OVARIAN VENOUS BLOOD PO_2 , PCO_2 AND pH IN WOMEN

I. S. FRASER, D. T. BAIRD AND F. COCKBURN

*Departments of Obstetrics and Gynaecology and Child Life and Health,
University of Edinburgh, Edinburgh*

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Summary. Measurements of PO_2 , PCO_2 and pH have been carried out in human ovarian venous, peripheral venous and arterial blood, and in ovarian follicular fluid. The PO_2 in ovarian venous blood is higher than in peripheral venous blood. Mean oxygen consumption by the human ovary has been calculated to be 1.4 ml oxygen/100 g ovarian tissue/min. Taken in conjunction with a mean ovarian blood flow of 20.3 ml/min, these findings are compatible with the presence of arterio-venous shunts within the human ovary. Oxygen tension in follicular fluid may be substantially lower than oxygen tension in peripheral and ovarian venous blood.

INTRODUCTION

It has frequently been noticed that ovarian venous blood is brighter red than peripheral venous blood, suggesting that the oxygen saturation of the haemoglobin in ovarian venous effluent is higher than in peripheral venous blood. This appears to occur in spite of the high metabolic activity of ovarian cells *in vitro* (Ahren, Hamberger & Rubenstein, 1969) and may indicate the presence of arterio-venous shunts within the ovary (Mattner & Thorburn, 1969).

In this study, the PO_2 , PCO_2 and pH of ovarian venous blood, arterial blood, peripheral venous blood and ovarian follicular fluid from sixteen patients have been measured, and a mean figure for the oxygen consumption of human ovarian tissue *in vivo* has been calculated.

MATERIALS AND METHODS

Samples were collected from anaesthetized patients undergoing hysterectomy. The patients were given epidural analgesia combined with a general anaesthetic using nitrous oxide, halothane and 25% inspired oxygen. Samples of ovarian venous blood and follicular fluid were collected after clamping and dividing the ovarian and broad ligaments to prevent contamination with uterine venous blood. Arterial samples were collected from the brachial or radial artery and peripheral venous samples were collected from the median cubital vein. All blood samples were collected through 21-gauge needles into glass Mantoux syringes, the 'dead space' of which contained heparinized saline. All blood

samples containing air bubbles were rejected. Follicular fluid was collected through 25-gauge needles with the same precautions, though it was extremely difficult to collect follicular fluid without drawing an air bubble into the syringe, particularly with follicles of less than 1 cm in diameter. The follicular fluid samples were analysed only if all air could be completely discharged from the syringe immediately after collection of the sample. All syringes were capped immediately and kept on ice until measurements were started. Samples from each patient were collected within 5 to 10 min of each other and measurements started within 30 min. Under these conditions, blood P_{O_2} , P_{CO_2} and pH do not alter significantly (Portnoy, Thomas & Gurdjian, 1965; A. McKinnon, unpublished observations). All measurements were carried out using a Clark electrode for P_{O_2} , a Severinghaus electrode for P_{CO_2} and an Astrup microelectrode for pH (Radiometer, Copenhagen). Calibration of the electrodes was carried out according to the manufacturer's instructions with the modifications suggested by Flenley, Millar & Rees (1967). The results from two patients in whom the P_{O_2} in arterial blood was below 80 mmHg and the arterial pH below 7.2 were excluded (Severinghaus, 1965).

Paired Student's *t* test analyses were carried out for each set of blood samples, comparing ovarian venous with arterial, ovarian venous with peripheral venous and peripheral venous with arterial samples for P_{O_2} , P_{CO_2} and pH (Snedecor, 1956); pH values were converted to the non-logarithmic hydrogen ion concentration values proper before statistical analysis since pH values do not have a Gaussian distribution and, hence, *t* tests would be invalid.

The data from follicular fluid have not been statistically analysed because values fluctuated markedly with minor errors in collection of samples. Follicular fluid (1 to 2 ml) could be left standing at room temperature in a capped glass syringe for up to an hour with less than 10 mmHg increase in P_{O_2} , provided that no air bubbles were present. In the presence of air bubbles, the P_{O_2} could increase by up to 50 mmHg within 4 to 5 min. These errors were more marked with smaller volumes of fluid. A small rise in P_{O_2} could occur even when bubbles of air were expelled immediately.

RESULTS

Clinical findings from each patient are summarized in Table 1. Patients have been grouped in the follicular or luteal phases of the cycle depending on the presence or absence of a corpus luteum and on the endometrial histology.

Blood P_{O_2} , P_{CO_2} and pH data are detailed for each patient in Tables 2, 3 and 4. Statistical analysis of this data gives the following results:

- (i) ovarian venous P_{O_2} is lower than arterial P_{O_2} with a mean difference of 21.8 mmHg ($P < 0.001$);
- (ii) ovarian venous P_{O_2} is higher than peripheral venous P_{O_2} with a mean difference of 15.5 mmHg ($P < 0.005$);
- (iii) ovarian venous pH is higher than peripheral venous pH with a mean difference of 0.026 ($P < 0.001$);
- (iv) the small differences between the other groups of data for pH, and between all three groups for P_{CO_2} , are not statistically significant.

Table 1. Clinical details of sixteen women from whom arterial, ovarian venous and peripheral venous blood and follicular fluid were collected at laparotomy

Patient no.	Age	Day of cycle	Phase of cycle*	Side of corpus luteum†	Endometrial histology‡	Haemoglobin (g/100 ml)	Haematocrit (%)	Diagnosis§
1	35	15	F	—	H	12.3	36.8	DUB
2	48	10	F	—	P	14.9	40.1	DUB
3	46	15	F	—	P	12.8	38.3	Fibroids
4	37	5	F	—	P	13.4	41.4	DUB
5	32	29	F	—	P	11.5	35.7	DUB
6	40	4	F	—	P	13.0	38.8	DUB
7	46	15	F	—	H	16.4	44.5	DUB
8	41	1-2	F	—	P	12.1	36.9	Tubal disease
9	30	19	L	L	S	12.3	36.2	DUB
10	46	13	L	L	S	14.7	42.6	DUB
11	42	17	L	L	S	13.5	39.6	DUB
12	47	19	L	R	S	13.0	38.2	DUB
13	30	19	L	L	S	12.8	37.5	Stage 0
14	36	13	L	R	S	14.1	42.8	Stage 0
15	30	17	L	L	—	12.9	37.2	Right ovarian fibroma
16	47	28	L	L	S	11.9	35.3	Fibroids

* F = follicular; L = luteal.

† L = left; R = right.

‡ H = hyperplastic; P = proliferative; S = secretory.

§ DUB = dysfunctional uterine bleeding; Stage 0 = carcinoma *in situ* of the cervix.

Table 2. Arterial, ovarian venous and peripheral venous blood PO_2 in sixteen women

Patient no.	Arterial	Ovarian venous		Peripheral venous
		Left	Right	
1	109.0	93.0	—	33.0
2	110.0	—	108.0	88.0
3	124.0	—	102.0	98.0
4	124.0	81.0	93.0	90.0
5	114.0	—	91.5	82.5
6	120.5	—	101.5	92.5
7	89.0	59.0	64.5	62.0
8	99.5	—	78.0	69.5
9	114.0	87.0*	—	53.0
10	105.0	83.0*	—	97.0
11	114.0	89.5*	—	76.5
12	101.0	—	99.0*	65.5
13	120.5	83.0*	97.0	74.0
14	102.0	88.5	—*	62.0
15	120.5	106.8*	—	54.0
16	90.5	77.5*	76.5	62.5
Mean	109.8	88.0		72.5
S.E.	2.8	2.9		4.6
S.D.	11.2	13.0		18.2

Values expressed in mmHg.

* Denotes corpus luteum.

Table 5 shows the data for follicular fluid samples in relation to follicle size and position, i.e. right or left-side. The PO_2 values for many of the medium-sized and large follicles are comparatively low and, in eight instances, are lower than the corresponding peripheral venous PO_2 value.

Table 3. Arterial, ovarian venous and peripheral venous blood PCO_2 in sixteen women

Patient no.	Arterial	Ovarian venous		Peripheral venous
		Left	Right	
1	31.0	41.0	—	52.5
2	33.0	—	32.0	30.0
3	28.0	—	25.0	30.0
4	56.0	55.5	58.0	55.0
5	39.0	—	35.0	36.0
6	48.0	—	48.0	45.0
7	38.0	45.5	44.5	43.5
8	47.5	—	45.5	49.0
9	—	—	—	—
10	44.0	34.5*	—	42.0
11	34.0	33.0*	—	34.5
12	67.0	—	62.0*	66.0
13	38.0	42.5*	41.0	40.0
14	36.5	33.0	—*	38.0
15	44.5	58.0*	—	56.5
16	54.0	50.0*	54.5	56.5
Mean	42.6	44.1		45.0
S.E.	2.7	2.4		2.8
S.D.	10.6	10.4		10.7

Values expressed in mmHg.

* Denotes corpus luteum.

Table 4. Arterial, ovarian venous and peripheral venous blood pH in sixteen women

Patient no.	Arterial	Ovarian venous		Peripheral venous
		Left	Right	
1	7.317	7.412	—	7.385
2	7.373	—	7.381	7.330
3	7.319	—	7.340	7.340
4	7.260	7.270	7.258	7.255
5	7.320	—	7.384	7.312
6	7.305	—	7.290	7.238
7	7.355	7.345	7.350	7.318
8	7.300	—	7.310	7.295
9	7.374	7.320*	—	7.302
10	—	7.340*	—	7.325
11	7.365	7.385*	—	7.350
12	7.220	—	7.255*	7.245
13	7.280	7.280*	7.285	7.265
14	7.285	7.292	—*	7.295
15	7.260	7.235*	—	7.185
16	7.253	7.220*	7.210	7.180
16	7.253	7.220*	7.210	7.180
Mean	7.306	7.308		7.278
S.E.	0.012	0.013		0.017
S.D.	0.047	0.058		0.068

* Denotes corpus luteum.

Table 5. Follicular fluid PO_2 , Pco_2 and pH in sixteen women

Patient no.	Follicle size*	Follicle side†	PO_2 (mmHg)	Pco_2 (mmHg)	pH
1	Medium	L	121.0	48.5	7.303
2	Medium	R	53.5	46.0	7.295
3	Medium	R	54.0	39.0	7.280
4	Large	L	65.0	57.5	7.302
5	Medium	R	53.0	40.5	7.398
	Medium	L	97.0	33.5	7.392
6	Medium	R	54.2	40.0	7.328
	Medium	R	90.0	39.0	7.320
7	Large	R	51.5	54.5	7.204
	Large	R	49.5	55.0	7.260
	Medium	L	87.5	37.0	7.440
8	Medium	R	123.0	33.0	7.330
9	Medium	L	141.0	—	7.442
10	Medium	L	138.0	—	7.265
	Small	R	138.0	—	7.446
11	Medium	L	98.0	38.5	7.348
	Small	L	146.0	—	—
12	Medium	L	95.0	56.0	7.438
	Small	R	130.0	47.5	7.470
13	Large	L	128.5	29.0	7.395
	Medium	R	121.5	34.5	7.300
	Small	L	151.5	—	—
14	Small	R	129.0	31.5	7.372
	Small	L	121.0	—	—
15	Small	L	140.5	48.5	—
16	Medium	L	114.0	54.0	7.235

* Large, > 2 cm diameter; medium, 1 to 2 cm diameter; small, < 1 cm diameter.

† L = left; R = right.

DISCUSSION

The relatively high P_{O_2} in ovarian venous compared to peripheral venous blood is unlikely to be due to low oxygen consumption in view of the calculations from animal ovaries *in vitro* (Handbook of Biological Data, 1956; Ahren *et al.*, 1969; Documenta Geigy, 1970). A more likely explanation is that ovarian blood flow is relatively high as has been reported in sheep by direct cannulation of the ovarian vein *in vivo* (Mattner & Thorburn, 1969). In ten of the women in this series, the mean ovarian blood flow, calculated from the secretion rate of oestradiol using the Fick principle (Baird, 1970) was 20.3 ± 3.3 S.E. ml/min/ovary (Baird, 1972) or 2.5 ml/g/min, assuming a mean ovarian weight of 8 g (Wehefritz, 1923). The presence of arterio-venous shunts in the sheep ovary has been postulated to explain the large differences between capillary flow measured by the Sapirstein technique (Sapirstein, 1958; Setchell, 1969) and direct measurements (Mattner & Thorburn, 1969; Goding, Baird, Cumming & McCracken, 1971). Anatomical evidence of arterio-venous shunts in the medulla and cortex of the human ovary has been reported (Clara, 1956).

Additional support is given to the suggestion that there are functional arterio-venous shunts from calculation of the oxygen consumption of the ovary *in vivo* derived by converting the P_{O_2} levels in arterial and ovarian venous blood to oxygen content using the Radiometer Blood Gas Calculator designed by J. W. Severinghaus. Allowance has also been made for the oxygen in solution (Albritton, 1952). The mean oxygen consumption (0.014 ml/g/min) is almost identical to that for the sheep ovary measured directly in the conscious ewe (D. T. Baird, M. Giles and F. Cockburn, unpublished observations) and suggests that anaesthesia *per se* has little effect on oxygen consumption by ovarian tissue. This is also in keeping with the *in-vitro* data.

Because of technical difficulties associated with sampling small follicles, it is not possible to draw definite conclusions about follicular fluid P_{O_2} and its relationship to blood P_{O_2} . It should be noted that any technical error would over-estimate the P_{O_2} level. It is possible, therefore, that the P_{O_2} of follicular fluid is normally relatively low and may influence the metabolism of the oocyte and the granulosa cells.

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