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Abstract

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KEYWORDS: respiration, vectorcardiogram, Frank lead system, maximum spatial vector, instantaneous QRS vector

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EFFECTS OF RESPIRATION ON THE VECTORCARDIOGRAM OBTAINED WITH THE FRANK LEAD SYSTEM

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Abstract. Vectorcardiograms were recorded with the Frank lead system using electrodes positioned at the level of the 5 th intercostal space with the subject in the supine position. Deep inspiration produced the following significant changes compared with deep expiration: (1) the maximum leftward forces of the P, QRS, and T vectors decreased, whereas the maximum anterior and posterior forces of the QRS and T vectors increased; (2) the maximum spatial QRS vector decreased in magnitude; (3) the maximum spatial P, QRS, and T vectors shifted vertically, posteriorly and vertically, and anteriorly, respectively; and (4) the spatial QRS-T angle increased remarkably. The spatial instantaneous QRS vectors were analyzed at 5 msec intervals in 35 of the 61 subjects. With inspiration, the 35- through 50-msec vectors shifted posteriorly with markedly reduced leftward forces and increased posterior forces. It was suggested that the respiration-related vectorcardiographic changes reflected cardiac anatomic positional change, distortion of lead-field potential by lung gases, and other mechanisms. Since the respiratory effect is potentially important for vectorcardiograhic interpretation, vectorcardiograms should be recorded under identical respiratory status.

Key words : respiration, vectorcardiogram, Frank lead system, maximum spatial vector, instantaneous QRS vector.

The effect of respiration on electrocardiograms (ECG) and vectorcardiograms (VCG) has been the focus of numerous studies since 1908 (1-14). Respiration-associated changes have been imputed to be related to alterations in cardiac position (2, 7-9, 12, 13), rotation of the heart around its axis, electrical resistance of the inflated lungs (12-14), altered chest configurations, autonomic feedback (2, 3, 9), and hemodynamic changes (5, 7, 9). Most investigators have assumed that cardiac positional changes were chiefly, if not solely (7), responsible. However, some authors have maintained that other factors, such as nervous and hemodynamic considerations were responsible (3, 5). Others have asserted that anatomic changes alone did not adequately explain the ECG alterations (6, 9, 10). Recently, inflation of the lungs has been shown to cause considerable deterioration of the transfer impedance vector (14-18), and thus it may be considered an important factor. In spite of numerous investigations, there is no unanimity of opinion on this problem.

The corrected orthogonal lead system of Frank (19) is most commonly used. While a few (8, 11, 12, 17) have discussed respiration-related alterations in terms of the

Frank lead system, these have not satisfactorily settled the questions. VCG changes in the QRS loops usually have been determined by measuring the maximum spatial vector, half area vector, or the maximum vector in the planar projection. Analyses using these measurements do not always observe the respiratory changes at identical vectors, and also do not consider the respiratory effects on the remainder of the QRS loop. A more detailed investigation is necessary to examine alterations in each instantaneous QRS vector. Such an approach has been employed by Ruttkay-Nedecky who used the McFee-Parungao lead system (9, 10), but changes in each instanteneous QRS vector have yet to be analyzed with the Frank lead system.

In the past decade, interest has focused on the change in R wave amplitude during and after exercise stress testing (20-25). This alteration has been attributed to left ventricular volume change, the "Brody effect" (26), or has been related to left ventricular function (20-23). Since the amount of air in the lungs varies during and after exercise (27), the cardiac electric field is distorted. Thus, it is equally important to consider other factors which may affect the lead vectors. The respiratory effect certainly cannot be neglected during and after exercise stress testing.

In the present study, a detailed statistical survey using the Frank lead system was undertaken to determine the respiration-associated changes in the spatial P, QRS, and T vectors.

SUBJECTS

VCG recordings were obtained from 61 normal subjects, including 34 males (age range 17-58 years, average age 31) and 27 females (17-63 years, average 34). Persons who had evidence of chest deformity, pulmonary disease, cardiovascular disease, or other diseases which frequently predispose the person to cardiovascular abnormalities (diabetes mellitus, renal disease, anemia, collagen disease, hypertension, or other types of peripheral vascular disease) were excluded. Each person had a normal vital capacity (males: VC 3980 ± 769 ml, % VC 95 ± 15 %, females: VC 2811 ± 384 ml, % VC 98 ± 9 %) and normal ECG and VCG recordings during resting expiration.

METHODS

VCGs were recorded with the corrected orthogonal lead system of Frank (1) using electrodes (A, C, E, I, and M) positioned at the transverse level of the 5th intercostal space on subjects in the supine position. While holding the breath for about 5 seconds at various levels of inspiration, three planar VCG loops and scalar orthogonal lead tracings were recorded with a Fukudadenshi Model VA-3FR Direct Writing Vectorcardiograph (Tokyo), and 35 mm photographs were taken from the oscilloscope screen.

The study consisted of three parts.

Part 1. VCG recordings were obtained while holding the breath during deep inspiration (IN) and deep expiration (EX) in all subjects. At the time of recording the VCGs, the following measurements were taken: chest circumference, anterior-posterior chest diameter and lateral chest diameter at the level of the fifth intercostal space, body weight, height, blood pressure and heart rate. The following parameters were measured manually in the three planar projections: (1) the maximum leftward, anterior, posterior, and inferior forces of the P, QRS, and T loops; (2) the spatial magnitude, azimuth, and elevation of the maximum spatial P (Pmax), QRS (QRSmax), and T (Tmax) vectors; and (3) the spatial angle between QRSmax and Tmax. Pmax, QRSmax, and Tmax were determined from the frontal and transverse planar projections. Data was analysed in the manner recommended by the 6th Symposium on Vector-cardiography, Japan, 1966 (28) (Fig. 1).

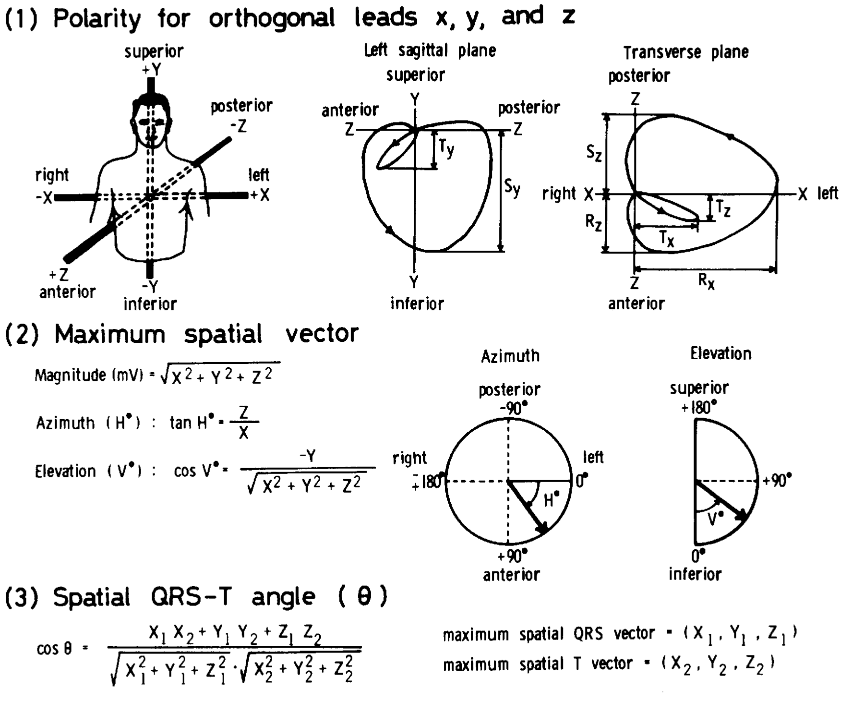

Fig. 1. The recommendation of the 6th Symposium of Vectorcardiography (Japan, 1966) (28)

In 18 males and 17 females, the following additional analyses were performed for each spatial QRS vector at 5 msec intervals: (1) X, Y and Z components and (2) the spatial magnitude, azimuth and elevation. The initial QRS forces were photographed with the P loop excluded.

Part 2. Six males and six females were studied while holding the breath during resting inspiration and at resting expiration. The following parameters were measured: (1) the maximum leftward, anterior, posterior, and inferior forces of the QRS and T loops; (2) the spatial magnitude, azimuth, and elevation of QRSmax and Tmax; and (3) the spatial angle between QRSmax and Tmax.

Part 3. In five males, a more quantitative study was made by using fractionated respiration cevering the whole range of vital capacity, as measured by a spirometer. VCGs were recorded at every 1,000-2,000 ml inflation from EX to IN.

RESULTS

Part 1: Comparison of ECG and VCG changes between deep inspiration and deep expiration. All items changed in much the same direction in both sexes, but extent was not identical.

(A) P Vector

Acceptable recordings of the P loop were obtained and analyzed in 51 (27 males and 24 females) subjects.

At IN, with regards to sex-matched, paired EX, the magnitude of the maximum leftward force was significantly reduced (25.6% in males, 16.4% in females) (Table 1). The magnitude of the maximum inferior force increased by 10.7% in males, but there was no significant change in females.

In IN, Pmax significantly shifted inferiorly by about 9 degrees (Table 1 and Fig. 2). There were no significant changes in azimuth or spatial magnitude.

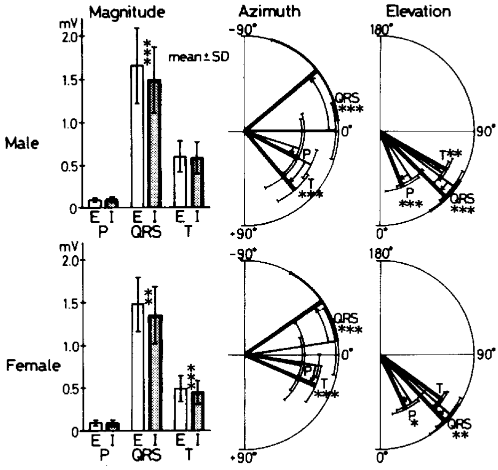

Fig. 2. Average changes in magnitude, azimuth, and elevation of the maximum spatial P, QRS, and T vectors from deep expiration to deep inspiration. Fine lines: deep expiration, Thick lines: deep inspiration, * : $p < 0.05$, ** : $p < 0.01$, *** : $p < 0.001$

(B) QRS Vector

The decrease in the amplitude of the maximum leftward force (Rx) was remarkable in IN: 38.4% in males, and 25.4% in females (Table 1). In contrast, the amplitude of the maximum posterior force increased markedly. The maximum anterior force (Rz) also increased in amplitude by about 10% in both sexes. The amplitude of the maximum inferior force increased in males, but not in females.

At IN, QRSmax was displaced posteriorly and inferiorly, with a decrease in spatial magnitude by about 10% in both sexes (Table 1 and Fig. 2). All these changes were statistically significant. The QRS duration was unchanged with respiration: 82 msec in males, 77 msec in females (Table 2).

TABLE 1. THE EFFECT OF RESPIRATION ON THE P, QRS, AND T VECTORS

	Male					Female				
	Deep expiration		Deep inspiration		p value	Deep expiration		Deep inspiration		p value
	mean	SD	mean	SD		mean	SD	mean	SD	
Px	0.06	0.02	0.04	0.01	***	0.06	0.01	0.05	0.01	***
Py	0.08	0.03	0.09	0.04	*	0.09	0.04	0.09	0.04	
Pz	0.03	0.01	0.03	0.01		0.02	0.01	0.02	0.01	
Pmax										
Mag	0.10	0.02	0.10	0.03		0.10	0.03	0.10	0.04	
Az	17.3	30.0	26.5	43.6		10.6	27.9	8.8	40.1	
El	32.4	15.7	22.2	17.8	***	32.6	17.0	25.3	14.3	*
Rx	1.28	0.41	0.79	0.35	***	1.07	0.23	0.80	0.29	***
Sy	0.97	0.31	1.07	0.36	**	0.99	0.37	0.97	0.35	
Rz	0.57	0.23	0.64	0.29	*	0.38	0.14	0.42	0.14	**
Sz	0.68	0.21	0.94	0.30	***	0.63	0.25	0.78	0.24	***
QRSmax										
Mag	1.66	0.43	1.49	0.38	***	1.48	0.32	1.36	0.33	**
Az	−0.6	17.6	−39.9	33.0	***	−8.9	21.8	−35.1	26.3	***
El	53.0	11.8	45.5	13.2	***	49.3	12.2	44.5	12.7	**
Tx	0.43	0.14	0.32	0.13	***	0.38	0.12	0.32	0.11	***
Ty	0.33	0.12	0.30	0.11	***	0.30	0.11	0.27	0.10	*
Tz	0.25	0.13	0.40	0.16	***	0.10	0.05	0.19	0.11	***
Tmax										
Mag	0.60	0.18	0.59	0.19		0.49	0.15	0.45	0.14	***
Az	26.6	12.6	49.2	15.2	***	8.7	9.4	22.9	15.2	***
El	55.7	10.6	59.9	9.9	**	53.2	6.7	53.5	7.7	
QRS-T angle	27.6	15.4	67.4	26.8	***	20.2	13.3	45.4	15.9	***

Px (mV): the maximum leftward forces of the P loop, Py (mV): the maximum inferior forces of the P loop, Pz (mV): the maximum anterior forces of the P loop, Rx (mV): the maximum leftward forces of the QRS loop, Sy (mV): the maximum inferior forces of the QRS loop, Rz (mV): the maximum anterior forces of the QRS loop, Sz (mV): the maximum posterior forces of the QRS loop, Tx (mV): the maximum anterior forces of the T loop, Ty (mV): the maximum inferior forces of the T loop, Tz (mV): the maximum anterior forces of the T loop, Pmax: the maximum spatial P vector, QRSmax: the maximum spatial QRS vector, Tmax: the maximum spatial T vector, Mag (mV): magnitude, Az (degree): azimuth, El (degree): elevation, QRS-T angle (degree): the spatial QRS-T angle between the maximum spatial QRS and T vectors, Statistically significant difference evaluated by paired t-tests: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

TABLE 2. CHANGES IN QRS DURATION, IN THE TIME OF OCCURRENCE OF THE MAXIMUM SPATIAL QRS VECTOR, AND IN THE MAXIMUM ANTERIOR, LEFTWARD, POSTERIOR, AND INFERIOR FORCES OF THE QRS LOOP.

	QRS duration	Maximum anterior force	Maximum leftward force	Maximum posterior force	Maximum inferior force	QRSmax
Male						
Deep inspiration	82 ± 7	24 ± 3	37 ± 4	51 ± 5	39 ± 3	41 ±4
Deep expiration	82 ± 6	25 ± 4	38 ± 4	54 ± 4	38 ± 2	39 ± 3
Female						
Deep inspiration	78 ± 7	22 ± 5	35 ± 4	50 ± 5	39 ± 4	40 ± 4
Deep expiration	77 ± 7	23 ± 5	37 ± 4	52 ± 5	38 ± 4	38 ± 4

QRSmax: maximum spatial QRS vector (mean ± SD) (msec)

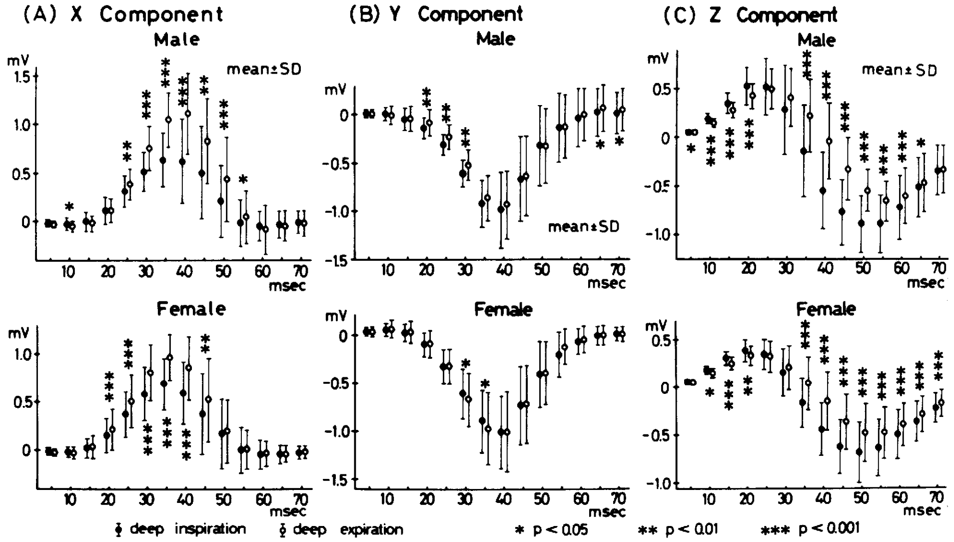

Fig. 3. Effects of deep inspiration and deep expiration on the X (A), Y (B), and Z (C) components of the spatial instantaneous QRS vectors in 18 males and 17 females. Closed circles represent the mean values of the amplitudes in the X components in the deep inspiration. Open circles represent those in the deep expiration. Ordinates: amplitudes of the X, Y, or Z components. Abscissa: time of spatial instantaneous QRS vectors.

There was no alteration either in the direction or in the speed of the QRS loop inscription.

For a more detailed analysis of the respiratory effect on the QRS vectors, the spatial instantaneous QRS vector at IN and EX was analyzed every 5 msec in 35 (18 males and 17 females) subjects. The X components of the QRS vectors decreased in amplitude at 25 through 45 msec, whereas the amplitudes of the Z

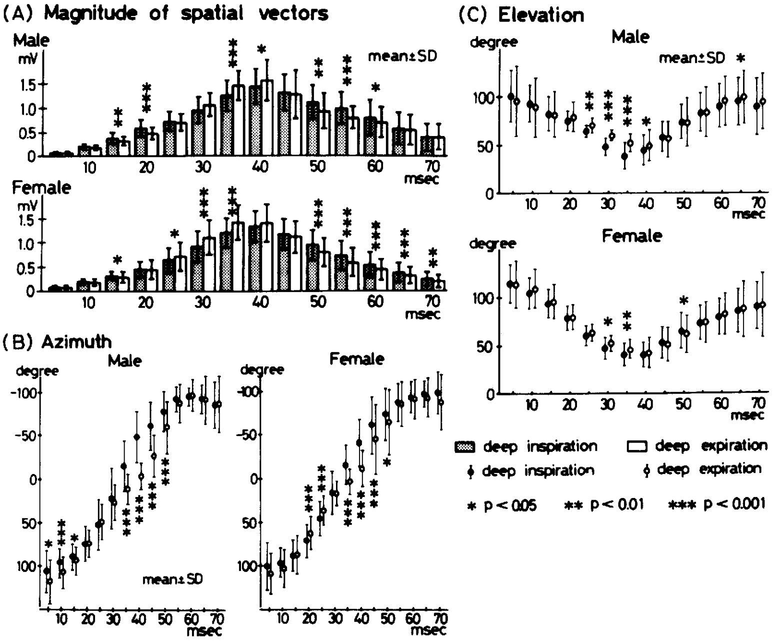

Fig. 4. Effects of deep inspiration and deep expiration on the magnitude (A), azimuth (B), and elevation (C) of the spatial instantaneous QRS vectors in 18 males and 17 females.

components increased at 15, 20, and 35 through 60 msec (Figs. 3A, 3C and 5). The amplitudes of the Y components of the 20-, 25-, and 30-msec QRS vectors increased in males, while those of the 30-, and 35-msec QRS vectors tended to decrease in females (Fig. 3B). The spatial magnitude of the 35-msec QRS vector was reduced, while those of the 50- and 55-msec QRS vectors increased (Fig. 4A). In addition, the 15- and/or 20-msec QRS vectors, with a few exceptions, increased in spatial magnitude. The QRS vectors were displaced posteriorly at 35 through 45 msec, and inferiorly at 35 msec (Figs. 4B and 4C). In males, the 10 msec QRS vector decreased in azimuth; thus, the initial deflection was shifted to the left.

Fig. 5 illustrates the loops reconstructed from the mean value of each instantaneous QRS vector. Not only the orientation but also the configuration of the QRS loop changed markedly from EX to IN. During IN, each QRS vector in the middle part of the loop was directed more posteriorly and vertically, resulting in marked reductions in the leftward forces and increases in posterior forces. The IN QRS loop exhibited a long and narrow configuration in the anterior-posterior direction. In the frontal planar projection, the IN QRS loop shifted vertically without change in the configuration. The 35- through 50-msec QRS vectors were influenced more by respiration than the initial and terminal vectors.

The time of occurrence of QRSmax, and the maximum anterior, posterior, leftward, and inferior forces were averaged (Table 2).

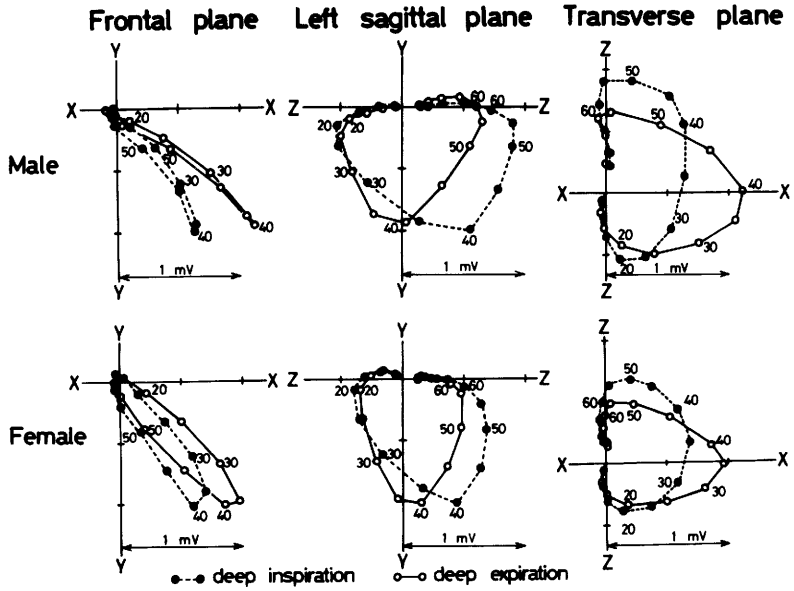

Fig. 5. QRS loop configurations in deep inspiration and deep expiration, reconstructed from the mean values of the spatial instantaneous QRS vectors. Closed circles connected with broken lines indicate QRS loops in deep inspiration. Open circles connected with solid lines indicate loops in deep expiration.

(C) T Vector

The maximum anterior force of the T loop markedly increased (57.1 % in males, and 91.8 % in females), whereas both the maximum leftward and inferior forces decreased (Table 1).

The magnitude of Tmax did not change in males, but decreased in females. In the transverse plane, IN caused a clockwise (anterior) shift in both sexes (Table 1 and Fig. 2). Furthermore, in males, Tmax was displaced more superiorly. The speed and direction of the T loop inscription were not altered with respiration.

(D) Spatial QRS-T Angle between QRSmax and Tmax

The spatial QRS-T angle calculated was enlarged (Table 1), due to a posterior-inferior displacement of QRSmax and the anterior shift of Tmax.

Part 2: Comparison of respiration-related VCG changes between deep inspiration, deep expiration, resting inspiration, and resting expiration. Resting expiration (functional residual capacity) was selected as the base line for comparison among four respiratory positions. Significant changes were found in azimuth with deep inspiration being different from the other three. QRSmax and Tmax represented posterior and anterior displacements with lung inflation, respectively (Fig. 6).

The spatial QRS-T angles calculated were unaltered between resting expiration and EX (Fig. 7). The angle increased in resting inspiration, and even further in

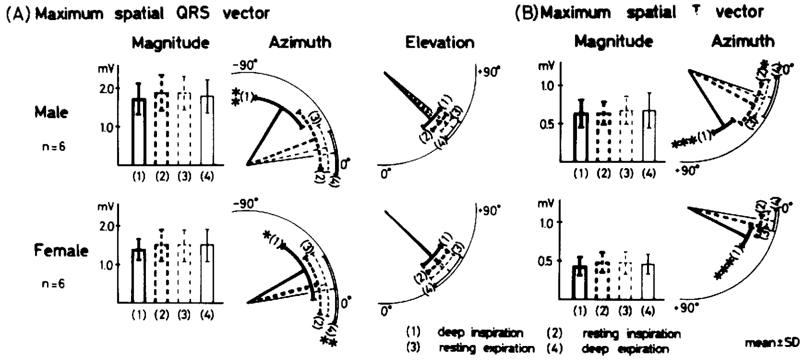

Fig. 6. Changes in the maximum spatial QRS vectors (A), and T vectors (B) in 6 males and 6 females, in deep inspiration, resting inspiration, resting expiration, and deep expiration.

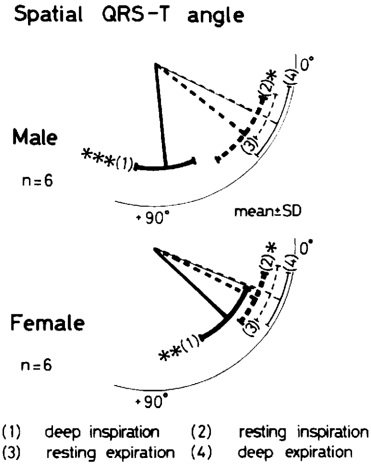

Fig. 7. Changes in the spatial QRS-T angle between the maximum spatial QRS and T vectors in 6 males and 6 females, in deep inspiration, resting inspiration, resting expiration, and deep expiration.

IN, with a highly significant difference compared to that of resting expiration.

Part 3: Effect of fractionated respiration on the QRS and T vectors (Fig. 8). In five males, VCGs were recorded at every 1,000-2,000 ml of vital capacity, to evaluate fractionated respiration. The azimuths of QRSmax and Tmax, spatial QRS-T angle, and the maximum leftward and posterior forces of the QRS loop changed in parallel with the lung inflation. These changes resulted mainly from the displacement of the azimuth.

Increases in the chest circumference, anterior-posterior chest diameter, and lateral chest diameter at the level of the fifth intercostal space were observed in IN (Table 3). Diastolic blood pressure decreased slightly. An increase in heart rate associated with inspiration was not maintained during breath-holding at the maximum inspiration, but a mean reduction by 5.5 beats per minute was observed in the present study, as described previously (8).

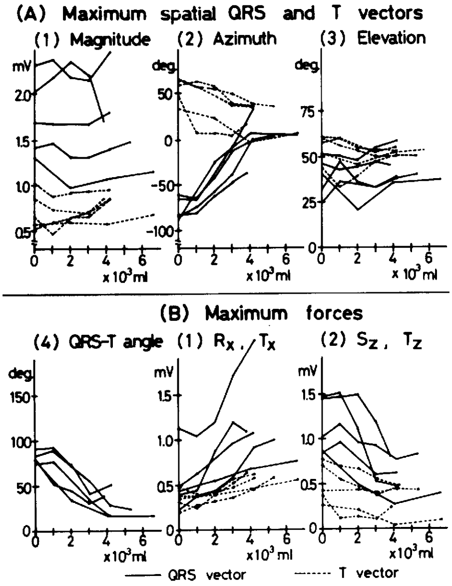

Fig. 8. Effects of fractionated inflation on the maximum spatial QRS and T vectors, the spatial QRS-T angle, Rx, Sz, Tx, and Tz, in 5 males. Solid lines represent alterations in the QRS vectors. Broken lines represent changes in the T vectors. Abscissa indicates the volume of air expired from the lungs from deep inspiration (0 ml indicates deep inspiration).

TABLE 3. EFFECTS OF RESPIRATION ON BLOOD PRESSURE (BP) AND HEART RATE (HR).

		Male					Female				
		Deep expiration		Deep inspiration		P value	Deep expiration		Deep inspiration		P value
		mean	SD	mean	SD		mean	SD	mean	SD	
HR	(/min)	66	10	61	9	***	69	9	63	9	***
Sys. BP	(mmHg)	114	11	110	14	*	110	19	110	19	
Dias. BP	(mmHg)	67	10	62	9	***	66	13	63	14	**
Circum.	(cm)	84.8	4.8	89.0	4.3	***	78.2	6.9	81.9	6.3	***
Lat.	(cm)	29.5	1.6	30.3	1.7	***	26.5	2.4	27.4	2.4	***
A-P.	(cm)	20.3	2.1	22.3	1.8	***	18.7	1.9	20.0	1.9	***

HR: heart rate, Sys. BP: systolic blood pressure, Dias. BP: diastolic blood pressure, Circum.: chest circumference at the level of the fifth intercostal space, Lat.: lateral chest diameter at the level of the fifth intercostal space, A-P.: anterior-posterior diameter at the level of the fifth intercostal space. *, **, ***. See Table 1.

DISCUSSION

The results of this study, which employed the Frank lead system, were compared to those of previous statistical studies using different lead systems (Table 4) (6, 7, 9).

TABLE 4. COMPARISON OF THE EFFECTS OF RESPIRATION ON VECTORCADIOGRAMS IN STATISTICAL STUDIES.

Author's name	Yamada (present study)		Simonson (6)		Ruttkay-Nedecky (9)	Beswick (7)
Lead system	Frank		Conventional	SVEC III	McFee-Parungao	Lead field
Analyzed vector	Maximum spatial vector		Mean spatial vector		Mean spatial vector	Mean spatial vector
Respiratory state	IN-EX		IN-EX	IN-Resting respiration	IN-EX	IN-EX
Sex	Male	Female	Male	Male	Male	Male
No. of subjects	34	27	38	22	7	23
QRS vector						
Magnitude	Decreased 10 %	Decreased 9 %	Unchanged	Decreased	Decreased	Decreased 8 %
Azimuth	Posterior 39	Posterior 26	Posterior 12	Posterior 8	Posterior 11	Unchanged
Elevation	Inferior 7	Inferior 5	Inferior 23	Inferior 9	Inferior 11	Inferior 4
T vector						
Magnitude	Unchanged	Decreased 9 %	Unchanged	Unchanged	Decreased	Decreased 10 %
Azimuth	Anterior 23	Anterior 14	Anterior 12	Anterior 16	Anterior 5	Anterior 6
Elevation	Superior 4	Unchanged	Inferior 8	Inferior 5	Inferior 1	Inferior 9
QRS-T angle	Increased 40	Increased 25	Increased 4	Increased 17	Increased 9	Unchanged

IN: deep inspiration, EX: deep expiration

The results were in agreement with those reported by Simonson (SVECIII lead system) (6) and Ruttkay-Nedecky (McFee-Parungao system) (9), but were not identical in extent. The degree of inferior deviation of the QRS vector was similar in all the lead systems except for the conventional lead system (Simonson). Both the azimuth and spatial QRS-T angle in the present study tended to change more drastically than those in the previous reports. Simonson and co-workers (6) asserted that the Frank lead system presented the largest increase in the spatial QRS-T angle in IN among eight different lead systems (conventional, SVECIII, SVECIIa, Duchosal-Sulzer, Grishman, Wilson-Burch, Briller, and Frank lead systems). The only parameter for which the present data differed qualitatively from the other reports was the elevational change in the maximum T vector. The reasons for this difference were not clear.

Analyses of the maximum or mean spatial QRS vector can not depict respiratory influences on other parts of the QRS loop. For this reason, a more detailed investigation is necessary to observe QRS alterations at identical instantaneous spatial vectors. Respiration-associated changes in instantaneous spatial cardiac vectors were previously reported by Ruttkay-Nedecký (9, 10). The differences between his results and those of the present study were the amplitudes in lead Z and the spatial magnitudes in the posterior direction. These discrepancies might be due to the lead system, subjective selection, and so on.

The basic findings of this study are: (1) Instantaneous QRS vectors recorded on the body surface at identical time-points after the beginning of the QRS loop altered their directions as well as magnitudes to a variable degree with respiration, and, furthermore, their directions changed more than magnitudes, which implies that the current flow pathway was altered easily. The QRS loop shifted more vertically, and exhibited a long and narrow configuration in the anterior-posterior direction in the transverse planar projection. (2) QRSmax and Tmax shifted in opposite directions (azimuth) with inspiration, resulting in a marked increase in the spatial QRS-T angle. (3) The direction of the elevational changes between QRSmax and Tmax was not always constant in individual subjects. (4) In the frontal planar projection, the 25- through 50-msec QRS vectors moved vertically to the same degree, resulting in a downward shift without changing the QRS loop configuration. (5) The directional displacement of each vector with lung inflation seemed to be determined by its position at EX. (6) Vectorial changes in parallel with lung inflation resulted mainly from displacement of the azimuth.

The two most probable causes for these vectorial alterations were cardiac anatomic positional changes and considerable changes in lead field-potential distributions resulting from lung inflation.

The frontal QRS loop was displaced vertically without change in its configuration (Fig. 5). As the frontal QRS loop is long and very narrow, rotation of the heart around its longitudinal axis may alter its configuration or the direction of its inscription. As such, it is unlikely that the heart rotates around its longitudinal axis with respiration. In the frontal planar projection, the 25- through 50-msec QRS vectors were displaced vertically in an identical manner (Fig. 5). Their vertical shifts did not result from cardiac anatomic positional changes alone. It should be noted that different factors participated in their vertical shifts in the efferent and afferent limbs of the QRS loop. At the 25- through 35-msec QRS vectors, their vertical shifts were due to elevational changes in the downward direction with little participation by decreased spatial magnitude. On the contrary, for 40- through 55-msec QRS vectors, vertical shifts were caused by backward azimuth displacements, while elevational changes participated little. It is also important that the 30-msec QRS vector was displaced toward the zero point in the transverse planar projection with a large elevational change (11.9 degrees in males and 5.3 degrees in females) (Figs. 4C and 5). The QRS vectors up to 25 msec and after 35 msec were displaced anteriorly and posteriorly, respectively, because of an alteration in current flow direction created by increases in electric resistance of the inflated lungs. The 30-msec QRS vector may hardly be displaced in the anterior or posterior direction by changes in lung conductivity. In a preliminary radiological study, the cardiac longitudinal axis shifted vertically from EX to IN (5.9 degrees in males and 6.7 degrees in females). Thus, cardiac displacement observed radiologically is close to that of the 30-msec QRS vector. In light of these results, it seems reasonable to suggest that the heart moves with respiration in the direction close to the displacement of the 30-msec QRS vector. Therefore, cardiac displacement with deep inspiration may be 7 to 15 degrees vertically, and 3 to 10 degrees posteriorly (Fig. 5). If only cardiac positional displacement is assumed to occur, the horizontal QRS loops in IN calculated from the frontal and left sagittal QRS loops in EX do not match those measured (Fig. 9). Furthermore, the azimuth of QRSmax and Tmax moved in opposite directions, resulting in increased spatial QRS-T angles (Table 1), and the directions of elevational changes were not always constant between QRSmax and Tmax in individual subjects. Though cardiac positional displacement certainly plays an important role in respiration-associated VCG changes, other factor (s) must be considered to explain these phenomena adequately.

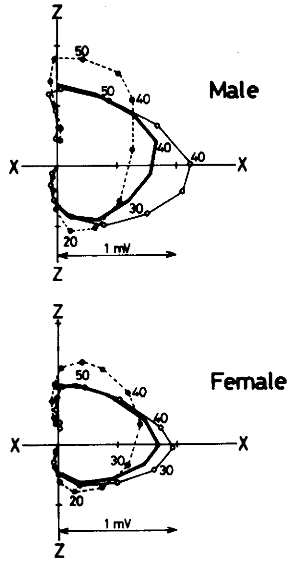

Fig. 9. Projected QRS loops (solid thick lines) in the transverse plane were calculated from the frontal and sagittai QRS loops in deep expiration, on the assumption that only cardiac positional displacement took place (15 degrees vertically, 10 degrees posteriorly for males, and 7 degrees vertically, 3 degrees posteriorly for females). Solid circles connected with broken lines represent the QRS loop in the transverse planar projection in deep inspiration. Open circles connected with solid lines represent that in deep expiration.

Several articles (14-18) have confirmed that the reduction in the electrical conductivity of inflated lungs alters the lead vector. Specific resistance of over-inflated lungs was 2.5-3.5 times that of lungs in the expiratory state, 6.0-15.0 times that of the blood, and 3.5-6.1 times that of the myocardium (18, 29, 30). When the lung model was placed into the torso model, the lead vectors decreased in Frank's lead X, increased in lead Y, and slightly increased in lead Z in the left anterior direction (17, 18). Toyama and co-workers (14) demonstrated that the potentials of leads X and Y were reduced with the lung inflation and that the amplitude of lead Z potentials generated from the dipoles implanted in the dog's posterior left ventricular free wall increased with lung inflation. These results suggested that the amount of electric current in IN decreased in the leftward direction and increased in the anterior-posterior direction. In the preliminary study, CT scannings of lung inflation demonstrated increased gas around the left or left-inferior portion of the heart in IN. Consequently, in IN, the conductivity surrounding the heart would have been reduced on the left side of the heart, while it would have been relatively increased in the anterior-posterior direction. The electric current must flow easily in the anterior-posterior direction with a reduction in the leftward direction, so that the azimuth should be altered considerably. Vectors toward the left-anterior direction at EX shift anteriorly at IN, whereas those toward the left-posterior direction shift posteriorly. This is obvious from the analysis of instantaneous QRS vectors (Fig. 5). There is no consensus concerning changes in the transfer impedance vector of lead Y with lung inflation (14, 17, 18, 29). In the present study, there were divergent changes in the Y component amplitudes between males and females (Fig. 3B).

When chest electrodes were moved from the level of the fifth to the fourth intercostal space, the direction of the QRS loop was altered by posterior and slightly downward shifts without changes in amplitude (31). Ikenaga (32) reported similar clinical findings. In the preliminary radiological study, the level of the chest electrodes rose 1.4 cm in IN, while the anatomic heart center determined radiologically descended 1.2 cm in IN. Ishizawa (12) and Ishibe (13) demonstrated similar findings. Therefore, the relation between the anatomic heart center and the chest electrodes at the fifth intercostal space in IN may be similar to that at the fourth intercostal space in EX. Alterations in the relation between the chest electrodes and the anatomic heart center also may be partly responsible for the posterior and inferior displacement of the QRS loop.

In addition to the directional changes, the spatial magnitudes were also modified. The ventricular activation process did not seem to be altered with respiration, for there was no change in QRS duration or conduction delay. Therefore, the factors producing the spatial magnitude changes may have deen alterations in lead vectors, such as changes in the volume conductors (lungs, thorax, blood, etc.). The main factor would seem to be conductivity of the lungs (14-18).

Since the anterior-posterior diameter of the thorax increased in IN (Table 3), the lead vector in lead Z should have been reduced (33-35). However, the opposite result was observed in the initial and terminal parts of the QRS loop in the transverse planar projection (Fig. 5). Thus, the alteration of the anterior-posterior diameter of the thorax played little part in these VCG changes.

Left ventricular end-diastolic volume was reduced in IN (36). Voukydis (37) reported that a reduction in the left ventricular end-diastolic diameter was accompanied by a decrease in the spatial magnitude of the middle part of the QRS complex, and a slight enlargement of the terminal forces. Therefore, the reduction of the left ventricular blood volume in IN may also influence spatial magnitudes of vectors.

The VCG is substantially affected by respiration through changes in: cardiac anatomic position, the shape and conductivity of the lungs and other factors such as the level of the chest electrodes and intracardiac blood volume.

Clinically, the respiratory effect on VCG or ECG becomes an important problem with increased lung gas, for example during exercise stress testing (27). Special caution should be employed in the interpretation of exercise ECG or VCG findings, especially as concerns the amplitude of the leftward, anterior, and posterior forces, the azimuth of the spatial vector, and spatial QRS-T angle. Furthermore, ECG or VCG analysis is often based upon an average of consecutive beats (20-25). While this approach has much merit, it may yield misleading results from a considerable increase in tidal volume and respiratory frequence during and after exercise.

In conclusion, the VCG is substantially affected by respiration through changes in cardiac anatomic position, distortion of lead-field potential distribution, and other mechanisms. Since the respiratory effect is potentially important from the point of view of diagnostic interpretation of VCG findings, VCG ideally should be recorded under identical respiratory status.

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