The Relationship between Limb and Adjacent Trunk Potentials in the Dog

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Potential measurements were made of limbs and the adjacent regions of the trunk employing an intrathoracic bipole as a current source. The potential of the most proximal portion of the forelimb was intermediate between that of the trunk and the more distal portion. The potential below the elbow was essentially uniform and was approximately equal to the potential at the junction of the middle and caudal thirds of the region of attachment of the limb to the trunk. The value of these data in relation to electrocardiographic practice is considered.

The precise relationship between the potentials of the limb and of the adjacent trunk has never been investigated; nevertheless, knowledge of this problem is desirable to clarify some of the assumptions which have become prevalent in electrocardiography. One of the earliest of these was that the limbs are at an essentially uniform potential. Another was that the potential of the upper extremity represents the potential at the uppermost part of the shoulder. This latter assumption arose from Einthoven's schematization in which the upper side of his triangle was formed by the line joining these shoulder points.

The potential is now known to vary widely over the region of attachment of the upper limb, in both man and dog. The value over the acromion is quite different from that near the axilla. In view of this, it becomes important to know (a) to what extent the limb potential is uniform, and (b) if it is uniform, which portion of the region of attachment has the same potential as the limb. Knowledge of these two points would be of value in the proper placement of the limb electrodes and in the interpretation of the significance of bipolar and unipolar limb leads.

Generally it is accepted, and rightly so, that no matter where the electrodes are placed on the forearm, the electrocardiogram recorded is always the same. Support for this clinical observation may be found in the experiments of J. E. Benjamin and his co-workers who successively severed the tissues of the limb proximal to the point of attachment of the electrode without producing any change in the electrocardiogram. If the limb formed an appreciable part of the total pathway for the cardiac currents, the procedure would have changed the electrocardiogram in magnitude if not also in form. Therefore, the limb does not carry appreciable current and must be at an essentially uniform potential. However, it is not known whether the potential is uniform over the upper arm, or what the potential represents in terms of the potential on the trunk. This knowledge would be of interest, the more especially because of the widespread belief that the potential in limb represents the potential at the shoulder. If the actual limb potential varied significantly from that of the shoulder, our view of the limb leads would require some modification.

The observations reported here were obtained as part of a study, previously reported, of the characteristics of the surface field of an intraesophageal bipole. As has already been pointed out in the previous communication, the essential properties of the artificial field, namely, frequency, voltage, and point of origin, are similar to those of the naturally occurring cardiac field, and the comparative simplicity in both form and control of the artificial field made it preferable for this study.

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METHOD

Eight experiments were performed on normal dogs anesthetized with intraperitoneal sodium pentobarbital. A bipolar electrode, constructed on a firm rubber stomach tube with the electrodes placed transversely to the axis of the tube, was passed into the dog's esophagus under direct vision. The electrodes were driven electrically by an audiofrequency signal generator, and the resulting surface potentials were measured at 13 points on the forelimb and at points on the adjacent thorax by means of a preamplifier and cathode-ray oscilloscope. This procedure has already been described.4

RESULTS

The results of a typical experiment are shown in figure 1. As may be seen, the equipotential

Fig. 1. Inner aspect right forelimb of the dog (dotted lines on outer side) showing the distribution of potential at different levels at and below attachment to the trunk. The source of the potential was an intrathoracic bipole so oriented that the limb fell between the poles of the distribution. The variation of potential is thus comparatively wide at the attachment.

of zero value (i.e., of the value equal to that of the reference electrode in the left thigh) passed through the region of attachment of the limb. The potentials over the region ranged from approximately +1 to −1 millivolts on either side of the zero.* The potentials recorded from the most proximal portion of the upper limb reflect those of the adjacent trunk, and have a value intermediate between that

Fig. 2. Inner aspect of left forelimb. The internal bipole is further away from the limb and is so oriented that the area of attachment is on one side of the poles. The variation of potential is therefore much less than in figure 1.

* Because alternating current was employed to drive the bipole, the actual potential at any point fluctuated rapidly from positive to negative with each cycle. For this reason the polarity of the potential values has not been indicated in the figures, but at any given instant potentials on opposite sides of the zero equipotential were of opposite polarity.
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of the trunk and the distal limb. The potentials recorded at and below the elbow are all the same. The value of this potential on the distal limb is the same as that of an equipotential passing through approximately the junction of the caudal and middle thirds of the region of attachment.

The results of a similar experiment are shown in figure 2, in which the potential variation over the region of attachment of the limb is comparatively small. The essential features of this experiment are the same as those of the preceding one. The potential of the distal limb is again constant at and below the elbow, and has a value intermediate between that of the cranial and caudal sides of the region of attachment.

Measurements for the lower limbs were obtained but are not reported because both for the artificial field and for the actual cardiac field the region of attachment is at an almost uniform potential, and the potential of the entire limb is the same as that at the attachment. This signifies that in contrast with the upper limbs, practically no current flow takes place through the lower extremity.

Discussion

In terms of the current flowing through the body, the potential measurements reported indicate that only the most proximal portion of the limb forms an appreciable portion of the current pathway through the body. The current flows in (or out) the cranial two-thirds and out (or in) the caudal one-third of this portion of the upper limb in such a way as to flow from the region of higher to that of lower potential across the equipotential surface whose value is that of the distal portion of the limb. There is, however, no appreciable flow of current in the distal portion of the limb where the potential is essentially constant.

These results are directly applicable to human electrocardiography where, as has already been pointed out, there is great variation of potential between the region over the acromion and that in the axilla. Clearly the horizontal line of lead one in Einthoven's triangle actually passes through the uppermost portion of the heart, and is much lower on the trunk than it is usually pictured.

In describing the probable nature of $V_R$ and $V_L$ in man it has been assumed that the proximal zones of these leads are the areas of the heart facing the points on the right and left shoulder, respectively. Since the correct points are much lower down on the trunk, the areas of the heart facing these points will be somewhat different than those previously described.

In recording electrocardiograms in the unusual cases of total or partial amputation these results should be kept in mind. Amputation of the leg or of the forearm undoubtedly will not affect the usual recording of the limb leads. However, in cases of amputation at the shoulder, it might be advisable to place the arm electrode within the area of the former limb attachment rather than, for example, on the shoulder.

Summary

Potential measurements of limbs and the adjacent regions of the trunk were made employing an intrathoracic bipole as a current source.

At the most proximal portion of the limb, the potential was intermediate in value between that of the trunk and of the limb below the elbow where the potential was uniform.

The potential below the elbow approximates the value of the potential at the junction of the middle and lower thirds of the region of attachment to the trunk.

The line of lead I is distinctly lower than the line joining points on each shoulder as previously assumed.

The hind limb was at an essentially uniform potential because its attachment was also at uniform potential.

References

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