Respiratory Changes of the P Loop in the Frank Vectorcardiogram

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SUMMARY

(1) Frank vectorcardiographic P loops of 25 healthy males were recorded at deep inspiration and expiration by using a minicomputer system with an averaging technique. Respiratory changes in 21 P parameters were quantitatively investigated.

(2) The maximal left component of the P loop, the magnitude of the horizontal maximal vector and the magnitude of the P polar vector significantly decreased at deep inspiration as compared with those at expiration. The frontal and the spatial maximal vectors were significantly deviated vertically at deep inspiration as compared to those at expiration.

(3) It was considered to be better to obtain P loops at a particular phase of respiration or to use those obtained by an averaging technique in order to analyse P loop in detail in various heart diseases, especially in the exercise stress test associated with rapid deep respiration.

(4) The mechanism of respiratory P loop changes was discussed.

Additional Indexing Words:
Polar vector Frank-vectorcardiographic P loop Computer-averaging technique

IN recent years, qualitative and quantitative analyses of P wave in the conventional 12-lead electrocardiogram (ECG) and P loop in the Frank vectorcardiogram (VCG) have been reported on various heart diseases. The relationship between parameters of P wave or P loop and hemodynamic variables has also been investigated.[1),2)] P wave and P loop have also been studied in acute heart failure and during exercise stress test in various heart diseases.[3),4)] It has been recognized that the analysis of vectorcardiographic P loop gives more significant clinical informaion for the clinical diagnostic purpose than that of electrocardiographic P wave.[5)] Thus, with progress in vectorcardiographic studies on atrial electrical activities, clinical usefulness of vectorcardiographic P loop will be even more enhanced in the future.

It has been pointed out that physiological factors, such as respiration

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and heart rate, influence atrial electrical activities.[6)-12)] In order to analyze P loop in detail, it is necessary to know the extent of the changes in P loop pattern caused by these physiological factors. The purpose of the present investigation was to evaluate quantitatively Frank-vectorcardiographic P loop changes in deep respiration.

Materials and Methods

The materials consisted of 25 healthy males who ranged in age from 22 to 45 years, the mean being 31. All of the subjects showed normal sinus rhythm. P loops were recorded with the subject in a supine position, and chest electrodes were placed at the level of the fifth intercostal space as Frank's original description.[13)]

Respiratory curve was obtained with use of a thermister inserted into a nostril. These curves were put into an amplifier-controller device (Fukuda, MCM-300) which delivered gate pulses of 400 to 750 msec in width in synchronization with both the maximal inspiration and expiration. The width and timing of the pulses were manually adjusted on an oscilloscopic screen. When the pulse included the zone of P wave, an interval of 350 msec preceding the QRS wave, X, Y, and Z scalar electrocardiograms of each phase was digitalized with an A-D converter (10 bits, 4-channel) at a frequency of 500 Hz and put into a JEC-6 digital computer (core memory: 8 KW) with 3 magnetic drum memory units (3KW×3). Digitalized data of 8 P wave zones averaged both for the maximal inspiration and expiration (Fig. 1). With the methodology described above, P wave and loop were obtained with a satisfactory signal-to-noise ratio on an X-Y plotter at a sensitivity of 40 cm/mV. The following 21 measurements of the P loop were automatically made through a computer: (1) P duration (the time interval from the earliest onset to the latest end of P wave among X, Y, and Z leads), (2) the time intervals from the

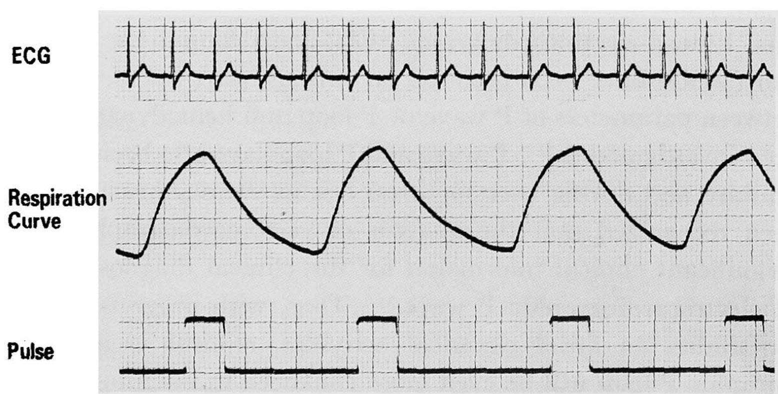

Fig. 1. Respiratory curves are obtained with use of a thermister inserted into a nostril. Gate pulses for data acquisition are adjusted to correspond to the maximal inspiratory or expiratory phase. When P wave is present during the gate pulse, X, Y, and Z scalar electrocardiograms are put into a digital computer. Eight P waves are averaged both for the maximal inspiration and expiration.

beginning to the maximal P vector in the 3 projection planes and also to the spatial maximal P vector, (3) the maximal P vectors in the 3 projection planes and the spatial maximal P vector, (4) the mean polar P vector, (5) the maximal amplitudes of the left, inferior, posterior, and anterior components of P loop.

The differences in the mean values between the P loop measurements in deep inspiration and expiration were statistically evaluated with paired t-test. The changes in heart rate in deep respiration were also evaluated.

With lead markers placed on Frank's A, E, and M points of the chest wall with the subjects in a supine position, postero-anterior and left lateral chest X-rays were taken both at deep inspiration and expiration. Then, positional changes of the cardiac silhouette in relation to Frank's A, E and M points were investigated in deep respiration.

Results

Means, standard deviations and ranges of P wave and loop measurements at deep inspiration and expiration are summerized in Table I and II.

(1) P duration

No significant changes in P duration were observed between at deep inspiration and expiration.

(2) Maximal left, inferior, posterior and anterior components of P loop

The mean amplitudes of the maximal left component at deep inspiration and expiration were 0.052 and 0.062 mV, respectively, showing a significant difference with a p value of less than 0.001 (Fig. 2). The mean amplitudes of the maximal anterior component at deep inspiration and expiration were 0.030 and 0.034 mV, respectively, also showing a significant difference ($p<0.05$). The maximal posterior and inferior components showed no significant respiratory changes.

(3) Maximal P vectors in the 3 projection planes

The frontal maximal P vector oriented more vertically at deep inspiration than at deep expiration (69.4° vs 64.6°, $p<0.001$). No significant differences were observed both in the time interval from the beginning to the maximal vector and in magnitude of the vector.

The mean magnitudes of the horizontal maximal vector at deep inspiration and expiration were 0.055 and 0.067 mV, respectively, which showed a significant difference ($p<0.001$). The time interval from the beginning to the maximal vector and the direction of the vector showed no significant changes.

The left sagittal maximal P vector oriented more posteriorly at deep inspiration than at deep expiration (94.3° vs 97.9°, $p<0.05$). However, no significant differences were observed both in the accession time to and the magnitude of the maximal vector between at deep inspiration and expiration.

Table I. Means, Standard Deviations and Ranges of the 21 Parameters of the P Loop

		Deep Expiration			Deep Inspiration		
		Mean	S.D.	Range	Mean	S.D.	Range
P duration		104.9	7.9	88~120	103.0	7.9	90~122
P positive amplitude in Lead X	(mV)	0.062***	0.016	0.023~0.088	0.052	0.020	0.003~0.086
in Lead Y	(mV)	0.110	0.027	0.051~0.146	0.111	0.027	0.054~0.160
in Lead Z	(mV)	0.019	0.013	0.0038~0.048	0.018	0.010	0.001~0.041
P negative amplitude in Lead Z	(mV)	0.034*	0.011	0.012~0.065	0.030	0.016	0.007~0.082
Maximal P-vector							
Frontal Plane: Peak time	(msec)	59.0	9.8	44~80	58.6	12.8	46~86
Magnitude	(mV)	0.125	0.019	0.086~0.163	0.121	0.022	0.072~0.168
Angle	(deg)	64.6***	15.4	31.0~84.5	69.4	14.8	36.0~90.0
Horizontal plane: Peak time	(msec)	69.0	14.3	42~90	67.5	15.3	38~100
Magnitude	(mV)	0.067***	0.018	0.025~0.105	0.055	0.017	0.030~0.092
Angle	(deg)	8.5	24.6	−33.7~74.0	9.8	31.6	−32.3~93.3
Left sagittal plane: Peak time	(msec)	56.3	9.6	42~78	56.9	9.6	42~86
Magnitude	(mV)	0.113	0.025	0.065~0.147	0.112	0.027	0.057~0.160
Angle	(deg)	97.9*	13.3	70.2~128.9	94.3	10.6	77.7~116.1
Spatial: Peak time	(msec)	58.8	9.9	42~80	58.2	9.8	46~86
Magnitude	(mV)	0.127*	0.018	0.090~0.164	0.122	0.022	0.072~0.168
Azimuth	(deg)	14.3	27.8	−52.9~51.9	15.9	37.8	−58.0~90.0
Elevation	(deg)	27.7***	15.1	7.1~61.5	23.4	13.2	6.8~55.6
Mean polar P-vector: Magnitude	(mV)	0.0038**	0.0014	0.0011~0.0063	0.0033	0.0015	0.0015~0.0071
Azimuth	(deg)	52.1	15.5	22.9~81.3	49.8	23.9	−13.3~101.1
Elevation	(deg)	102.7	18.0	78.6~142.5	100.0	18.5	74.9~140.9

* $p<0.05$ ** $p<0.01$ *** $p<0.001$

Table II. Percent Changes of P Loop Measurements in Deep Respiration Calculated by the Following Formula, (b−a)/b×100, where a is Mean Value of P Loop Parameter at Deep Inspiration and b is the Same Value at Deep Expiration

	Mean (%)	Range (%)
P positive amplitude in Lead X	−16.1***	−53.2∼10.0
P negative amplitude in Lead Z	11.8*	−120.6∼41.8
Maximal P-vector		
Frontal plane: Angle	7.4***	−5.7∼32.4
Horizontal plane: Magnitude	−17.9***	−46.7∼12.4
Left sagittal plane: Angle	−3.7*	−30.4∼ 7.9
Spatial: Magnitude	−3.9*	−15.7∼18.9
Elevation	−15.5***	−65.7∼21.3
Mean polar P-vector: Magnitude	−13.2**	−73.7∼36.8

* $p<0.05$ ** $p<0.01$ *** $p<0.001$

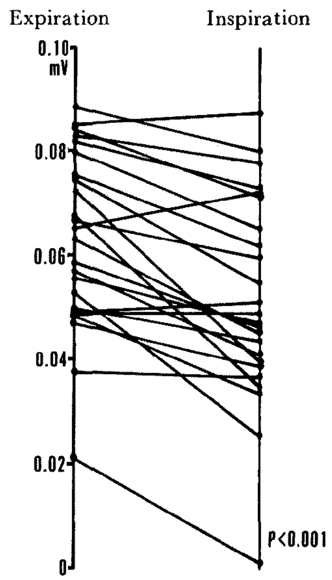

Fig. 2. Respiratory changes of maximal left component of P loop at deep inspiration and expiration.

Typical respiratory changes in P loop configuration were shown in Fig. 3. P loops at deep inspiration and expiration were shown in the upper and lower pannel, respectively. It was clearly seen that the frontal maximal vector shifted vertically and the maximal left magnitude of the P loop considerably diminished at deep inspiration as compared with those at deep expiration. At deep inspiration the afferent limb of the P loop in the left sagittal plane was anteriorly deviated, while magnitude and direction did not change so much.

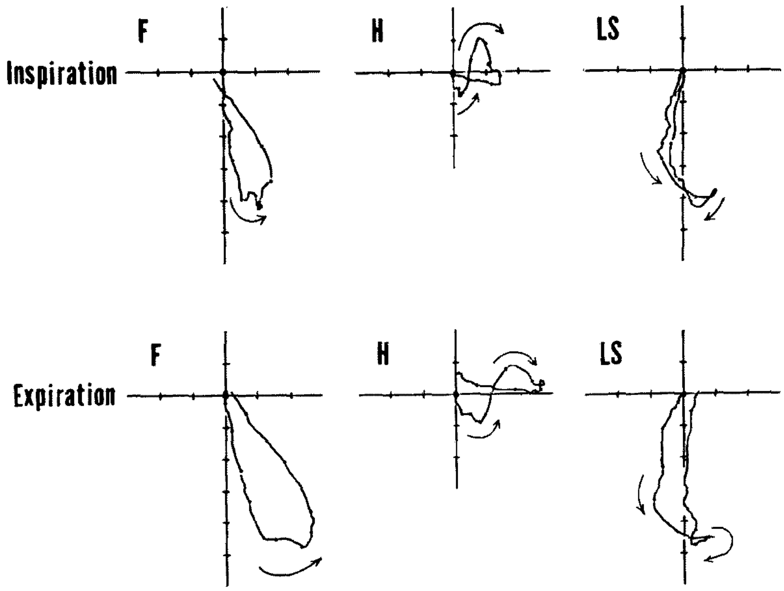

Fig. 3. An example of typical respiratory changes in P loop configuration. The frontal maximal vector shifts vertically and the maximal left magnitude of the P loop considerably diminishes at deep inspiration as compared with those at deep expiration.

(4) Spatial maximal P vector

The mean magnitudes of the spatial maximal vector at deep inspiration and expiration were 0.122 and 0.127 mV, respectively. The difference was statistically significant. The elevation angle of the vector oriented more vertically at deep inspiration than at deep expiration (23.4° vs 27.7°, $p<0.001$). No significant difference was observed both in the accession time to and the azimuth of the maximal vector.

(5) Mean polar P vector

The mean magnitudes of the polar vector at inspiration and expiration were 0.0033 and 0.0038 mV^2, respectively, which decreased significantly at deep inspiration ($p<0.001$). The azimuth and elevation showed no significant changes.

The mean heart rates at inspiration and expiration were 72 and 65 beats/min, respectively, showing a significant difference ($p<0.005$).

Analysis of chest X-rays revealed an increase in the inner width of the thoracic cage, a decrease in the transverse diameter of the cardiac silhouette, and also caudal shift of the heart. A significant increase was observed in the distance between the left cardiac border and Frank's A point, and also beteween the posterior cardiac border and E and M points. Cephalad shift of E and A points was also observed.

Discussion

Since the report of respiratory variations in electrocardiographic waveforms by Einthoven et al,[6] many studies have been published on this subject.[6)-12),14)-18] However, the majority of these were studies on respiratory variations in QRS and T waves. Only a few reports have been published about those of P waves.[9)-12] The reason for this seems to be the difficulty in obtaining P waves with a satisfactory signal-to-noise ratio. Because of the relatively low voltage, P waves are frequently obscured by artifacts such as electromyogram. However, a computer-averaging technique which we have employed[19] in the present study facilitated detailed analysis of atrial electrical activities with a satisfactory signal-to-noise ratio and enabled us to analyze respiratory changes much more precisely.

In the present study, significant alterations caused by deep respiration were observed in a number of P measurements, especially in the maximal left component, which decreased at deep inspiration by 40 to 50% as compared to that at deep expiration in several subjects. Vertical shift of frontal maximal P vectors, which was seen during the exercise stress testings,[3),20] was also observed at deep inspiration. Decreased magnitudes of the maximal left component and vertical shift of the frontal maximal P vectors at deep inspiration were very similar to P loop changes observed in pulmonary emphysema. Flaherty et al[16] reported that respiratory variations of the QRS complex on the body surface isopotential map were greater in a diseased heart than in a normal heart. From findings mentioned above, a study of the respiratory changes of P loop is not only of theoretical interest, but also may have some clinical significance. Because of the presence of beat-to-beat variations,[19),21] especially during deep respiration at exercise stress testings, it is considered to be better to obtain P loops at a particular phase of respiration or with employing an averaging technique[19] for the purpose of a detailed analysis of the P loop.

It is generally considered that respiratory changes of electrocardiogram are related to various factors such as (1) anatomic changes in the cardiac position,[17] (2) variations in electrical impedance of the surrounding organs, mainly the lung,[23] (3) changes in stroke volume of the heart,[25] (4) alterations in the tone of the autonomic nervous system,[6),7] (5) changes in heart rate, and (6) variations in coronary blood-flow.[26]

In the present study, with the basis of our observations concerning the respiratory P loop changes, various factors which produced these phenomena were considered.

(a) Factors which affect the maximal left component

The mean amplitudes of the maximal left component at deep inspiration and expiration were 0.052 and 0.062 mV, respectively, and they significantly decreased at deep inspiration.

According to Grayzel,[27] an electrical field produced by the cardiac electromotive forces is distorted by the presence of the lung between the heart and the electrodes. The experimental study with a torso model using human lung models and canine lung by Nagata et al[22] showed that magnitudes of lead vectors decreased at the points where the electrically highly resistive lung models interposed thickly, filling the space between the heart and the body surface. They observed that potentials produced by the electrical current through a torso lung model were distributed in a manner which avoided the highly resistive field. Okada[23] and Toyama[24] reported that magnitudes of lead vectors gradually decreased as aeration of the lungs increased. In our chest X-ray study, an increased distance between the left border of the cardiac silhouette and Frank's A point was noted at deep inspiration. From findings described above, one can deduce that the decreased maximal left component during inspiration was due to increased aeration of the lungs. Furthermore, the vertical shift in the electrical axis associated with the positional change of the heart during deep inspiration should also lead to decrease of the maximal left component.

Four cases in the present study showed slight increase in the maximal left component. Causes of the results, however, could not be found in spite of the detailed analysis of the data.

(b) Factors which affect the maximal inferior component

The mean amplitudes of the maximal left component at deep inspiration and expiration were 0.111 and 0.110 mV respectively, which showed statistically no significant difference.

Vertical shift of the heart at deep inspiration should be expected to increase the maximal inferior component. We observed that the maximal inferior component increased when the heart rate increased with intravenous administration of atropine.[20] Therefore, an increase in the heart rate associated with deep inspiration may also lead to an increase in the maximal inferior component.

On the other hand, Okada[23] and Toyama[24] noted in their experiments, that the degree of the decrease in magnitudes of lead vectors due to increased aeration of the lungs was greatest in the inferior component. In their experiments in which the anatomical relationship between the heart and the thoracic cage was constant, an increased aeration of the lungs did not cause caudal shift of the heart only with the diaphragm depressed inferiorly. Therefore, the intimacy of contact of the heart with the diaphragm, which is a

relatively good electrical conductor, decreases, and aerated lungs, which have higher electrical resistivity, slip under the heart. Under physiological conditions, although the heart is not kept fixed, similar changes as mentioned above may occur because the diaphragm is markedly depressed inferiorly. According to Katz et al,[28] electrical conductivity between the heart and the surrounding tissues depends upon the intimacy of contact between the heart and those tissues. Thus, decreased conductivity to the inferior direction at deep inspiration should lead to a decrease in the maximal inferior component. These opposing factors may mutually cancel out and produce no apparent changes in the maximal inferior component.

(c) Factors which affect the maximal anterior component

The mean amplitude of the maximal anterior component was smaller at deep inspiration (0.030 mV) than at deep expiration (0.034 mV).

In chest X-rays the cardiac silhouette descended at deep inspiration while Frank's E point ascended. As a result, the distance between them increases, and aerated lungs cover the anterior cardiac surface. Such changes should lead to decreased maximal anterior component. However, the degree of decrease in the maximal anterior component was small. One reason for this may be attributed to that the lungs covering the anterior cardiac surface are thin. The fact that increased negative intrathoracic pressure during inspiration promotes filling of the right atrium with blood[29] may partly contribute to an increase in the maximal anterior component.

(d) Factors which affect the maximal posterior component

The mean amplitudes of the maximal posterior component at deep inspiration and expiration were 0.018 and 0.019 mV, respectively, and no significant differences between them were observed. However, Okada[23] observed that the posterior component of Frank Z lead vector gradually increased as the lungs were progressively aerated. He speculated that this increase might be attributed to a relative decrease in electrical resistance in various tissues and organs located posteriorly to the heart. As the topical relationship between the heart and the thorax was fixed, the distance between the heart and posterior chest wall could not be changed in his experiment.

On the other hand, the distance between the posterior border of the cardiac silhouette and Frank's M point was found to increase at deep inspiration in the left lateral chest X-ray, reducing the intimacy of contact between the heart and the various tissues located posteriorly to the heart. Consequently, the relative decrease in electrical resistance of these tissues may be impeded, and thus, lead to no significant changes in the maximal posterior component.

(e) Factors which affect the frontal maximal P vector

The frontal maximal P vector oriented more vertically at deep inspiration than at deep expiration (69.4° vs 64.6°).

According to Ruttkay-Nedeky,[11] respiratory changes of the maximal QRS vector were usually observed in the supine, sitting, and right recumbent position but were practically absent in the left recumbent position. This finding suggests that the cardiac location is relatively unaffected in the left recumbent position. Thus, the vertical shift of P vector at deep inspiration may be ascribed mainly to the vertical shift of the heart due to diaphragmatic descent. We found that the orientation of the frontal maximal P vector tended to shift vertically when heart rate increased with the administration of atropine.[20] Therefore, it can not be denied that the effect of increased heart rate, which is usually associated with deep inspiration, may have some influence on the P vector.

As discussed above, important factors causing respiratory P loop changes may chiefly be variations of electrical impedance of the lungs due to changes in the aeration, alterations in the contact area between the cardiac surface and various tissues surrounding the heart and anatomic changes in the cardiac position. Hochrein et al[26] demonstrated that the blood flow in coronary arteries varied regularly during the respiratory cycle in their experiment. Further investigations are needed to determine its significance in respiratory changes in electrocardiogram.

We observed an increase in the maximal inferior component and a tendency for the frontal maximal vector to shift vertically during suppression of vagal activity with admininstration of atropine.[20] Einthoven et al,[6] and Chondorelli[7] reported that sympathetic stimulation or vagal suppression could cause electrocardiographic changes similar to respiratory changes. Thus, alterations in the tone of the autonomic nervous system must also be regarded as playing a possible role in respiratory P loop changes.

It is also important to note that increased pulmonary blood volume during inspiration, may lead to decreased electrical resistance of the lungs.[30]

Increased pulmonary electrical resistance during deep inspiration enhances electrical heterogeneity in human torso. At the same time, increased intracardiac blood volume, centrally located in thoracic cavity, may change the distribution of body surface potentials by 'Brody effect'.[31,32]

As considered above, various factors may bring about respiratory changes of P loop and influence each other. Further investigation should be required for understanding this phenomenon.

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