The Normal Vectorcardiogram and a System for the Classification of Vectorcardiographic Abnormalities

By W. R. Milnor, M.D.

The essentially 3-dimensional nature of the spatial vectorcardiogram (sVCG) requires that it be studied as a vector sequence in space, and not merely in its projections on the arbitrary frontal, sagittal, and transverse planes. One striking characteristic of the normal QRS sV-loop is that it lies approximately in a single “plane of predilection,” which does not coincide with any of these 3 arbitrary planes. This paper describes the variations observed in the sVCG, recorded by a cubical lead system, with particular reference to the “QRS plane,” in a group of normal subjects and suggests a system for classifying abnormalities of the sVCG, based on the QRS plane.

Spatial vectorcardiography and the more familiar scalar electrocardiography are 2 different methods of recording the same phenomena. The essential difference between them is that the spatial vectorcardiogram (sVCG) gives a 3-dimensional synthesis of information that is not readily obtainable by the methods of scalar electrocardiography.

If the vectorcardiographic method is to add any new information to the knowledge already acquired from clinical electrocardiography, it is reasonable to assume that it will be found in the inherent 3-dimensional characteristics of the sVCG: the spatial orientation and the contour of the sVCG loops. Definition of the normal vectorcardiogram and departures from normality should take this into account, and should not be limited to the projection of the sVCG on the frontal, sagittal, or transverse planes, which are, after all, chosen quite arbitrarily as far as the heart is concerned.

Vectorcardiographic study of a number of normal subjects and patients with various types of heart disease has led us to the conclusion that the “QRS plane” (Schellong’s “plane of the QRS loop,” Rochet and Vastesaeger’s “plane of predilection”10) is a constant normal finding and provides a useful standard of reference for defining the normal sVCG. This report describes our findings in a group of normal subjects and suggests a classification of sVCG abnormalities based on the “QRS plane.”

Methods

The panoramic vectorcardiograph used in this investigation has been described previously,2 and allows the observer to view or photograph any projection of the sVCG. This instrument is ideal for the identification of the QRS plane of predilection and departures from it, the only alternative method being construction of wire models of the sVCG.

Figure 1 shows the lead system used for vectorcardiology. Three electrodes lie in a transverse plane passing through the second costosternal junction: (1) on the right anterior thorax, just medial to the anterior axillary line, (2) on the right back, on a sagittal axis passing through electrode 1, (3) on the left back, just medial to the posterior axillary line. A fourth electrode is placed on the right lower back, in such a position that its distance from electrode 2 equals the distance between electrodes 2 and 3, and the axis of electrodes 2 and 4 is at right angles to a line between 2 and 3. No correction factors are applied to the voltages obtained from these leads. This system has been in use in our laboratory since 1950; it was chosen because it provided a bipolar lead system in which the electrodes are roughly equidistant from the anatomic center of the heart. The records obtained by this system are usually very similar to those obtained by other cubical bipolar systems, such as Grishman’s9 but often differ in detail from records obtained in the same patient by the tetrahedral system.19

It must be emphasized that the specific measurements in this report apply only to vectorcardiograms recorded by this lead system. Comparison with different lead systems suggests that other generally used systems1,10–19 give similar, although not identical, sVCG’s. The principles on which this study is based could be applied to any lead system. The relative merit of different lead systems is a problem that is being investigated in a number of laboratories, and no claim of superiority is made for

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the system described here. A "corrected" system such as that developed by Frank is probably to be preferred. In each subject frontal (xy), sagittal (yz), and transverse (xz) projections of the sVCG were recorded, as well as standard and "unipolar" limb leads, standard precordial "V" leads, and additional unipolar leads from the right chest and the back. In addition, the panoramic unit was used to rotate the sVCG until the closest approximation to a QRS plane could be identified, (fig. 2) and records were made of the "edge view," "open view," (defined below) and other projections.

A spatial coordinate system previously described was used to identify the orientation of axes. This coordinate system is analogous to geographic lines of latitude and longitude, with azimuthal values being equivalent to longitude, elevation equivalent to latitude, and the null-point at the center of the globe. Elevation is negative for "northern latitudes," and positive for "southern." In the hemisphere anterior to the null-point azimuth is positive; in the posterior hemisphere, negative. The 0 coordinate is the axis of intersection of the transverse and frontal planes, extending from the null-point toward the patient's left.

Definitions

1. Axis. Any line passing through the hypothetical electric null-point. The more anterior end of an axis is used to define its position.

2. Plane of Predilection of an $sE$-Loop. The plane in which the ratio of major/minor amplitude is smallest. In practice the QRS plane is located by rotating the sVCG on the oscilloscope screen with the panoramic unit (fig. 2) at elevation = 0°, until the projection with the maximum major/minor amplitude (edge projection) is found.

The term "plane" as applied to the QRS $sE$-loop "cannot be accorded a mathematical rigor." The normal QRS $sE$-loop lies approximately in a plane, and the closeness of the approximation can
be defined by the maximum ratio of major to minor amplitudes.

The plane of an sE-loop can be considered to have a cephalad and a caudal surface for descriptive purposes, except when it is perpendicular to the transverse plane. In the latter event the 2 surfaces may be identified as left or right.

Two measurements suffice to determine the position of an sE-loop plane: the axis of its intersection with the transverse plane, and the minimum angle between the caudad surface of the sE-loop plane and the transverse plane.

3. **Edge Projection.** sVCG projection on a plane perpendicular to the sE-loop plane. (The terms “projection” and “view” are used synonymously.)

4. **Open Projection.** sVCG projection on the sE-loop plane. When not otherwise specified, “open projection” and “edge projection” refer to the QRS plane.

5. **Maximal Instantaneous Vector of an sE-Loop.** This term is self-explanatory, but it should be appreciated that it is not identical with the mean vector, e.g., \( \vec{A} \) QRS, although it often approximates it.

6. **Major Axis.** The axis of the maximal instantaneous vector.

7. **Minor Axis.** An axis perpendicular to the major axis.

8. **Major Amplitude.** Over-all length of the sE-loop projected on the major axis (fig. 5).

9. **Minor Amplitude.** Over-all width of the sE-loop projected on the minor axis (fig. 5).

10. The angle between an sE-loop plane and an axis not in the plane is defined as the angle subtended by the axis and the line of intersection between the sE-loop plane and a plane perpendicular to it, passing through the axis. The minimum angle between the QRS plane and the maximal T vector is an example.

**Subjects**

A total of 103 subjects was studied, including physicians and technicians of the hospital staff, and hospital patients with no historic or clinical evidence of heart disease or other disease known to affect the electrocardiogram. The age and sex distribution in this “normal” group is shown in figure 3. No effort was made to secure a statistical cross-section of the populace, and the group is heavily weighted in the third and fourth decades. Complete panoramic study was carried out in 59 of these subjects, with an age and sex distribution similar to that of the total group.

Our observations on the abnormal sVCG are based on study of more than 600 patients with heart disease of various kinds. Detailed panoramic investigation of the QRS plane was made in 92 of these cases.

**Results**

**Normal sVCG**

Measurements on the sVCGs of normal subjects are summarized in table 1. In each case explored with the panoramic unit a QRS plane could be identified, and the edge view of the QRS sE-loop had a major/minor amplitude ratio of at least 8/1 (average, 14/1). The average orientation of the QRS plane and its range of variation are illustrated in figure 4. The average intersection of QRS plane and transverse plane was azimuth +65°, with a range from +5° to 135°.

The acute angle between the cephalad surface of the transverse plane and the relatively caudad surface of the QRS plane always lay toward the patient’s right, and ranged from 22° to 80°, with a mean of 51°.

In the open projection on the caudad surface of the QRS plane the direction of QRS rotation was invariably clockwise. The contour of the QRS loop in this projection was surprisingly similar in all patients, although many indi-
TABLE 1.—Measurements of Normal Spatial Vectorcardiograms

<table>
<thead>
<tr>
<th>Measurement</th>
<th>59 Cases</th>
<th>103 Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Open</td>
<td>Frontal</td>
</tr>
<tr>
<td>Maximum QRS vector: direction (°)</td>
<td>+90*</td>
<td>+51 (+6 to +95)</td>
</tr>
<tr>
<td>Major QRS amplitude (mv.)</td>
<td>1.18 (0.87 to 1.95)</td>
<td>1.15 (0.51 to 2.20)</td>
</tr>
<tr>
<td>Ratio: major/minor amplitude</td>
<td>3.37 (1.1 to 7.0)</td>
<td>4.8 (0.9 to &gt;8.0)</td>
</tr>
<tr>
<td>QRS rotation: (% of cases)†</td>
<td>Clockwise</td>
<td>100</td>
</tr>
<tr>
<td>Counterclockwise</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>Figure-8</td>
<td>0</td>
<td>18</td>
</tr>
<tr>
<td>Linear</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>10 msec, QRS vector: direction (°)</td>
<td>-24 (-55 to -10)</td>
<td>-137 (-170, 0, +175)</td>
</tr>
<tr>
<td>P sE-loop: maximum vector: direction (°)</td>
<td>+85 (+62 to +91)</td>
<td>+42 (-2, 0, +90)</td>
</tr>
<tr>
<td>T sE-loop: maximum vector: direction (°)</td>
<td>+71 (+60 to +92)</td>
<td>+45 (0 to +70)</td>
</tr>
<tr>
<td>Angle between maximum QRS and T vectors (°)</td>
<td>19 (0 to 30)</td>
<td>17 (0 to 94)</td>
</tr>
</tbody>
</table>

Values given are means, with range of observed values in parentheses. Where the range includes both positive and negative values, either 0° or 180° is listed between the extremes, to indicate which segment of the coordinate system is included. For example, (-2, 0, 180) means that the range includes negative values between 0° and -2°, and positive values between 0° and 180°.

The open projection is viewed on the caudal or rightward surface of the QRS plane.

* In the open projection the coordinate system is determined by the maximum QRS vector, which is arbitrarily placed at +90°.

† Rotation is termed “figure-8” only if both loops of the “8” have a major amplitude equal to at least one-fourth the major amplitude of the whole QRS loop in the same projection. “Linear” indicates that the major/minor amplitude ratio is 8/1 or more.

Individual variations were present. As reported by others,6, 10, 16, 17 the normal QRS sE-loop describes a fairly smooth elliptical curve. Small irregularities in the curve (Schellong's "ein- und ausbuchtung") are not unusual in normal records when the frequency response of the apparatus extends to 100 c.p.s. or more, but sharp reversals of direction were not seen. Measurements of the major and minor amplitudes, and other characteristics of the sVCG in this projection, are summarized in table 1, and shown diagrammatically in figure 5. A typical normal sVCG is shown in figure 6. Figure 8 shows an sVCG from a normal subject with counterclockwise frontal QRS rotation, which is less frequently seen.

As pointed out by Schellong (p. 42)17 and others, the direction of rotation of the QRS loop in the frontal plane is related to the orientation of the QRS plane. When the QRS plane-transverse plane intersection was between +5° and +75°, the frontal plane QRS loop rotation was usually clockwise. When it lay between +75° and +90°, the frontal plane QRS loop was narrow and often "figure-8" in contour. When it was +90° to +135°, the frontal plane QRS rotation was usually counterclockwise (fig. 7).

The T sE-loop usually lay in almost the same plane as the QRS sE-loop, with the maximal T vector slightly cephalad to the QRS plane. The minimum angle between the maximal T vector...
vector and the QRS plane* averaged 3° cephalad of the QRS plane, and ranged from 17° cephalad to 13° caudad.

The angle between the maximal QRS and T vectors in the open projection averaged 19°, with the maximal T vector anterior to the maximal QRS vector. The variations in position of the maximal T vector observed in this projection ranged from 2° on the posterior side of the maximal QRS vector to 30° anterior to it.

The orientation of the P sE-loop showed relatively little variation in all projections. The minimum angle between the maximal P vector and the QRS plane was usually less than 5°, caudad or cephalad.

The plane of predilection of the P and T sE-loops was not studied in detail.

**DISCUSSION**

Schellong first reported the observation that the normal QRS sE-loop lies approximately in a single plane, and Rochet and Vastesaeger later described the normal QRS plane and its physiologic variations in some detail. Our observations confirm in general the descriptions of these investigators, and give them a quantitative expression.

The most valuable characteristic of the open projection of the sVCG in the QRS plane is the relatively narrow range of normal variation in this projection, in comparison with the usual frontal, sagittal, or transverse projection.

Variations in the 10-msec. QRS vector in the open projection, for example, were limited to a range of 45° (−10° to −55°) while in the frontal plane projection its normal range covers almost 360°. The angle between maximal QRS and T vectors is another example; its range in the open projection is considerably less than that reported for the frontal plane or for the spatial QRS-T angle.

There is a systematic difference between our findings in normal subjects and those of Burch, Abildskov, and Cronvich, in that their maximal QRS vectors in the sagittal projection generally lie more anterior than ours. Comparison of different lead systems indicates that this

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* This minimum angle is not necessarily the angle between maximal QRS and T vectors observed in an edge projection of elevation = 0°. Exploration of the edge projection at other elevations is necessary to determine the true minimum angle (see definitions, item 10).
is an essential difference between cubical and tetrahedral lead systems. The division of normal records into "Type 1" (elliptical) and "Type 2" (more circular and more posterior) described by the New Orleans group has not been apparent in our series. It is of interest that comparison of records from the equilateral tetrahedron and from a "corrected" lead system has shown more uniformity among normal subjects with the latter.

**Significance of the QRS Plane**

The existence of a QRS plane in the sVCG of normal subjects is in itself somewhat surprising. Considering the diverse paths along which the ventricular muscle is activated, and the widely separated muscle fibers that are activated simultaneously, one would hardly expect *a priori* that the successive vector sums of these separate events would lie in the same plane. The possibility that this apparent plane is an artifact imposed by the conducting materials between the heart and our electrodes should not be ignored, but observations on the isolated rabbit heart in a homogeneous fluid medium in our laboratory show that the QRS plane is still present under these conditions.

The normal orientation of the QRS plane roughly parallels that of the interventricular septum, and it is tempting to assume that individual differences in orientation of the plane reflect individual differences in the anatomic...
position of the heart, but there is no direct evidence for this assumption.

It is easy to demonstrate by wire models or diagrams that rotation of the QRS plane can explain much of the variability of the conventional scalar electrocardiographic leads in normal subjects, as Gardberg and Ashman,7 Jouve (p. 104),11 Wolff,20 and others have done. This demonstration by no means proves, however, that such rotations in the QRS plane are related to corresponding variations in the anatomic position of the heart. In the present study, the normal variations in orientation of the QRS plane seem to be considerably greater than could be explained by variation in heart position.

The autopsy studies of Grant8 provide strong evidence that the rotation of the heart about an anterior-posterior axis varies less than 45° in different subjects, and that very little rotation around the longitudinal axis of the heart occurs. He pointed out that the extreme longitudinal axis rotations described in electrocardiography have simply been assumed as convenient explanations of certain electrocardiographic findings, without supporting anatomic evidence. We are in complete accord with his views on this point, and believe they are amply confirmed by routine roentgenography and angiocardiography. It seems much more likely that the position of the QRS plane varies in normal subjects principally because of normal variations in the structure of the ventricles and the sequence of myocardial activation.

Relation between Orientation of the QRS Plane and the Maximal QRS Vector

Our results do not show a close correlation between the orientation of the QRS plane and the frontal plane maximal QRS vector. Rochet and Vastesaeger15,16 reported that a mean frontal QRS axis of 0° to about +30° was usually accompanied by a QRS plane very near the frontal plane, and counterclockwise QRS rotation in the frontal projection. Mean QRS axes more rightward than +60°, according to these authors, were correlated with a nearly sagittal QRS plane, and clockwise QRS rotation in the frontal plane, while mean QRS axes in the neighborhood of +45° were associated with narrow or figure-8 frontal plane QRS
loops. Gardberg and Ashman\textsuperscript{7} reached similar conclusions.

Figure 7 shows that our data do not support this generalization. The direction of rotation of the QRS sE-loop in the frontal projection is definitely related to the orientation of the QRS plane: clockwise rotation is found only when the QRS plane falls between 0° and +90°, counterclockwise rotation when it lies beyond +90°, and figure-8 contours when it is in the neighborhood of +90°. There is only a slight relationship, however, between the orientation of the QRS plane and the maximal QRS vector in the frontal projection: clockwise, counterclockwise, and figure-8 rotations are found throughout the range of maximal frontal QRS vectors.

It is of interest that attempts to reconstruct the spatial QRS loop from routine electrocardiograms led Gardberg and Ashman\textsuperscript{7} and more recently Peñaloza and Tranchesi\textsuperscript{14} to conclude that frontal QRS rotation is usually counterclockwise in the normal subject, while in our investigations, as well as those of Grishman and Scherlis\textsuperscript{10} and Burch, Adildskov, and Cronvich\textsuperscript{4}, it was clockwise in the majority of instances.

Abnormal sVCG

The relative constancy of the QRS loop contour within its own plane, in spite of variations in QRS plane orientation, is a convenient basis for classifying abnormalities of the sVCG. The following classification lists the possible departures from normality: (1) the QRS plane may be displaced beyond its normal

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure9.png}
\caption{Female, age 37 years, with rheumatic mitral stenosis. An example of the second class of sVCG abnormality, with the QRS sE-loop in a plane, but a distorted QRS contour within the plane. QRS duration = 0.09 second. The P-R interval is prolonged.}
\end{figure}
range, (2) the QRS contour may become abnormal within its plane, or (3) the plane itself may be bent or otherwise distorted. P and T loop abnormalities could be classified in the same way, and a final category added to include abnormal relations between P, QRS, and T loops, e.g., abnormalities of the angle between QRS major axis and T major axis.

The first type is frequently seen in the early stages of left or right ventricular hypertrophy, and is the spatial analog of right and left axis deviation in the standard electrocardiogram. With early right ventricular hypertrophy, for example, the QRS plane tilts to bring the maximal QRS vector rightward and anteriorly. With mild degrees of hypertrophy the QRS contour may be normal and continue to lie in a plane, but in later stages bending of the QRS plane appears.

An example of the second type, in which the QRS contour is abnormal within its plane, is shown in figure 9. In this instance the QRS contour is radically distorted, as seen in the frontal and sagittal projections, but in spite of the meandering contour in these projections the whole QRS loop lies approximately in a single plane, which happens to present an edge projection in the standard transverse projection.

In the third type, where the QRS loop is distorted so that it no longer lies in a plane, any degree of distortion may occur from simple bending of the original plane to very complex patterns in which no semblance of a plane can be found.

The example in figure 10 shows a relatively simple longitudinal folding of the plane. One cannot really speak of an "edge" or "open" projection in this situation but if we view the loop from a position a little anterior to the transverse view (azimuth = +90°, elevation = −70°) it can be seen that at least the first half of the QRS complex lies in a plane, while its later portions have been bent forward. An approximate open projection is found at azimuth = +105°, elevation = 50°, in which the terminal appendage is foreshortened. The electrocardiogram shows the pattern of right bundle-branch block, and the late portion of the QRS loop, which is bent forward, corresponds to the slow S and R-V of the scalar electrocardiogram.

A similar case, but with the early QRS loop displaced to the left and upward, has been published elsewhere.18

Longitudinal twisting of the QRS plane is another variety of distortion, as illustrated in figure 11. This case, with the electrocardio-

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**Fig. 10.** Female, age 67 years, with arteriosclerotic heart disease. An example of relatively simple distortion of the QRS plane, with folding along the major axis. QRS duration = 0.14 second and electrocardiographic pattern of right bundle-branch block.
Fig. 11. Male, age 55 years, with angina pectoris and arteriosclerotic heart disease. Somewhat more distortion of the QRS plane with twisting around the major axis, and abnormal contour. The projection at azimuth = +90°, elevation = −28°, is the closest approximation to an edge projection. QRS duration = 0.130 second, with electrocardiographic pattern of left bundle-branch block.

Fig. 12. Complex distortion of the QRS plane, in a patient aged 48 years, with a history of myocardial infarction and electrocardiographic signs of old anterior myocardial infarction. The QRS voltage is reduced, so that the P sE-loop looks relatively big. Graphic pattern of left bundle-branch block, shows displacement of the QRS loop to the left, and longitudinal twisting of the loop best seen from a viewpoint slightly above the standard frontal position (azimuth = +90°, elevation = −28°). The closest approximation to an open view shows a distorted triangular contour, with a curious bowing of the distal limb of the triangle.

Finally, the QRS contour may be radically distorted, with multiple bends and twists, as in figure 12. In this instance, there was a clear history of previous myocardial infarction, and the scalar electrocardiogram showed signs of an old anterior myocardial infarction.

This proposed classification cuts across the conventional categories of clinical electrocardiographic diagnosis, as well as the etiologic types of heart disease. Myocardial infarction, for example, may destroy the QRS plane as in figure 12, but it may also produce simple displacement of the plane, changes in contour only, or no chronic abnormality at all. Cases with the electrocardiographic pattern of right ventricular hypertrophy may have vectorcardiograms of any one of the 3 major types described.

This is not necessarily a disadvantage, and might be expected if the classification reflects underlying abnormalities of structure and function not yet clearly recognized. It is impossible to evaluate the significance of these
different types of abnormality until the significance of the normal QRS plane and its relation to the detailed spread of activation in the myocardium is clarified.

For the present, this concept at least offers a way of thinking about the normal spatial vectorcardiogram and departures from normality that is based on the vectorcardiogram itself and not on preconceived ideas borrowed from scalar electrocardiography.

**Summary**

A quantitative study of the characteristics of the normal spatial vectorcardiogram (sVCG) was carried out on 103 normal subjects. The normal limits so determined apply only to the specific cubical lead system employed, but the principles can be applied to any lead system. In 59 of these normal subjects the panoramic vectorcardiograph was used for systematic exploration of the sVCG. In each case the QRS sE-loop lay approximately in a plane, so that an edge projection with a major/minor axis amplitude ratio of 8/1 or more could be found.

The orientation of the QRS plane varied considerably, but the contour of the QRS sE-loop within the plane was relatively constant. The normal limits of the sVCG projected on the QRS plane were narrower than in the conventional frontal, sagittal, or transverse projections.

A classification of vectorcardiographic abnormalities is proposed, based on the normal QRS plane. This classification emphasizes the 3-dimensional nature of the sVCG, without reference to conventional scalar electrocardiography.

**Acknowledgment**

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**Summario in Interlingua**

Un studio quantitative del characteristicas del normal vectocardiogramma spatial (VCGs) esseva effectuate super le base de observationes in 103 individuos. Le limites del manifestaciones normal que esseva assi determinate es applicabile solmente al sistema de derivation cubical (i.e. le systema usate in iste studio), sed le principios es equalmente applicabile a non importa qual altere sistema de derivation.

In 59 del 103 subjectos normal le vectorcardiographo panoramic esseva usate pro le exploration systematic del VCGs. In omne casos le spira sE de QRS jaceva approximativalemente in un plano de manera que un projection angular poteva esser trovate con un proportion de al minus 8 a 1 inter major e minor amplitude axial.

Le orientation del plano QRS variava considerablemente, sed le contorno del spira sE de QRS intra le plano esseva relativemente constante. Le limites normal del VCGs projecte super le plano QRS esseva minus late que in le projectiones conventional frontal, sagittal, e transverse.

Es proponite un classification de anormalitates vectocardiographic, basate super le plano QRS normal. Iste classification sublinea le natura tridimensional del VCGs sin referentia al electrocardiographia scalar conventional.

**REFERENCES**


The authors presented various observations in the literature to refute the view that fat embolism the emboli consist of mechanically released particles of fat, usually narrow fat from fractured bones. They also presented experimental evidence against such a hypothesis. In one series of rabbits a hind leg was crushed by means of a blunt instrument without perforation of the skin, while in another the hind limb was ligated for 1 to 2 hours. In most of the animals in both series an increase of the lipid content in serum was noted, which was considered to be the result of the injuries. However, no definite change in esterase activity could be observed. Fat droplets were demonstrated in the capillaries using Sudan III. The authors concluded that accumulations of droplets of fat in the tissue capillaries, of the type commonly considered pathognomonic of so-called fat embolism, occur as frequently in connection with injuries to soft tissue as in the case of fractures with injuries of the marrow. They were unable to cast any light on the cause for the increase in content of lipid of the serum after trauma.

Abramson
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