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Artículo:

An experimental contribution to the concept of "Jumping Wave" phenomenon in the interventricular septum

INVESTIGACIÓN BÁSICA

An experimental contribution to the concept of "Jumping wave" phenomenon in the interventricular septum

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Summary

Objective: The purpose of this study was to evaluate the existence of a histologically bipartite interventricular septum and the electrical independence of both septal masses, as well as to understand the changes of septal activation fronts in the presence of bundle branch blocks. **Methodology:** We examined the histological characteristics of both septal masses in 12 canine hearts. Furthermore, in another 11 anesthetized dog hearts, we analyzed morphological and chronological data of intraseptal records with normal activation and in the presence of proximal blocks. **Results:** A histological discontinuity between the two septal masses in canine hearts seems to exist. Analysis of intraseptal and intracavitary electrical records confirmed slow transmission of the activation fronts from one septal mass to the other when proximal blocks were present. Morphological and chronological changes of the intracavitary complexes agree with the "jumping wave" phenomenon theory. **Conclusions:** These results support the validity of this approach to the activation of both septal masses and explain the chronological and morphological changes of the intracavitary records in the presence of ventricular blocks. In addition, this approach is a useful tool to detect the possible coexistence of dead septal tissue.

Resumen

CONTRIBUCIÓN EXPERIMENTAL AL CONCEPTO DE "SALTO DE ONDA" EN EL TABIQUE INTERVENTRICULAR

Objetivo: El propósito de nuestro estudio es aportar datos objetivos a la teoría de la bipartición histológica del tabique interventricular y de la independencia eléctrica de las dos masas septales, así como a la de los cambios de los frentes de la activación septal en los bloqueos de rama. **Método:** Hemos examinado las características histológicas de ambas masas septales en corazones caninos y humanos. Además, hemos analizado los datos morfológicos y cronológicos de los registros intraseptales con activación normal y en presencia de bloqueos tronculares de diferentes grados en 11 perros anestesiados. **Resultados:** Hallamos datos objetivos a favor de una discontinuidad entre las dos masas septales tanto en el corazón canino como en el humano. El análisis de los registros eléctricos intraventriculares ha confirmado la transmisión lenta de los frentes de activación de una a otra masa septal, en presencia de bloqueos tronculares. Los cambios morfológicos y cronológicos de los complejos QRS intraventriculares concuerdan con la teoría del fenómeno de "salto de onda". **Conclusiones:** Nuestros resultados apoyan la validez del punto de vista de la independencia funcional de ambas masas septales y permiten explicar los cambios morfológicos de los registros intraventriculares, en presencia de bloqueo de rama. Este enfoque es también de gran

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ayuda para detectar la posible coexistencia de miocardio septal inactivable.
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Key words: Septal histology. Septal function. Septal normal activation. Septal delayed activation. *Jumping wave* phenomenon. Proximal bundle branch blocks.
Palabras clave: Partición septal histológica. Partición septal funcional. Activación septal. Fenómeno del “salto de onda”. Bloqueos de rama.

Introduction

Electrocardiography still provides the most important clues for the diagnosis of depolarization and repolarization events both in atrial and ventricular myocardial fibers and under normal and abnormal conditions. This fact is particularly relevant in the presence of bundle branch blocks and ventricular arrhythmias, in which septal electromotive forces predominate.

The concept of “jumping wave” through an “intraseptal barrier” was expressed a long time ago by Sodi Pallares[1] and seems to function quite well, as an operational concept, for accentuated branch blocks and for ventricular arrhythmias. It must be taken into account that the septal activation process is similar in both cases.

The purpose of the present publication is to provide experimental data to support the “jumping wave” concept. We have already published another article[2] on this subject, suggesting-both macroscopically and microscopically—the existence of a mid longitudinal bundle in the interventricular septum. This seems to constitute a structural limit between both septal masses and to determine the histological substrate of the so-called intraseptal barrier.[3]

Some researchers, however, believe that such a bundle could just represent a simple optical effect, demonstrable with confocal microscopy techniques. Therefore, in this study, we decided to examine whether those points at which the difference in the mean septal activation times starts to become significant in the absence or presence of experimental bundle branch blocks, coincide with the points that correspond to the position of this bundle determined by microscopical examination.

Based on the above, this study was aimed at evaluating the existence of a histologically bipartite interventricular septum and the electrical independence of both septal masses.

Material and methods

I. Histological study

Cross sections were made in 12 dog hearts previously fixed in 10% formaldehyde. We chose the ventricular slices of the medial portion, which correspond to the insertion point of the papillary muscles of the left ventricle. Histological sections were made on the medial anterior portions of the interventricular septum of the dog hearts *(Fig. 1A)*. Tissues were embedded in paraffin; 4-µm sections were obtained and stained with hematoxylin-eosin and Masson’s trichrome for further analysis. Measurements of the position of the observed septal longitudinal bundle were performed on slides, using a ruler under microscopic control, from the left septal surface in a regular fashion to the longitudinal bundle in the middle third of the interventricular septum. On the same preparations and under the same conditions, measurements were also made from a middle point of the right septal surface, irregular due to the presence of myocardial trabeculae, to the muscular bundle.

Histological sections of the interventricular septum were made also in 6 rat hearts *(Fig. 1B)*.

II. Electrical study

On another 11 dog hearts, beating *in situ* in the open thorax, and artificially breathing by means of a Palmer pump,[4] we recorded the septal activation times without and with bundle branch blocks.

Bipolar and unipolar recordings were obtained from all these animals, anesthetized with sodium pentobarbital (30 mg/kg, intravenously applied). We used a No. 15 or 16 trocar perforated with 10 or 12 holes of 0.5 mm along the sheath and at a 1 or 1.2 mm distance. Two very fine isolated copper wires were introduced in each hole, a total of 20 or 24, along the sheath of the trocar. An arrowhead was attached to the tip of the needle and the device was covered with Lucite, which once dry was varnished. The unit was tested with an ohmmeter to detect possible short circuits in contiguous wires.

The trocar was introduced through the middle part of the anterior third of the right ventricular free

Fig. 1A. Cross section of a dog heart at the level of the root of papillary muscles. The longitudinal muscular band separating the septum in two portions can be observed.

Fig. 1B. Histological section of the interventricular septum in rat heart. It corresponds to a muscular bundle located between two groups of myocardial fibers oriented in different directions.

wall and directed to the middle portion of the right septal surface, from right to left, from the front to the back, and from the top down. This was done to avoid damaging the trunk of the right branch of the His bundle, and to reach the middle portion of the left septal surface, away from and below the main trunk of the left branch as well as the first portions of its distal subdivisions. The arrowhead trocar was then removed gently and placed on the septal surface. The initial portion of the main trunk of the left branch at the level of the septal sigmoid valves of the aorta was subjected to pressure and friction by means of a blunt-tipped stylet, causing an advanced degree left bundle branch block (LBBB). Its morphologies were recorded with the neighboring bipolar and unipolar leads. Once the LBBB had disappeared, the right branch at its mid third or slightly above its mimetic portion was subjected to pressure. Recordings of each block were made with a cathode rays oscilloscope.

Bipolar recordings were obtained at each perforation and between two neighboring perforations; however, those obtained at the perforations were more reliable and constant even without filtering the slow frequencies. In fact, the bipolar records were obtained filtering the slow frequency (7 cycles per second), using a high frequency recording bandwidth of 150 cycles per second. Unipolar records were obtained with a bandwidth of 150 cycles for the high frequency and of 0 filtered for the low frequencies.

The bipolar records depicted positive or biphasic inflections between the slow flat pre- and post-intrinsic phenomena. The vertex of the positive deflection or the fast drop closest to the vertical line was judged by two observers -one of the authors and an unbiased expert, not involved in this work- as the instant corresponding to the passage of the activation dipole through the pair of exploring electrodes. The explored points are be shown in Figures 2 and 3.

III. Statistical analysis

The values of the difference between the time of septal activation onset and the arrival of the activation wave to each of the contact points of the electrodes in the interventricular septum exploratory needle were included in the database of the SPSS software. This matrix was used for the corresponding analyses. Analyses included central tendency and dispersion of all measurements of each experiment. The arithmetic mean, the standard deviation, and the standard error of the mean were obtained for each explored point. The obtained values were compared using paired "t" test to determine the significant difference at a probability of 0.05% of the initial point with respect to each exploring electrode. Mean values and standard error of the mean were plotted separately in two graphs: one to examine the behavior of septal activation in the presence of an experimental LBBB compared to a control, and the other in the presence of RBBB with its respective control.

Results

1. Histological findings

Microscopic sections of the 12 canine hearts revealed a different orientation of the myocardial septal fibers at the papillary muscle level. Histological preparations showed a longitudinal muscular bundle located among the septal myocardial fibers, directed transversely in the opposite direction. This bundle unevenly divides the interventricular septum. Figure 1A depicts a macroscopic canine heart preparation, revealing that in the middle third of the interventricular septum, the bundle is closer to the right septal surface than to the left one. The opposite orientation of the septal myocardial fibers can be seen clearly even in the rat heart *(Fig. 1B)*, as was evident in six observations.

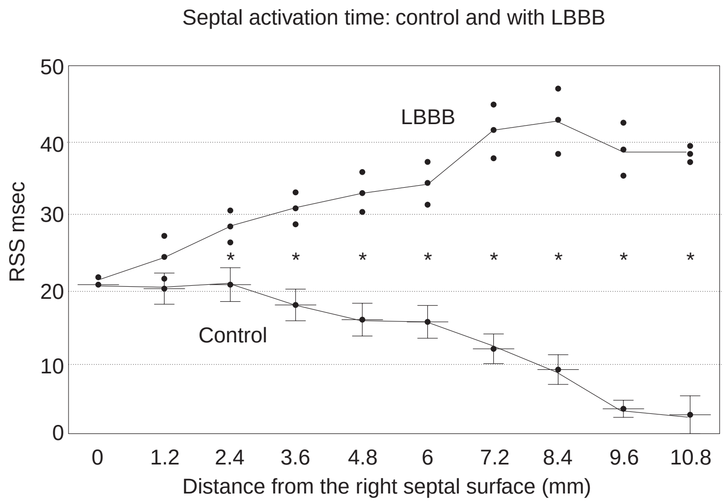

Fig. 2. Difference between the average times of control septal activation (below) and delayed septal activation due to a LBBB (top). This difference becomes significant at 2.4 mm depth from the right septal surface. Abscissa: Distance in millimeters from the right septal surface. Ordinate: Time of septal activation in milliseconds. RSS = Right septal surface.

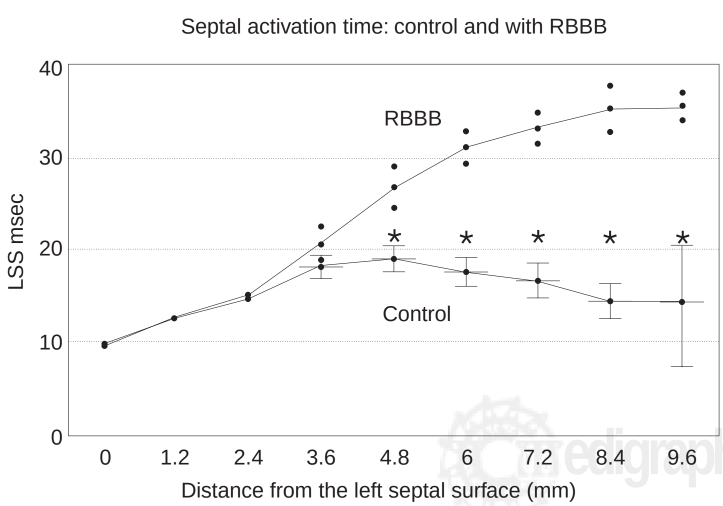

Fig. 3. Difference between the average times of control septal activation (below) and delayed septal activation due to a RBBB (top). This difference becomes significant at 4.8 mm depth from the left septal surface. Abscissa: Distance in millimeters from the left septal surface. Ordinate: Time of septal activation in milliseconds. LSS = Left septal surface.

Table I. Position of the septal longitudinal fascicle.

	Mean mm	N	STD Deviation	STD Error
From the left septal surface	4.14	11	1.14	0.344
From the right septal surface	3.14	11	0.95	0.286

Paired "t" = 3.403; 10 freedom degrees and 2 tails. p = 0.007

Measurements performed by one of us (Aranda) in 11 dog hearts allowed us to locate the longitudinal fascicle at an average of 4.14 mm (range 3 to 6) from the left septal surface and at an average of 3.14 mm (range 1.5 to 4) from the right septal surface *(Table I)*. These distances were significantly less than those from the left septal surface. Comparison analysis revealed a statistically significant difference, at a confidence interval of 99%.

2. Electrical findings

The analysis of the changes in the septal activation process at the mid-third of the interventricular septum, performed on the oscilloscope recordings from the other 11 dogs, revealed the following findings. In the presence of a LBBB *(Fig. 2)*, a significant difference was found between the average time of activation in the control and the delayed activation induced by the block (asterisk) starting at 2.4 mm of depth from the right septal surface. In contrast, when a RBBB *(Fig. 3)* was produced, the difference between the control and the delayed activation induced by the block (asterisk) was observed starting at 4.8 mm of depth from the left septal surface. Dots on the lines indicate the average experimental values and the bars ("greater than" to "less than") correspond to the standard error of the mean. Asterisks indicate a statistical significance of $p < 0.05$ when analyzing the experimental values with their corresponding control using the paired "t" test.

These findings could satisfactorily explain the morphology and chronology of an accentuated LBBB when the right septal mass is electrically stimulated[3-5] and of an accentuated RBBB when the left septal mass is stimulated.[6] In fact, LBBB morphologies *(Fig. 4)* appear in the intracardiac and external leads when stimulating the apex of

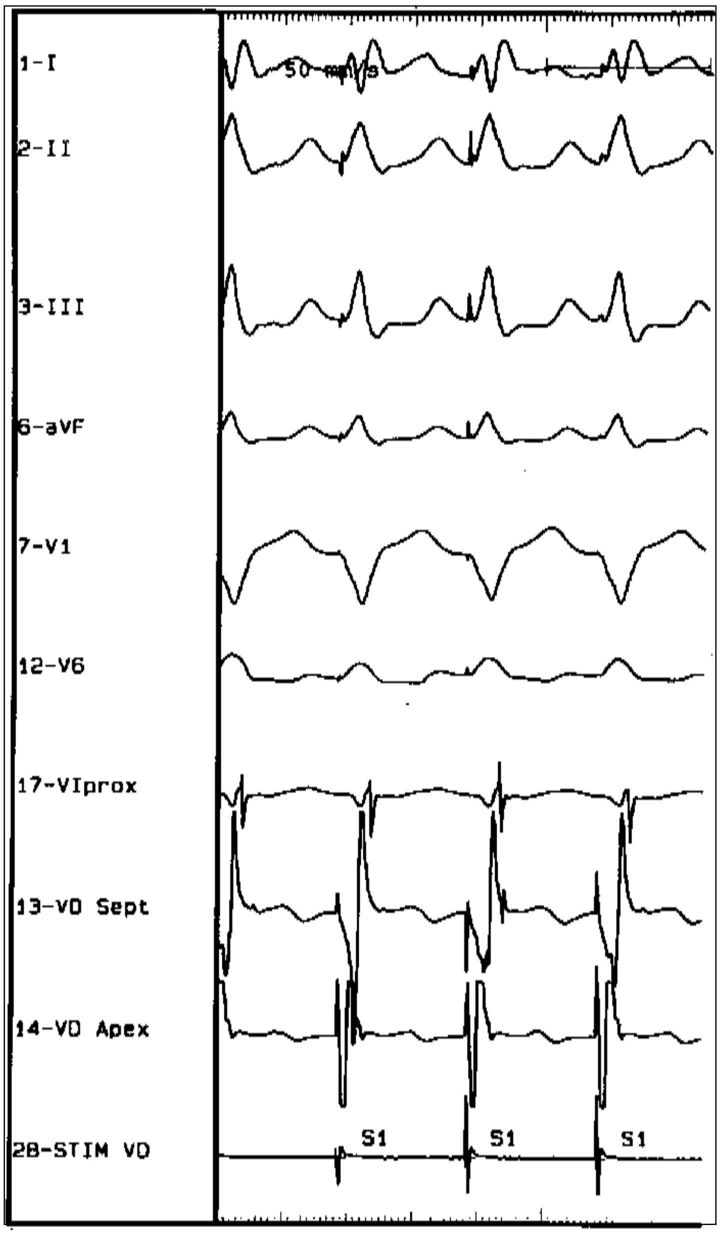

Fig. 4. LBBB morphologies appear in left leads when stimulating the apex of the right ventricle (STIM VD) with a stimulation cycle of 400 msec. The ventricular activation sequence is from the apex of the right ventricle (VD Apex) to right septal mass (VD Sept) and, finally, to the apex of left ventricle (VI prox). VD = right ventricle. VI = left ventricle.

the right ventricle (STIM VD) with a stimulation cycle of 400 msec. In this example, the ventricular activation sequence goes from the apex of the right ventricle (VD Apex) to the right septal mass (VD Sept) and, finally, to the apex of the left ventricle (VI prox). On the other hand, RBBB morphologies *(Fig. 5)* are recorded in the intracardiac and external leads when stimulating the apex of the left ventricle with a stimulation cycle of 400 msec. In this case, the ventricular activation sequence goes from the apex of the left ventricle (STIM VI) to the right septal mass (VD Sept) and, finally, to the apex of the right ventricle (VD Apex).

Commentary

There are embryological and histological data in favor of the separation of the two septal masses.

Embryological data

According to De Vries and Saunders,[7] the interventricular septum is formed by coupling of the right and left walls of the primitive ventricle and of the *bulbus cordis* (left and right prospective ventricle, respectively). In turn, Harh and Paul[8] demonstrated experimentally the mechanism described by the aforementioned authors: the interventricular septum is formed by the folding and fusion of the two primitive ventricular walls, explaining why each septal mass possesses a specific design pattern. In fact, a separation between the right and left septal masses can be clearly observed in Jean Lenègre's and Maurice Lev's histological preparations[9] that reveal an apparent cleavage plane between the right and left septal masses at the anterior lower half of the interventricular septum.

Histological data

Macroscopic evidence obtained in our study agree with the findings of Torrent-Guasp.[10] In our histological preparations, the change in fiber orientation is more pronounced at the mid-third level of the interventricular septum: a large proportion of the septal fibers are transversally arranged, emerging in angles that produce a cleavage with the longitudinal ones. These angles were also studied by LeGrice *et al*.[11] Their description corresponds to our findings: transverse fibers moving perpendicular to longitudinal ones. According to certain electrophysiologists,[12,13] the opposite orientation of the myocardial fibers, when observed in a three-dimensional perspective through a confocal system, produces the image of a medial band. Nevertheless, the work of LeGrice *et al*. (1997)[12] refers to the structure of ventricular free walls and the paper of Young *et al*,[13] only addresses the left ventricular free wall of the rat heart.

We believe that the muscular longitudinal bundle, observed in our histological preparations,

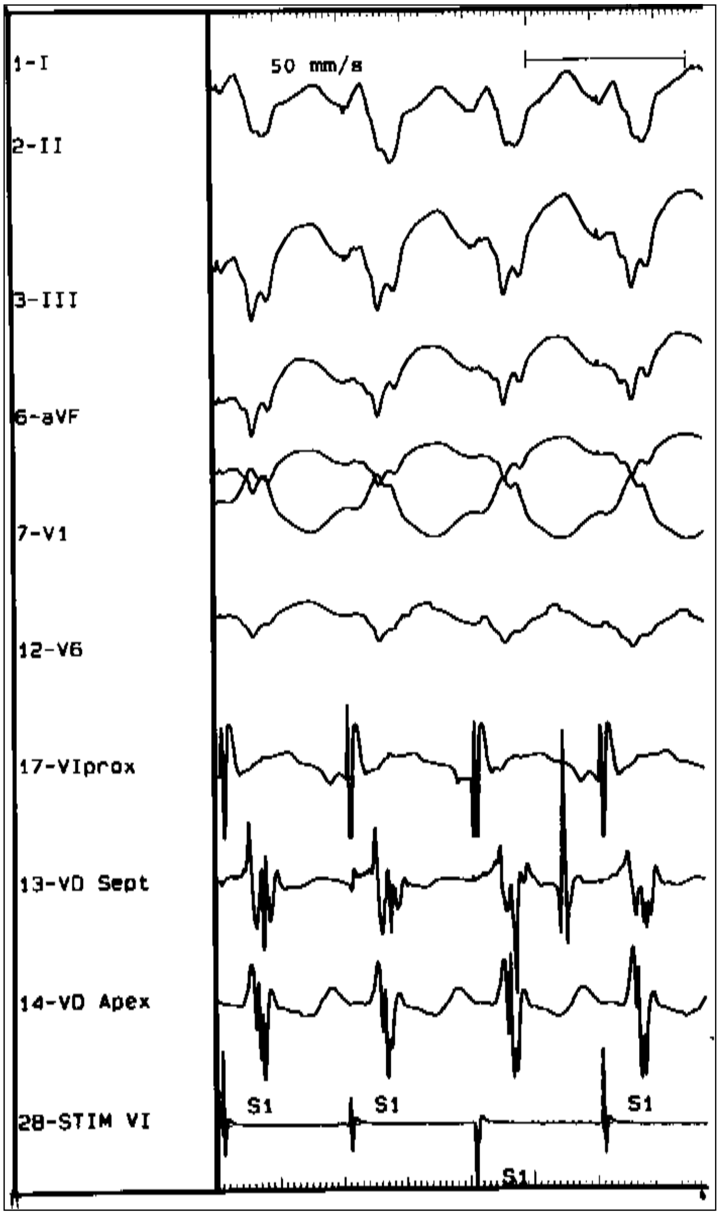

Fig. 5. RBBB morphologies appear in recording leads when stimulating the apex of the left ventricle (STIM VI) with a stimulation cycle of 400 msec. The ventricular activation sequence is from the apex of the left ventricle (STIM VI) to the right septal mass (VD Sept) and, finally, to the apex of the right ventricle (VD apex). This figure corresponds to the same case of figure 4. VD = right ventricle. VI = left ventricle.

constitutes an actual structure and is not an optical artefact, although we have not been able to perform an *ad hoc* study using a confocal system. On the other hand, the separation of the two septal masses observed in our histological preparations seems to coincide with the region where the difference between the average time of normal activation and that of the delayed activation induced by the blocks becomes significant: it is closer to the right septal surface than to the left one. Furthermore, the human heart slice, at the papillary muscle level, also shows an opposite orientation of the myocardial septal fibers.[2]

Electrical data

Our findings indicate that the region through which the activation fronts pass from one septal mass to the other –slow and delayed- is closer to the right septal surface than to the left. This agrees with the frequent observation that at the medial portion of the interventricular septum, the left septal mass predominates over the right. It also agrees with the asymmetric position of the mid muscular bundle, which apparently separates the septal masses at an average of 3.14 mm from the right septal surface and at an average of 4.14 mm from the left septal surface. The difference between the control and the block-induced delayed activation times is even more marked at the points farthest from the septal surfaces, where the depolarization fronts, after crossing the intraseptal barrier, must be transmitted from one contractile fiber to another through high electrical resistance cellular junctions.

The electrical independence of the two septal masses was documented many years ago by Maekawa,[14] by Rubio and Rosenblueth,[15] and by the Mexican School of Electrovectorcardiography.[16] In fact, the advance of depolarization fronts through the interventricular septum is different from normal activation when bundle branch blocks or ventricular arrhythmias are present. At the boundaries of the septal masses, the activation fronts advance slowly as they do in the region of the atrioventricular node.[2] This phenomenon, defined as “jumping wave” by the Mexican School,[1] can be satisfactorily explained based on the existence of an “intraseptal barrier”.[17] This can be demonstrated by intraventricular unipolar recordings during experimental[18] and invasive[19] electrophysiological studies. The slow depolarization observed deep within the septal mass, in the presence of a BBB or PVC, could be explained by axial and/or transverse septal depolarization. In fact, some authors[20] have stated that transverse or perpendicular depolarization is two to four times slower than axial depolarization.

Statistical analysis

The reference point is the first measurement, and it contains the basal value before the maneuver.

The following points are the time series of the induced activation, either plain (control) or delayed by the experimental branch block (the maneuver). Exploratory intervals between them are fixed by the exploratory needle.

Student's "t" test was used to compare the activating behavior time between control and experimental conditions. The intention was to determine the point where the difference became significant based on the time intervals. ANOVA was not selected because it would nullify the changing moment. Since the activation time for each exploratory point was given by multiple experimental measurements at different points, to appreciate the time difference between control and the experimental measurements it was necessary to compare data arrangements point by point. Actually, each point represented population data, and the comparison between two points became the difference between two populations.

Statistical analysis of the experimental values revealed that arrival time of the activation front during branch blocks differed significantly from the control activation time tended to be earlier with a LBBB than with a RBBB. In other words, the point of onset of a significant delay in septal activation during a block is much closer to the right septal surface than to the left septal surface when compared to control time. This was to be expected in the middle third of the interventricular septum, where the left septal mass is thicker than the right septal mass.

Likewise, records obtained by stimulating ventricular myocardial fibers, both under normal conditions and in the presence of ventricular arrhythmias or BBB,[21,22] offer invaluable information for the diagnosis of a necrotic septal zone. Thus, the "jumping wave" phenomenon helps to detect a septal necrosis complicated by an accentuated left bundle branch block[23-29] or a ventricular arrhythmia.[23] In fact, the activation fronts advancing from the septal mass that first activate toward the contralateral side must surround the obstacle formed by the no activated myocardium. This induces an initial negative deflection in the left leads, which should record exclusively positive ventricular complexes.

Conclusions

The findings described here support the concept of a histological and functional bipartition of the interventricular septum in experimental animals, and probably in human hearts as well. Both septal masses, left and right, receive independent activation impulses, each by the corresponding conduction pathway. In fact, the septal activation is not of a syncytial type. If the conduction pathway is blocked, the direction and duration of the septal depolarization will change and thus the morphological and chronological aspects of the intracavitary complexes are changed. It seems therefore justified to infer the "intraseptal barrier" and "jumping wave" concepts. In the presence of bundle branch blocks, the chronological and morphological changes of intraventricular and external complexes in clinical tracings resemble those obtained in experimental records.

The findings reported here satisfactorily explain the slowing down of the activation fronts, as well as the concept of the "jumping wave" phenomenon, which in turn could explain the slurred and notched R waves in leads exploring the blocked ventricle. These aspects of the ventricular electrical phenomenon help to establish the coexistence of a necrotic septal zone in the presence of ventricular conduction disorders. In fact, when a LBBB is present, the activation fronts, in the interventricular septum, must surround the obstacle and, therefore, make it possible to recognize signs of septal "necrosis" despite the presence of an accentuated left bundle branch block.

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