R wave amplitude during exercise

Sir,

The excellent paper of Baron *et al.*¹ demonstrates that the increase of the R wave amplitude during stress testing is an important diagnostic sign of coronary artery disease. On the basis of the well-known interrelation between the R wave voltage and the ventricular volume, the authors seemed to conclude, reasonably, that the increase of the R wave amplitude results from an augmentation of the ventricular volume, which, in turn, is provoked by abnormalities of ventricular contraction.

Surprisingly, however, neither in this article nor in other reports on this topic (see Ref.¹), has it ever been considered that the increase of R wave amplitude observed during a positive exercise test could be an identical phenomenon to that present in animals and in man during hyperacute ischaemia. In variant angina,² acute myocardial infarction,³ and in any type of experimental ischaemia⁴⁻⁶ an augmentation of the R wave voltage has been repeatedly observed. This increase is proportional to the reduction of the coronary flow rate,^{4,6} and is brief: it ceases as soon as the coronary flow rate returns to normal in transient ischaemia, or when Q waves develop in myocardial infarction. Until now the mechanism of this R wave voltage change has not been convincingly explained.⁷

We⁴ recently showed that the ischaemic increase in the R wave voltage also occurs in global ischaemia. Since ST changes are not seen in global ischaemia,⁴ and can be present with a high coronary flow rate,⁸ the increase of the R wave amplitude seems to be the only specific electrocardiographic sign of any type of hyperacute ischaemia. It is independent of modification of spatial activation, such as disturbances in His-Purkinje and/or intraventricular conduction, of delay in intramural conduction, or of a variation in the non-spatial factors, such as the myocardial resistance and/or intravascular or extravascular volume. The ischaemic increase of the R wave voltage, therefore, results from a variation in transmembrane potential. We observed that the ischaemic increase of the R wave voltage was strictly related to the reduction of coronary flow rate, diminution of myocardial energy stores (adenosine triphosphate and creatine phosphate), and depression of myocardial contractility. Furthermore, it was counteracted by the reduction of intracellular calcium and by verapamil. Therefore, the dynamics of the ischaemic increase of the R wave voltage may be represented in order of succession by: metabolic ischaemic alterations, augmentation of $[Ca^{2+}]_i$, increase of potassium con-

ductance, and, finally, transient hyperpolarisation of cardiac cells.

Although a certain caution in extrapolating results from an experimental model to events occurring in man is necessary, we believe that our hypothesis can explain, much better than others, the basis of the increase of the R wave voltage during positive exercise testing.

When two phenomena are interrelated, one need not depend on the other: both can be provoked by a third factor. In the case of a positive stress test, such as in that of spontaneous angina, the precipitating factor is represented by myocardial ischaemia which, altering the myocardial metabolism, on the one hand provokes alterations in $[Ca^{2+}]_i$, potassium conductance, and the depolarization of cardiac cells, that is the increase of R wave voltage, and on the other hand, abnormalities of ventricular contraction, that is the augmentation of ventricular volume.

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This letter was shown to the authors of the paper who reply as follows:

Sir,

We are grateful to Carbonin and co-workers for drawing our attention to their work and hypothesis concerning the influence of myocardial ischaemia on R wave amplitude. The experiments to which they allude¹ were performed on isolated rat hearts perfused by the Langendorff technique with a physiological fluid and without venting the left ventricle. In such a preparation the perfusion pressure affects mechanical performance, ventricular size, and ventricular wall thickness.^{2,3} The R wave amplitude can be altered by perfusion pressure even in the absence of ischaemia.³ Carbonin and co-workers argue that the increase of R wave amplitude (which was constant for 20 minutes) during ischaemia in their experiments is related to hyperpolarisation of the cell. An alternative possibility is that geometrical changes during ischaemia are the cause of the change in R wave amplitude; such an explanation easily accounts for their failure to show a change during hypoxia in the presence of maintained coronary flow. In the dog both an increase,⁴ and a decrease⁵ of epicardial R wave amplitude have been reported after 15 minutes of ischaemia.

We⁶ agree with Carbonin and co-workers and with others⁷ that several factors contribute to the change of R wave amplitude in man recorded from the surface of the chest during exercise. These factors include not only electrophysiological changes, but also blood conductivity, blood potassium, electrical axis, orientation of the heart, and movement of the chest wall and diaphragm. The importance of ventricular volume, however, should not be underestimated. We have recently shown that the height of the R wave changes appropriately when ventricular volume is manipulated by administration of glyceryl trinitrate, or by atrial pacing.⁸ Part of the increase of R wave amplitude early

in myocardial ischaemia or during exercise can probably be accounted for by volume changes, whereas the later fall in R wave amplitude during ischaemia may reflect a decrease in the amplitude of the action potential.

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