rheumatoid arthritis, surgical division of the transverse carpal ligament usually gives rapid and complete relief. Other compression neuropathies may occur, as of the ulnar nerve by the arcuate ligament below the elbow (Osborne, 1957), in the feet, and elsewhere. The subject is discussed in some detail by Thompson and Kopell (1959) and by Kopell, Thompson, and Postel (1962). Treatment lies in the localization of the compression and surgical release of the compressed nerve.

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Use of Capillary Blood in Measurement of Arterial Po_2

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Summary: In this study we investigated the possibility of obtaining accurate values of arterial Po_2 from specimens of capillary blood stored in glass capillary tubes and measured in an oxygen microelectrode. It has been shown that Po_2 measurements made on the Radiometer oxygen microelectrode are as accurate as those made on the macroelectrode and that the storage of blood is as satisfactory in glass capillary tubes as in glass syringes. The important feature in obtaining accurate values for arterial Po_2 is the choice of the capillary bed and its method of preparation for sampling. If the ear lobe is massaged with thurfyl nicotinate (Trafuril) it is possible to obtain values of Po_2 from the capillary blood which are in close agreement with arterial Po_2 in normal, hyperoxic, and shocked vasoconstricted patients.

Introduction

There is an increased awareness of the need to monitor the blood oxygen tension when efficient systems of oxygen administration are used in the management of severely ill patients suffering from a variety of anoxic conditions. It is of considerable importance to maintain adequate tissue oxygenation in states of stagnant anoxia until the underlying pathology is corrected, and where hyperbaric oxygen techniques are used frequent arterial Po_2 measurement is needed if oxygen poisoning is to be avoided (Norman and Smith, 1967). Capillary blood specimens can now be used for a variety of biochemical measurements, and with the recent advent of the oxygen microelectrode it should be possible to use specimens of capillary blood as an index of arterial oxygen tension. This would facilitate the management of patients receiving oxygen at normal and increased atmospheric pressures and may prove invaluable in paediatric practice, where repeated arterial samples are less easily obtained. Initial attempts to correlate capillary blood Po_2 and arterial Po_2 proved unsatisfactory, however, and this study was devised to assess the errors inherent in making such measurements.

Various electrode systems have been used to measure blood oxygen tension (Staub, 1961 ; Elridge and Fretwell, 1965 ; Johnstone, 1966 ; Moran, Kettel, and Cugell, 1966 ; Rhodes and Moser, 1966). Considerable errors can, however, be made if care is not taken in calibration of the electrode (Moran *et al.*, 1966 ; Rhodes and Moser, 1966 ; Adams and Morgan-Hughes, 1967), in the sampling of blood (Nunn, 1962 ; Johnstone, 1966), and if allowance is not made for time lapse between sampling and measurement (Nunn, 1962 ; Elridge and Fretwell, 1965 ; Lenfant and Aucutt, 1965 ; Johnstone, 1966). In practice the latter may be the most important source of error if the measurements are made in a laboratory situated at some distance from the patient.

It seemed desirable to evaluate (1) the accuracy of the oxygen microelectrode in the measurement of Po_2 of blood contained within glass capillary tubes as compared with that of the macroelectrode in the measurement of blood contained within glass syringes ; (2) the rate of decline of Po_2 of blood stored in glass capillary tubes, glass syringes, and plastic syringes, and to observe the effect of time, temperature, and initial oxygen tension on these three storage methods ; and (3) the importance of the capillary sampling site and the mode of preparation of the capillary bed previous to sampling in different states of peripheral perfusion.

Methods

The oxygen electrodes used were the Radiometer microelectrode (Radiometer Ref. E5046) and the Radiometer macroelectrode (Radiometer Ref. E5021). The electrodes were calibrated with nitrogen, air, and oxygen which had been warmed and humidified by passage through sintered glass humidifiers immersed in a thermostated water-bath maintained thermostatically at 37° C. The use of gases allowed the calibration

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to be checked before and after the introduction of each blood specimen. All measurements were made after the cuvettes had been flushed with nitrogen to produce a zero current output and to exclude a hysteresis effect. No correction was made for the blood-gas differences of the two electrodes, which were 8 mm. Hg for the macroelectrode and 1 mm. Hg for the microelectrode at a Po_2 of 710 mm. Hg.

Specimens of arterial blood were taken anaerobically by percutaneous radial or brachial arterial puncture or from indwelling intra-arterial cannulae into 20-ml. glass syringes, the dead space of which had been filled with heparin. After sampling, the syringes were immediately sealed by pushing the attached needle into a rubber stopper.

Capillary samples were obtained from either the ear lobe or thumb pulp of normally perfused subjects and from a group of patients in various shocked states with peripheral vasoconstriction. The sampling sites were prepared as follows: (1) the unprepared thumb pulp; (2) the hand immersed in warm water till the skin temperature at the proposed donor site was 37° C. as measured by the skin lead of a Sierex thermocouple thermometer; (3) the ear lobe massaged for three minutes; and (4) the ear lobe massaged with nicotinic acid (thurfyl nicotinate; Trafuril) for three minutes. Capillary specimens were taken into heparinized glass capillary tubes whose ends were immediately closed with sealing substance (Radiometer Ref. D553).

Blood specimens used for comparison of the accuracy of the measurements of the microelectrodes and macroelectrodes were freshly drawn venous blood, in the normal *p*H and haematocrit ranges, equilibrated with humidified warmed gas mixtures of known Po_2 in a range from 2 to 2,100 mm. Hg in a closed tonometer immersed in a water-bath maintained at 37° C. for a period of 30 minutes. Samples were then withdrawn anaerobically into syringes and capillary tubes and the oxygen tensions measured simultaneously on the oxygen macroelectrodes and microelectrodes, respectively. Many of the measurements were made in a hyperbaric chamber at atmospheric pressures ranging from 1 to 3 atmospheres absolute.

Samples were stored by immersing the sealed containers in either a beaker of melting ice at 4° C. or in a water-bath maintained at 21 or 37° C. All measurements of Po_2 were made at the same predetermined time intervals. A check on the efficiency of the sealing of the syringes and capillary tubes was made by equilibrating normal saline with 100% O_2, storing at 21° C., and making Po_2 measurements at zero time, three hours, and 48 hours. The efficiency of glass and plastic syringes as storage vessels for blood was further tested by storing blood equilibrated with humidified oxygen in sealed syringes at 21° C. and measuring the Po_2 at intervals for three hours.

Results

There was good statistical agreement between the oxygen tensions of capillary tube blood specimens measured on the oxygen microelectrode and the oxygen tensions of paired syringe samples of blood drawn from the same sample of equilibrated blood measured on the macroelectrode, over the whole range of oxygen tension (Fig. 1). The correlation between the results is best in the lower ranges of oxygen tension, but the correlation coefficient (r) is statistically significant over the whole range—Po_2 0–100 mm. Hg: $P<0.005$, $r=+0.79$; Po_2 100–300 mm. Hg: $0.005>P>0.0025$, $r=+0.75$; Po_2 500–700 mm. Hg: $0.0025>P>0.0005$, $r=+0.69$; Po_2 1,250–1,500 mm. Hg: $P<0.0005$, $r=+0.70$; Po_2 1,900–2,400 mm. Hg: $0.0125>P>0.01$, $r=+0.50$.

Fig. 2 presents the results obtained by measuring the Po_2 at time intervals for three hours of blood equilibrated with gases of mean oxygen tensions of 143 and 680 mm. Hg and stored in sealed glass capillary tubes. It can be seen that decline in

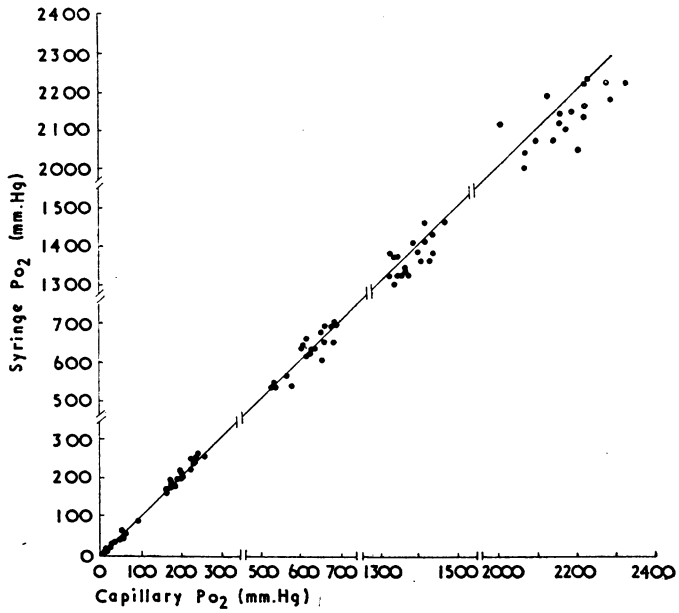

FIG. 1.—Po_2 of capillary tube samples measured on the oxygen microelectrode plotted against Po_2 of paired syringe samples measured on the oxygen macroelectrode.

Po_2 with time is maximal in the blood with the highest initial Po_2 and stored at the highest temperature.

When these experiments were repeated with storage of the blood in glass syringes (Fig. 3) identical results in respect of decline in Po_2 with time and temperature of storage and initial oxygen tension were obtained.

To show that in both instances this decline in Po_2 was due entirely to the utilization of oxygen by the blood components and not to a leak in or absorption by the syringe parts, 0.9% saline was equilibrated to a similar high Po_2 and stored at 37° C. in both the previous storage vessels and in plastic

TABLE I.—*Po_2 of 0.9% Saline Stored at 37° C for 3 and 48 Hours in Glass and Plastic Syringes and Glass Capillary Tubes. Each Figure is the Mean of 20 Measurements*

Time in Hours	Glass Syringes	Glass Capillary Tubes	Plastic Syringes
	Po_2 mm. Hg		
0	709 (±3·0)	676 (±5·0)	695 (±15·0)
3	709 (±3·0)	675 (±8·0)	545 (±22·0)
48	706 (±7·0)	674 (±4·0)	230 (±29·0)

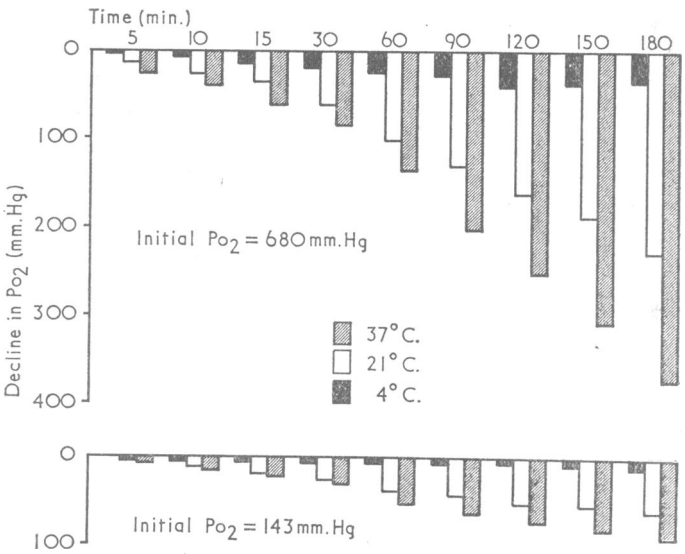

FIG. 2.—Decline in Po_2 of blood samples stored at 4, 21, and 37° C. in sealed glass capillary tubes, plotted against time.

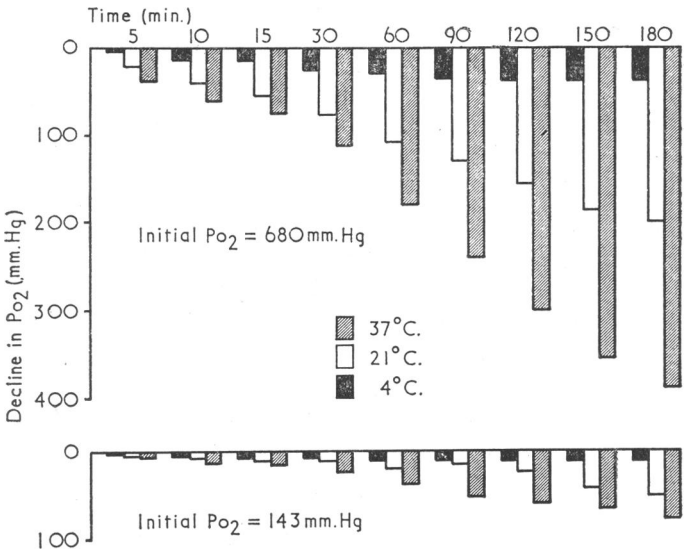

FIG. 3.—Decline in Po_2 of blood samples stored at 4, 21, and 37°C. in sealed glass syringes, plotted against time.

syringes. The results, which confirm that there was no significant loss of oxygen from the capillary tubes or glass syringes over three to 48 hours, are shown in Table I. This study shows that plastic syringes lose oxygen amounting to 21% of the initial Po_2 of the saline over three hours and of 67% over 48 hours.

That this loss of oxygen from plastic syringes also occurs when blood is stored in these vessels was shown by storing aliquots of the same equilibrated blood in glass and plastic syringes at 37° C. for three hours. There is a considerably greater fall of Po_2 from the plastic syringes after 15 minutes' storage (Fig. 4).

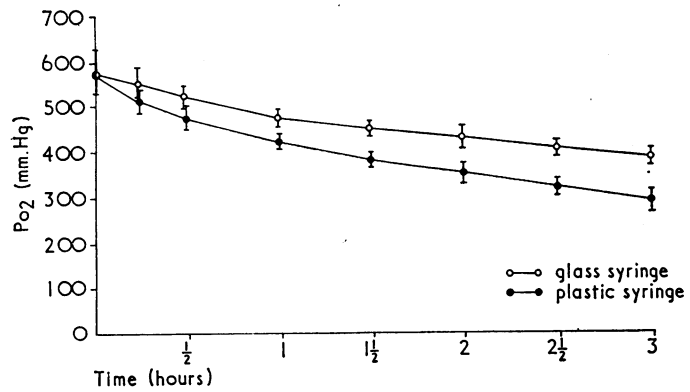

FIG. 4.—Po_2 of blood stored in glass and plastic syringes at 37° C., plotted against time.

In Table II can be seen the results of Po_2 measurements made on arterial blood samples and on capillary blood samples obtained from the ear lobe and thumb pulp after attempts had been made to "arterialize" the capillary bed in normal individuals at rest breathing room air. There was a highly significant correlation between arterial Po_2 and ear lobe capillary blood Po_2 after either method of preparation ($r = +0.87\%$). There was, however, no statistically significant correlation between thumb pulp blood and arterial blood.

There was again a statistically significant correlation between arterial blood and "arterialized" ear-lobe blood after thurfyl nicotinate massage in a group of normally perfused resting subjects made hyperoxic by breathing various high tensions of oxygen ($r = +0.87$) (Table III).

In a third group of hypotensive patients with peripheral vasoconstriction due to a variety of causes, the Pao_2 again correlated well with arterialized ear lobe capillary blood after thurfyl

TABLE II.—*Simultaneous Measurements of Arterial Blood Po_2 and Capillary Blood Po, After Various Methods of Preparation of the Capillary Bed in Normally Perfused Subjects*

	Arterial Po_2 (mm. Hg)	Capillary Po_2 (mm. Hg)			
	Brachial Artery	Ear Lobe with Thurfyl Nicotinate	Ear Lobe with Massage	Thumb at 37°	Thumb Untreated
	107	100	105	100	105
	99	95	96	70	86
	102	99	96	76	84
	102	101	100	89	95
	96	89	90	78	80
	84	80	92	72	64
	89	101	98	86	88
	89	94	110	76	90
	75	74	76	70	74
	98	100	109	105	106
	110	114	123	85	92
	107	102	85	72	85
	88	90	82	72	87
	89	91	90	76	82
Mean S.D.	95·5 (±9·7)	95·0 (±9·5)	96·5 (±11·9)	80·5 (±10·7)	87·0 (±9·5)

TABLE III.—*Simultaneous Measurements of Arterial Blood Po_2 and Capillary Blood Po_2 After "Arterialization" of the Ear Lobe with Thurfyl Nicotinate Massage in Hyperoxic Subjects*

	Arterial Po_2 (mm. Hg)	Ear Lobe Capillary Po_2 after Thurfyl Nicotinate Massage (mm. Hg)
	270	270
	445	460
	240	242
	365	360
	375	380
	275	270
	440	400
	435	400
	465	445
	188	181
	360	330
	185	188
	290	284
	188	188
Mean S.D.	323 (105)	330 (92·5)

nicotinate massage, and there was close individual agreement between the values (Table IV). With massage of the ear lobe alone, however, it was not always possible to obtain adequate samples for analysis, and where this was possible there was no statistically significant correlation with simultaneously obtained arterial blood.

TABLE IV.—*Simultaneous Measurements of Arterial Blood Po_2 and Capillary Blood Po_2 After Ear Lobe Massage With and Without Thurfyl Nicotinate in Hypoxic Vasoconstricted Subjects*

	Arterial Po_2 (mm. Hg)	Capillary Po_2 (mm. Hg)	
		Ear Lobe with Thurfyl Nicotinate	Ear Lobe with Massage
	121	128	100
	88	76	70
	98	94	80
	99	96	85
	98	97	90
	55	58	80
	69	66	65
	60·5	63·5	88
	65·5	61·5	—
	63	63	—
	62	63	—
Mean S.D.	80·0 (20·6)	78·7 (21·0)	81 (10·1)

Discussion

It has been shown that the measurement of Po_2 in a microsample by the microelectrode shows close statistical agreement with the measurement of Po_2 in a macrosample of the same blood by the oxygen macroelectrode over a Po_2 range from 2 to 2,100 mm. Hg. The values are most closely related in the range of Po_2 from 0 to 300 mm. Hg, which is the range most commonly measured. The tendency to obtain somewhat higher values of Po_2 from the micromethod, compared with the macro-

method, at the highest range of Po_2 can be accounted for by differences in the blood-gas factors of the two electrodes. Johnstone (1966) found similar results when he tested the microelectrode system up to a Po_2 of 200 mm. Hg.

In this study the Po_2 of blood specimens stored at 37° C. for three hours fell at the rate of 2.3 mm. Hg/min. when the mean initial Po_2 was 680 mm. Hg. This agrees with the figures of Asmussen and Neilsen (1961), Rhodes and Moser (1966), Laver and Seifen (1965), and Greenbaum, Nunn, Prys-Roberts, and Kelman (1967). It was also found that the Po_2 fell at the rate of 3.0 mm. Hg/min. during the first hour, 2.5 mm. Hg/min. during the second hour, and 2.3 mm. Hg/min. during the third hour. The decreasing rate of decline in Po_2 with time is explained by the consideration that at constant oxygen consumption by blood cells there will be a greater fall in Po_2 when the initial Po_2 is high compared with that found when the initial Po_2 is low. This is due to the shape of the oxygen dissociation curve. Thus the error in Po_2 caused by storing blood for a given time will be greater at high initial Po_2 values than at low values. Though it has been shown that the rate of decline in Po_2 of blood stored at room temperature is much less than that found when it is stored at 37° C., considerable errors will still be caused if there is much delay in measurement. Since storage of blood samples at 4° C. virtually abolishes oxygen consumption, there is an obvious need to store blood samples in ice if measurement has to be delayed. Since metabolism will proceed until the blood temperature reaches 4° C., capillary tubes are more efficient for storage of samples than glass syringes, which have a longer and variable lag cooling time (Kelman and Nunn, 1966). The total unsuitability of plastic syringes as storage vessels for blood samples in which Po_2 measurements are to be made is also shown in this study, contrary to the finding of Laver and Seifen (1965).

Since it has been shown that the microelectrode is capable of as accurate measurement as the macroelectrode and that a glass capillary tube is as efficient a storage vessel as a glass syringe, discrepancies between arterial and capillary Po_2 measurements can arise only from errors in sampling technique. The capillary bed of the thumb pulp is not a suitable site for obtaining arterialized capillary blood for this purpose even if the skin temperature is raised to 37° C. by heat or the skin is massaged with thurfyl nicotinate. In the normally perfused subject the capillary bed of the ear lobe will, however, provide a sample which gives the same Po_2 value as a simultaneously drawn arterial sample, after the ear lobe has been massaged with thurfyl nicotinate for three minutes, or even after massage alone for the same time. Since Po_2 measurements are most commonly required in either anoxic or hyperoxic patients it is of significance that the ear lobe massaged with thurfyl nicotinate for three minutes will give Po_2 values—in these two categories—which are in close statistical agreement with arterial oxygen tension.

It can be said, in conclusion, that the use of the oxygen microelectrode system with capillary blood specimens obtained from the ear lobe after massage with thurfyl nicotinate for three minutes affords a method of obtaining Po_2 measurements on capillary blood which are in close agreement with arterial Po_2 in normal, hyperoxic, and hypoxic subjects.

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Long-term Follow-up of Surgically Treated Thyrotoxic Patients

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Summary: Review of 123 patients whose thyroidectomy for thyrotoxicosis had been performed more than five years previously showed that there were no deaths attributable to surgery, while one hundred patients (81.3%) had been rendered euthyroid. Varying degrees of hyperthyroidism had occurred in 15 (12.2%), and six of these were first diagnosed at follow-up. Hypothyroidism was present in eight (6.5%). Long-term complications of operation were found in 20 patients—subjective voice disturbance in 13, unsightly scars in 4, and hypoparathyroidism in 3.

Introduction

The treatment of thyrotoxicosis is far from ideal. All current methods have their own advocates, but all have a significant incidence of complications. Radioiodine (^{131}I), which in the 1950s seemed to be gaining pride of place in the management of thyrotoxicosis, certainly in the over-40 age group, has come under serious criticism, mainly because of the high incidence of subsequent myxoedema. As a result surgery has again been advocated as the treatment of choice in the majority of cases. However, there is a lack of data on the long-term effects of thyroid surgery for thyrotoxicosis comparable to that available for ^{131}I therapy.

In view of this it seemed worth while to report on the outcome of thyroid surgery in a group of thyrotoxic patients, all of whom were treated in one surgical unit and all of whom had been followed up for at least five years after thyroidectomy.

Material

In the Southern General Hospital, Glasgow, records showed that 185 patients had been treated for thyrotoxicosis by partial thyroidectomy during the years 1953 to 1960. On perusal of

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