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THE OXIDATION AND UTILIZATION OF GLUCOSE AND ACETATE BY THE MAMMARY GLAND OF THE GOAT IN RELATION TO THEIR OVER-ALL METABOLISM AND TO MILK FORMATION

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It is well established that in ruminants dietary carbohydrate is largely fermented to short-chain fatty acids. Acetate, the major product of ruminal fermentation, is absorbed together with smaller amounts of propionate and butyrate to constitute a major source of energy. The paucity of alimentary glucose, when considered with the low concentrations of blood glucose and relative insensitivity to insulin which characterize ruminants, has tended to obscure the importance of glucose in ruminant metabolism. However, recent work based on the dilution of constantly infused isotope (Searle, Strisover & Chaikoff, 1954; Steele, Wall, de Bodo & Altszuler, 1956) has shown that rates of turnover and oxidation of glucose in sheep (Annison & White, 1961, 1962; Bergman, 1963; Ford, 1963) and cattle (Davis & Brown, 1962) are not markedly lower than in non-ruminants. Similar studies with acetate have confirmed the quantitative importance of this substrate in ruminant metabolism and shown that, relative to glucose, acetate makes a two- to three-fold greater contribution to total oxidative metabolism in the intact animal (Annison, Brown, Leng, Lindsay, West & White, 1963).

The dominant role of acetate in the over-all economy of ruminants is not reflected in the metabolism of all individual tissues. McClymont & Setchell (1956) demonstrated the uptake of glucose but not acetate by the sheep brain, and Annison, Scott & Waites (1963) showed that the testis and epididymis in the anaesthetized ram oxidize more glucose than acetate. Extensive studies on the metabolism of acetate and glucose by the isolated perfused mammary gland of the lactating goat have also shown that glucose is oxidized about twice as rapidly as acetate and is essential for milk secretion (Hardwick, Linzell & Price, 1961; Hardwick, Linzell & Mepham,

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1963). These findings were unexpected since Folley & French (1950) reported that slices of mammary glands of lactating sheep were inert towards glucose, and that glucose merely increased the utilization of acetate. During a study of mammary blood flow in conscious goats Linzell (1960*b*) found that the glucose uptake by the lactating gland was much greater than that required for milk lactose synthesis, suggesting that substantial amounts are oxidized under normal conditions, as in the isolated gland.

The present studies were undertaken to investigate the uptake and oxidation of glucose and acetate by the mammary gland of the normal animal in relation both to the over-all metabolism of these substrates, and to milk production. As in the experiments of Annison, Scott & Waites (1963) with the testicle of the ram, the isotope dilution technique has been combined with the measurement of mammary blood flow and measurements of the specific radioactivities of the substrate and the CO_2 in both arterial and mammary venous blood during a constant I.V. infusion of ^{14}C-labelled glucose or acetate. From these data values have been calculated for the amounts of acetate and glucose entering the circulation, the amounts taken up by the udder and for the contribution of the two substrates to CO_2 production by the whole body and by the udder. Knowledge of the uptake and extent of oxidation of glucose and acetate by the udder has allowed quantitative assessment of the role of these substrates as precursors of milk fat and lactose.

A preliminary account of the work has been given by Annison & Linzell (1964).

METHODS

Animals. Four adult Saanen goats were studied (Table 1). They were kept on a constant diet of hay, fed *ad libitum*, and a standard cereal ration fed twice daily according to the milk yield. The animals were prepared for the measurement of blood flow through one mammary gland (half the udder) and the collection of arterial and mammary venous blood by the exteriorization of a carotid artery, a 'milk' (caudal superficial epigastric) vein and the separation of the left and right halves of the udder to divide the blood vessels crossing between the two glands (Linzell, 1960*b*). The volumes of the empty glands were measured by displacement of water to compare the flows/g of tissue with those made previously (Linzell, 1960*b*) and to estimate the total udder blood flow assuming that the flow/g was the same in both glands.

Experimental procedure. The infusions of isotopes were carried out in the animals' own pens, using an apparatus similar to that of Jewell (1957). The peristaltic infusion pump of constant output was placed above the pen on a swivelling platform. The plastic outflow tubing passed to a leather harness worn by the animal through flexible metal tubing and a counterbalanced levelling device that followed the animal's movements. The plastic tube ended at a tap on the loose collar of the harness from where a catheter entered a jugular vein and another catheter in the carotid loop was similarly fixed to another tap on the collar. Thus blood samples could be collected without necessarily restraining the animal and I.V. infusions carried out whilst the animal was quite free to move in any way within its pen and to feed and drink as it customarily did on other days. The animals were accustomed to the apparatus before the experiment.

The catheters (Jugular: P.V.C. 'Portex' NT/3 Shore Scale 95, 1·4 mm bore, 2·0 mm O.D.; Carotid: Nylon 'Portex' Flexible Grade 3, 1 mm bore, 1·34 mm O.D.) were inserted into the carotid and jugular over flexible wires or nylon rod by Seldinger's (1953) technique under local anaesthesia after the morning milking on the day of the experiment.

TABLE 1. Details of Saanen goats used

Goat	Jill	Jill	Sally	Angel	Angel	Balham*
Age (yr)	7	7·5*	7	3·5	3·5	2·5
Lactation	7th	7th	6th	3rd	3rd	2nd
Time of experiments (weeks after parturition)	6, 12	36	12,15	17, 18	23	35
Weight (kg)	68, 63	62·5	74	69	66	60
Milk yield (l./day) (mean of 7 days)	4·93, 4·51	1·52	2·85, 2·61	3·16, 3·07	0	2·36
Mean milk composition (bulked from 3 days)						
Fat (g/100 ml.)	3·4	4·75	3·2	3·1	—	4·0
Lactose (g/100 ml.)	4·4	3·9	4·0	4·2	—	4·0
Volume of udder, (empty) (l.)	3·43	2·59	2·39	2·95	2·00	1·6
Mean udder blood flow (ml./min.)	1780	700	1170	1330	480	840

* At this time Jill and Balham were 6 weeks pregnant.

Uniformly labelled [^{14}C]-glucose in 0·9 % (wt./vol.) NaCl (0·3 μc; 1 mg/ml.) was infused at 1 ml./min immediately after a priming dose (30 μc) of isotopic glucose (Annison & White, 1961). Sodium [1,2-^{14}C]-acetate in 0·9 % (wt./vol.) NaCl was infused at 1 μc, 1 mg/min without a priming dose. Infusions of both isotopes were continued for 4 hr at constant rate. During the last hour of infusion three to six pairs of arterial and mammary venous blood samples (10–30 ml. each) were taken simultaneously at 10–15 min intervals. The venous samples were taken from the exteriorized 'milk' vein whilst the animal was standing and whilst another person manually compressed the external pudic vein at the base of the udder (Linzell, 1960*a*). In most experiments the milk formed during the hour of sampling was collected by milking out after the intravenous injection of 400 m.u. of oxytocin.

Estimates of mammary blood flow were made on other days at the same level of milk yield by the method previously described of measuring the flow in the exteriorized 'milk' vein by the thermodilution method and assessing the proportion of the total flow in this vein by manual clamping of the other main vein, the external pudic (Linzell, 1960*a*, *b*). This can only be done with the animal standing and the measurements were made on the milking stand with the goat feeding.

Radioactive materials. Sodium [1,2-^{14}C]-acetate, uniformly labelled [^{14}C]-glucose, sodium [^{14}C]-bicarbonate and calibrated *n*-hexadecane were obtained from the Radiochemical Centre, Amersham, Bucks.

CHEMICAL METHODS

Assay of radioactivity. All substrates were assayed by wet oxidation to $^{14}CO_2$ (Van Slyke & Folch, 1940), which was absorbed in 2 ml. of ethanolamine: methyl cellosolve (1:2 vol./vol.). Radioactivity was measured by liquid scintillation counting after adding 4 ml. of toluene containing 2,5-diphenyl oxazole (0·6 %). Calibrated *n*-hexadecane (1 μc/g) was used as a reference standard.

Plasma glucose specific radioactivity. Glucose was isolated from plasma (5 ml.) as glucosazone after the addition of carrier glucose (20 mg) by the method described earlier (Leng & Annison, 1963) and assayed for radioactivity by oxidation to $^{14}CO_2$, as described above.

Plasma glucose concentrations were measured with glucose oxidase (Huggett & Nixon, 1957).

Blood acetate specific radioactivity. Acetate was isolated from blood by steam distillation as described earlier (Annison & White, 1962), and after titration the dried samples were oxidized to $^{14}CO_2$ and assayed for radioactivity as described above.

Specific radioactivity of blood carbon dioxide. Blood CO_2 was isolated as $BaCO_3$ as described by Annison & Lindsay (1961), and using the same gas transfer apparatus weighed amounts of $BaCO_3$ were heated gently with concn. H_2SO_4 (5 ml.) *in vacuo* and the liberated CO_2 absorbed in 2 ml. of ethanolamine:methyl cellosolve (1:2 vol./vol.). The solution was assayed for radioactivity as described above.

In the acetate experiment on the goat Angel during lactation the radioactivities of the titrated blood acetate and the $BaCO_3$ from the blood CO_2 were estimated on planchets and an end-window counter by Dr D. C. Hardwick as in the experiments of Hardwick *et al.* (1963).

Blood gases. Blood O_2 and CO_2 were measured on the same blood sample (1 ml.) by the procedures of Peters & Van Slyke (1932).

Analysis of milk. Milk total solids, ash, lactose and fat were determined by standard methods as described by Hardwick & Linzell (1960).

RESULTS

Experimental conditions. In experiments with conscious animals it is important to have the stable physiological conditions which were largely achieved in the present study. Experiments were usually started 1·5–2 hr after the morning milking when the animals were finishing their morning feed. They were not apparently upset by the harness or catheters. The worst disturbance seemed to be that they were made to stand for each pair of blood samples during the last hour of infusion, when they would otherwise have been lying down and ruminating. However they tolerated this patiently and frequently continued to ruminate during the taking of the blood samples. Their heart rates (95–110/min), mean blood pressure (90–95 mm Hg), plasma glucose and free fatty-acid concentrations were not significantly altered or different from other lactating animals in this herd. The arteriovenous differences of O_2, CO_2, glucose and acetate (Table 2) were within the range of values for conscious lactating goats obtained earlier (Linzell, 1960*b*).

Equilibration of bicarbonate pools. The specific radioactivities of CO_2 in arterial and mammary venous blood were followed during the continuous infusion of $NaH^{14}CO_3$ (Fig. 1). The time required to approach equilibration of body CO_2 pools (100–200 min) was appreciably less than with anaesthetized rams (Annison *et al.* 1963). Evidence of a CO_2 pool in the mammary gland was given by the much lower specific radioactivities of mammary venous CO_2 relative to arterial CO_2 during the early stages of the infusion. After 200 min the mean difference in the specific radioactivities of arterial and venous blood draining the mammary gland was roughly accounted for by the dilution of arterial blood with unlabelled CO_2 produced by the tissue.

The roughly constant specific radioactivities of $^{14}CO_2$ in arterial blood during the terminal stages of infusion of labelled glucose and labelled acetate (Table 2) indicated that body CO_2 pools were largely in equilibrium during the sampling periods.

The effect of oxytocin. In the first experiments the milk formed during the infusions was obtained by milking the animals either hourly or at the beginning and end of the blood sampling period. Milking releases oxytocin and in addition extra oxytocin (400 m-u.) was injected I.V. to ensure thorough emptying of the glands. However, oxytocin has been reported

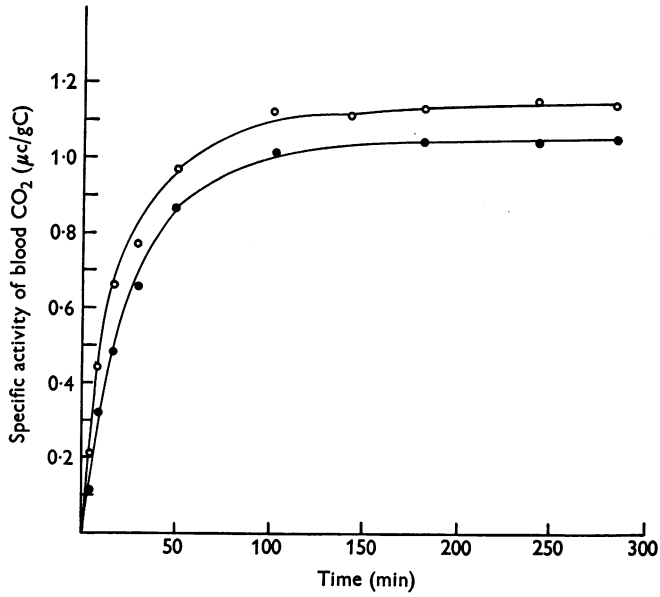

Fig. 1. Specific radioactivity–time curves of blood CO_2 in a lactating goat (Sally) receiving a constant I.V. infusion of $NaH^{14}CO_3$ (100 mg/100 ml. in 0·9 % (wt./vol.) NaCl; 0·5 μc/ml.) 1 ml./min. Open circles, arterial blood; closed circles, mammary venous blood.

in rats to have an insulin-like activity *in vitro* on mammary tissue (Goodfriend & Topper, 1961), in dogs to raise the plasma levels of free fatty acids (Mirsky, 1963) and glucose (Heidenreich, Kook & Reus, 1962) and in the human to increase the heart rate, cardiac output and hand blood flow and to decrease the blood pressure (Kitchin, Lloyd & Pickford, 1959). Although we calculated that the doses of oxytocin that we used were below the levels producing these metabolic responses and Assali, Holm & Parker (1961) reported that there were no cardiovascular effects in preg-

TABLE 2. Data from experiments on lactating goat Jill. Isotopes infused at constant rate into jugular vein and blood samples taken simultaneously from carotid artery and a mammary vein

(1) Infusion of (U ^{14}C) glucose 0·3 μc/min in the 6th week of lactation

Sample	Time (min)	Blood glucose concentration (mg/100 ml.)	Blood glucose specific radioactivity (μc/gC)	Blood gases (vol. %) CO_2	Blood gases (vol. %) O_2	Blood CO_2 specific radioactivity (μc/gC)	Blood acetate (m-mole/l.)
A 1	181	47	2·45	46·6	12·2	0·24	2·3
V 1		34	—	54·2	6·6	0·39	0·9
A 2	192	47	2·44	47·4	13·0	0·24	—
V 2		30	—	56·4	6·6	0·39	—
A 3	205	48	—	48·9	12·7	0·23	—
V 3		34	—	58·5	6·3	0·40	—
A 4	219	51	2·42	47·9	11·8	0·26	—
V 4		33	—	56·5	5·9	0·41	—
A 5	234	51	2·55	45·9	12·1	0·26	1·9
V 5		36	—	54·9	6·8	0·38	0·6

(2) Infusion of (U ^{14}C) acetate 1·0 μc/min in the 12th week of lactation

Sample	Time (min)	Blood acetate concentration (m-mole/l.)	Blood acetate specific radioactivity (μc/gC)	Blood gases (vol. %) CO_2	Blood gases (vol. %) O_2	Blood CO_2 specific radioactivity (μc/gC)	Blood glucose (mg/100 ml.)
A 1	191	1·61	5·5	50·2	10·7	1·22	45
V 1		0·37	3·3	57·0	5·0	1·21	28
A 2	211	2·00	6·4	56·3	10·7	1·36	45
V 2		0·57	3·2	64·6	4·6	1·15	18
A 3	234	1·88	5·9	55·2	10·4	1·24	38
V 3		0·69	3·0	64·3	4·4	1·25	24

nant sheep, the influence of oxytocin in our experiments was examined and in some experiments no oxytocin was given and the animal was not milked during the infusions.

Single I.V. injections of oxytocin (synthetic or Pitocin, Parke, Davis & Co.) 400–1000 m-u. had no effect on the mean blood pressure, heart rate, or the levels of blood sugar or volatile fatty acids. Neither were there any significant arterio-venous differences between three pairs of samples taken over a period of half an hour before and after oxytocin, in respect of blood gases, substrates or radioactivities. On two occasions with different goats there was an increase in udder blood flow of 15–30% 7–11 min after oxytocin but on other days no effect in the same animals; random variations of this order were previously detected by Linzell (1960*b*).

In view of these findings data obtained in experiments with and without oxytocin have been pooled.

Metabolism of acetate. Acetate was an important source of energy in these goats as in other ruminants (Table 3). The mean entry rate (i.e. rate of entry into the total body pool) was 5·5 mg/kg/min during lactation but the mammary glands were taking up 11–41 mg/kg/min according to the rate of milk secretion. From the specific radioactivities of the arterial CO_2 it was calculated that 28% of the total circulating CO_2 came from this substrate. The specific radioactivity of the CO_2 in the mammary venous blood was not significantly different from that in arterial blood and thus it was concluded that the proportion of mammary CO_2 derived from acetate is the same as the average for the rest of the body (i.e. about 27%). One goat (Angel) was prematurely dried up when in full lactation and when studied 5 weeks later the acetate utilization was somewhat less (4·0 mg/kg/min for the whole animal and 9·5 mg/kg/min for the udder), but the proportion of total CO_2 derived from it was similar (23%). From these data and the mean mammary arterio-venous differences of acetate and CO_2 it was calculated that 46% of the acetate taken up by the udder was oxidized during lactation and 57% in the dry animal (Table 3).

The specific radioactivity of acetate in mammary venous blood was always measurably lower than that in arterial blood (Table 2), indicating some production of acetate in addition to the large acetate uptake.

Metabolism of glucose. The mean entry rate of glucose into the total body pool (3·6 mg/kg/min) was less than for acetate and the proportion of total CO_2 derived from it much less at 9% (Table 3). However the mammary glands took up 25–89·5 mg/kg/min according to the milk yield, which is 2–3 times the mammary acetate uptake and 8–25 times the body average. Moreover, in all experiments, the mammary venous CO_2-specific radioactivity was always higher than the arterial level, indicating a greater oxidation of glucose in the mammary glands than in the rest of the body.

TABLE 3. Metabolism of acetate and glucose by the whole animal and by the udder

Goat	Rate of milk secretion (ml./min)	Whole animal entry rate (mg/min/kg)		Udder: Uptake of substrate (mg/min/kg)		Udder: Percentage of substrate oxidized		Percentage of CO_2 derived from substrate: Whole animal		Percentage of CO_2 derived from substrate: Udder	
		Acetate	Glucose	Acetate	Glucose	Acetate	Glucose	Acetate	Glucose	Acetate	Glucose
Jill	3·3	5·3	5·3	41	89·5	29	34	21	10	21	49
Angel	2·2	6·5	3·6	24	49	69	20	37	9	33	33
Sally	1·9	4·9	3·0	24	75	51	26	27	11	27	49
Balham	1·6	5·3	3·1	32	76	38	16	27	8	27	29
Jill	1·0	—	3·2	11	25	—	31	—	7	—	34
Angel	0	4·0	3·6	9·5	9·5	57	76	23	14	23	20

Comparison of the specific radioactivities of circulating glucose and of mammary CO_2 (calculated from arterial and venous CO_2 concentrations and specific radioactivities) showed that 39% of the mammary CO_2 was derived from the oxidation of glucose in the lactating state and only 20% in the one dry animal. In lactation a smaller proportion of the total glucose taken up by the udder was oxidized (25%) than in the case of acetate, whereas in the dry animal 76% of the glucose was oxidized (Table 3).

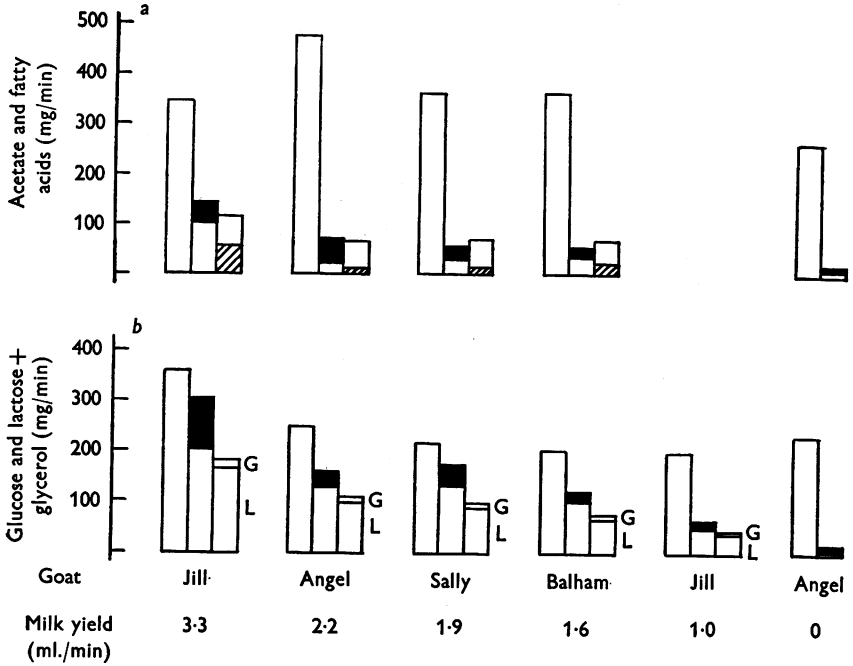

Fig. 2. The mammary uptake of acetate (*a*) and glucose (*b*) compared with their total utilization and the output of their derivatives in the milk. Left-hand column, total entry rate into circulation; middle column, uptake by the udder; right column, output in the milk. ■, Proportion oxidized, in *a*, acetate, in *b*, glucose; ▨, Fatty acids that could be formed from acetate; G, Glycerol; L, Lactose.

Mammary metabolism of acetate and glucose in relation to milk formation. Measurements were made of the net mammary uptake (blood flow times A-V difference) of acetate and glucose for comparison with the output of their major derivatives in the milk, fatty acids and lactose plus glycerol respectively. It has been assumed that over each period of study when the mean daily milk yield did not vary more than 10%, the metabolic activity of the udder did not vary significantly, so that experiments done on different days can be compared. Previous work (Linzell, 1960*b*) in lactating

goats showed that minute-to-minute, hour-to-hour and day-to-day variations in blood flow and A-V differences were random so long as the milk yield was steady, results which are confirmed in the present work (e.g. Table 2). It is well known that the rate of milk secretion readily falls in response to mild stress (e.g. fasting, a change in environment, slight illness) but in none of the experiments reported here were the milk yields on the days of the experiments significantly different from the previous few days or from each other. The results are shown in Fig. 2. It will be seen that during lactation the mammary glands use a large proportion of the total acetate and glucose available to the whole body. This is particularly true of glucose where in the fully lactating animals 60–85 % of the total glucose entering the circulation was used by the udder. In the case of acetate 14–15 % was taken up by the udder in three animals and in the highest yielding one (Jill) 41 %. These unexpectedly high uptake figures gain credence when compared with output of fat and lactose in the milk. After subtracting the proportion of glucose oxidized the milk lactose and glycerol accounted for 79–95 % of the glucose uptake. In the case of acetate the amount oxidized left only sufficient to form 17–29 % by weight of the fatty acids in three animals and 45 % in the high yielding one.

DISCUSSION

There are no published data on the rates of entry and oxidation of acetate and glucose for the whole body in goats and none for lactating dairy animals so that we can only compare our figures with those made in non-lactating ruminants. The goat is similar to the sheep and cow in that more of the total CO_2 is derived from acetate than from glucose. Acetate entry rates were similar to the figures of Annison & Lindsay (1961) in sheep but about half those of Essig, Norton & Johnson (1961). Entry rates of glucose were almost the same as those reported for sheep by Annison & White (1961) and Kronfeld & Simesen (1961) but about $1\frac{1}{2}$–2 times the values of Bergman (1963) and Ford (1963) in sheep and Davis & Brown (1962) in steers. It seems highly likely that such measurements will be affected by the time after feeding and the diet and plane of nutrition. Our goats were studied after feeding and were on a standard diet similar to those fed to lactating dairy cows.

The results show clearly that during lactation the udder uses both substrates at many times the average rate of the other organs and in addition that over 4 times as much CO_2 originates from glucose in secreting mammary tissues as in the rest of the body so that in most cases more CO_2 is derived from glucose than from acetate as was found in isolated perfused goat

mammary glands (Hardwick *et al.* 1963). The proportion of mammary CO_2 derived from acetate is the same as in the rest of the body, but because the net uptake of acetate is less than for glucose a greater proportion of the acetate is oxidized than is glucose. Another difference is that during lactation acetate and glucose together account for about two-thirds of the total mammary CO_2, whereas they account for just over one-third in the whole animal. A major part of the remainder probably arises from propionate and butyrate in the whole animal but the contribution of these substrates to oxidative metabolism has not yet been measured in the goat. Plasma-free fatty acids (FFA), which may account for as much as 25% of the CO_2 production in starved (24 hr) sheep (West & Annison, 1964), is not a major source of CO_2 in the fed goat. Isotope dilution experiments with ^{14}C-labelled stearic, oleic and palmitic acids have shown that under these conditions the contribution of plasma FFA to total CO_2 production is only about 2–3% (Annison, Fazakerley, Linzell & Nicholls, unpublished).

A most unexpected finding was that in these goats the fully lactating udder was apparently using 60–85% of the total glucose produced in the body. At first this figure seemed improbably high but when the amount of glucose that was being oxidized by the udder was calculated it was seen that the remainder was in reasonable agreement with the amounts of lactose and glycerol being put out in the milk (Fig. 2); a great deal of isotopic evidence from several laboratories has shown that glucose is the main precursor of these substances. Even if no glucose were oxidized by the mammary tissue milk lactose production would demand nearly half of the circulating glucose available in full lactation. It should be mentioned that the Saanen goats used in this work are a dairy breed selected for high milk yields and that the udder in these animals was 2·5–5% of the body weight, as large or larger than the liver, and could well be taking 15–20% of the cardiac output. Further evidence in favour of the magnitude of the udder uptake of substrates is that after single injections of labelled substrates Kleiber, Black, Brown, Baxter, Luick & Stadtman (1955) recovered 50% of glucose in milk lactose in a cow, Kleiber, Smith, Black, Brown & Tolbert (1952) recovered 9–12% of acetate in the milk fat of cows and Lascelles, Hardwick, Linzell & Mepham (1964) recovered 38 and 67% of tritiated chylomicra in the milk fat of two goats.

The proportion of the total circulating acetate that is used by the secreting udder (14–41%) is less than for glucose but a greater proportion of that taken up is oxidized by the mammary glands (29–69%). It has been known since the experiment of Popjak, French, Hunter & Martin (1951), who injected ^{14}C-labelled acetate into a lactating goat, that in ruminants acetate is the main source of milk fatty acids up to and including C16. It has been known also for a long time that secreting mammary

tissue produces more CO_2 than the O_2 used because an oxygen-poor molecule (fat) is being produced from an oxygen-rich one (acetate in ruminants). In lactating goats Linzell (1960*b*) found the R.Q. to be 1·24 ± 0·23 (S.D.). The oxidation of glucose and acetate would give an R.Q. of 1 and from the present data of the amount of acetate available for forming fatty acid, it can be calculated that sufficient O_2 would be 'spared' to raise the R.Q. to 1·1–1·28, which is in reasonable agreement with the observed values (1·21–1·51).

Knowledge of the amount of acetate that is oxidized is also interesting in determining how much of the milk fatty acids is formed from acetate and how much from blood triglycerides. The fatty acids that can be formed from acetate constitute the major part of the total ruminant milk fatty acids. However, Lascelles *et al.* (1964) showed that tritiated chylomicra from intestinal lymph are avidly taken up by the lactating goat's udder and incorporated into milk fat and Barry, Bartley, Linzell & Robinson (1963) found in the same goats used in this work, that sufficient chylomicra are taken up to account for most of the milk fat formed. These findings now appear more reasonable when allowance is made for the amount of acetate oxidized by the udder because sufficient remains to form only 17–45 % of the milk fatty acids so that a considerable proportion of milk fat must be derived from triglycerides.

In our experiments we have been unable to demonstrate any effects of oxytocin (endogenous or exogenous) on mammary metabolism that could not have occurred by chance, but we were chiefly interested in deciding whether the doses we injected were influencing our results. The hypothesis that, in addition to squeezing the milk from the alveoli, oxytocin released during milking and suckling also has a metabolic effect on the udder (e.g. increasing the uptake and oxidation of glucose) is plausible. Our results suggest that the small amounts released (40–400 m-u. in goats according to various authors) at the morning and evening milking would have a negligible effect, but the idea merits more detailed study.

SUMMARY

1. The isotope dilution method of measuring substrate turnover and oxidation has been used on four trained conscious female goats under normal animal-house conditions and combined with measurements of substrate uptake and oxidation by the mammary gland.

2. The total entry rate of acetate in the whole animal was 4·9–6·5 mg/kg/min in lactation and 4·0 mg/kg/min in a dry goat; 21–37 % of total CO_2 was produced from acetate. In both lactating and dry goats the glucose entry rate was 3·1–5·3 mg/kg/min and glucose accounted for 7–14 % of total CO_2 production.

3. During full lactation the udder took up 24–41 mg/kg/min of acetate and 49–89·5 mg/kg/min of glucose; 21–33 % of the mammary CO_2 came from acetate and 29–49 % from glucose; 29–69 % of the acetate taken up and 16–34% of the glucose were oxidized.

4. During lactation the udder accounted for 60–85 % of the glucose used by the animal and 15–41 % of the acetate.

5. After allowing for the amount oxidized sufficient acetate remained to form only 17–45 % of the milk fatty acids, but there was enough glucose to form all the lactose and milk fat glycerol.

6. The injection of oxytocin (400 m-u.) did not significantly alter the rates of entry or oxidation of glucose or acetate under our conditions.

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