

New Electrocardiographic Leads and Regional Vectorcardiograms

Nuevas derivaciones electrocardiográficas y vectorcardiogramas regionales

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ABSTRACT

Precordial bipolar leads (PBL) provide new information from the standard 12-lead ECG. These leads are an ideal complement to the traditional unipolar leads (V1 to V6) of the ECG because they are practically perpendicular to the latter and allow evaluation of the right-to-left and anteroposterior precordial axes, as well as the construction of regional vectorcardiograms (RVCG) that enable the selection of the specific myocardial region to be studied without interference from other parts of the heart.

An important advantage is that, using the appropriate software, it is possible to simultaneously generate the standard ECG and VCG as well as the new leads and RVCG. All this information can be derived from data stored in a hospital database, provided they have been digitally recorded by a simultaneous 12-channel ECG. This means that no additional electrodes or cables and no extra technical work are required.

Using typical ECG data, various bipolar leads, weighted unipolar leads, RVCG and ECG circular charts can be created. These new displays have made it possible to identify previously undetected abnormal electrophysiological patterns.

Keywords: Electrocardiography - Myocardial ischemia - Arrhythmia - Myocardial infarction

RESUMEN

Las derivaciones bipolares precordiales (PBL, Precordial Bipolar Leads, por su denominación en inglés) proporcionan nueva información a partir del ECG estándar de 12 derivaciones. Estas derivaciones son un complemento ideal de las derivaciones unipolares clásicas (V1 a V6) del ECG porque son prácticamente perpendiculares a estas últimas y permiten evaluar los ejes precordiales derecha-izquierda y anteroposterior, así como crear vectorcardiogramas regionales (VCGR). Los VCGR posibilitan la selección de la región miocárdica específica que se desea estudiar sin interferencias de otras partes del corazón.

Una ventaja importante es que, usando el software adecuado, es posible generar simultáneamente tanto el ECG y el VCG estándar como las nuevas derivaciones y VCGR. Toda esta información puede derivarse de los datos almacenados en la base de datos de un hospital, siempre y cuando hayan sido registrados digitalmente por un ECG de 12 canales simultáneos. Esto significa que no se requieren electrodos o cables adicionales, ni trabajo técnico extra.

Con el uso de los datos del ECG clásico, se pueden crear diversas derivaciones bipolares, unipolares ponderadas, vectorcardiogramas regionales y gráficos circulares del ECG. Estas nuevas presentaciones han permitido identificar patrones electrofisiológicos anormales que antes no habían sido identificados.

Palabras claves: Electrocardiografía - Isquemia miocárdica - Arritmias - Infarto de miocardio

INTRODUCTION

Precordial bipolar leads (PBL) have been described more than a century ago. In addition to the Lewis, Nehb, Cossio and Fontaine leads, (1-4) PBL are commonly used in operating room and intensive care monitoring and also in the Holter study. However, their use is empirical, not systematized and their electrodes are not the same as those of the standard ECG.

In contrast, this review analyzes a new systematized electrocardiographic method that does not require additional cables or extra technical work, since it is based on the processing of data obtained from a simultaneous 12-channel digital electrocardiogram, either from a patient or stored in a database. (5,6) Recombination of recordings allows the creation of various bipolar leads, weighted unipolar leads and regional

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vectorcardiograms, as well as ECG circular charts. (7) These new presentations not only help in the detection of electrocardiographic pathologies, but also, as with PBL, show electrical phenomena in the right-left and anteroposterior axes that are not visible in the 12 standard ECG tracings.

RATIONALE FOR PRECORDIAL BIPOLAR LEADS (PBL)

A PBL measures the potential difference between two classic precordial electrodes, one designated as positive and the other as negative. It is important to remember that standard ECG precordial leads are unipolar leads (PUL), using the central Wilson terminal as neutral and an electrode applied to the skin as positive. By different combinations of PUL V1 to V6, up to 15 PBL can be generated, almost perpendicular to the midline joining the originating PUL, and study the cardiac sector between the two PUL electrodes. (8) For example, Fontaine lead II is similar to PBL V4-V1 or V5-V2. (4)

Therefore, PBL created from V1 to V4 explore the right-left axis, while V6-V3 does so in an oblique plane and V6-V4 examines the anteroposterior axis (Figure 1).

DESCRIPTION OF THE NEW METHODOLOGY

This new technology involves the generation of PBL, weighted precordial unipolar leads (WPUL) and the construction of regional vectorcardiograms (VCGR), plotting a PBL versus a PUL or a WPUL. Moreover, since they are digital data, reliable measurements can

be made of the time and amplitude of electrical phenomena, which is crucial for detecting time and amplitude alterations secondary to myocardial ischemia.

The digital ECG standards studied to apply our new methodology are from the STAFF III and PhysioBank ATM: PTB DIAGNOSTIC ECG databases, which are publicly available. (9-11)

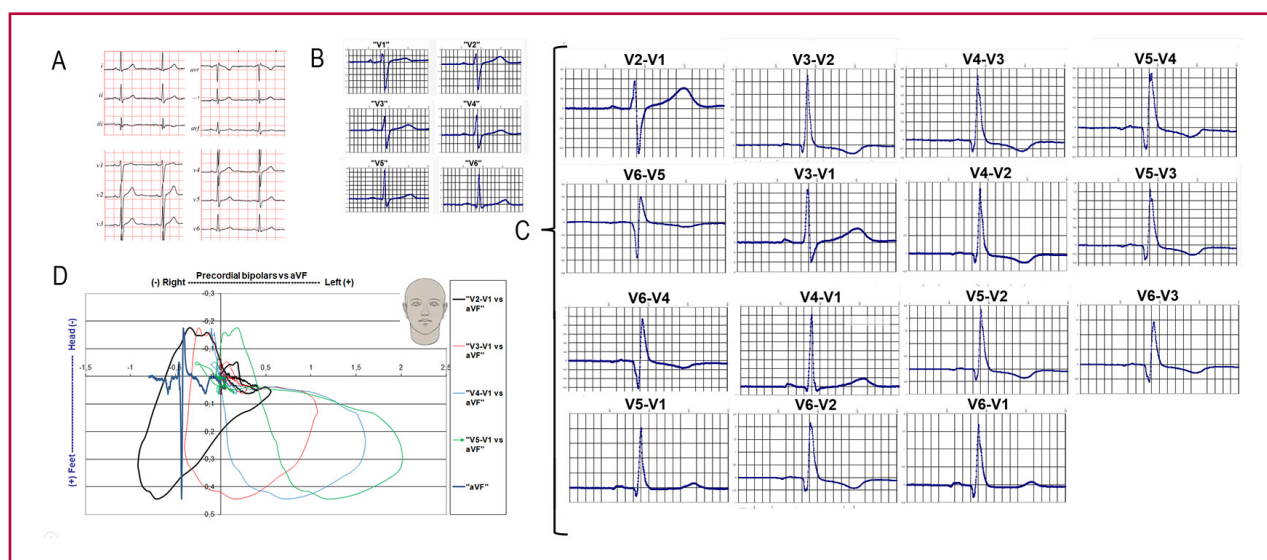
Precordial bipolar leads (PBL)

It is important to remember that leads I, II and III of the standard ECG are bipolar. Therefore, PBL simply consist of selecting one of the precordial electrodes as the right arm (negative) and the other as the left leg or arm (positive). As a working rule, we have established that the leftmost electrode is considered positive [e.g., V2 (+) V1 (-), V6 (+) V1 (-), V6 (+) V4 (-), etc.].

Then, by comparing V2 with V1, we obtain PBL V2-V1, and by doing so between V6 and V4, we obtain PBL V6-V4. PBL V2-V1 is especially important, as it scans the retrosternal area and is highly sensitive to septal and right ventricular (RV) disorders.

Weighted precordial unipolar leads (WPUL)

Weighted precordial unipolar leads are created using complementary ratios of two PUL. The most common ratio is the average of the two (50% of each). Therefore, WPUL V2+V4 is equal to the average of both and should be equivalent to PUL V3 (or PUL V5 in the case of WPUL V4+V6). Similarly, WPUL V1+V2 would be equivalent to having an electrode in the middle of the sternum. This method has been validated in



PBL: precordial bipolar lead; PUL: precordial unipolar lead.

Fig. 1. Control patient. A. Standard simultaneous 12-channel ECG. B. Digital tracings of PUL in "A" differ in that they are plotted to show more detail, sacrificing the relative amplitude comparison. C. The 15 PBL that can be created with the standard ECG PUL, using the leftmost electrode as positive and the rightmost electrode as negative. Note that the lateral PBL (V6-V4 and V6-V5) have their positive electrode to the back, so they start with a significant Q wave, indicating that the initial vector has a postero-anterior direction. D. Comparative graph showing the PBL loop in the frontal plane, built using aVF as a cephalocaudal reference

other publications (5-7) and is routinely used in many electrocardiographic machines to calculate some of the standard leads. (12,13)

Regional electrical activity loops (regional vectorcardiograms: RVCG)

These loops are created by combining classic PUL or WPUL with PBL, which are perpendicular to the former. Regional vectorcardiograms allow the study of the septum and anterior wall, (14) as well as the cardiac apex. (15) In addition, they magnify local electrical phenomena compared with other regions. To facilitate interpretation, especially for users unfamiliar with vectorcardiography, it is possible to add to these loops the tracings that give them origin. Using the coordinate axes to indicate time and voltage, the two measurements can be compared. For example, the "X" axis represents the voltage of the "right-to-left" lead, but also constitutes the time base for the anteroposterior lead (Figure 2). On the other hand, the opposite is true for the "Y" axis. This not only allows observation of the RVCG loop distortions, but also facilitates estimation of time and electrical amplitude of each phenomenon.

Monitoring the progress of cardiac activation (Circular ECG)

Unlike the ECG recording slip, the circular ECG presents all the leads of a plane superimposed in a circle, where the radius represents amplitude and the perimeter represents time. This representation facilitates the appreciation of temporal differences in electrical activity, which makes it especially useful for observing pre-excitation syndromes (Figure 3). (7)

REPRESENTATION OF REGIONAL ELECTRICAL ACTIVITY

Since each PBL scans a particular region of the myocardium, it is not possible to analyze all of them in one review. Therefore, in this review we focused only on that related to the retrosternal area leads.

Weighted unipolar lead V1+V2 (WPUL V1+V2)

As mentioned above, this lead represents the average of the classic V1 and V2 leads. Therefore, it is positioned in the center of the sternum, perpendicular to PBL V2-V1. This spatial arrangement allows the construction of a RVCG that explores the retrosternal area in the transverse plane. In addition, using the cephalocaudal aVF lead associated with PBL V2-V1, a retrosternal frontal plane RVCG can be generated. In the latter case, although the amplitudes are slightly dissimilar, the spatial arrangement is maintained.

Precordial bipolar lead V2-V1 (PBL V2-V1)

This lead is similar to placing the right arm electrode in V1 and the left arm electrode in V2. It is one of the most useful leads because it examines the right-left axis of the retrosternal space, which is not explored in the standard ECG. The center of this lead is in the middle of the sternum and clearly defines the patient's

electrical right and left. This distinction is important to contrast the differences between these new leads and those of the standard ECG; while in the latter it is accepted that the first vector is directed to the right, we have observed in 43 of 52 (83%) controls that in PBL V2-V1, the first vector is directed to the left (unpublished data). This discrepancy may be attributed to the fact that PBL V2-V1 only encompasses the retrosternal sector, whereas the traditional ECG considers the whole heart, resulting in different initial vectors.

Regional retrosternal vectorcardiogram (WPUL V1+V2 vs. PBL V2-V1 and aVF vs. V2-V1)

As mentioned above, the creation of these two RVCGs allows a three-dimensional appreciation of retrosternal electrical activity (Figure 2).

In the transverse plane, the efferent branch of the retrosternal RVCG QRS loop points to the left and forward while the afferent branch ends in the right and posterior quadrant, drawing an oval. In the case of anterior wall infarction, septal electrical forces are lost and the leftward deflection of PBL V2-V1 disappears (Figure 4, right panel). (12) In complete left or right bundle branch blocks, the loop formed by PBL V2-V1 vs. WPUL V1-V2 points backward. (7) PBL V2-V1 is especially useful in right coronary artery (RCA) occlusion because it shows a rightward shift of the ST-segment, suggesting right ventricular ischemia. (16)

NEW METHODS AND CARDIAC PATHOLOGY

Acute myocardial infarction

Because PBL V2-V1 focuses on the retrosternal region and excludes much of the left ventricle, the initial normal QRS vector, unlike the standard ECG, tends to point to the left. This transverse retrosternal RVCG loop is oval, counterclockwise, and passes through all four quadrants.

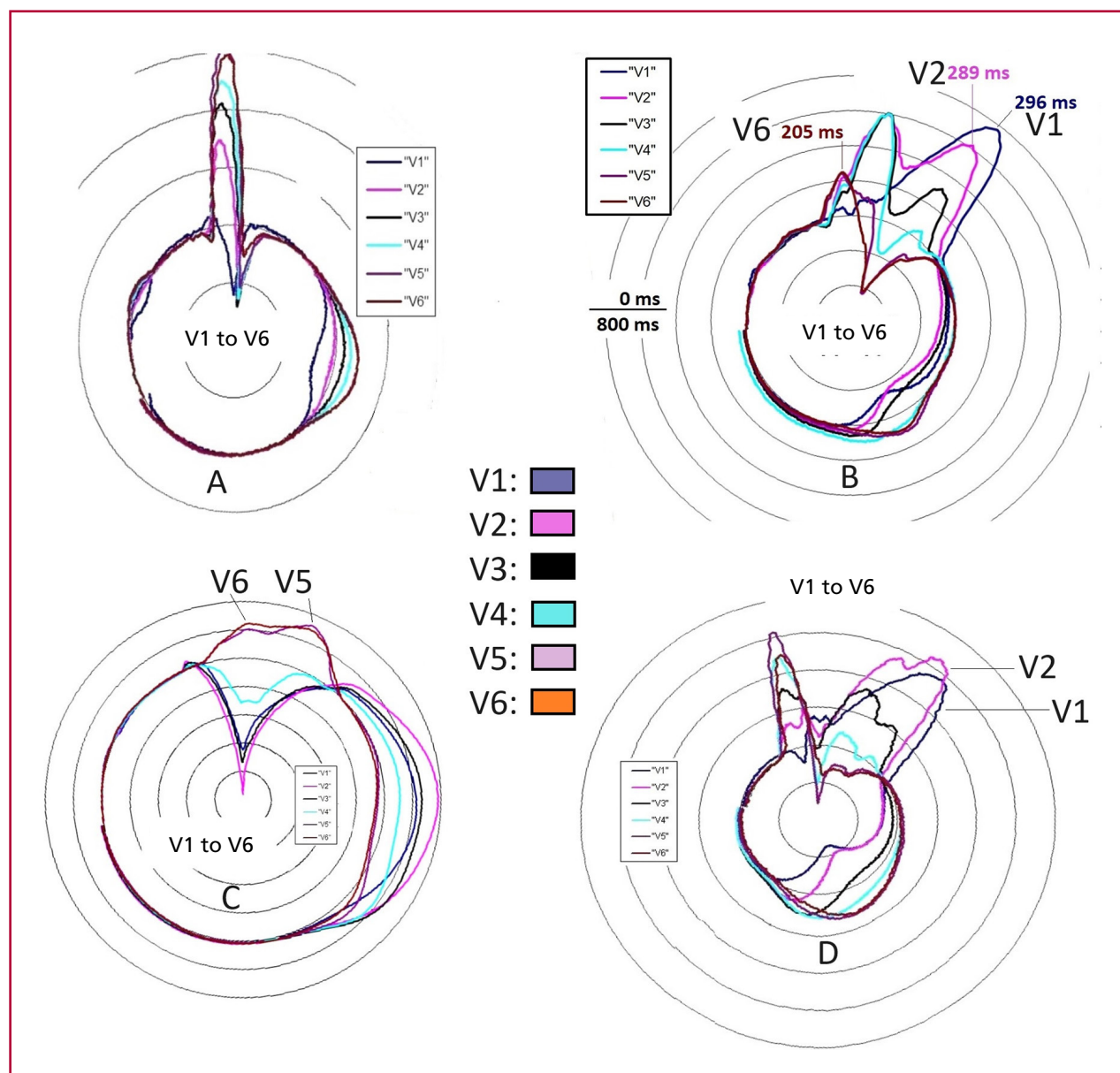
In patients with anterior myocardial infarction, necrosis overrides the electrical forces of the interventricular septum. (7) As a result, electrical forces from the right ventricle take on greater representation and deflect the vectors to the right. In this pathology, PBL V2-V1 may present three different patterns: a. QS (indicating absence of leftward forces in PBL V2-V1), b. Initial Q (i.e., the initial vector goes to the right) and c. Negative notch after the onset of the QRS wave, giving a "bitten apple" pattern in the RVCG of the area (Figure 4).

Hyperacute ischemia

Precordial bipolar leads have been shown to be particularly useful in the evaluation of ST-segment elevation in hyperacute ischemia. In a study of sixteen patients presenting with acute proximal left anterior descending artery (LAD) occlusion, the retrosternal transverse loop showed two typical patterns: 1. QRS folding or 2. QRS transport. (17)



Fig. 2. Patient with RCA middle third occlusion. Panels a, b, c and g: retrosternal transverse plane. Panels d, e, f and h: retrosternal frontal plane. Panels a and d show only the unipolar lead and its influence on the loop (a: WPUL V1+V2 and d: aVF). Panels b and e show PBL V2-V1 and its influence on the loop. Panels c and f show the sum of the two leads and the loop they generate. Panels g and h integrate the traces and the RVCg loop. It is important to note that in the transverse plane there is continuity in the QRS complex loop and the T-wave loop, which generates the “omega” sign of ischemia. In all panels, the “X”, “Y” and “Z” axes represent time (milliseconds) for one tracing and amplitude (mV) for the other. In aVF, the positive vector is directed towards the patient's feet. Therefore, in these graphs, the aVF tracing is inverted compared with the standard ECG

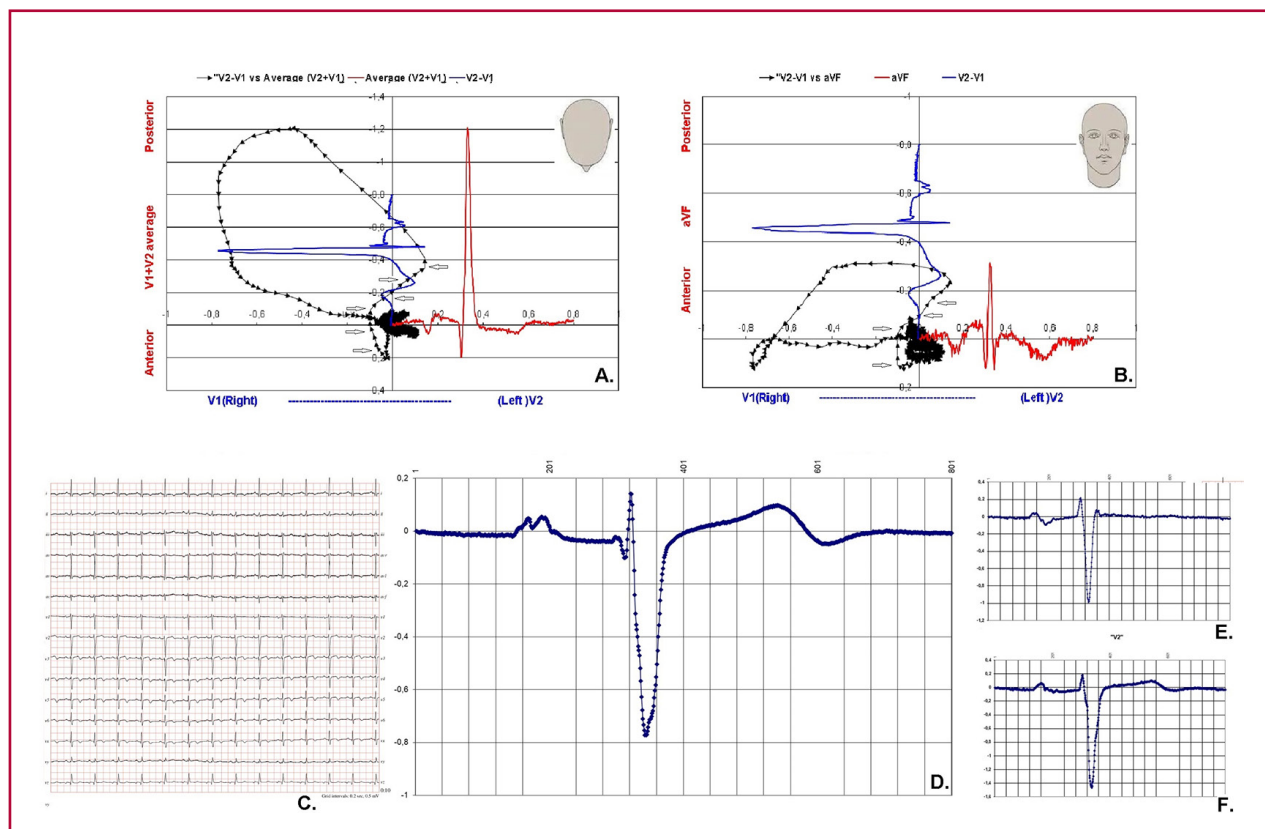


RBBB: complete right bundle branch block; LBBB: complete left bundle branch block; WPW: Wolf Parkinson White.

Fig. 3. **A.** Normal circular ECG of the transverse plane (V1 to V6). **B.** Circular ECG in a patient with WPW syndrome. Depolarization is seen to begin in V6 (205 ms) while V2 and V1 show a delay (289 and 296 ms respectively). V1 peaks 91 ms after V6. The dissociation between left and right precordial leads suggests two different depolarization pathways. **C.** Circular ECG in LBBB. The typical "plateau" of V5 and V6 is observed, as well as the negative depression in V1 to V4. **D.** Circular ECG in a RBBB. A delay is seen in the final portion of V1 and V2. Normally, the delay in V1 is greater than in V2

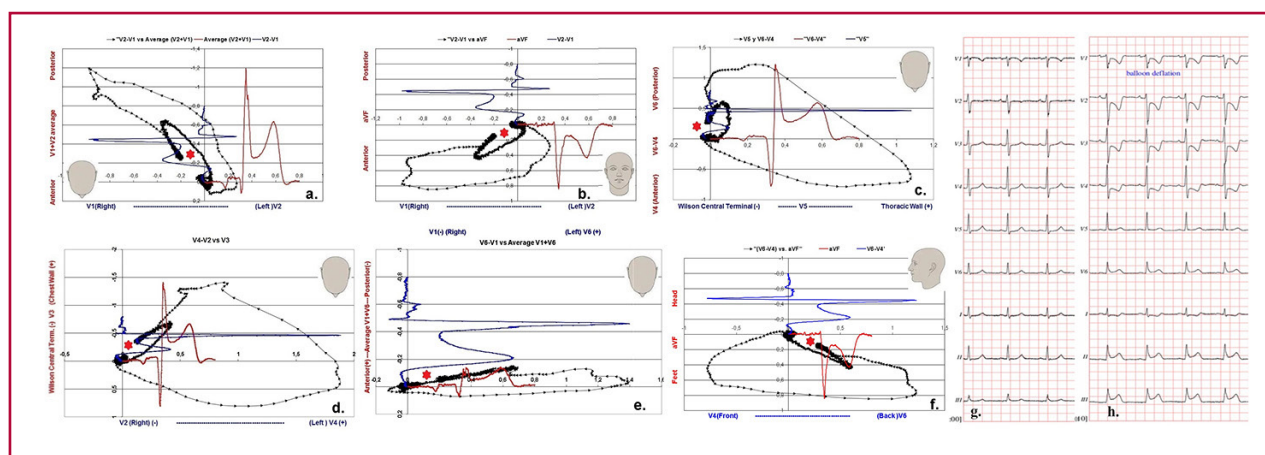
In turn, in a group of 45 patients, 16 with left anterior descending artery (LAD) occlusion, 17 with right coronary artery (RCA) occlusion and 12 with circumflex artery (Cx) occlusion, 100% showed lesion current in PBL V2-V1. (16-18) The direction of the lesion current varied in these patients: in 16 of the 45 patients (15 with LAD occlusion and 1 with RCA occlusion), the lesion current was to the left, whereas in the re-

maining 29 (1 with LAD occlusion, 16 with RCA occlusion and 12 with Cx occlusion), the lesion current was to the right. Importantly, these lesion currents, which are always present in the retrosternal loop, can coexist (especially in cases of Cx occlusion) with lesion currents of opposite direction in standard PUL V5 and V6. This may generate electrical cancellation on the 12-channel ECG (Figure 5). (16-18)



PBL: precordial bipolar lead; RVCG: regional vectorcardiogram.

Fig. 4. 75-year-old male patient with a 2-day evolution anterior infarction. Tracings and retrosternal RVCG in transverse and frontal plane (A and B), standard ECG (C), PBL V2-V1 (D), and standard PUL V1 and V2 (E and F) are shown. In both RVCG, the bitten apple sign (arrows) is observed due to a rightward return of the initial portion of the QRS, indicating momentary predominance of the electrical forces from the right. Note that subtraction of the V1 recording (E) from V2 (F) causes the P negative portion of V1 to become positive, forming a bimodal P in the PBL (D). The PBL V2-V1 tracing shows a negative wave after the onset of the QRS which translates into the "bitten apple" sign in RVCG.



PBL: precordial bipolar lead; WPUL: weighted precordial unipolar lead.

Fig. 5. Transverse (a, c, d and e), frontal (b) and sagittal (f) planes. Baseline (panel g) and ischemic (panel h) ECGs. Coordinate axes represent millivolts and milliseconds.

Panel a: PBL V2-V1 vs. average WPUL V1+V2. Panel b: PBL V2-V1 vs. aVF. Panel c: PBL V6-V4 vs. V5. Panel d: PBL V4-V2 vs. V3. Panel e: PBL V6-V1 vs. average WPUL V1+V6. Panel f: PBL V6-V4 vs. aVF. All loops were obtained during maximal ischemia. In panels a and b a lesion current is seen directed to the right while in panel c the same current is directed backwards. In panels d and e the lesion current is directed to the left while in panels b and f the J point and ST-segment are deflected downwards. A positive omega sign is observed in all the loops (asterisk).

Additionally, the presentation of the loops in two axes or in three dimensions allows to clearly identify the J-point, the ST-segment deflections and the omega sign even when no displacement of this is observed in the standard ECG (Figure 5). (19)

Complete left bundle branch block (LBBB)

As mentioned above, PUL V5 constitutes the midpoint between PUL V6 and V4. When conduction disorders suppress the forward-pointing vectors, PBL V6-V4 tracing shows only an R wave, without the initial Q seen in healthy patients. In cases of LBBB, where the initial septal depolarization is abnormal, the entire QRS loop observed from PBL V6-V4 is posterior to the PUL V5 axis. In addition, because in LBBB, PUL V1 and V2 have the same negative amplitude and are almost simultaneous (both electrodes are stimulated at almost the same time), PBL V2-V1 will be of very small

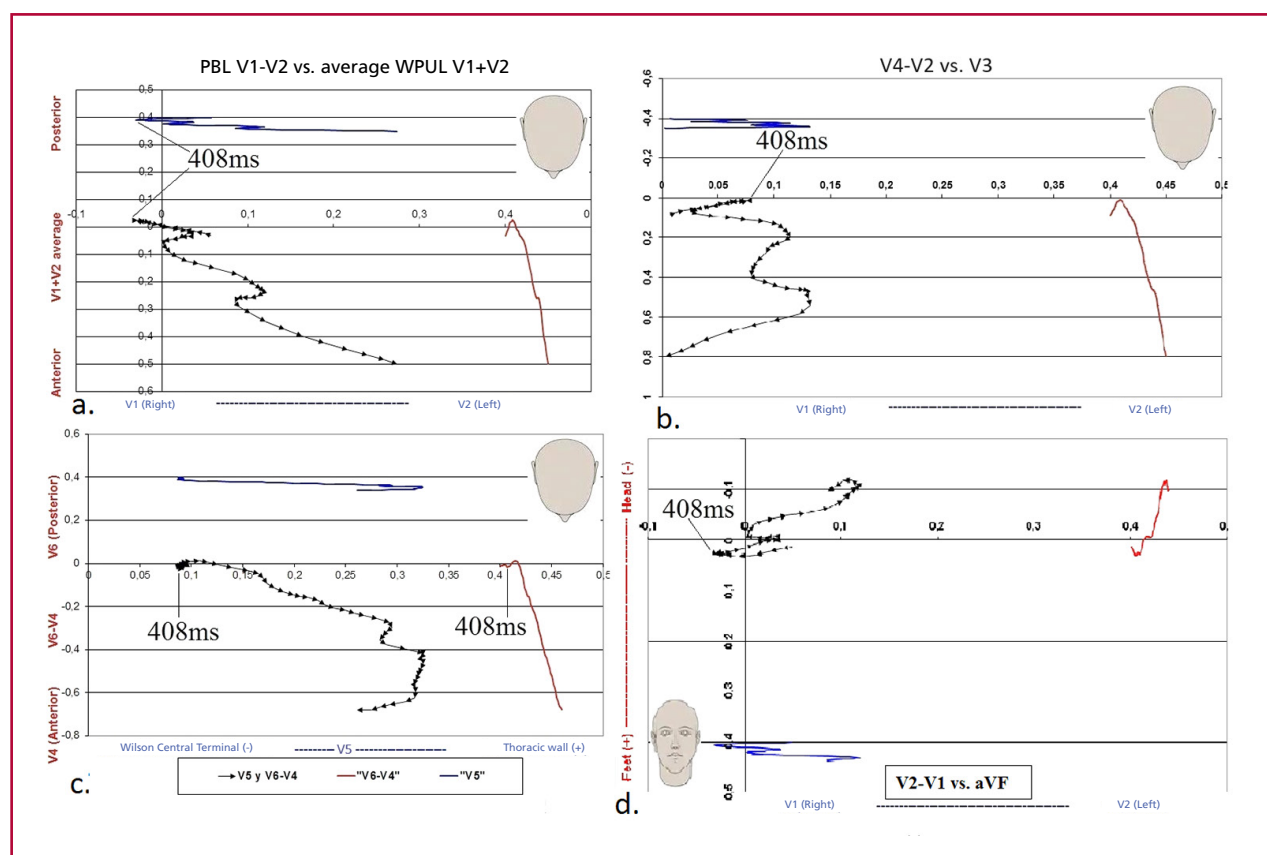
amplitude and will only show the slightest differences between the two in time. (5-7) The circular ECG will very clearly show the delayed activation with a typical wide-mouth “pac-man” figure in the right precordial leads and a “plateau” figure in the left leads (Figure 3, panel C).

Complete right bundle branch block (RBBB)

In patients with RBBB, the final QRS forces in PUL V1 show a significant delay, with an increase in voltage, so that it always appears posterior to the PUL V2 peak R wave. Also, the normal time difference between the intrinsic deflection of PUL V6 and PUL V1 is reduced. (5-7) In the circular ECG, the delay of the PUL V1 peak R wave is clearly observed (Figure 3, panel D).

Arrhythmias

Because these new methods analyze only one beat at



PBL: precordial bipolar lead; PUL: precordial unipolar lead; RVCG: regional vectorcardiogram; WPUL: weighted precordial unipolar lead.

Fig. 6. Onset of an arrhythmia as seen from different RVCg. The first 393 ms and the last 350 ms of the QRS loops have been removed to show the onset of the arrhythmia.

Panel (a): PBL V2-V1 vs. WPUL V1+V2. Panel (b): PBL V4-V2 vs. WPUL V3. Panel (c): PBL V6-V4 vs. PUL V5. Panel (d): PBL V2-V1 vs. aVF. The initial tracing shows the last 15 milliseconds of the normal beat before the arrhythmia, which begins at 408 ms. In the 3 panels of the transverse plane, the vectors at the end of the normal beat and at the beginning of the ectopic beat are almost identical, but of opposite direction, whereas in the frontal plane (d), there is a U-turn with the normal part slightly more caudal than the abnormal one. It should be noted that when the observation point varies from (a) to (b), there is a specular inversion of the tracing. In (c), the phenomenon is observed from the lateral side (PBL V6-V4 vs. PUL V5) and the tracing of the arrhythmia onset is reduced to one point.

a time, the investigative or diagnostic value of this methodology is limited. Figure 6 shows the onset of an arrhythmia after balloon inflation in the proximal LAD. Only an interval of approximately fifty milliseconds from the onset of the arrhythmia is shown, which was examined using different RVCG. (19)

In the case of pre-excitation syndromes, the circular ECG shows with high accuracy the activation sequence of the various ECG leads, and allows clear identification of the area that depolarizes first (Figure 3, panel B).

CONCLUSION

Although electrocardiography is almost 150 years old, this new information supports the implementation of new electrocardiographic diagnostic methods, resulting in a valuable addition to current clinical practices. Weighted PUL that match PUL V3 and V5 allow verification of correct electrode positioning. Moreover, PBL, due to their proximity to the myocardium, provide signals of higher amplitude and quality, with a better signal-to-noise ratio (PBL V6-V1 is similar to the standard ECG lead I, but with much higher amplitude and signal-to-noise ratio). Given that PBL V2-V1 has a high sensitivity for detecting ischemic ST-segment changes, it would be highly desirable to use it in patients with suspected acute myocardial infarction. This would involve repeating the ECG but placing the electrode of the right arm in V1 and that of the left arm in V2.

Although experienced cardiologists can make accurate diagnoses with the traditional ECG, it is important to consider that electrocardiograms are often interpreted by less experienced physicians, for whom any assistance would be beneficial. Therefore, it would be desirable to incorporate an algorithm into electrocardiography machines to show the additional diagnostic information provided by this new methodology.

In addition, it is important to keep in mind that many hospitals store their electrocardiograms in databases. The ability to access these records and reprocess data from prior studies could reveal new signs of previously undocumented pathologies. (20)

Ethical considerations

The authors report that approval by the corresponding ethics committee does not apply.

An informed consent request does not apply.

Artificial intelligence was not used in this article.

There was no sex or gender bias in the present work.

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None

Conflicts of interest

None declared.

(See authors' conflict of interests forms on the web).

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