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31. THE INFLUENCE OF A SMALL STENOSIS IN THE CAROTID ARTERY BULB ON ADJACENT AXIAL VELOCITY PROFILES

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1. INTRODUCTION

The detection of atherosclerotic lesions at an early stage of disease, which means only minimal narrowing of the artery lumen, is important to obtain more insight into the natural course of the disease. An area of special importance is the internal carotid circulation, where emboli generated by these lesions can cause cerebral disturbances like transient ischemic attacks. In the neck the common carotid artery divides into the external and internal carotid arteries. The latter supplies the brain with blood and generally shows a dilatation at its offspring: the carotid artery bulb. Since atherosclerotic lesions are often located proximally in this bulb, this site in the internal carotid artery has been subject to investigation to evaluate whether there is a relation between these lesions and the local flow velocity pattern so that they could be diagnosed by detecting the flow velocity disturbances. This possibility has became pertinent because multigate pulsed Doppler systems have been developed to measure velocity profiles with high spatial and temporal resolution in man (Hoeks et al,1981).

To obtain better insight into the flow velocity patterns in normal carotid arteries, Bharadvaj and Ku studied these patterns in perspex models of the carotid artery bifurcation in stationary as well as pulsatile conditions (Bharadvaj,Mabon and Giddens,1982, Ku and Giddens,1983). From their results it can be concluded that the velocity field in the carotid artery bulb is very complicated. Helical flow patterns and areas of recirculation with time-dependent length can be observed. In the present study we investigated the influence of small stenoses (=minor degree of narrowing) on the velocity field in the carotid artery bifurcation with special emphasis on smooth filling in of the carotid artery bulb opposite to the flow divider, a situation known to occur in man (Zarins et al,1983)

2. MATERIAL AND METHODS

The experiments were performed on a perspex model of the carotid bifurcation dimensioned according to the geometry data presented by Bharadvaj et al (1982). Small stenoses were incorporated by filling in smoothly the non-divider side of the bulb. The flow entering the model was stationary, fully developed and laminar.

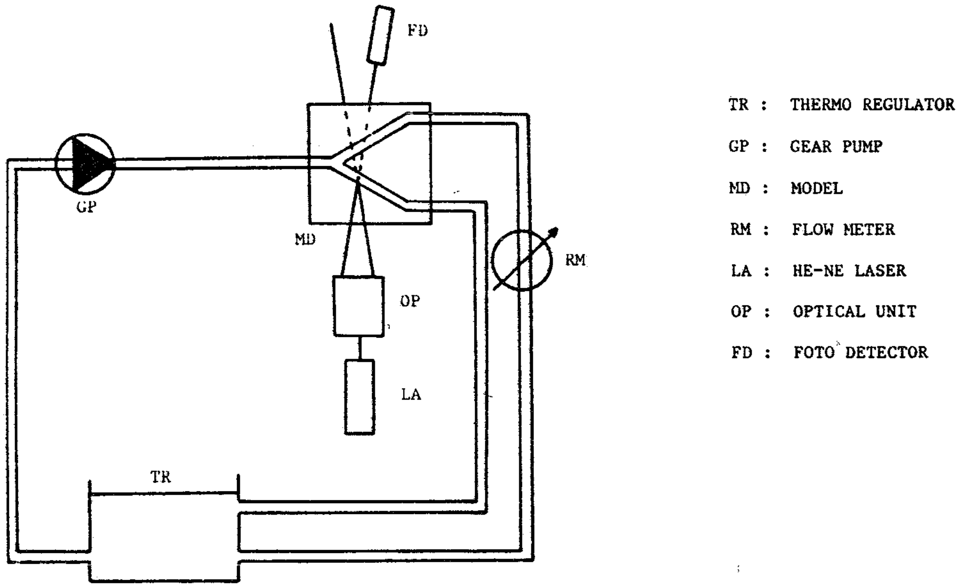

FIGURE 1. Schematical representation of the experimental set-up.

The fluid in the model (Fig.1) consisted of a mixture of oil (Shellflex 214 BG) and kerosine. This substance was chosen because its index of refraction is similar to that of perspex. The oil mixture was kept at a constant temperature of 40 degrees centigrade in order to lower the viscosity (30 cP at 20^{0}, 10 cP at 40^{0}). Seeding was employed to facilitate laser-Doppler measurement. For this purpose silicagel (Lichrosorb SI-100) was used. This forms a homogeneous dispersion of particles of ≈ 5 μm. By a gear pump (VERDER) the fluid was pumped into a circular glass pipe (Ø = 8 mm) with a length of 2 m to ensure full development of the flow pattern at the entrance of the carotid model (Re ≈ 700). A flowmeter (ROTAMETER) was placed in the outstream of the external branch to adjust the flow ratio between internal and external carotid artery to $Q_{interna} : Q_{externa} = 70 : 30$.

The fluid velocity was measured by a one component laser Doppler instrument (DISA, measuring volume ≈ 200 x 20 x 20 μm^3) with a Bragg cell to discriminate velocity directions. A microcomputer (8085 Intel) is used to control the traversing mechanism: a three stage step motor positions the sample volume at the desired location whith an accuracy of 0.016 mm. By traversing the sample volume both in the plane of the bifurcation and perpendicular to it, the radial distribution of the axial velocity could be determined with a resolution of 0.4 mm. The microcomputer also controls the data acquisition and data transport to a minicomputer (Prime 750) where the velocity profiles are calculated as averages with confidence intervals together with some parameters characterizing the profiles.

It is of clinical interest to obtain dimensionless parameters, which discriminate the normal from the diseased situation. To characterize the axial velocity profiles, Olson considered the velocity distribution as a probability distribution and determined moments depicted as follows (Olson,1971):

$$M_0 = \int_{-1}^{1} |v(r)|\, dr = S \qquad M_1 = \frac{1}{S}\int_{-1}^{1} r\, |v(r)|\, dr = \bar{r}$$

$$M_2 = \{\frac{1}{S}\int_{-1}^{1} (r - \bar{r})^2\, |v(r)|\, dr\}^{1/2} = \sigma \qquad M_N = \{\frac{1}{S}\int_{-1}^{1} (r - \bar{r})^N\, |v(r)|\, dr\}/\sigma^N$$

The radial coordinates are scaled so that the integration extends from -1 to 1. Moments 1 thru N are devided by the zeroth moment to scale the area under the profile to 1. To evaluate the moments, we also determined the moments 1 thru 4 from the axial velocity profiles and wall coordinates measured.

3. RESULTS

The axial velocity profiles as measured in the model of the carotid artery bifurcation are presented in Fig.2a. These measurements show that the influence of the flow divider (apex) is limited to a small region proximally in the internal and external carotid arteries. In both the internal and external carotid arteries the velocity gradient is high near the flow divider, while a relatively large area with low flow velocities is found opposite to it. Even reversed flow can be observed at this site.

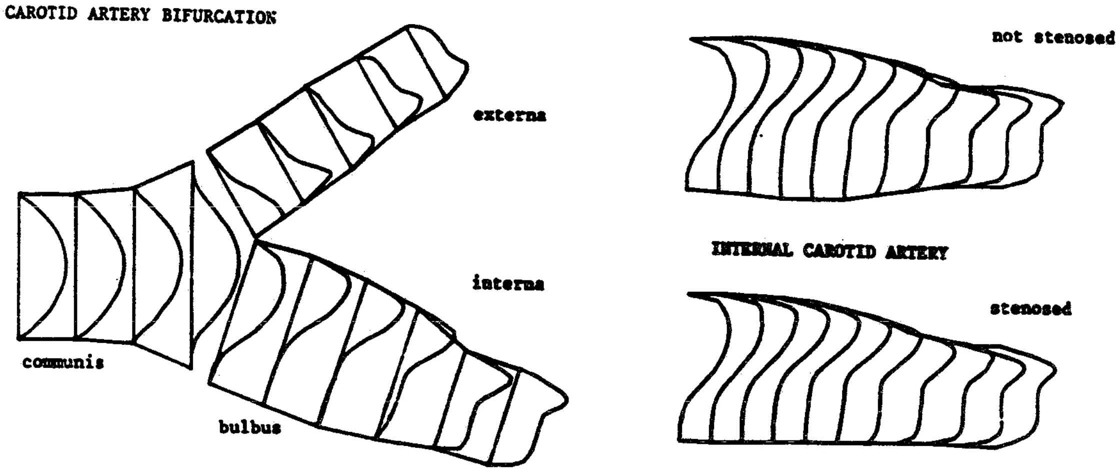

FIGURE 2. a) The axial velocity profiles in the carotid bifurcation for stationary flow (Re=700). Shifts in the profiles correspond with 4mm resp. 2.5m/s.

FIGURE 2. b) The axial velocity profiles in the interna for stationary flow (Re=700), Shifts in the profiles correspond with 2mm resp. 1.25m/s.

The influence of a small stenosis in the carotid artery bulb (i.e. the non-divider side) is shown in Fig.2b. The axial velocity profiles in the internal carotid artery are plotted in more detail for a non-stenosed and a stenosed artery. It can readily be seen that this degree of stenosis does not induce a clear change in the shape of the profiles. Only a slight decrease of the velocity gradients on the flow divider side of the bulbus can be noticed.

The result of the moment analysis performed on the velocity profiles in the internal carotid arteries is shown in Fig.3 representing the moments as a function of the axial coordinate in a normal and a stenosed internal carotid artery. The 95%-confidence intervals are indicated by two symbols per measurement.

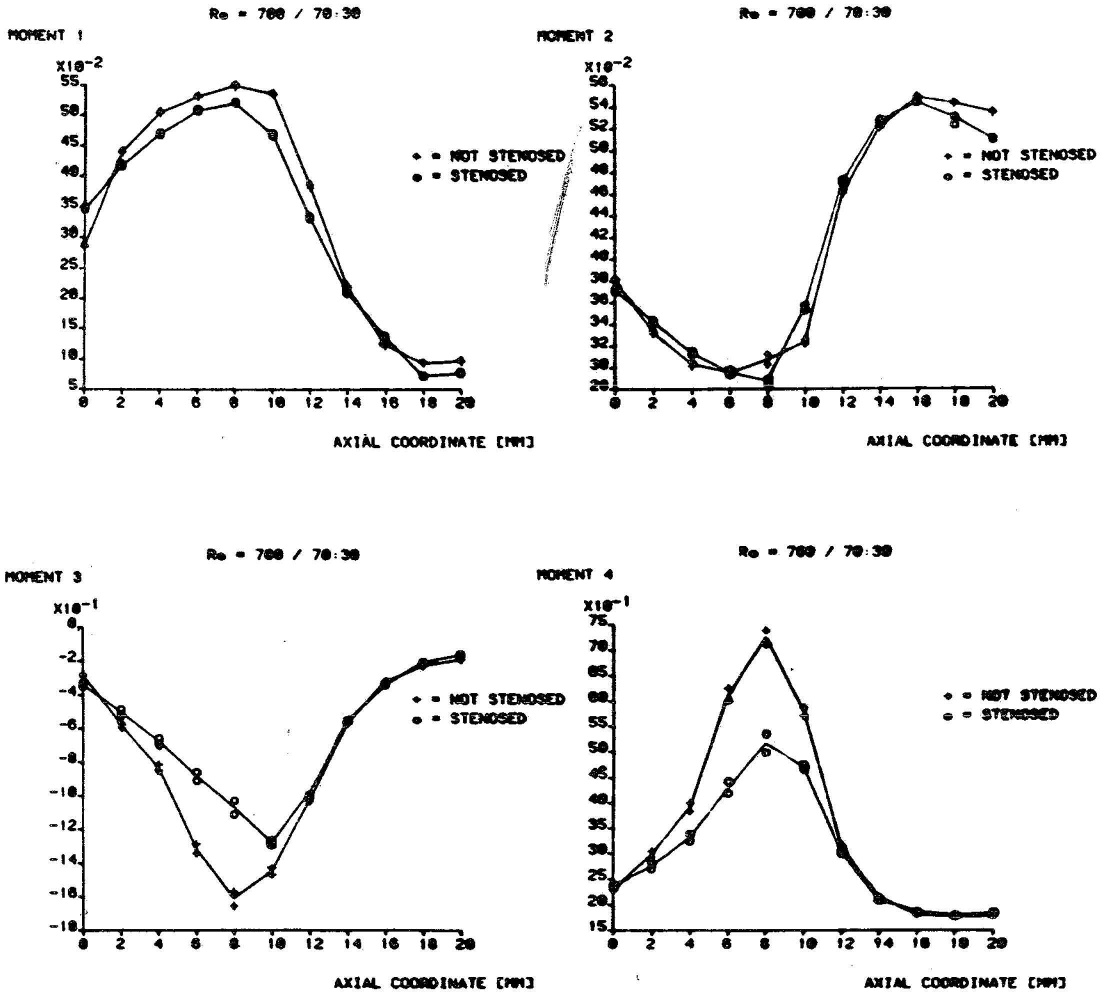

FIGURE 3. The first four moments of the axial velocity profiles and their 95%-confidence intervals as a function of the axial coordinate in the internal carotid artery.

Noteworthy is the little but significant influence of the stenosis on the first two moments and the much wider difference that occurs in the third and fourth moments, particularly in the middle of the carotid artery bulb.

4. COMMENTS.

From the measurements in the common carotid artery it can be concluded that the influence of the flow divider is noticable 1.5 mm proximal to it, as indicated by a distortion of the axial velocity profiles. In agreement with Bharadvaj et al (1982), a relatively large area with low velocities and partly reversed flow was found in the carotid artery bulb opposite to the side of the flow divider. Relatively high velocity gradients were found near the flow divider in both the internal and external carotid artery. A small stenosis on the non-divider side of the bulb hardly affected the velocity field. Experiments, however, revealed that, in the stenosed situation, significant differences occurred in the moments as compared to the normal situation although the area reduction was very small (< 5 %).

From the experiments it was concluded that the region of the non divider side of the bulb contributes very little to the main stream. However, the measurements of the axial velocities only took place in the plane of symmetry of the carotid bifurcation. A more complete picture of the situation will be given by contour plots of the entire axial velocity together with streamline plots of the secundary velocities. That will be the next step in our research. Finally the applicability of ultrasound to detect the differences between normal and stenosed situations has to be evaluated.

The significant differences in the moments of the axial velocity profiles as defined by Olson are caused by the difference in recirculation regions as we conclude from the above mentioned. The parameters seem to be useful for diagnostic purposes. However also here some caution is necessary. The defined moments are not only determined by the form of the velocity profile but also by the actual position of the vessel walls. The question then remains, whether Pulsed Doppler techniques are sensitive enough to distinguish recirculation regions with very low axial velocities from tissues surrounding the vessel and to determine accurately the position of the wall. Another problem is the absence of a reliable reference situation. Especially the variety of carotids between humans and even between two carotids in one person makes it extremely difficult to differentiate normal and diseased carotids.Hence, research has to be continued to define diagnostic relevant parameters which are quite independent of geometry variations and accurately detectable by ultrasound.

REFERENCES

1.Bharadvaj B.K. et al; J.Biomech., 15, No.5, pp.349-378, 1982.
2.Hoeks A.P.G. et al; IEEE Trans., Vol. SU-28, No.4, 1981.
3.Ku D.N. et al; Atherosclerosis, 3, No.1, 1983.
4.Olson D.E.; PhD-thesis, Imperial College London 1971.
5.Zarins C.K. et al; Circulation Research, 53, No.4, 1983.