound path crossing the vein center, *Td* is the distance from the skin to the vein wall and *Th* is the distance between the vessel walls (Figure 2). In this way *Ld*, *Lh*, *Td* and *Th* constitute the anatomical landmarks of the investigated vessel.

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Contributions: FS developed the geometrical model and the equations, collected and analysed the raw data, performed the statistical analysis and wrote the paper. EM performed the color-Doppler scannings and collected the data. SG, GD and AT wrote the paper and revised it critically. AMM, MT contributed to collect and analyse the data. MG provided scientific supervision and founded the study. All authors participated in the design study, read and approved the final manuscript.

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Patient population

Four consecutive healthy volunteers (age ranging from 23 to 25 years old, male:female ratio 1:1), were enrolled in this study. All the study participants underwent CD investigation (ESAOTE My-Lab 70, Genoa, Italy) with the same condition of room temperature (23°C). Measurements were all performed in the morning hours following the recommendation to drink 500 mL after waking up, for comparable hydration conditions.[11]

Color Doppler study of the internal jugular veins

First subject

The first subject underwent a recorded IJV transverse scanning from J1 to J3:[11] the assessment was performed at a constant velocity, for a total length of 12 cm, and lasted 5 seconds. The total number of analyzed frames was 38. The analysis of each frame image included *a*, *b*, *Th*, *Td* and *CSA* measurements. The CSA was measured by manually tracking the boundaries of the lumen. In the following we call this measure contoured CSA (*conCSA*). For reliability purposes, the operator repeated the same scanning 5 times. The reliability of the constant velocity assumption was previously tested in the laboratory by asking the operator to scan a phantom having a thickness linearly related to the displacement (PMMA step wedge). After the operator training, the chi square test showed a P>0.9 indicating a uniform motion of the probe. By dividing the 12 cm total length (*L*) by the number (*N*) of acquired images, we calculated the sampling distance and we named this value as unit length (UL). Then we multiplied the image number (*In*) by *UL* to obtain the exact observation site along the IJV (*y*).

$$y = In \times UL \tag{1}$$

Besides, we obtained the manually traced *conCSA*, the vessel circular *CSA* (*cirCSA*) and the elliptical *CSA* (*ellCSA*) by using the measured *Th*, *a* and *b* values. The circular area can be calculated using the radius $r=b/2$ as follows:

$$cirCSA = \pi \times r^2 \tag{2}$$

While the elliptical one can be calculated using maximum ($R=a/2$) and minimum (r) radii:

$$ellCSA = \pi \times r \times R \tag{3}$$

We measured the mean *conCSA* from all the acquired frames. The Pearson's *r* coefficient was calculated to determine the linear correlation between the *conCSA* and the *Td* and *Th* parameters.

Three control subjects

The subjects were placed in supine position and underwent IJV transverse scanning at level of J1, J2 and J3. Each assessment (total of 9) was performed by keeping the probe in a fixed position among J1, J2 and J3. The acquired image sequences were processed by considering a number of frames within at least one cardiac cycle. For each analyzed frame we measured the major and minor axis (*a* and *b*), while the *conCSA* was obtained by manually tracking the boundaries of the lumen. Total of 370 data record (corresponding to about 40 records for each IJV segment) was collected, and the analyses were performed either separately for each subject or as a whole.

Statistical analysis

The statistical difference among the *conCSA*, the *ellCSA* and the *cirCSA* was tested by using appropriately homoscedastic and heteroscedastic Student's *t* test; P value<0.05 was considered significant. Homoscedasticity and heteroscedastic hypothesis of the variances has been tested by F Test. The Pearson's *r* coefficient was calculated to measure the linear correlation between the *conCSA* and the *Td* and *Th* parameters. The reported uncertainties refer to one standard deviation.

Table 1. P-value of T-test for elliptical and circular cross sectional area hypothesis.

Subject no.	P-value conCSA *vs* ellCSA	conCSA *vs*
1	0.95	<0.001
2	0.35	<0.001
3	0.09	<0.001
4	0.11	<0.001

conCSA, contoured cross sectional area; ellCSA, elliptical CSA; circCSA, circular CSA.

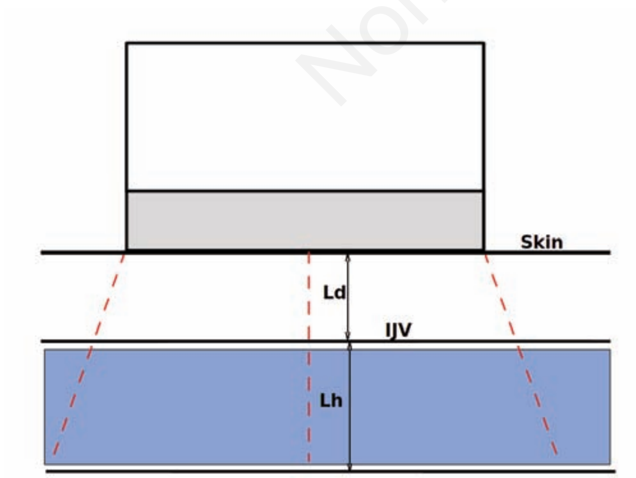

Figure 1. Schematic representation of an ultrasound probe insonating an internal jugular vein (IJV) in the L plane. The IJV's walls are represented. The distance *Ld* between the IJV and the skin and the wall distance *Lh* of the IJV are shown.

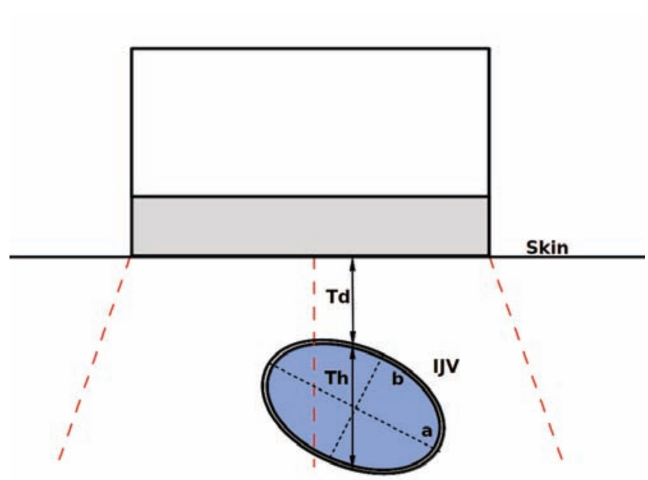

Figure 2. Schematic representation of ultrasound probe insonating an internal jugular vein (IJV) in the T plane. The IJV is represented as an ellipse of major and minor axis *a* and *b* respectively. The distance *Td* between the IJV and the skin and the depth *Th* of the IJV are shown.

Results

First subject

The measured *conCSA* data range from a maximum of 0.82 cm^2 in J1 to a minimum of 0.14 cm^2 in J3 with a mean value of 0.36±0.17 cm^2 (Figure 3). The mean *cirCSA* was 0.22±0.16 cm^2, while the mean *ellCSA* was 0.36±0.16 cm^2. In Figure 4 elliptical and circular IJV CSA are plotted as a function of the contoured CSA. It shows a significant lack of overlapping between *conCSA* and *cirCSA* while there is a good agreement between *ellCSA* and *conCSA.* This also results in a significant statistical difference between these quantities (see the P value in Table 1). The correlation coefficient *r* between *Td* and *conCSA* resulted 0.5 while it resulted 0.95 between *Th* and *conCSA*.

Three control subjects

In Figure 5, elliptical and circular IJV CSA are plotted as function of the contoured CSA. Again, the plot shows a significant lack of overlapping between *conCSA* and *cirCSA* while there is a good agreement between *ellCSA* and *conCSA*. P values are reported separately for each subject in Table 1. This finding is very interesting because it shows that the elliptical shape assumption remains valid also in the vein pulsation phase, and thus suggesting that the use of the *Th* and *Lh* landmarks is reliable.

Discussion

The main outcome of a *cirCSA* lower than the *conCSA,* in the observed T scanning, demonstrates the risk of a flow rate underestimation, under the assumption of a cylindrical venous shape (Figures 4 and 5). Moreover, the significant *conCSA* variability along the vein tract points out the consistency loss when the US probe is positioned in a different anatomical site between T and L scannings. The present study offers an assessment methodology, endowed with anatomical landmarks (*Ld*, *Lh*, *Td* and *Th*) that can become extremely useful for a correct sample volume positioning, in particular thanks to the high *Th* correlation coefficient. Conversely, the lack of correlation between *Td* and *conCSA* indicates that this parameter is unsuitable for our purpose. It is worth noting that although this method helps to identify the same anatomical site in both L and T planes, the actual CSA of the vein depends on the probe compression applied by the operator. Anyway, this does not affect the flow calculation because also the blood velocity is affected by the CSA change hence, if the velocity and the CSA are measured by using the same pressure, the resulting calculated flow is virtually invariant (high compression can alter the haemodynamics and the flow). Since there are no warranties that the operator applies the same pressure on both the T and L plane, there is no certainty that the CSA assumes the same value when measured in the T and L plane hence, there is the risk to use the landmarks in a misleading way. For this reason we are investigating the use of a correction factor that allows to calculate the elliptical CSA based on the *Lh* parameter that has to be measured on the same plane where the TAV is also measured. The true reliability of the novel measuring method has not been assessed in this paper since no direct flow measurement is done. Actual flow measurement is not possible on human subjects with

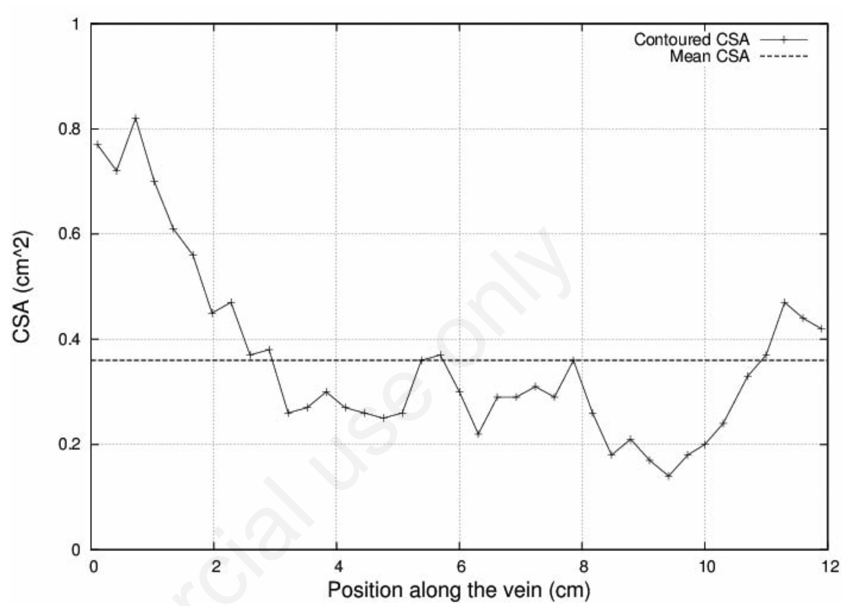

Figure 3. The measured cross sectional area is plotted as function of the position along the internal jugular vein (IJV) from J1 to J3.

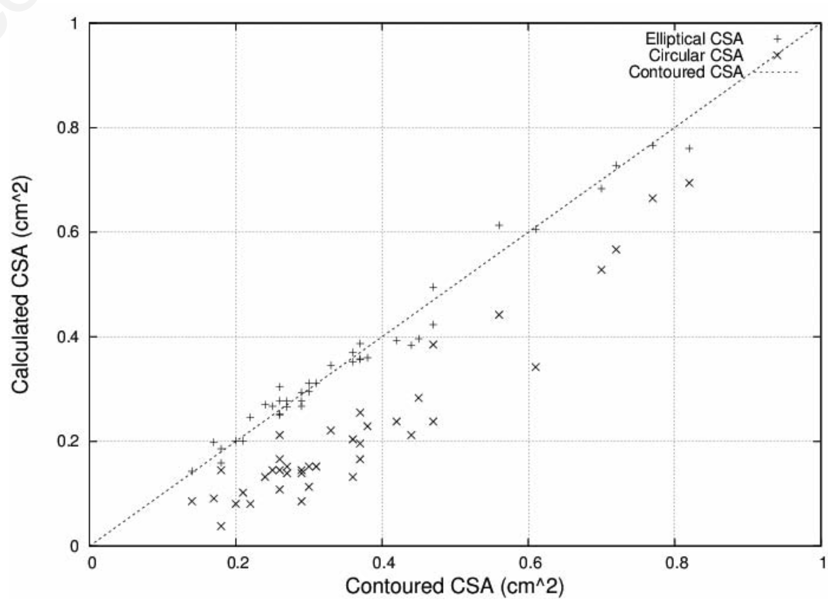

Figure 4. Elliptical and circular internal jugular vein (IJV) cross sectional area (CSA) of one subject are plotted as function of the measured CSA. Different measured CSA correspond to different assessment along the IJV length.

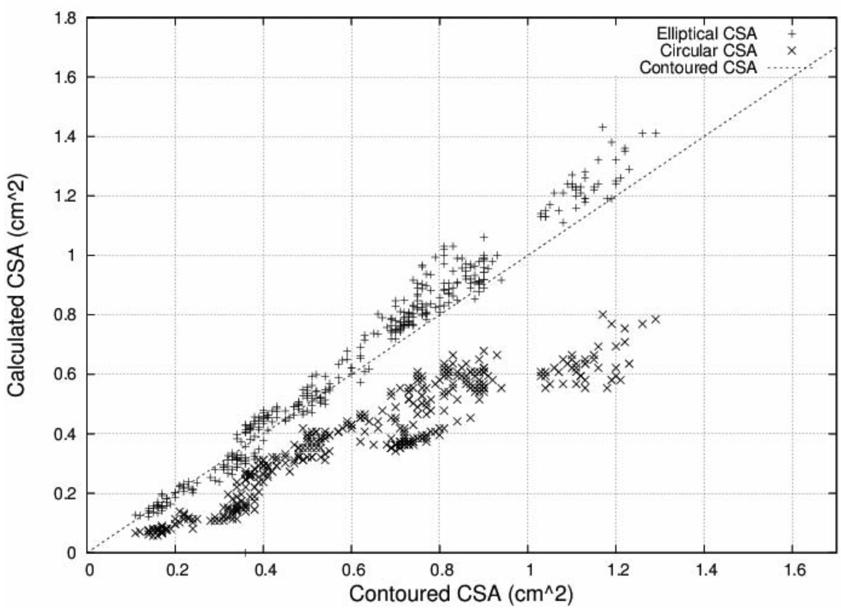

Figure 5. Manually contoured, elliptical and circular internal jugular vein (IJV) cross sectional area (CSA) of three subject are plotted as function of the contoured CSA. Different measured CSA correspond to different assessment along the IJV length and to a different assessment during the cardiac cycle.

non-invasive methods. For this reason we are planning to verify this methodology by laboratory *in vitro* investigation. Finally, if a quantitative flow calculation of the IJV is requested for a clinical reason, we believe that its calculation based on the vein diameter acquired in the L plane is not correct.

Conclusions

The flow value assessment is often based on the assumption of constant CSA, which can generate a possible significant inaccuracy.

We have demonstrated that, thanks to validated longitudinal and transversal landmarks, the TAV can be measured in the L plane in a point where the *Lh* is equal to *Th*.

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