Analysis of the blood flow in the aortic arc

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Introduction

neloop techniques for MR image acquisition make it ssible a non invasive investigation of the blood flow the aorta. In this note preliminary results on the alysis of the blood motion in the aortic arc by means an optical flow technique are presented. Let us first ;ablish the basic anatomy of the problem, describe :efly the cineloop MR technique, and then discuss ıat can be inferred from a sequence of MR images visual inspection.

⁄IR image sequences of the blood flow

llowing the arc shaped aortic segment, the blood ınges the direction of motion gradually flowing tord the head in the initial part and toward the feet the final part of the segment. Through MR tech-ıues it is possible to obtain image sequences of the ›od motion in the aorta. Over a single cardiac cycle, ıumber of images (typically 15 or 16) of the aortic :, relative to the same plane of interest, are grabbed ı, by means of suitable gradient echo parameters, a ·y high contrast between the flowing blood and the ıer visible structures can be obtained. See Fig. 1*A* ı *B*, for example.

Due to the relatively small radius of curvature and her high speed, the blood flow is probably not lami-: and the arterial wall is subject to pressure of vari-.e intensity. Excessive pressure over small areas of : aortic arc has often been indicated as a main cause arteriosclerotic and aneurismatic pathologies. The : of optical flow techniques for the estimation of the ›od motion in the aorta can be useful in order to ıluate and compare quantitatively pointwise pressure ı stress differences along the arterial wall and detect portant dynamical properties of the observed blood ›tion (like laminarity, vorticity, or turbulence).

To this purpose an algorithm for the pointwise computation of the blood flow was applied over the acquired ıge sequences. The algorithm is based on the match-; of features from two images [Poggio *et al.*, 1986]. e flow is assumed to be locally constant, that is, the placement of nearby points under the optical flow is : same. At each point, under each integer displacement, the nth and $n+1$th images are compared and a measure of the matching between points is computed, and summed over a small region of $m \times m$ pixels. This can be interpreted as matching small patches from the first image with small patches in the second. The displacement is chosen to maximize the matching measure over all displacements (in fact, to minimize the sum of the absolute value of the pointwise differences between image intensities). The accuracy was improved by interpolating the matching measure.

Experimental results

Let us now present some of the experimental results obtained by computing the optical flow according to the algorithm previously described over three sequences of MR images.

Fig. 1*C* shows the optical flow relative to the square region marked by the white frame superimposed to Fig. 1*A*. The image of Fig. 1*A* is the tenth of sixteen images relative to the blood flow in the aorta of a normal patient. It can easily be seen that the computed blood motion shows a high degree of spatial coherence and flows nearly parallel to the direction of the aorta in the marked region.

Fig. 1*D*, instead, shows the optical flow within the region contained by the white frame superimposed to Fig. 1*B*. The image of Fig. 1*B* is the sixth of sixteen images of a sequence from a pathological patient. The square is centered on a vortex of the flow caused by a flap which can be located near the left vertical edge of the marked region. By inspection of Fig. 1*D*, both the vorticity of the flow and the much smaller degree of spatial coherence with respect to the flow of Fig. 1*B* can be inferred.

Fig. 2*A* and *B* show the seventh and tenth image of a third sequence in which the blood flow within an aneurismatic region (marked by the white frames) is observed. Visual inspection of the image sequence shows that the blood enters the aneurism in the first few frames flowing from the lower left toward the upper right, and then comes back following the upper arterial wall. This behavior is qualitatively captured by the optical flows shown in Fig. 2*C* and *D* respectively.

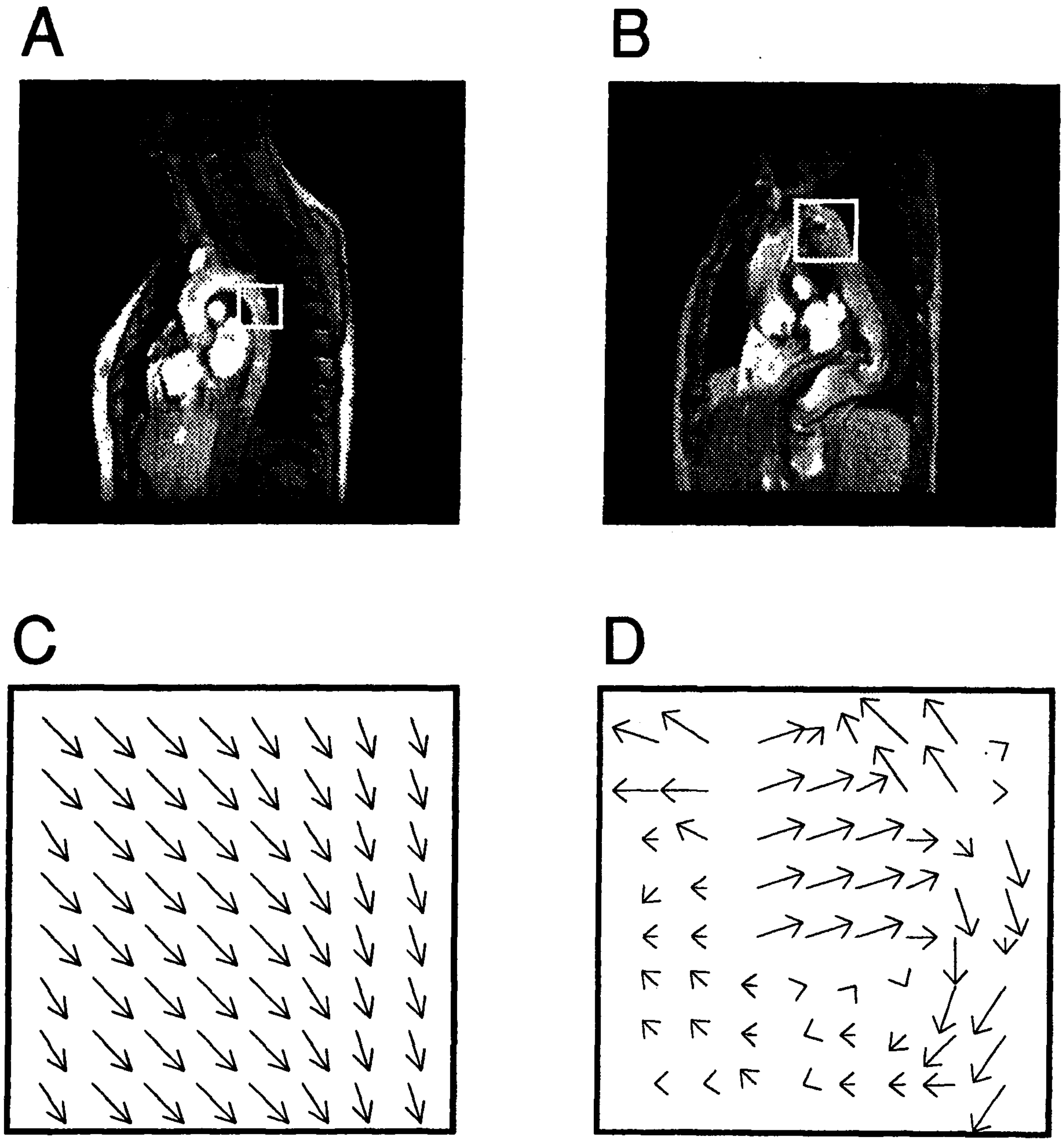
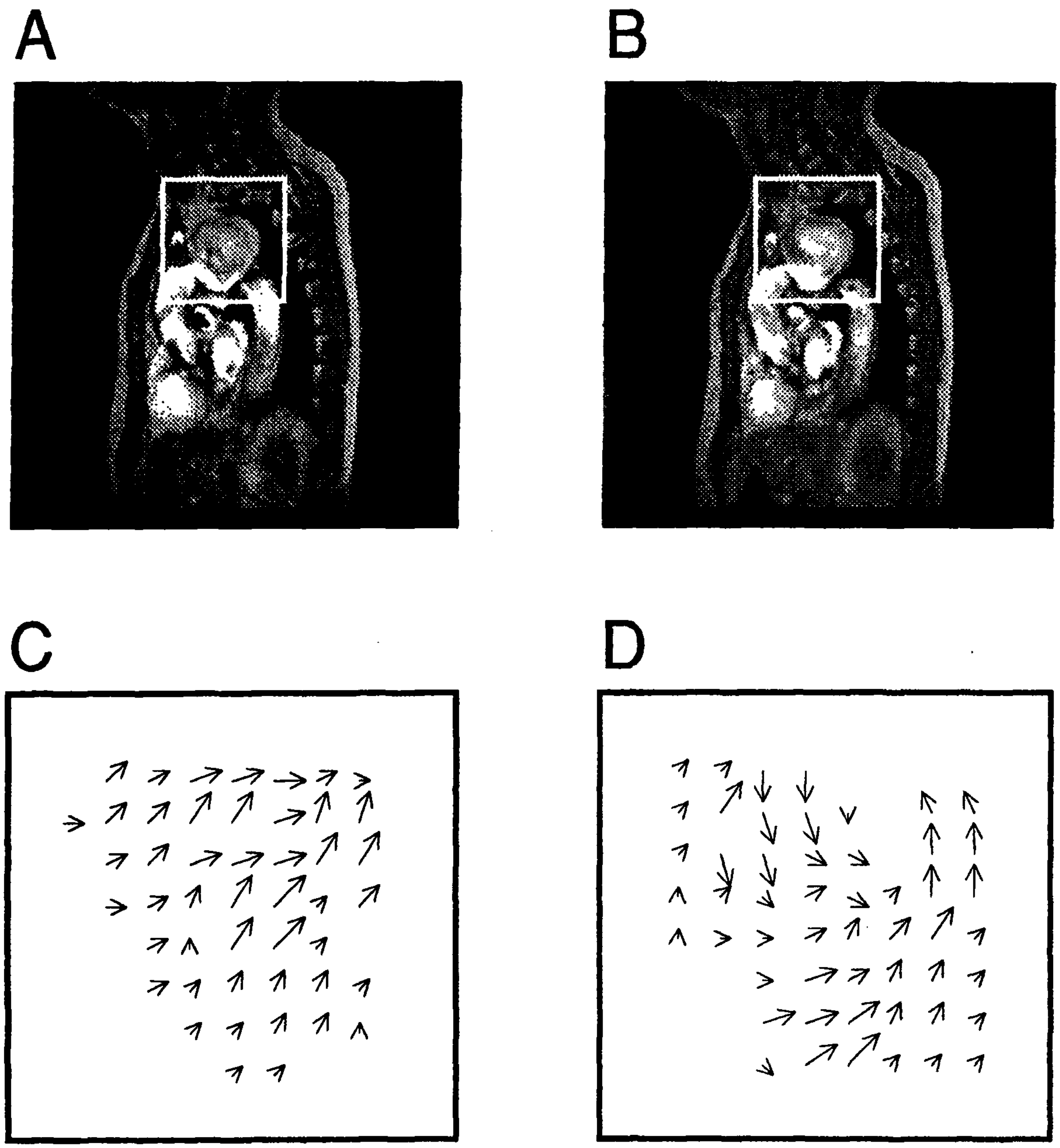


Figure 1: Computing the blood flow in the aortic arc. (A). Tenth image of an MR sequence obtained by a suitable choice of the gradient echo parameters (TE 15, FA 35°, ecg gated sagittal-oblique single plane). The image consisted of 256×256 pixels of 16 bits. (B). Sixth image of a second MR sequence. Same parameters as in (A). (C) and (D). Optical flow relative to the region enclosed by the square frame of (A) and (B) respectively obtained by means of the algorithm described in the text (with $m = 10$pixels).



ure 2: Computing the blood flow within an urism. (A) and (B). Seventh and tenth images of ıird MR sequence. Same parameters as in the leg- . of Fig. 1(A). (C) and (D). Optical flow relative to the region enclosed by the square frame of (A) and (B) respectively obtained by means of the algorithm described in the text. Same parameters as in the legend of Fig. 1(B).

Discussion

Although the experimental results described in the previous section appear to be very promising, much more work needs to be done from both the theoretical and experimental point of view. Let us briefly comment on the main directions of future research in the analysis of the blood flow by means of MR image sequences.

First, a quantitative comparison of the existing algorithms for the computation of optical flow on MR images is needed. Preliminary results seem to indicate that matching algorithms are more suitable than differential techniques, but a tuning or rewriting of the equations underlying the observed flow may overturn this qualitative impression.

Second, the obtained quantitative motion estimates need to be correlated with dynamical properties of the blood flow, like pressure concentration and changing stress along the arterial wall. Third, it must be kept in mind that the observed flow originates from a truly three-dimensional flow. The presence of a vortex, for example, merely indicates that the blood flow has a component of motion in the direction orthogonal to the acquisition plane. In order to capture all the relevant information, a reconstruction of the full three-dimensional flow from a number of "different views" may be necessary.

Finally, it would be desirable to extend the presented single frame analysis to an intermediate or long term analysis in which the blood flow in the aorta is observed along the entire cardiac cycle. In a long term analysis the features of the flow which can be tracked along the sequence have to be determined. First order properties of the optical flow [Campani and Verri, 1992] seem to be good candidates to this purpose.

Conclusion

Concluding, it appears that optical flow information can be very useful for the analysis of the blood flow in the aorta. Preliminary results obtained on three sequences of MR images indicate that, by means of the computed optical flow, it is possible to study interesting properties of the blood flow, like laminarity, divergence, and vorticity. Future work will correlate quantitatively the obtained optical flow with dynamical properties of the observed blood motion, like pressure concentration over small areas in the proximity of aneurismatic dilatations, parietal thrombosis, and flow vortices.

References

[Campani and Verri, 1992] M. Campani and A. Verri. Motion analysis from first order properties of optical flow. *CVGIP: Image Understanding*, 56:90–107, 1992.

[Poggio *et al.*, 1986] T. Poggio, J.J. Little, and E.J. Gamble. Parallel optical flow. *Nature*, 301:375–378, 1986.