DISCUSSION

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Study of pulmonary functions was carried out randomly in normal healthy pregnant and nonpregnant subjects. Quantitative and descriptive analysis of expiratory and inspiratory parameters in the form of static lung volumes and capacities, minute ventilation, flow rates – large and small airways, breathing reserve and respiratory efficiency tests as tabulated (pg. 58) was intended.

Study was conducted on one hundred and sixty female subjects in age range of 25 – 35 years divided in four study groups, viz. – controls, first, second and third trimester according to their nonpregnant state and gestational period. The proforma as per Annexure I was filled for each subject. Environmental, technical and operational factors affecting pulmonary functions as mentioned in material and methods were taken care of. Precautions were taken to minimize errors in recording the pulmonary function tests from various sources. Pulmonary function tests were conducted with help of Hutchinson's spirometer, Ludwig's kymograph and mercury manometer. All the results were statistically analyzed.

Discussion attempts to focus on some changes in pulmonary functions that are encountered during the normal pregnant state. The present results are discussed on the basis of articles reviewed in published literature for certain parameters that are tabulated as well as on the basis of hypothesis formulated and assumptions put forth by the present author. Tabulated review in the text briefly gives observers name and reference number as documented in bibliography (column1). The abbreviations NPS, PS, EP, MP and LP stand for nonpregnant state, pregnant state, early pregnancy, mid pregnancy and late pregnancy respectively. Remark column gives the overall change in % or ml. The direction of arrow shows increase (upward), decrease (downward) or no change (horizontal) in that parameter.

The results of present study are briefly presented in Table 33 for inferring the changes that have occurred at glance. It gives an overall view of mean of all parameters incorporated in the study in NPS and in three trimesters (trim). The mean of all the three trimesters was calculated to get an overall average change during pregnancy for each parameter (X in PS). Remark column gives increase (+) or decrease (-) as difference (diff) between nonpregnant and pregnant state and percentage of the parameter.

Table 33 – mean values of all parameters in sample.

Parameter	NPs	1st trim	2nd trim	3rd trim	X in PS	Remark	
						Diff	%
f	14.50	19.00	23.08	30.13	24.07	+9.5	+66
TV (ml)	561	442	512	446	467	-94	-17
RMV(l/m)	7.9	8.4	11.7	13.4	11.19	+3.21	+40.3
ERV(ml)	806	778	550	647	658	-147	-18.3
IRV (ml)	1502	1165	1145	956	1089	-413	-27.5
IC (ml)	2063	1607	1657	1402	1556	-507	-24.6
VC (ml)	2863	2335	2177	2022	2178	-685	-23.9
MVV(l/m)	86.15	74.60	66.78	46.91	62.76	-23.4	-27.1
RR (l/m)	78.17	66.21	55.01	33.50	51.57	-26.6	-34.0
BRR (%)	90.52	88.34	81.98	70.92	80.41	-10.1	-11.1
FEVC(ml)	1822	2092	1706	1806	1868	+46.5	+2.55
$FEV_{0.75}$%	73.68	60.8	57.5	56.7	58.39	-15.3	-20.7
FEV_1%	90.3	78.25	77.5	74.1	76.6	-13.6	-15.1
FIVC	1311	1423	1059	1275	1253	-58.3	-4.45
$FIV_{0.75}$%	66.13	70.84	72.57	68.56	70.65	+4.52	+6.84
FIV_1%	84.9	88.1	91.3	86.0	88.3	+3.53	+4.15
$FIV/FEV_{(.75)}$	0.91	1.33	1.46	1.41	1.4	+0.49	+53.8
FIV_1/FEV_1	0.94	1.21	1.26	1.26	1.24	+0.30	+32.3
MEFR(l/m)	103.6	90.35	84.87	85.10	86.77	-16.8	-16.2
MIFR(l/m)	83.91	91.65	86.48	85.01	87.7	+3.8	+4.5
MIFR/MEFR	0.88	1.15	1.09	1.01	1.08	+0.20	+23.1
MMEFR(l/m)	114.2	116.0	93.4	92.1	100.5	-13.7	-12.0
MMIFR(l/m)	77.23	92.35	83.95	87.33	87.87	+10.6	+13.8
MMIFR/ MMEFR	0.73	0.93	0.93	1.01	0.95	+0.22	+31.1
BHT(sec)	65.2	22.4	21.1	16.8	20.1	-15.0	-42.8
40 ET (sec)	31.3	20.9	20.0	16.7	19.2	-12.1	-38.6
MET(mmHg)	83.2	67.7	56.18	58.4	61.1	-22	-26.5
Hb (gm%)	12.8	12.2	11.7	10.9	11.6	-1.2	-9.37
HR beats/min	87.4	92.9	95.9	98	95.6	+8.2	+9.4
SBP(mmHg)	103.8	106.3	110.4	114.6	110.4	+6.63	+6.3
DBP(mmHg)	68.3	70.9	67.2	72.5	70.2	+1.9	+2.8

Respiratory rate

Respiratory rate (table & graph 1) was obtained simply by inspection of breathing pattern (thoraco-abdominal pattern).

Comparison of f (breaths/min) as given by various authors						
Authors	N P S	P S	E P	M P	L P	Remark
Benjamin (5)	16				18	I
Cugell (25)	15				16	I
Krunholtz (55)			18	20		I
Burrow (12)						I
Bernes (7)						10% I
Chhabra (19)					4.1%	I
Puranik (68)	12		11	13	15.7	I
Bernard (6)		I				I
Bonica (10)						15% I
Duncun (37)		I				I
Knuttgen (54)	15.6	15.2				–
Rees (74)						–
Rasheed (71)			23.5	23.4	22.6	v
Alaily(1)	17.75	16				9.85% v
Spatling (87)	18				16	v
Present study	14.5	24.07	19	23.6	30	66% I

Respiratory rate (breaths/min) increases as the pregnancy advances (graph 29). Maximum increase was observed in third trimester. On comparing all experimental groups with control, a rise of 3.5 (31.03%), 8.24 (59.13%) and 15.63 (107.75%) was observed. During advancing pregnancy from first to second and second to third trimester rise of 7.05 (21.44%) and 4.08 (30.55%) was observed respectively. The rise at all the stages and within groups was statistically highly significant.

Most of the published reports on increase respiratory frequency state insignificant rise in the range of 6% - 15% giving the mean values within the normal range (5,6,7,10,12,19,25,26,37,55,68). All these studies support the present findings of increased respiratory frequency. Few studies report significant decrease (1,87), insignificant fall (71,74). or no change (54,74,93). In present study highly significant rise in respiratory rate throughout the pregnancy as well when compared with nonpregnant state was noted. None of the studies have reported a significant rise.

It has been mentioned that progesterone exerts influence on respiratory centers (26,94), thereby increasing respiratory frequency and estrogen facilitates this action of progesterone as is demonstrated by study of Hosenpud et al. (1983). During pregnancy activity of thyroid gland increases leading to secretion of thyroid stimulating hormones viz. human chorionic gonadotrophins, chorionic thyrotrophin and molar thyrotrophin by placenta (40) leading to increased metabolism, body temperature and oxygen consumption, hence increase in f.

As pregnancy advances adrenaline increase causes rise in f (76). Peripheral and central administration of adrenaline increases f (76). Increased adrenoreceptor density (88) and increase in brain adrenergic receptors (86) cause increase f.

Tidal volume

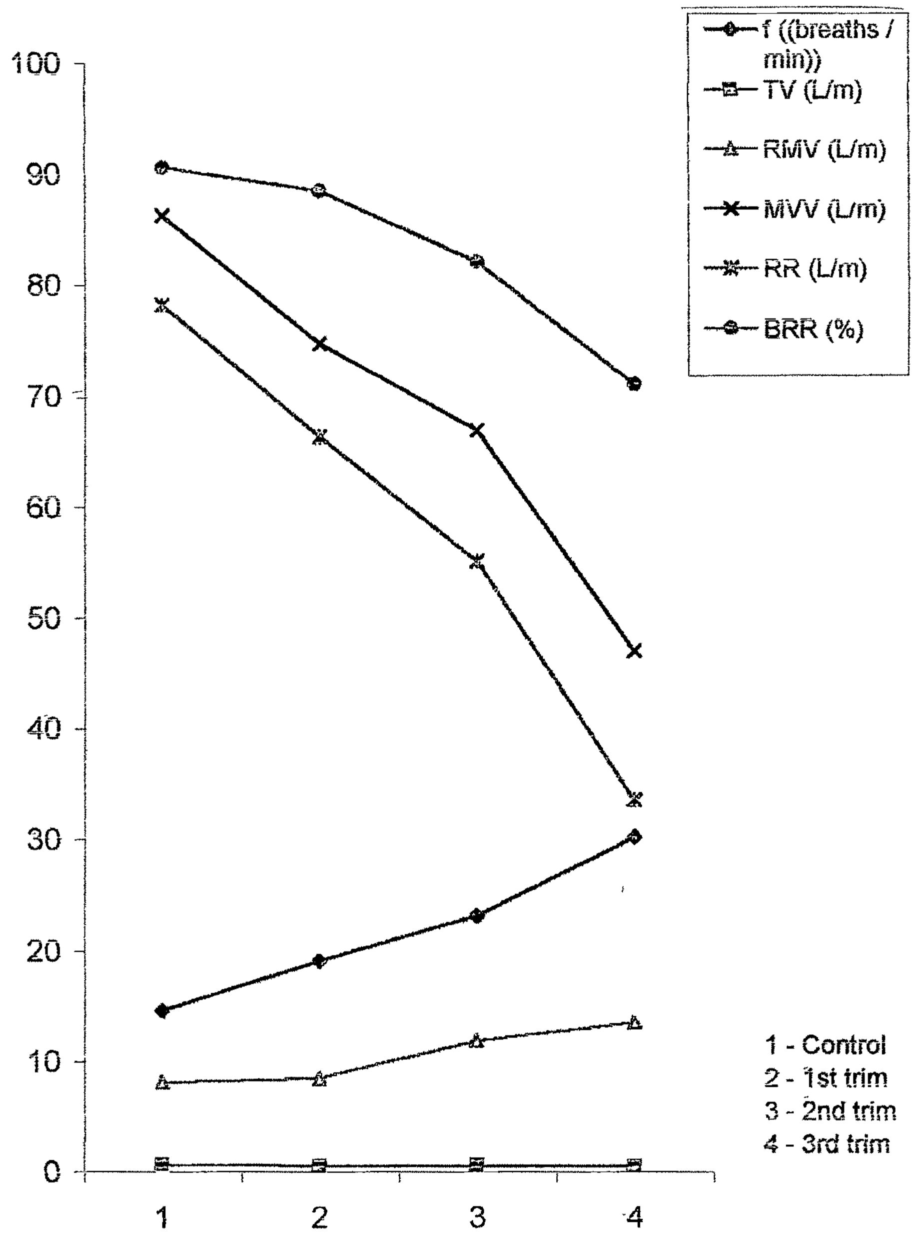
Tidal volume is normal expiratory and inspiratory volume of a single breath without any forceful and conscious effort. It occupies mid position of spirogram.

Tidal volume (mean values in ml) during gestational stage (table & graph 2) decreases by 21.29% in first trimester (441.75), 8.68% in second trimester (512.50) and 21.29% in third trimester (446.25) as compared to controls (561.25). Fall of TV in first trimester from nonpregnant state leads to rise in second trimester by 16.01% and again a fall in third trimester by 12.92%. Changes in TV were found to be significant except an insignificant rise during late pregnancy when equated with early pregnancy (graph 29).

Negligible increase in TV from 6% to notable increase up to 45% is reported in various studies (1,2,7,19,25,37,54, 56,64,68,73,74,87). A very few studies (14,55) report a decrease in tidal volume from first to third trimesters that identify with present observations. Krunholtz et al (1964) noted a fall of 100 from nonpregnant state to late pregnancy while in present study a fall of 114 was observed.

Comparison of TV (ml) as given by various authors						
Authors	N P S	P S	E P	M P	L P	Remark
Cugell (25)	487				678	30% ↑
Duncun (37)						45% ↑
Pandya (64)	272			284	288	↑
Bernes (7)	500	700				40% ↑
Knuttgen (54)	370	650				↑
Leontic (56)	450				600	25-40% ↑
Alaily (1)					28% ↑	
Artal (2)						38% ↑
Chhabra (19)	279		299	347	374	31% ↑
Rees (74)	400		550		600	15% ↑
Spatling (87)			560		715	27% ↑
Puranik (68)	740		790	770	1060	↑
Krunholtz (55)			660		560	↓
Butler (14)						↓
Present study	561	467	442	512	446	17% ↓

Graph 29 – Relation of RMV with other related parameters in controls and three trimesters (trim).



Displacement of diaphragm towards the thoracic cage by growing fetus reduces vertical diameter of thorax restricting lung movement. Consequently, a decrease in tidal volume and depth of respiration occurs that may be leading to mild dyspnea during pregnancy. Overall rise in f and fall in TV infers that tachypnea occurs in pregnant state that accounts for hyperventilation.

Respiratory minute volume

RMV has proportional relationship with two variables – f and TV. RMV gives reserve for MVV. It is expressed in lt./min and is a product of TV and f (RMV = TV x f). Increase in RMV is also termed as hyperventilation or minute ventilation (graph29).

RMV (lt./min) increases throughout pregnancy and is more in experimental group as compared to control group (table and graph 3). The increased RMV in early stage of pregnancy as compared to nonpregnants (7.98) is statistically insignificant. Rise is highly significant from early (8.40) to mid (11.77) and in late (13.42) during gestation. The rise from early to mid pregnancy (40.21%) is more than rise from mid to late pregnancy (13.97%). This could be due to optimal fetal growth and optimal level of progesterone – the effect of which contributes in hyperventilation due to direct action on respiratory centers.

The maximum rise is from early pregnancy to late pregnancy 59.80% and at term increase is by 68.08% when matched with controls.

Comparison of RMV (lt./min) as given by various authors								
Authors	N P S	PS	EP	MP	LP	Remark	TV	f
Cugell (25)	7.27	10.3				40%↑		
Duncun (37)						50%↑	↑	↑
Burrow (12)						↑		
Rubin (75)						57%↑	↑	↑
Bernes (7)		50%↑					40%↑	10%↑
Knuttgen (54)	5.54	8.5				↑	↑	-
Leontic (56)			48%↑		57%↑		40%I	↑
Alaily (1)	9.15		10.2		10.9	19-26%↑		
Pernoll (65)						50%↑		
DeSwiet (34)	7.5	10.5				↑		
Rees (74)	6.6		7.7		40%↑			
Spatling (87)	9.4	12.6				↑	↑	
Puranik (68)	7.3		7.91	9.73	16.07	↑	↑	
Clapp (20)	7.4		10	9.5		28.5%↑		
Present study	7.98	11.2	8.4	11.7	13.4		17%↓	66%↑

As RMV has proportional relationship with two variables – f and TV, both variables show highly significant change in the study. A net increase of 9.57 breaths/min from nonpregnant (14.5) to pregnant state ($\bar{X}$ 24.07) and a net decrease of 94.41 in TV from 561.25 in nonpregnant state to average of 466.8 during pregnancy were observed. Increase in RMV by 45.23% is the resultant of increase in f by 66% and decrease in TV by17% (graph 29).

Most of the authors have postulated that pregnancy exerts influence on minute ventilation and its sub components – TV and f (75,92) by increasing sensitivity of respiratory centers to increased CO_2 (23,35,46,59,66,74,78) and have direct broncho-dilatory action (68). Progesterone increase during luteal phase has been reported to increase minute ventilation by increasing TV more than increase in f (27,31,38,58).

Some of the studies (37,74,87) infer increase in oxygen consumption during pregnancy leading to hyperventilation through direct action of progesterone on central medullary centers (7) so as to keep pCO_2 low (43,50,53,74,87).

Studies on animal treated with progesterone (11,39) and estrogen along with progesterone results in hyperventilation that is more in latter case and could be due to estrogen effect on progesterone receptor synthesis (31). Medroxyprogesterone related products increase in plasma and CSF exerts central effects (11,78,84). Clapp et al (1988) argued increase RMV to be chronic adaptive change to balance respiration and metabolic functions in response to change in sensitivity of respiratory centers to CO_2 tension.

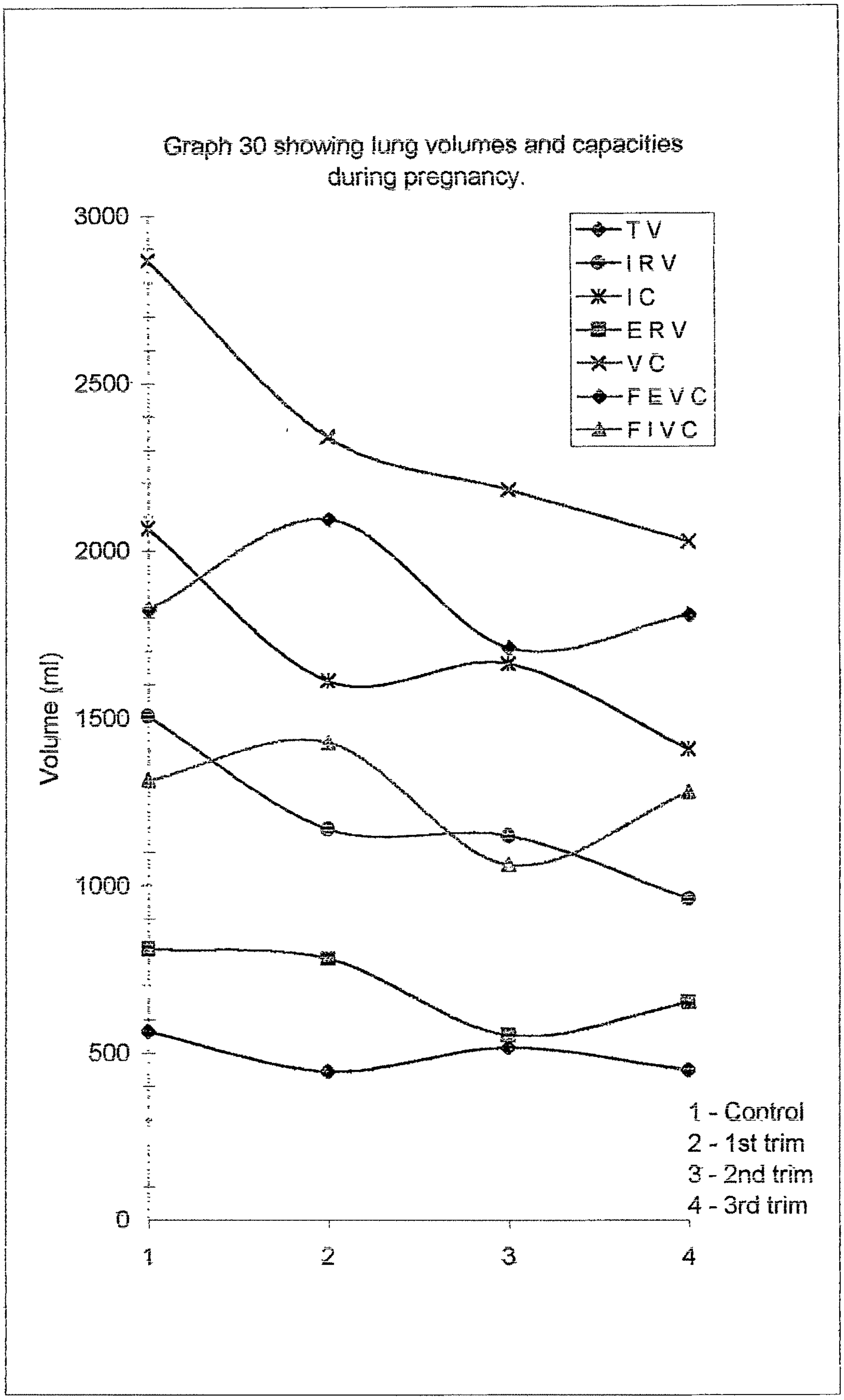
In present study it is hypothesized that increase in RMV causing hyperventilation is primarily due to increase in f and secondarily due to decrease in TV. Increase in f could be due to increased oxygen consumption and CO_2 concentration in blood. Increase oxygen consumption is well known fact since metabolism in pregnancy increases due to increased thyroid function (39) and increase fetal demand, thus resulting in hyperventilation. As stated earlier decrease depth of respiration does not meet the demands of oxygen consumption and CO_2 washout. To fulfill maternal and fetal oxygen demand f increases primarily in relation to decreased TV resulting in hyperventilation thereby decreasing $paCO_2$. This is brought about by direct action of progesterone on respiratory centers. Progesterone makes the respiratory centers more vulnerable to pCO_2 by increasing their sensitivity and lowering their threshold. Estrogen affecting progesterone receptor synthesis in uterus may be a possible cause of hyperventilation (57). Progesterone is said to modify the permeability of chemoreceptor sensitivity (68). Progesterone has more stimulatory effect on respiratory center then bronchial smooth muscles relaxing effect. Altered thoracic configuration also contributes in hyperventilation. Increased uterine size and its pressure exerted upon the inferior surface of diaphragm by the abdominal contents which tend to limit severely the normal movements of this structure and other local changes viz. augmented dead space, unsatisfactory intrapulmonary distribution of gases, defective diffusion across the alveolo–capillary membrane or a combination of these that are found during pregnancy may be responsible for hyperventilation. Increase in RMV occurs as a chronic adaptive change and is a compensatory mechanism.

Expiratory reserve volume

Expiratory reserve volume is the maximal volume of air that can be expired forcefully from the normal resting expiratory level. ERV reflects thoracic and abdominal muscle strength, thoracic mobility and the balance of elastic forces that determine mid position at the end of spontaneous expiration.

ERV (ml) was observed more in controls than in pregnant subjects. Mean values (table and graph 4) for control, first, second and third trimester subjects were 806.25, 778.75, 550 and 647.5 respectively. It was seen that in pregnancy insignificant decrease occurs in first trimester by 3.41% leading to further significant fall by 31.78% and in third trimester by 19.68% as compared to control.

Comparison of ERV (ml) as given by various authors						
Authors	N P S	P S	E P	M P	L P	Remark
Cugell (25)	655	555				15% ↓
Rubin (75)						↓
Duncun (37)	700	600				100ml ↓
Pandya (64)	796			686	730	↓
Bernes (7)						100ml ↓
Knuttgen (54)	1210	1020				6% ↓
Butler (14)	940	790				20% ↓
Baldwin (3)						17% ↓
Chhabra (19)	703	482				↓
Burrow (12)						150 ml ↓
Bernard (6)						40% ↓
Krunholtz (55)			1140		1170	30 ml ↑
Present study	806	659	778	550	647	18% ↓


Graph 30 showing lung volumes and capacities during pregnancy.
Volume (ml)
3000
2500
2000
1500
1000
500
0
1
2
3
4
T V
I R V
I C
E R V
V C
F E V C
F I V C
1 - Control
2 - 1st trim
3 - 2nd trim
4 - 3rd trim

During pregnancy a significant fall is viewed from first to second trimester (29.37%) while a rise from second to third trimester (17.72%), though the rise at term is observed but ERV is still less than first trimester by 16.85%.

Majority of published reports supports the present finding – a decrease in ERV (3,6,7,12,14,19,25,37,54,56,68, 75). Overall decrease in ERV with increase from second to third trimester as in present study has also been reported (64,82). A decrease in ERV could be attributed to decrease in VC (75), flaring of ribs (56), nausea in early to mid pregnancy (82), relaxation of bronchial smooth muscles at term (64), upward displacement of diaphragm (12,56) by 4 cm (7), mechanical effect of growing uterus (14) and /or reduced power of expiratory muscles (68).

All these factors have additive role in decrease ERV as have been observed in present study (graph 30). Slight rise at term is probably because of adaptive change. Nausea does not occur and bronchial smooth muscles as relaxed due to effect of progesterone, do not actively take part in forceful expiration. Apart from this the strength of expiratory muscles is reduced due to stretching of abdominal wall with progress of pregnancy.

Inspiratory reserve volume

Inspiratory reserve volume is maximal volume of air inspired forcefully with efforts after normal resting inspiration. IRV is the reserve available for increase in TV. It reflects the balance between lung and chest elasticity, muscle strength, and thoracic mobility and mid position of lung volumes.

Inspiratory reserve volume (table and graph 5) measured in ml decreased with advancing pregnancy and least volume was observed in third trimester (956.25). Difference between first (1165.75) and second (1145) trimester was only of 20.75, an insignificant decrease of 1.77% and that between second and third trimester was 188.75, a less significant decline of 16.48%. Comparing control (1502.5) with three trimester groups, the fall in IRV was observed to be highly significant in the experimental group. The highly significant decrease from early to late pregnancy was from 22.41% - 36.35%. The average of 1089 ml IRV was calculated during pregnancy (equals to 48.5ml or 27.52% less than controls).

Increase in IRV (7,55) or no change (56) and a fall during pregnancy has been mentioned (64). The latter studies support the present finding of decrease in IRV during pregnancy.

Instrumental factor or technique of measuring IRV could be the cause of decrease in IRV. The subject has to inspire forcefully the moist, humid and warm air from spirometer that may be nauseating, restricting the patient to perform accurately. Moreover persistence of morning sickness in early pregnancy and altered body configuration in mid and late pregnancy may play a role in reducing IRV.

The decrease in IRV suggests that reserve for increasing TV is not available and hence a decrease in TV is obtained (graph 30). Progressive fall in IRV during pregnancy also suggests that though the lung compliance may be normal but chest elasticity is not in proportion due to decrease in muscle strength. Thoracic mobility decreases and mid position of lung volumes lower during pregnancy as is indicated by decrease in TV.

Inspiratory capacity

Inspiratory capacity is the maximum volume of air that can be inspired from resting normal expiratory level. To get this the subject had to maximally inspire from the spirometer after normal expiration. IC in other terms can be expressed as sum of TV and IRV.

IC (ml) shows a highly significant fall from nonpregnant to pregnant state (all three trimesters). On an average there is a decrease of 507.92 (23.94%) in pregnant as compared to nonpregnant subjects. A nonsignificant rise of 3.11% from first to second and then a significant decline of 15.36% from second to third trimesters were observed (Table 6 & Graph 6 & 30).

Comparison of IC (ml) as given by various authors						
Authors	N P S	P S	E P	M P	L P	Remark
Cugell (25)	2625	2745				5% ↑
Duncun (37)	2600	2700				100ml ↑
Leontic (56)	2500	2650				150ml ↑
Alaily (1)						10.7% ↑
Knuttgen (54)	2140	2520				380ml ↑
Chhabra (19)	1244		1315	1485	1581	374ml ↑
Burrow (12)						↑
Bernard (6)						5% ↑
Puranik (68)	1610		1610	1780	2200	↑
Krunholtz (55)			2210		2230	↔
Rubin (75)						↔
Baldwin (3)						↓
Present study	2063	1556	1607	1657	1402	24% ↓

Increase in IC has been advocated by many (1,6,12, 19,25,37,45,54) while a few acclaimed no change (55,75). To equipoise decrease ERV and to maintain VC, IRV and IC increase (56). IC increases at expense of decrease ERV, RV and FRC (3). Increase in IC possibly may be due to altered thoracic configuration and to heighten sensitivity to the nervous stimuli required for muscular contraction (68).

In the present study decrease in IC was measured that gets support only from Baldwin (1977). Decrease in IC has not been rationalized in literature. Though mechanical changes as increase subcostal angle and flaring of ribs cause overall increase in diameter but the vertical diameter decreases and limitation to intense expansion of thoracic cage and thereby lungs may likely be the reason for decrease IC. Moreover the pregnant subjects experience maximum discomfort at term. The restraint to expansion of thoracic cage is practically due to enlarged breast and growing gravid in late pregnancy. Discomfort is brought about by the stated factors described earlier and descent of diaphragm because of intense inspiration causing increase in pressure on uterus. This maneuver also brings apprehension in pregnant state in third trimester. The decrease of 32.04% in IC at term as compared to nonpregnant state was observed in current study.

Vital capacity

Vital capacity is the volume of air that can be expelled out from the lungs after maximal and forceful inspiration or volume that can be inhaled maximally after forceful expiration, thus giving the expiratory VC or inspiratory VC respectively. VC limits the augmentation of TV during maximal ventilatory effort. VC is one of the important tests in diagnosis of respiratory dysfunction. Presence of dyspnea and orthopnea during pregnancy can be ascertained from VC.

Highly significant reduction in VC (ml) was espied during the course of pregnancy as compared to control subjects (table & graph 7). Significant fall in VC by 18.46% from nonpregnant state (2863.75) to first trimester (2335) is observed that persists till third trimester (2022.5) by 29.37%. A decline of 6.74% in VC from first to second (217.5) is insignificant statistically and from second to third by 7.11% is less significant.

The decrease in VC is disapproved by some (15,37,54,55,90) but approved by substantial number of (6,64,65,68,75,81) studies though few report no change (1,3,51). Increase is postulated to increase subcostal angle and circumference of chest (90). Decrease is rationalized by

Comparison of VC (ml) as given by various authors						
Authors	N P S	P S	E P	M P	L P	Remark
Thomson (90)	3284	3345		3300	3455	↑
Duncun (37)	3150			3260	3450	205ml ↑
Krunholtz (55)			3350		3390	40 ml ↑
Knuttgen (54)	3340	3530				16% ↑
Chhabra (19)	1947		1937	2052	2071	73ml ↑
Cotes (24)	3600	3600				↔
Baldwin (3)						↔
Alaily (1)						↔
Rubin (75)	3054	2759				295 ml ↓
Pandya (64)	1893			1610	1678	249 ml ↓
Butler (14)	3920	3700				220ml ↓
Sheikh (81)						10 ml ↓
Puranik (68)	2500		2530	2510	2490	↓
Present study	2863	2178	2335	2177	2022	24% ↓

trifling change in lung compliance (6) or VC is maintained by increase in IC due to decreased ERV (81) as compared to increased TV (65). Lung volumes and capacities are independent of physical changes as increased body weight, height and surface area. No change in VC could be due to any true restriction of diaphragm movement though higher end expiration could be noticed (65).

In present study maximum VC measured in controls is feasibly because of obligatory healthy status. Whereas pregnant subjects from early to mid pregnancy experience morning sickness, squeamishness, vomiting while mild dyspnea and growing gravida limiting scope of abdominal respiration causes apprehension at term likely to give poor performance of VC.

Progressive decrease in VC throughout pregnancy is conceivably due to progressive growth of gravida that pushes diaphragm towards thoracic cavity. This causes compression of basal lung tissues and increased angulation of bronchi. Apart from this increase in pulmonary blood volume known to occur in pregnancy may contribute in lowered VC. Lowered subcomponents as TV, ERV and IRV also give less of VC as is in present study (graph 30). Limitation to thoracic expansion imposed by tight strapping of enlarged and heavy breast may reduce VC.

Maximum voluntary ventilation

Maximum voluntary ventilation (MVV) also termed as maximum breathing capacity (MBC) signifies the ability of the patient to breath at a sustained high velocity and impend on many factors – muscular force available, compliance of lung and thoracic cage, resistance of airway and pulmonary thoracic tissues (22). It is a crude but useful test for overall assessment of lung mechanics. It is the only test that measures the total ability of the patient to exchange air between lungs and environment. It correlates well with FEV_1. Failure to obtain the normal value of MVV indicates a poor effort, fatigue and discoordination. Success of its performance requires a normal VC, absence of bronchial constriction and integrity of entire neuromuscular and skeletal respiratory apparatus.

Subjects were asked to inhale maximally and forcefully from atmosphere and exhale in Douglas bag for 15 seconds. The air collected was passed through gasometer to calculate the MVV (lt./min).

Mean values – 86.15, 74.60, 66.78 and 46.91 of non pregnant and pregnant state of three trimesters depict decrease of MVV to a great extent in experimental group as compared to controls and a progressive fall with progress in pregnancy (table & graph 8). MVV decreases almost by half 39.24 lt./min i.e. 45.54% in late pregnancy and by one third by 27.69 lt./min i.e. 22.47% in mid pregnancy in comparison to controls. The progressive decline from first to second trimester is by 10.48% and second to third trimester by 29.75% (graph 29).

Comparison of MVV (lt./min) as given by various authors						
Authors	N P S	P S	E P	M P	L P	Remark
Butler (14)						↑
Chaudhuri (16)						↑
Chaudhuri (18)						↑
Rubin (75)						↑
Burrow (12)						↔
Duncun (37)						↔
Chhabra (19)	46	29				↓
Krunholtz (55)	94	88				↓
Bernard (6)	102	96				↓
Present study	86.15	62.8	74.6	66.7	46.9	27% ↓

Some observers (6,19,55) favor present results but not few (14,16,17,18) while some have reported no change (12,37,75). Those reporting increase put forward their view that progesterone being the cause of increase as it relaxes smooth muscles leading to decreased resistance and increased lumen, hence free flow of air. Those noting no change opine that muscular efficiency is not impaired or airway obstruction is not there in pregnancy. Authors that acclaim a decrease gave no reason for the same though

MBC is expected to decrease due to mechanical alteration (14). MVV usually reduces in obstructive conditions. In present study the decrease observed, suggests presence of obstructive element. Great effort is required to perform MBC. The smooth muscles are relaxed due to progesterone and relaxin. They may hamper maximum contraction and relaxation of muscles required for performance of MBC in spite of great effort input by subjects causing fall in MVV. MVV is reduced, out of proportion to decrease in VC in obstructive condition (22). As in present study reduction in MVV is parallel to and roughly in the same proportion as VC, this also adds to our inference that decreased MVV during pregnancy is of restrictive type. MBC measurement requires free movement of abdominal muscles and diaphragm as well as good motivation. Growing fetus and agitation may impose restriction during third trimester causing maximum fall in MVV. Above factors lead to infer that decreased MVV shows presence of obstructive as well restrictive elements.

Tertiary factors causing decrease might be morning sickness, alkalosis on account of hyperventilation, lack of motivation and resistance of the pregnant state to exertion.

Respiratory reserve

Respiratory reserve (RR) in lt./min was calculated as a difference of MVV and RMV (41) (table & graph 9).

Mean values – 78.17 (controls), 66.21 (first trimester), 55.01 (second trimester) and 33.50 (third trimester) show continuous fall in RR during pregnancy as well when compared with control subjects. Average RR during pregnancy was 51.57. It maximally falls by 57.14% (44.67 lt./min) in third trimester as compared to nonpregnant subjects. Least fall of 16.91% (11.20 lt./min) was noted between early to mid pregnancy with rise of 39.11% (21.51 lt./min) from mid to late pregnancy.

Significant decrease in MVV and significant increase in RMV throughout pregnancy and hence the difference of these variables would obviously lead to significant decrease in RR that has been attained in present study (Graph 29).

RR does lack mention in literature. Therefore conclusion put forth require comparative results to be endorsed.

Breathing reserve ratio

Breathing reserve ratio is the percentage RR to MVV (BRR = RR / MVV x 100). BRR is directly proportional to RR and inversely to MVV. BRR is one of the most important index in the diagnosis of dyspnea during pregnancy. If its value falls below 60% – 70% dyspnea is generally present. Breathing reserve less than 90% has been reported, sometimes less than value of control subjects (6).

The BRR was found to decrease during pregnancy (table & graph 10). The decrease within the three trimesters and as compared to controls was highly significant. The maximum decline by 21.65% was seen from nonpregnant (90.52) to late pregnant (70.92) states while during pregnancy maximum decline by 13.49% was seen from second trimester (81.98) to third trimester. Decrease from first trimester (88.34) to second trimester was by 7.20%. Average BRR was 80.41% during pregnancy and that is less by 11.16% than control sample.

Though there is a decrease in BRR but the values in experimental groups are seen to be within the normal range showing that dyspnea does not occur in true sense during pregnancy and gets support from only two studies author has come across (6,25). The discomfort experienced during mid and late pregnancy can be termed as mild dyspnea. Dyspnea during pregnancy is in some way related to the individual's adaptation to the inevitable hyperventilation that accompanies the gravid state (61)

There is decrease in RR and a proportionate decrease in MVV in experimental groups; hence BRR though declines, falls in normal range justifying pregnancy as an adaptive change (graph 29).

Data for comparing the present finding of BRR and RR are unavailable.

FLOW RATES

Flow rates specify obstruction or closure of the small and large airway function. Expiratory flow rates as $FEV_{.75}$%, FEV_1%, $FEF_{0.2-1.2}$% (MEFR) and FEF_{25-75}% (MMEFR) were deduced from FEVC curve while inspiratory flow rates as $FIV_{.75}$%, FIV_1%, $FIF_{0.2-1.2}$% (MIFR) and FIF_{25-75}% (MMIFR) were deduced from FIVC curve. Collating inspiratory and expiratory flow rates helps to differentiate between obstructive and restrictive conditions.

Large airway functions

FEVC, FIVC, $FEV_{.75}$%, FEV_1%, $FIV_{.75}$% and FIV_1% are the large airway functions detect obstruction in upper respiratory tract.

Forced expiratory vital capacity

Forced expiratory vital capacity (FEVC) is simple rapidly performed reproducible quantitative stratagem involving only the expiratory phase of ventilation. The usual method of getting FEVC tracing is to instruct the subject to take in the deepest breath and then breath out into spirometer as fast and forcefully that is maximum inspiration followed by recording maximum rapid expiration. The terminal portion of FEVC is predictably the most sensitive indicator of diffused obstructive bronchpulmonary disease. Factors as neuromuscular coordination and maintenance of the effort that are nonbronchopulmonary factors predominate this phase. The initial phase requires neuromuscular factors apart from mechanical equipment factors as inertial distortion. Since above factor influence the initial and terminal phase of FEVC therefore maximum mid expiratory flow rate (MMEFR) is most reliable indicator of diffused obstructive bronchpulmonary disease.

FEVC (ml) showed fluctuations during gravidity (table & graph 11). There is less significant rise of 270.2 ml (14.8%) in early pregnancy, a significant fall of 375.87 ml (18.44%) in mid pregnancy and insignificant rise of 100.3 ml (5.87%) during late pregnancy as calculated from the mean values – 1822.09 (controls), 2092 (first trimester), 1706.42 (second trimester) and 1806.75 (third trimester). Insignificant drop between control vs second and third trimester and a rise from second to third trimester was

Comparison of expiratory flow rates given by various authors						
Authors	N P S	P S	E P	M P	L P	Remark
FEVC						
Milne (62) (lt.)			3.61	3.67	3.75	↑
Knuttgen (54)						↔
Das (29) (lt.)			3.90	3.89	4.00	↑
Puranik (68) (lt.)	2.2		2.19	2.15	2.16	
Collete (21)						↓
Present study (ml)	1822	1868	2092	1706	1807	2.55% ↑
FEV_1%						
Rubin (75) (%)	80.3	73.1				↓
Krunholtz (55) (%)			85		84	↓
Knuttgen (54) (%)	89.3	86.5				↓
Butler (14) (lt.)	3.3	3.2				↓
Cugell (25) (%)	84				82	↓
Alaily (1) (%)	83.6	82.3				
Puranik (68) (%)	2.2		2	2.07	2.10	↔
Bernard (6)						↔
Baldwin (3)						↔
Milne (62) (lt)			3.1	3.05	3.1	↔
Das (29)			3.34	3.33	3.41	↔
Cameron (15)						↔
Hytten (52)						↔
Present study (%)	90.30	76.63	78.25	77.50	74.15	15% ↓

observed. Average FEVC was 1868.48 showing an increase of 46.39 ml or 2.55% from nonpregnant state.

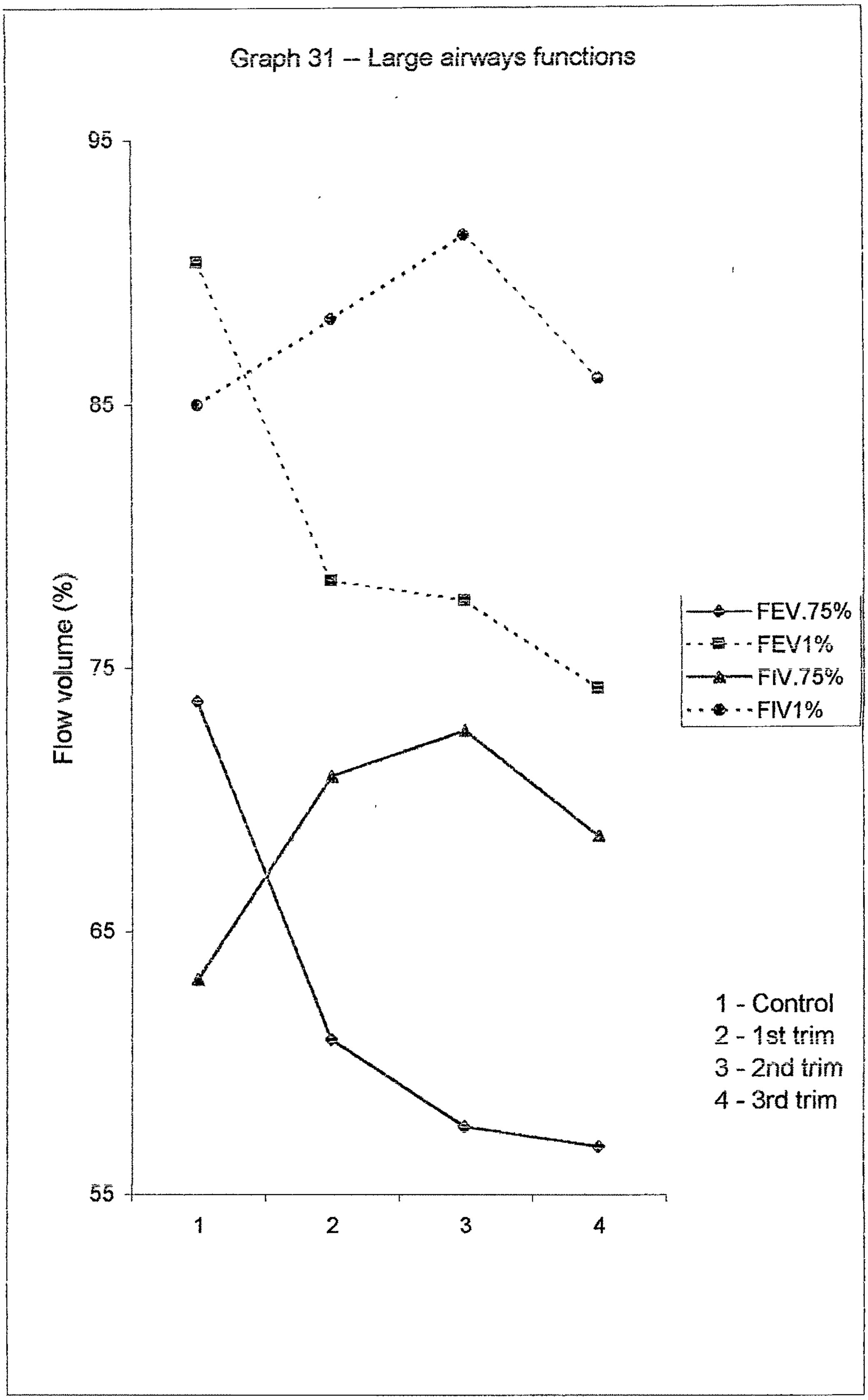
Reports published on FEVC (FVC) are so small in number that present results cannot be testified. Slight increase during progestational (70) or luteal (69) phase, increase in FEVC (62), no change (33,54) and decrease (68, 63) at term and or during pregnancy has been documented. The fluctuations in the FEVC during pregnancy as seen in present study are in accordance with a very few studies (29,62,68) where a fall from early to mid pregnancy and then a rise from mid to late pregnancy is ascertained. Fall in mid pregnancy is due to restrictive effect of enlarging uterus. This effect wanes at term due to attunement, proving gestation being an accommodative change as means at term and that of controls are almost same, indicting performance also being same. Expiratory effort by first trimester subjects is more during pregnancy.

FEVC ($\bar{X}$=1868.48) is found to be lower than VC ($\bar{X}$=2178.33) during pregnancy (graph 30). Though the strategy for performing VC and FEVC is same except that VC is measured directly from spirometer and FEVC is calculated from spirogram. The lowered value in all groups could be attributed to the inertia of lever (resistance of the writing device). End inspiration before recording FEVC may not be maximal. Moreover FEVC was done by inspiring air from spirometer instead of atmosphere as was instructed for performing VC.

Timed expiratory vital capacity

The measurement of $FEV_{.75}\%$ and $FEV_1\%$ is essential to access ventilatory capacity of the pulmons (24) or to access the ability of bellows to ventilate. $(FEV_{0.75}/FVC)*100$ and $(FEV_1/FVC)*100$ expressed as $FEV_{0.75}\%$ and $FEV_1\%$ help in interpreting pulmonary functions. $FEV_{.75}\%$ and $FEV_1\%$ is more sensitive as they are less reliant on the nascent period of the expiration that is influenced by subject's cooperation.

The normal values' of $FEV_{0.75}\%$ with advancing age is not much affected as velocity of air breathed out is optimal in initial phase of expiration but the normal values are much below $FEV_1\%$. This ratio is slightly affected in obstructive and restrictive conditions. $FEV_1\%$ decreases with advancing age (20 to 60 years) from > 80% to >70%. In obstructive airway the ratio FEV_1/FVC is reduced while in restrictive condition it is normal even though both variables individually are reduced.


Graph 31 -- Large airways functions
95
85
75
65
55
Flow volume (%)
1
2
3
4
FEV.75%
FEV1%
FIV.75%
FIV1%
1 - Control
2 - 1st trim
3 - 2nd trim
4 - 3rd trim

Forced expiratory volume in 0.75 second

Mean values (table & graph 12) for control and experimental groups are 73.68, 60.84, 57.54 and 56.79% respectively showing a decline from nonpregnant state to gestational stage as well during pregnancy but falls within normal range (graph 31). Highly significant decrease in $FEV_{0.75}\%$ was revealed during first trimester (17.43%), second trimester (21.91%) and third trimester (21.92%) as compared to controls. The insignificant decrease of 6.65% in $FEV_{0.75}\%$ from early to late pregnancy was observed.

Studies on TVC do not furnish information on $FEV_{0.75}\%$.

Forced expiratory volume in 1 second

Changes in $FEV_1\%$ (graph 31) are analogous to those of $FEV_{0.75}\%$. Mean values (table & graph 13) observed for all four groups were 90.33, 78.25, 77.5 and 74.15% denoting that nonpregnant subjects could exhale almost 90% air in 1 second while pregnant subjects exhales less amount, about 78% – 74% with advancing pregnancy. The decrease of $FEV_1\%$ in experimental group is highly significant as compared to control but inconsiderable within the three trimesters.

A number of studies as reviewed show decrease in $FEV_1\%$ from nonpregnant to pregnant state (1,25,54,63,68,78) or decrease in progestational (70) or luteal (69) phase of menstrual cycle owing to increase in progesterone that subsist results of present study. No change (19,29,33,62) or an increase (68) during pregnancy finds a place in literature. In present study $FEV_{0.75}\%$ ($\overline{X}_1=58.3$) and $FEV_1\%$ ($\overline{X}_2=76.6$) though declines in pregnancy in all the three groups, remains within the normal range as compared to controls ($\overline{X}_1=73.6$ & $\overline{X}_2=90.3$). This was because FEV_1, FEVC and VC decrease in experimental group proving that pregnancy is a restrictive condition and not obstructive. The decrease in values of these three parameters also suggests that dysfunction of expiratory muscle is not there though weakness may be there and mechanical properties of respiratory system are normal that are due to altered configuration affecting elastic recoil of chest and intrathoracic diameter (80).

Rates of gas flow both average and maximum during inspiration or expiration are little altered in pregnancy. Pressure required to achieve flow rates is inadequate in pregnancy than nonpregnant state. Airway resistance decreases and cross sectional area of airway is augmented due to relaxation of smooth muscles in airways by relaxin

(52). Progesterone is known to increase ß adrenergic activity that causes bronchodilatation (73).

Forced inspiratory vital capacity

The equivalent of the FEVC termed as forced inspiratory vital capacity (FIVC) during inspiration was determined. FIVC requires a rapid maximum effort after a full expiration.

Changes in FIVC (table & graph 14) follow the same pattern as that of FEVC. FIVC (ml) is maximum in subjects of first trimester (1423.98) as compared to control group (1311.40), second trimester (1059.46) and third trimester (1275.68). Drop in FIVC from first to second (25.59%) and rise from second to third (20.40%) trimester was highly significant. The fall from first to third trimester (10.41%) is less significant. The average FIVC during pregnancy is 1253.04, an overall decrease of 58 ml.

Restrictive effect gives fall in FIVC during mid pregnancy and adaptation brings it back to almost equivalent to control value at term. FIVC is less than FEVC (graph 30) during pregnancy suggesting the degree of restriction being more for inspiratory maneuver. Inspiring humid and warm air from spirometer may not be pleasant to the subject. Lifting of load counterbalancing the bell against gravity and the writing device recording upwardly for inspirogram against gravity might be contributing to mild degree in lowering the values.

Searching through the literature the author of present study had not stumbled upon any paper describing FIVC during pregnancy. Insignificant rise during luteal phase has mention in literature with no rationale (69). Hence the decrease or increase could not be explained on basis of other studies.

Timed inspiratory vital capacity (TIVC)

The measurement of $FIV_{.75}\%$ and $FIV_1\%$ is essential to access not only ventilatory capacity of the lungs but also the influence of restriction brought about by altered body configuration on the ability of bellows to ventilate. $(FIV_{0.75}/FIVC)*100$ and $(FIV_1/FIVC)*100$ expressed as $FIV_{0.75}\%$ and $FIV_1\%$ help in interpreting pulmonary functions. The normal values of $FIV_{0.75}\%$ with advancing age may not be much affected as velocity of air breathed out is optimal in initial phase of inspiration but the normal values are much below $FIV_1\%$. This ratio is slightly affected in restrictive conditions. $FIV_1\%$ decreases with advancing age probably due to decreasing stamina.

Forced inspiratory volume in 0.75 second

On glancing at mean values of $FIV_{.75}\%$ (66.13% – controls; 70.84% – first trimester; 72.57% – second trimester and 68.56% – third trimester) rise from early pregnancy to mid pregnancy by 2.43% than a fall to late pregnancy by 5.50% expresses minor changes throughout the pregnancy. $FIV_{.75}\%$ was more in pregnant as compared to nonpregnant subjects (table & graph 15). $FIV_{.75}\%$ ($\overline{X}$=70.65) was observed to be more than $FEV_{.75}\%$ (58.39) as is depicted in graph 31.

Forced inspiratory volume in 1.00 second

$FIV_1\%$ (table & graph 16) insignificantly rises by 3.8% during early pregnancy (88.17) and by 1.12% in late pregnancy (85.90) while less significant rise of 7.53% in mid pregnancy (91.34) when compared with control (84.94). During pregnancy least significant difference of 5.95% from second to third trimester was noted (graph 31). Overall change of 3.53% is computed between pregnant and nonpregnant subjects that equals to increase by 4.15%.

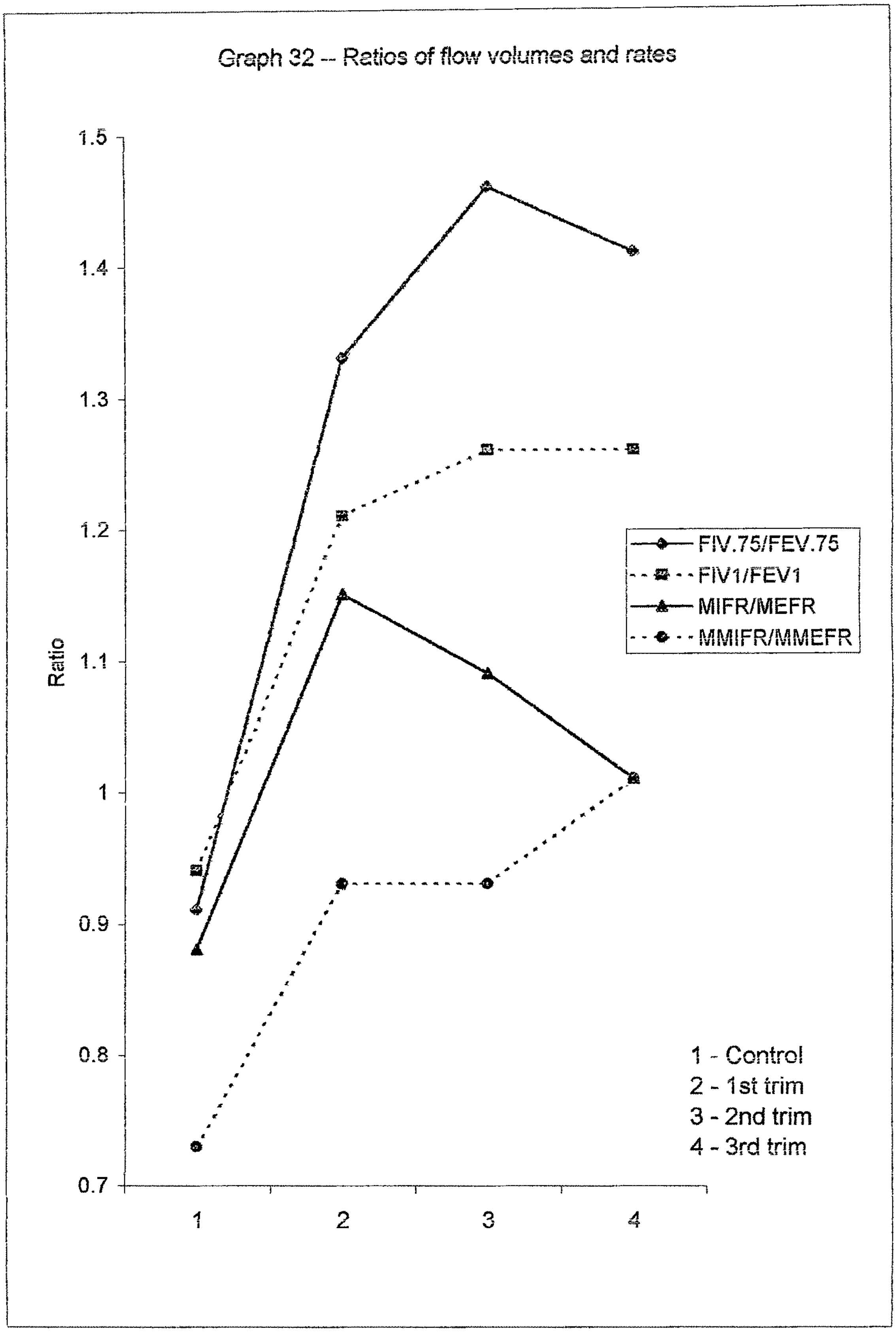
TIVC values are more than TEVC values. TIVC shows an average rise in pregnant state when compared with controls (66.1 and 84.9). This is because cross sectional area is augmented as airway resistance decreases by progesterone and relaxin causing free inflow of more air with effort. Moreover more amount of air is inspired in initial phase of inspiration and end inspiratory volume is affected by restrictive element.

Ratios of inspiratory to expiratory timed vital capacity

Ratio of $FIV_{0.75}\%$ / $FEV_{0.75}\%$ (table and graph 17) shows less significant increase during early pregnancy (45.22%) but highly significant during mid pregnancy (59.72%) and late pregnancy (54.53%) when related with controls (0.91). There is insignificant rise and fall of ratios from early to mid and mid to late pregnancy respectively (graph 32).

Parallel were the changes in ratio of $FIV_1\%$ / $FEV_1\%$ (table and graph 18). The ratio significant increase in all three trimester by 27.71%, 33.53% and 33.23% as compared to controls (0.94). On analyzing within three trimester there was insignificant rise from early to mid (4.55%) and rise from early to late (4.31%) while fall from mid to late (0.22%) pregnancy in the ratios.

Rise is seen in these ratios from nonpregnant to pregnant state. Rise and fall is seen during gestation from early to mid and mid to late period respectively (graph 32).


Graph 32 -- Ratios of flow volumes and rates
Ratio
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
1
2
3
4
FIV.75/FEV.75
FIV1/FEV1
MIFR/MEFR
MMIFR/MMEFR
1 - Control
2 - 1st trim
3 - 2nd trim
4 - 3rd trim

Large airways significant decline from control to first trimester is perhaps because of sudden rise of placental and other hormones to which the body is incapable to adjust contiguously. It can be on account of cytotrophoblastic cells and syncytial trophoblasts that are reported to traverse through the uterine sinuses and reach the alveoli of maternal lungs and can rationalize sudden attack of dyspnea and respiratory embarrassment in pregnant women (36,64). Nausea, vomiting, morning sickness and other psychological changes may be responsible for fall in TEVC percentage. As conception advances both remain steady along with gradual decrease in VC means that there is restrictive ventilation without much obstructive element.

Small airway functions

MEFR ($FEF_{.2-1.2}$lt./min) and MIFR ($FIF_{.2-1.2}$lt./min) were calculated by measuring the time taken to expire or inspire a given volume one liter after discarding initial 200 ml from maximal expiration or inspiration. MMEFR (FEF_{25-75}%) and MMIFR (FIF_{25-75}%) are mid portion i.e. 25% to 75% of the FEVC and FIVC respectively. MMEFR is reliable indicator of diffused obstructive bronchopulmonary disorders. FIF_{25-75}% is normally at least equal to and usually greater than FEF_{25-75}%. Since inspiratory flow is more conditional on effort than is expiratory flow, a fall in

$FIF_{25-75}\%$ is usually more sensitive to respiratory muscle dysfunction or a suboptimal effort than is $FEF_{25-75}\%$. The strength of respiratory muscles decreases as long as the relaxing effect of progesterone on muscles persist and discomfort experienced in late pregnancy affects $FIF_{25-75}\%$. When airway resistance is high a disproportionate fall in $FIF_{25-75}\%$ relative to $FEF_{25-75}\%$ suggests an extrathoracic site of airway obstruction. Graph 33 gives a clear picture of relation of flow rates.

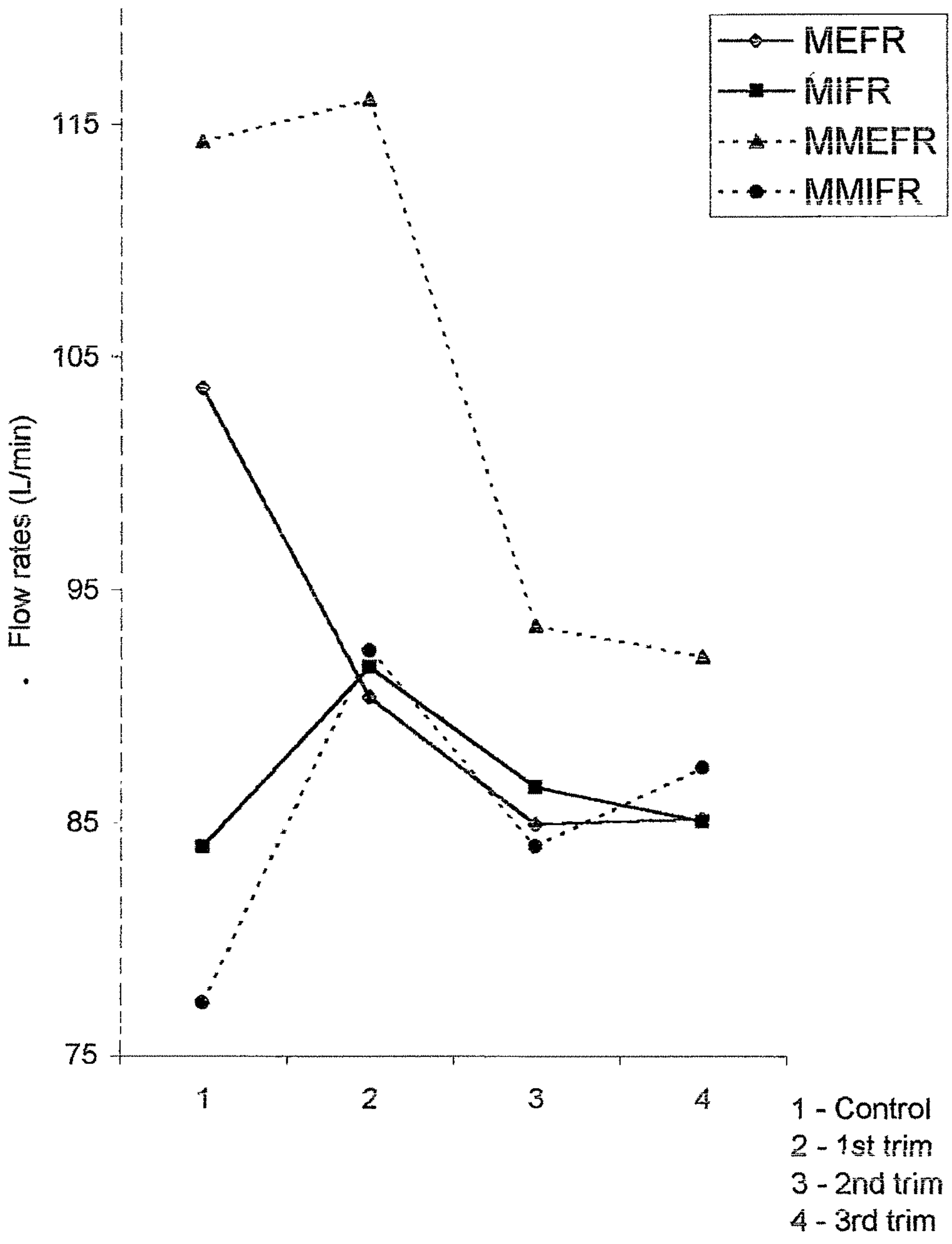
Maximum expiratory flow rate

MEFR shows (table & graph 19) a decrease in pregnant subjects (mean values – 90.35, 84.87 and 85.1 in three trimesters) when identified with nonpregnant group (103.60). A decrease by 12.78% in early pregnancy with further decrease of 6.06% in mid pregnancy and a very slight increase of 0.27% in late pregnancy was viewed. These fluctuations were statistically inconsiderable. Average MEFR in pregnancy was found to be 86.77 with 16.24% decline.

Maximum inspiratory flow rate

Mean values 83.91, 91.65, 86.48 and 85.01 of MIFR in control and experimental group (table and graph 20) show rise from control to first trimester and thereafter all the

Graph 33 -- Small airway flow rates



while decreases till term indicating it to be higher in pregnancy than nonpregnant state. The fall in the range of 1.7% – 7.2% seen during pregnancy and a rise from nonpregnant state in the range of 1.3% – 9.2% are found to be statistically nonsignificant. MIFR on an average is more by 4.53% (3.80 lt./min) in pregnancy.

Trifling changes in MEFR and MIFR in pregnancy and nonpregnant subjects has been narrated in few studies (3,29,30,55,75). Parallel were the results of MEFR and MIFR in present study. MEFR and MIFR also are corresponding with FEVC and FIVC. Former decrease while latter increase from control to first trimester but during pregnancy there is insignificant decline in both.

MEFR being greater MIFR in controls could be due to the fact that controls can perform forceful expiration effortlessly, as there is no intrathoracic and extrathoracic restriction (graph 33). MEFR values in second and third trimesters are lower than MIFR. This is by virtue of progesterone increase during pregnancy rationalizing bronchodilatory effect that does not facilitate expiration. MIFR values are higher in second and third trimester as restriction brought about by decrease in intrathoracic volume, is of mild to moderate degree from early to mid pregnancy along with bronchodilatory effect that favors inspiration. Decrease in MEFR during pregnancy could be due to lesser force of contraction of main expiratory muscles like anterior abdominal muscles and internal intercostal muscles (42). Reduction in MEFR indicates mechanical problems existing during expiration and inspiration (22,89)

Ratio of MIFR/MEFR

Ratio of MIFR/MEFR (graph 32) is more by 23.1% during pregnancy as compared to controls. Ratio is seen to decrease in control subjects (0.88), as MEFR is greater than MIFR. This rise in ratio in pregnant vs. nonpregnant state is less significant as depicted by P value (table 21). The fall from early to late stage of pregnancy by 5.87% is insignificant. Ratio shows increase in early (1.15), decline in mid (1.09) with no change in late (1.01) pregnancy (graph 21). This is obvious from MIFR being higher than MEFR in early and mid pregnancy while both values are same in late pregnancy giving a ratio of one. In third trimester, increased severity of restriction brought by growing gravida and enlarged breast on inspiratory effort while the stretched abdominal muscles prevent expiratory effort for obtaining optimum flow rates, consequently values of MEFR and MIFR are more or less same.

Ratios of MIFR/MEFR do not hold any reference in studies, as MIFR during pregnancy has not been recorded so far.

The expiratory efforts are poor than inspiratory efforts in pregnant subjects due to mechanical restrictions. Moreover expiratory volumes are less (as compared to inspiratory volumes) in restrictive conditions in pregnancy whereas no such restrictions exists in controls.

Maximum mid expiratory flow rate

It is noted that the first 25% of FVC maneuver is totally effort dependent while terminal phase involves neuromuscular factors. Therefore MMEFR and MMIFR are believed to be more important and more sensitive tests as they are relatively effort independent (13,85).

Nonpregnant and pregnant subjects of all trimesters provided MMEFR (lt./min) mean as 114.21, 116.00, 93.37 and 92.13 respectively displaying minor rise from nonpregnant to early pregnancy while least significant fall throughout pregnancy (table and graph 22). Highly significant fall at term was observed on comparing it with early pregnancy (graph 33). Average MMEFR during pregnancy was computed to be 100.5 with increase of 13.7

(12%). $FEF_{25-75}\%$ is reported to reduce in restrictive condition (47).

Maximum mid inspiratory flow rate

MMIFR (lt./min) shows (table and graph 23) overall rise of 13.78% from nonpregnant to pregnant state and wavers during pregnancy. MMIFR during three trimesters (92.35, 83.95 and 87.33) is more than control group (77.23). The rise from nonpregnant to pregnant state is consequential while the fall and rise within three trimesters is insignificant. The changes are identical to those of MEFR and MIFR (graph 33)

Ratio of MMIFR/MMEFR

There is average increase of 31.05% in ratio MMIFR/MMEFR (table & graph 24) from nonpregnant to pregnant state. Mean values are 0.73 (control), 0.93 (first trimester), 0.91 (second trimester) and 1.01 (third trimester). The ratio in early and mid pregnancy is almost same whereas a negligible rise from mid to late pregnancy is seen. Insignificant change in ratio is seen within three trimesters (graph 32). The pattern of change seen in ratio is same as that of MIFR/MEFR. The logic is same as conferred for MEFR and MIFR.

There are no studies to support or dissentiate the present finding of MEFR and MMEFR as well as of forced inspiratory flow rates. MMEFR has been reported to increase during progestational phase of menstrual cycle (69,70).

The ratio is said to be high in obstructive and normal in restrictive conditions. All the flow rates ratios show inconsiderable fluctuations during pregnancy. Ratio is more in early pregnancy suggesting obstructive pattern. Later from early to mid pregnancy falling ratio and from mid to late pregnancy rising or steady ratio gives a picture of restrictive pattern.

In present study there is a decrease in expiratory and inspiratory flow rates during pregnancy. The expiratory flow rates show continuous decline from early to late pregnancy while the inspiratory flow rates show slight rise in mid pregnancy. Ratios of inspiratory to expiratory flow rates show trivial fluctuations (increase or decrease) in early pregnancy while they are almost same in mid and late pregnancy. All the parameters of flow rates and their ratios show a decrease at term (graph 32).

Psychological factors related to body discomfort due to increased body weight and mild dyspnea slacken performance for flow rates. The restriction brought about by enlarged breast and growing gravid and the fear of complications arising at term due to abdominal pressure required to forcefully inspire and expire for executing flow rates could render lowered values during pregnancy.

In present study the inspiratory to expiratory flow rates decline from first to third trimester within the normal range proving that pregnancy is a restrictive condition. But all the flow rate parameters do not follow the pattern of restrictive condition from nonpregnant state to early pregnancy suggesting the selective adaptive changes.

From this it can be inferred that during pregnancy there is development of both obstructive and restrictive element but by and large results of most of the respiratory parameters indicate pregnancy as a restrictive condition, obscuring obstructive element that is revealed by the results of few parameters. Obstructive condition developed in early pregnancy is superimposed by restrictive condition thereafter, throughout gestational period as adaptive change to cope up with pregnancy. The respiratory response to pregnancy appears to be largely mediated by the action of progesterone and perhaps to a lesser extent, estrogen, at least in the first and second trimester. The mechanical effects of gravid uterus cause relatively adaptive changes in pulmonary mechanics (61).

RESPIRATORY EFFICIENCY TESTS

Breath holding test

Basis of breath holding test (BHT) lies in the fact that the time taken for the breath to be held is inversely related to ventilatory sensitivity to hypoxia and hypercapnia. However, BHT is not only affected by chemosensitivity but also by reflexes originating in the vagus and in the muscles.

Breath holding is voluntary apnea that persists until ventilatory drive exceeds the cortical inhibition, a subject will or can exert. The length of time that the breath can be held is contingent upon pCO_2, pO_2, pH, lung volume, level of physical activity, prior hyperventilation, level of CO_2 acclimatization (tolerance), motivation and self discipline. This test throws some light on the regulation of pulmonary ventilation. Every one who holds his breath experiences a desire to breathe. This sensation of air hunger, having both intensity and quality, is the cortical appreciation of several factors including the brain stem excitation that results from chemical factor input. During breath holding molecules of oxygen move from lung to blood at a relatively constant rate that is a function of cardiac out put. Lung volume decreases, passively increasing the fractional concentration of remaining lung gases (N_2 and O_2). Thus alveolar pCO_2 would increase even if no CO_2 were to enter the lungs from the blood.

Average breath holding time during pregnancy was calculated as 20.14 sec (mean values in experimental group 22.43 sec, 21.15 sec and 16.85 sec) that is significantly lower than nonpregnant state by 15.08 sec or 42.82% (table and graph 25). A significant fall from control to early pregnancy (36.33%) could be due to morning sickness and from mid pregnancy to late pregnancy (20.33%) could be due to maximum oxygen consumption. Insignificant fall from first to second trimesters could be due to adaptation to pregnant state.

Increase pCO_2, decrease pO_2 and decrease pH concentration during pregnancy shorten breath holding time to bring the compensatory mechanism that normally operate to regulate respiration to wash off these effects. This may be one cause for increase respiratory frequency and hence increase RMV during pregnancy.

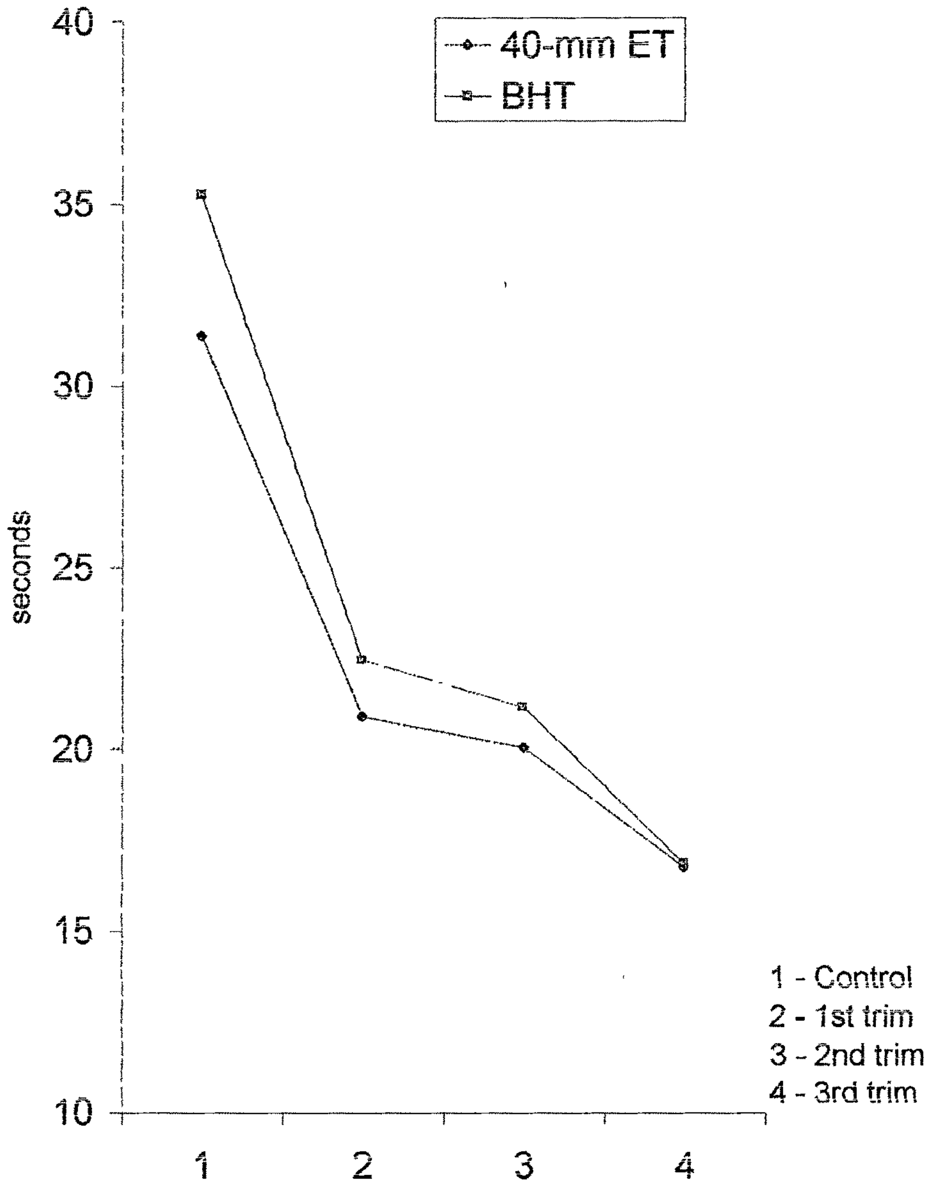
Breath holding time depends on the status of lung volumes and vulnerability of respiratory centers. Most of the lung volumes in present study decrease, hence BHT as expected is also found to be reduced. Not only this but alveolar pCO_2 would also increase to initiate reflexes and stimulation of respiratory centers as they become more sensitive to CO_2 by direct action of progesterone. Logically all this would compel the subject to breathe out earliest possible, as oxygen consumption increase as is shown to occur during pregnancy.

40 mm Hg endurance test

40 mm Hg endurance test, hereafter termed as ET in the text signifies endurance of respiratory centers to CO_2 and strength of respiratory muscles. For ET the time taken to raise and keep the mercury level raised at 40 mm Hg in manometer is noted. Initially the person has to raise the mercury level with forceful expiration without inhaling throughout the maneuver and maintain it holding breathe with sustained expiratory effort at 40 mm Hg with help of main expiratory and accessory expiratory muscles of neck, face and chest. Thus this test measures the integrity of central respiratory centers and coordination of all expiratory muscles along with cortical component of voluntary effort.

The time taken (table and graph 26) to keep the mercury level elevated was seemingly less in pregnant subjects ($\overline{X}$=19.22 sec) as compared to nonpregnant

Graph 34 -- Breath holding time (sec) during 40-mm Hg endurance test and breath holding test.



subjects ($\overline{X}$=31.33 sec) by 12.11 sec (38.65%). During pregnancy the decrease was insignificant from first ($\overline{X}$=20.88) to second trimester by 4.07% and less significant from second ($\overline{X}$=20.03sec) to third ($\overline{X}$=16.75 sec) trimester by 16.35%. Highly significant difference was seen between control and experimental groups (decrease of 33.35%). Nausea, vomiting, morning sickness, altered food habits, decrease intake of food and discomfort due to stated reasons may be endowing great decrease in time in contrast to controls. A significant decrease in second trimester (36.07%) and third trimester (46.52%) as compared to controls is perhaps because of mechanical alterations, muscular weakness and anxiety as stated earlier.

The time taken to keep mercury level raised at 40-mm level was much less than breath holding time in all the four groups (graph 34), this indicates that time taken to hold the breath with efforts as in ET is much less than holding breath without efforts as in BHT. It can be said that metabolism and oxygen consumption increases as all the expiratory muscles are active for sustained maintenance of mercury level at 40-mm. This shows that respiratory centers are stimulated earlier in ET coercing person to breathe earlier than in BHT.

Maximum Expiratory Effort Test:

Expiratory pressure test (MET) and inspiratory pressure test assess strength of expiratory, inspiratory and accessory respiratory muscles. A normal subject can develop 60 – 100 mm Hg positive or negative pressures depending on some extent on lung volume and degree of effort. The test has been used but little clinically largely because high pressure is also developed within the middle ear and this causes discomfort. Decrease in these forces point to muscular weakness. This is also one of the critical factor causing decrease in MVV.

Though the normal person can raise the mercury level from 60 – 100 mm Hg, but the pregnant subjects of three trimesters in present study could raise mercury level from 56.18 – 67.70 mm Hg only and this lowered level was found to be highly significant when compared with control (83.20 mm Hg) subjects (table 27).

On an average there is decrease of 22 mm Hg (26.52%) as compared to the control subjects. Graph 27 depicts a significant fall from control to first trimester by 18.62%, a further decline from first to second trimester by 17.02% (total decline of 32.48% from controls) and insignificant rise of 5.96% from second to third trimester (total decline of 29.80% from controls).

The significant fall in MET in early to mid pregnancy could be attributed to morning sickness, muscular weakness and action of progesterone and relaxin on reducing muscular tone.

Lack of studies on respiratory efficiency tests during pregnancy in literature could not accord or dissentiate the given interpretation.

Thus though pregnant women has apparent handicaps causing restrictive changes in respiratory apparatus the anatomical, physiological and hormonal changes compensate for them causing no discomfort.

CARDIOCIRCULATORY PARAMETERS

Only few related parameters were incorporated in the study as they accredit the rationalization of pulmonary parameters. Their values are tabulated but as quantitatively, dispensable in present study are not discussed in detail. The relevant importance with respiration has been put forth.

Hemoglobin

A significant decrease in hemoglobin (Hb) is observed in pregnancy ($\overline{X}$=11.6), a decrease of 9.3% or 1.2 gm% from control group (mean=12.8). Mean values for all the four groups exhibited in table 28 & graph 28 reveal maximum fall by 15.03% in third trimester corresponding to controls. Of the sample of forty subjects in each group twelve in control group, five in first, three in second and one in third trimester had 14 *dl* Hb. Minimum Hb estimated was 8.5 in second and 9 gm % in third trimester subjects that is less than accepted norms. Mean values of Hb for three trimester are 12.2, 11.7 and 10.9.

Analogous was the fall in Hb level during pregnancy given as 11.7 at term compared to 12.8 pre term (54) and 12.1 post term and 13.2 pre term (55), denoting increase in circulating plasma volume by 10% (87). The decrease in Hb indirectly increases RMV along with mild dyspnea on account of low oxygen carrying capacity.

Heart rate

Heart rate (HR) tabulated (table 29) as pulse rate gives mean values of the control and experimental sample. Statistically significant increase in heart rate (HR) from nonpregnant (87.4) to pregnant (95.6) states is 9.4%, a difference of 8.2. Gradual increase during gestation was recorded. Highest mean was obtained in third trimester, an increase by 12.21% when collated with controls (graph 28). Mean values of HR are 92.9, 95.9 and 98 in three trimester respectively.

This is affirmed by studies that report increase in HR throughout pregnancy (47) with peak values at term rising by 17% (23) and by 18% (87). Mean as 80 beats in second trimester and 90 beats in third trimester (87) while 80 in control subjects, 93 in first trimester and 94 in third trimester (20) are reported.

Blood pressure (BP)

BP, systolic and diastolic varies in pregnancy and has close relation with HR but compensatory mechanisms defend the increase or decrease in normal individuals.

Mean values (rounded off) for SBP / DBP obtained were 103/68, 106/70, 110/67 and 114/72 in control subjects, first trimester, second trimester and third trimester subjects respectively. This gives a rise by 6.63 mm Hg / 1.9 mm Hg that is 6.3% / 2.8%. SBP and DBP remain (graph 28) within normal limits though significant rise is recorded for systolic (table 30) and significant fluctuations in three trimesters are noted for DBP (table 31). Similar finding has been reported (87). Significant difference between the systolic pressure in the pre and post menstrual phase, being higher in the premenstrual phase explained on basis of increased fluid and salt retention induced by ovarian steroids and a higher sympathetic activity (60). Diastolic pressure on the other hand and pulse rate do not differ significantly (60). No change in BP has been reported (54). Decrease in mean arterial BP, as 91 in control subjects, 83 in first trimester and 81 in second trimester have also been stated (20).

From control to first trimester a less significant rise in SBP and insignificant rise in DBP shows that pregnant status does not affect the BP though HR significantly increases. There was significant rise of BP and less significant rise in HR from early to mid pregnancy. Second trimester to third trimester rise in SBP was less significant while highly significant rise in DBP along with insignificant rise in HR was observed.

Correlating fluctuations in these parameters minor changes in BP led to considerable rise in HR and vice-a-versa findings were recorded. This may be brought about by irradiation of impulses from respiratory centers to cardiac centers or by feedback mechanisms through reflexes.

Significant Hb fall and SBP rise while less significant changes in DBP corresponding to control subjects were noticed. The decrease in Hb could be due to hemodilution as the progesterone and estrogen causes water retention. This might be leading to increase in BP where SBP is more affected by DBP. All the changes in Hb and HR in relation to BP are within the normal range. Hemodilution causes insignificant rise almost no change in HR and mean arterial pressure due to increased activity of right atrial type–B receptors (9) and causes alteration in smooth muscle tone (48). Hence it's predominately the role of hormones that lead to changes in HR and BP and not the ß adrenergic receptors or hemodilution that play insignificant role.

Cordial relationship of respiration with HR, BP, Hb and blood volume characterizes the overall stamina that is healthy state of pregnant woman. With successive growth of fetus the demand for its sustenance also increases. To accomplish this, load over heart and lungs increases optimally. Integration and the feedback of cardio-circulatory parameter play an important part in regulation of respiration as reflected in the changes brought about in pulmonary function tests during pregnancy. This also depicts the integrity of pulmonary, cardiac and endocrine system during pregnancy exemplifying pregnancy as a selective adaptation.

Physiological changes observed in various cardiopulmonary parameters may prove to be a reasonable screening techniques for unexpected abortion and other complications of pregnancy.

As these parameters were not reviewed extensively, the changes exhibited in cardiopulmonary parameters are explained in brief, to the best of author's knowledge.