Nature of His Potential in His Electrogram

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SUMMARY

Unipolar His bundle electrograms were recorded with the muscle preparation isolated from the rabbit or the dog heart at as various sites as possible on and near the A-V conduction system and changes in appearance time and configuration of the so-called His (H) potential were examined. When the exploring electrode was shifted from the coronary sinus orifice down to the transition between the A-V node and the His bundle, the H potential was small but observed distinctly and its appearance time was rather fixed. The earliest excitation of the His bundle is thus assumed to be not much earlier than $\frac{1}{3}$ or $\frac{1}{4}$ the P-R interval before the Q wave. The nodal (N) potential appeared in addition to the H potential at variable time points while the electrode was shifted on the A-V node and disappeared when it was reached the His bundle. The appearance did not give the impression that the N potential changed to the H potential according to the electrode shift. Over the His bundle the H potential changed its appearance time successively. The H potential was also compared with the action potential obtained from the points as close as possible to the exploring electrode or with the other reference electrogram. It took the electrical field generated by the electrical activity of the whole of the His bundle, but it was influenced more by the local electrical activity than in the case of the electrocardiogram of the whole heart in situ.

Additional Indexing Words:

Earliest excitation of His bundle  Electrical field  Intrinsic deflection  Local electrical activity  N potential  Second derivative of action potential  Slow conduction velocity of A-V node

In the His electrogram obtained by cardiac catheterization 2 groups of deflections are observed between the atrial deflection (A) and ventricular deflection (V). The former is a small, rounded wave closer to the atrial deflection, obtained only occasionally, and is called the N potential. The latter is a more constant spiky deflection and is usually called the H potential. Occasionally another spiky deflection is observed immediately before the ventricular deflection and is called the RB or LB potential. There have been several reports proposing that these actually originate from the A-V node, the
His bundle, and the right or left bundle branch, respectively, but a much more extensive application of this method has been made, without some fundamental questions about these deflections being solved.

One of the wonders is that the H potential occurs at a fairly constant time point while the exploring electrode-catheter is moved to the various points of the His bundle. Since the movement of the electrode in clinical catheterization is greatly limited, it is necessary at first to decide whether this is true or not. If true, this arouses in us a question whether the H potential is an electrical activity of the His bundle on the whole or of some portion of it. This question arises because the H potential occupies then a certain time point between the N potential and the ventricular deflection while the cells of the His bundle, which is a continuous structure from the A-V node, are activated electrically one after another continuously. Namely, there must be an electrical activity of some cells of the His bundle in all the time points between the N potential and the H potential. The second question is whether the electrogram resembles more in nature the extracellular recording of an isolated nerve or skeletal muscle fiber or the direct lead electrocardiogram on the surface of the whole heart. This question is raised from a practical demand to solve whether a unipolar leading is sufficient or a very close bipolar leading with a pair of electrodes 1 mm. or less apart is necessary to localize a portion of the His bundle, especially because the technical difficulty of finding the H potential is occasionally increased by the latter.

Methods

An atrial muscle preparation including the opening of the coronary sinus, the A-V node, the His bundle and the tricuspid A-V ring was isolated from the dog or the rabbit. In some preparations the right or left bundle branch or both were included. The preparation was mounted in the muscle chamber filled with about 70 ml. of Tyrode solution gassed with a mixture of 95% O₂ and 5% CO₂. When the preparation was large, coronary perfusion was performed in addition. In the present clinical method of the His bundle electrogram either the unipolar lead or the bipolar lead taken by electrodes, which are usually more than several millimeters apart, are employed. The latter method, different from the very close bipolar lead, is usually only slightly better in taking up the local electrical activity but makes the analysis much more complicated than the former method. Therefore, unipolar leading was employed in this study. Namely, one of the Ag-AgCl electrodes insulated except for the tip was used as the exploring electrode, and the other was placed distantly in the muscle chamber as the indifferent electrode. Another pair of electrographic electrodes was sometimes placed at convenient sites of the muscle preparation to obtain deflections for a time reference. A rectangular pulse wave of usually 5 msec. in duration and of twice the threshold intensity was given for stimulation. Stimulus frequency was 1–1.5 cps. for the dog heart and 2–3 cps. for the rabbit heart.
A microelectrode was also inserted in the vicinity of the electrographic exploring electrode. Our method of the microelectrode was reported elsewhere.

**Results**

When the electrographic exploring electrode was placed on the His bundle above the tricuspid valve in the dog and the rabbit heart, the H potential appeared about 40 msec. before the ventricular deflection. The interval (the H-V interval) was almost constant after the preparation was mounted, while in the atrial muscle preparation employed in this study the interval between the stimulus artifact and the H potential (the S-H interval), which was slightly larger than that between the atrial deflection and the H potential.

![Fig. 1. The configuration of the H potential of the His electrogram above the tricuspid valve. Rabbit.](image)

Sites of origin of each picture are shown by the same letters and numbers in the lower schema. The dot under each tracing shows the time point of 200 msec. after stimulation. Stimulation was given in 3 cps.

The horizontal bar denotes 40 msec.

IAS: interatrial septum.
IVS: interventricular septum.
AVV: atrioventricular ring.
CS: coronary sinus.
RB: right bundle branch.
(the A-H interval), prolonged occasionally thereafter. But it became steady usually after half an hour from the time of being mounted. The S-H interval ranged thus from twice to 3.5 times the H-V interval. The experiments were begun thereafter and finished in 1 or 2 hours, while it was steady. Since the chief problem lies in the nature of the H potential, which did not participate in this prolongation, such preparations were also studied with proper caution in evaluation of the results. When the microelectrode was inserted into the His bundle or into the parts nearly, the potential was generally closer in time

![Fig. 2. The N potential and the H potential of the electrogram at various points of the coronary sinus, A-V node and the His bundle on the atrial side of the fibrous skeleton. Dog.](image)

- a. A schema for explanation of placement of the electrodes.
- A-E: from the vicinity of the coronary sinus to the A-V node.
- F: the transitional zone from the A-V node to the His bundle.
- G-Q: over the His bundle.
- Stimulation was given in 1 cps.

Abbreviations are the same as in Fig. 1. HB: the His bundle.

An example of the whole picture by the lower sweep is shown. A part of each such picture was cut and shown in b to save the space.
to the action potential of the His bundle than that of any other structure. Furthermore, when the exploring electrode was placed at any portion of the His bundle, the H potential was obtained. This was obtained even when the

b. The lower pictures were taken by a faster sweep than the upper pictures. In each picture the upper tracing is the recording of the explored point, the localization of which is shown by the same letter in a. Polarity reversed. The lower tracing is the reference bipolar electrogram, the electrodes of which are shown also in a. The horizontal bars denote 100 msec. for the upper pictures and 40 msec. for the lower pictures.
exploring electrode was placed on the part supposed to be the atrial region close to the His bundle, but in this case the potential was smaller in amplitude and the obtainable extent was small. The width of this extent vertical to the course of the His bundle including it was about 5 mm. Therefore, it was assumed that the H potential originated from the His bundle, but it did not originate from some particular portion of the His bundle.

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2c. A measurement on b.

Each horizontal bar expresses the total time span of the H potential obtained from each of points A-Q. The time scale measured from the beginning of the stimulus is shown at the top. On the right column summits and nadirs of the H potential of the corrected polarity are indicated by a, b, c, d, and e and their time points are shown in the corresponding horizontal bar.
It is supposed that the situation of the His bundle might resemble more, the extracellular recording of the isolated nerve fiber or skeletal muscle fiber which shows a more constant configuration like the second derivative of the action potential, than that of the whole heart. Actually, however, the configuration of the His deflection was more variable and that above the tricuspid valve was more negative than expected from this theory, although not so variable as the QRS complex of the conventional electrocardiogram (Fig. 1). This trend of being more negative is probably because the greater mass of the His bundle lies downstream of the explored points, but the exact mechanism of each deflection is not known in detail.

The exploring electrode was first placed at the opening of the coronary sinus and successively shifted down through the A-V node, the His bundle, and the right bundle branch. It was found that the H potential was recorded even in the utmost upstream, around the opening of the coronary sinus. This was small but it was clearly recognized as such because of the coincidence in time with the H potential of the reference electrogram (Fig. 2b). It appeared slightly earlier than that obtained in the downstream of the His bundle. When the electrode was shifted down, the time and shape of the H potential did not change significantly until the electrode reached the His bundle (Fig. 2c).

When the electrode reached the A-V node below the opening of the coronary sinus, a small, rounded wave appeared between the atrial deflection and the H potential, closer to the former. This is usually called the N potential. The rising limb of the nodal action potential obtained by the microelectrode close to the exploring electrographic electrode was found to be close to it in time. In this region, therefore, both the N and H potentials were observed. By shifting down the A-V node, the N potential appeared slightly later mostly in succession but somewhat irregularly. When the electrode reached the His bundle, the nodal potential usually disappeared before changing its position markedly and only the H potential remained beside the atrial and ventricular deflections. It might be expected that the N potential gradually changed to the H potential, but this usually was not the case. In some cases, especially in rabbits, a wide, queer configuration was observed at the time point of the H potential instead of the N and H potentials, when exploration was made around the transition area between the A-V node and the His bundle with an electrode (Fig. 1, column A). The H potential became larger and now showed a change in shape and appearance time while the electrode was shifted down the His bundle. The shift of the H potential was several milliseconds in total, when the electrode was shifted down from the opening of the coronary sinus through the His bundle to the A-V ring. At no sites the H potential
appeared much earlier than 40 msec. before the ventricular deflection. Considering the results of the other experiments, it was presumed, therefore, that the earliest excitation of the His bundle is not more than several milliseconds earlier than the H potential usually recorded above the tricuspid valve, which appeared about \( \frac{1}{3} \) or \( \frac{1}{4} \) the P-R interval before the Q wave.

The situation was different in the relationship between the H potential and the RB potential. It was technically difficult to explore the penetrating portion of the His bundle. But, by exploring down the conduction system after emerging on the surface of the right side of the ventricular septum, the H potential gradually receded and changed into the so-called RB deflection (Fig. 3). The presence of both the H and RB potentials was experienced only

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Fig. 3. The H potential and the RB potential of the electrogram at various points of the ventricular portion of the His bundle and of the right bundle branch. Dog.

a. In each picture the upper tracing is the recording of the explored point, the localization of which is shown by the same letter in the middle schema. The lower tracing is the reference bipolar electrogram, the electrodes of which are shown also in the middle schema.

Stimulation was given in 1.8 cps.

Abbreviations are the same as in Fig. 1. HB: the His bundle.

APM: anterior papillary muscle.
in the bipolar leading (Fig. 4).

At each exploring site a microelectrode was inserted at several points as close as possible to the electrographic exploring electrode. When this exploring electrode was shifted down, in the upstream above the His bundle the main deflection of the H potential moved little in time as mentioned above. However, when the exploring electrode and the microelectrode were shifted down the His bundle, both the tip or the nadir of the H potential and the transmembrane action potential receded together, although the time points of both were not the same (Fig. 5). The delay of the H potential was irregular even if a regular shifting of the electrode was made.
Fig. 4. Unipolar leading and bipolar leading of the His bundle. Dog. The upper tracing is a unipolar leading, the exploring electrode of which was placed at a point of the His bundle above the A-V ring. The lower tracing is a bipolar leading, in which one electrode was placed close to the above-mentioned point and the other electrode was placed around the point K in the right bundle branch in the same experiment as Fig. 3. See text for explanation.

If the His electrogram resembles in nature more the extracellular recording of an isolated nerve or skeletal muscle fiber, the configuration of the H potential would be theoretically close to the second derivative of its transmembrane action potential, being relatively constant everywhere, and the crossing point of its deflection with the base line would correspond to the steepest rise of the action potential. In order to test this, the microelectrode was inserted at various points around each exploring position of the electrographic electrode. Two examples are shown in Fig. 6. The steepest rise of the action potential obtained closest to the electrographic electrode usually corresponded to some time point between the summit and nadir of the main deflection of the electrogram (Fig. 6). But it was not limited to some particular point. The configuration of the H potential varied depending upon the explored position. This relationship was observed also when the action potential obtained
Fig. 5. The extracellular H potential and the intracellular action potential obtained closest to each other at each portion of the His bundle. Rabbit. A, B, C . . . N are the points of the His bundle from the most proximal portion to the penetrating portion. Actual examples are shown as the right pictures taken from points C, D, G, T, K, and N. In each picture the upper tracing is a bipolar leading of the His bundle used for a time reference. The middle tracing is the action potential and the lower tracing is the H potential with reversed polarity, which were taken as close as possible to each other at each point of the His bundle. In the left schema summits and nadirs of the H potential of the corrected polarity are indicated by a, b, c, and d and their time-points are shown on each horizontal bar expressing the total time-span of the His potential at each point. On each bar the time of the steepest rise of the action potential obtained closest is shown by an arrow and the point of crossing the base line of the H deflection is shown by a closed circle.
Stimulation was given in 2 cps.
Fig. 6. The extracellular H potential and the intracellular action potential. Rabbit.

a. An example. The exploring electrographic electrode was fixed at the point indicated by an open circle in the His bundle and the microelectrode was shifted to various points indicated by dots, figures and numbers. On the back side of the electrographic electrode (upper part in the schema) the microelectrode could not be inserted because of the presence of the former.

In each picture shown in the upper part the upper tracing is the H potential taken by the former and the lower tracing is the rise of the action potential obtained by the latter.

by the fixed microelectrode was compared with the H potential obtained by shifting the electrographic electrode to the various points in its vicinity (Fig. 7). This situation is not so different from the above theory as what we found previously between the direct electrocardiogram on the surface of the tortoise heart in situ and the action potential obtained closest to each explored point was different from the theory. However, if we take a certain corresponding time of the H potential, for instance, the nadir, it tended to shift more or less in parallel with the steepest rise of the action potential (Fig. 5).
b. Another example. The polarity of the His electrogram is reversed.

After an experiment with placement of the exploring electrographic electrode at a point indicated by an open circle on the left hand, this was shifted to a point shown by another open circle on the right hand and a similar experiment was carried out.

Sometimes the steepest rise of the action potential closest to the explored point corresponded to the extrinsic deflection of the electrocardiogram (Fig. 6b). Rather the one obtained from a slightly more distant point corresponded to its intrinsic deflection. It was interpreted that the point explored by the microelectrode in this case might have been closer to the point explored by the electrographic electrode in 3 dimensions.

**DISCUSSION**

There seems to be little doubt about the H potential originating from the His bundle. In the isolated dog heart Alanis\(^2,3\) showed that the H potential was registered from the location in accordance with the original anatomical description of the His bundle, that vagal stimulation or acetylcholine injections produced a lengthening of the A-H interval without changes in the H-V interval and that severance of the His bundle caused disappearance of the ventricular electrogram but the H potential persisted. Studies by Hoffman and his associates\(^6,7\) showed that the H potential was recorded from the region anatomically visualized and also in situ in chronic dogs. Scherlag and his associates\(^1\) obtained the H potential by human catheterization and showed that this was the same with the extracellular H potential in the animal heart de-
Fig. 7. The intracellular action potential and the extracellular H potential. Rabbit.

The microelectrode was fixed at the point indicated by the dot in the His bundle and the electrographic electrode was shifted from point A to G. In each picture shown in the upper part the upper tracing is the H potential taken by the latter and the lower tracing is the rise of the action potential obtained by the former.

The horizontal bar denotes 40 msec.

scribed above. As for the N potential Alanis also showed evidence that it originated from the A-V node, although there were some who doubted this origin. In our result the appearance time of the H potential was similar to what was described in the above-mentioned reports and the coincidence of the H potential was noted with the action potential, which was obtained very close to the electrographic electrode and seemingly from anatomical position of the His bundle and which showed the features of the His action potential.

The impression of relative constancy of the time point of the H potential in spite of movement of the catheter comes probably from the relatively small shift of the H potential above the A-V ring and from difficulty of following the right bundle branch by the catheter in the ventricle.

The finding that the N potential did not change usually to the H potential as the electrode was shifted downstream while the H potential changed to the RB potential suggests either there is a discontinuity in conduction at the
junction between the A-V node and the His bundle or the conduction velocity in the A-V node is much smaller than in the His bundle. Alanis\(^3\) supposed that there is a membrane discontinuity between the A-V node and the His bundle. Our previous study on the A-V node by the microelectrode supports the latter possibility.\(^{14}\) The observation in this study that on some occasions exploration around the junction between the A-V node and the His bundle yielded a wide, queer and transitional-like deflection supports also this possibility. In this study, however, whether the N potential actually originated from the A-V node or not was not confirmed, except for the finding that the nodal action potential was roughly consistent with the N potential in time.

The above-mentioned result shows that the H potential takes up the electrical field of the whole His bundle. But, when the electrode is on the His bundle, the influence of the local electrical activity was stronger than when the electrode was placed on the whole heart. This was shown by the fact that, when the electrode was upstream in relation to the His bundle, the H potential did not change in time and configuration prominently. This was shown also by the fact that in general the H potential showed a delay successively like the action potential and showed changes in configuration when the electrode was shifted down the His bundle. At least it is different from the usual cases when the electrical field is taken, for instance, when the electrode is placed on the whole heart. In our previous experiment with the whole tortoise heart the shift of the summit of the electrocardiographic deflection was much smaller than the shift of the action potential, even if both were taken very close to each other.\(^{13}\)

As was described above, the H potential cannot be regarded as the record of the local electrical activity of the explored portion of the His bundle and the electrical field generated by the whole of the His bundle influences the deflection. On the other hand, the local electrical activity seems to influence the H potential more strongly than in the case of the direct electrocardiogram from the surface of the whole heart and much more strongly than in the case of the conventional body surface electrocardiogram. Alanis\(^3\) described that the shape and amplitude of the H potential were similar and independent of the site of recording. This statement cannot be entirely supported, nor entirely rejected. This is because many, although not all, of the configurations showed rS, rSr' or RS type and that there was a tendency of some parallelism between the shift of the corresponding time of the H potential and that of the steepest rise of the action potential. Therefore, a certain time point of the H potential may be roughly regarded as showing a local electrical activity, if a variable error is permitted. This casts a doubt as to whether a close bipolar lead with 1 or 2 mm. of interelectrode distance is necessary or not in
the usual cases of catheterization, if the purpose is mainly to take a local electrical activity especially because this method makes the recording more difficult.

REFERENCES