MASTER

CALCIUM-47 KINETICS IN GOATS AS A FUNCTION OF AGE
AND DURING PREGNANCY AND LACTATION ^{1,2}

By: J. J. B. Anderson, Y.-H. Kuo, W. C. Crackel and
A. R. Twardock

Department of Veterinary Physiology and Pharmacology
College of Veterinary Medicine
University of Illinois
Urbana, Illinois 61801

Address correspondence to:
Dr. John J. B. Anderson
at the above address

1. The data reported here were presented in part at the Federation Meetings (Fed. Proc., 27:311, 1968), Atlantic City, New Jersey, April 16, 1968, and in part at a Conference on Parturient Paresis in Dairy Animals held at the University of Illinois, Urbana, November 18, 1968 (see reference 13).
2. This research has been supported by grant No. AT (11-1)-1339 from the U. S. Atomic Energy Commission

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:
A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or
B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.
As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

feg

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

ABSTRACT

A 34 experiment study of the ^{47}Ca kinetic parameters of the readily exchangeable calcium pool (RECaP) of dairy goats was undertaken to evaluate their dynamic changes as a function of pregnancy, parturition and lactation for a period of two years. Goats were injected intravenously with about 15 μCi ^{47}Ca every 2 to 4 weeks and, from blood samples drawn at several intervals up to 150 hr post-injection, a plasma specific activity curve was constructed. From this plot the size (E), biological half-life ($T_{1/2}$) and transfer rate (TR), an index of turnover, of the RECaP were calculated. As gestation proceeded $T_{1/2}$ drastically fell from about 35 to a low of about 15 to 20 peri-parturition, whereas E increased only slightly in the last few weeks prior to kidding. During lactation E and $T_{1/2}$ underwent dramatic excursions up and down in synchrony as milk production remained high and subsequently at drying off returned to normal pre-gestational values of about 5 gm and 30 hr. Changes in TR reflected the fetal and lactational demands for calcium. Kinetic parameters of non-pregnant non-lactating mature female goats remained nearly constant over the period of two years in great contrast to goats passing through successive reproductive stages. However, study of these mature and other young immature goats demonstrated that E decreased and $T_{1/2}$ increased as a function of age from 11 months and on.

Milk specific activity curves mirrored the plasma curves when lactational time lag was considered. Blood calcium concentrations fell slightly during late pregnancy and even more so during lactation.

INTRODUCTION

The etiology of parturient hypocalcemia and paresis in dairy cows has long been an enigma to those interested in this complex metabolic disease. Two recent symposia (1, 6) have been devoted to this complex syndrome, but the research reports from a variety of experimental approaches failed to reveal any breakthrough in our understanding of the disturbances of the basic mechanisms regulating calcium homeostasis in the peri-parturient cow. Among other hypotheses, reductions in both intestinal calcium absorption and bone calcium mobilization have more generally been suggested as being inadequate to restore the normal blood calcium concentration in parturient cows with marked hypocalcemia attributed to colostrum formation and lactation. (7, 10-12) However, it is generally regarded that the disturbance in calcium metabolism must begin at least a week or so prepartum because negative calcium balances start then in incipient paretic cows, whereas such negative balances do not occur in normally calving cows (14).

Rapidly mobilizable calcium has been shown to decrease as a function of age in two different bovine studies (2,4) and intestinal calcium absorption has also been found to decrease with age in cows (5). The readily exchangeable calcium pool (RECaP) has been thought to play a major role in the animals calcium homeostatic challenge during the physiological stress accompanying parturition and the initiation of lactation (13). An additional stress on the RECaP may be the level of dietary calcium and phosphorus intake. Low calcium intakes have been demonstrated by one group of investigators (8) to increase the amount of mobilizable calcium, whereas another group (3) found the reverse employing the kinetic approach used in this communication.

The intent of this study was to evaluate the changes in the kinetic behavior of the RECaP of goats as a function of the successive events of gestation, parturition and lactation and to compare these findings to a kinetic analysis of the calcium pool in goats which had never been pregnant or lactating. Calcium-47 was chosen as the tracer of stable calcium because of its short physical half-life (4.5 days) which allows for repeated measurements and its emission in the same animal every two weeks of gamma photons which are easy to detect. The dairy goat was selected as a model for the cow because of its smaller body size and, hence, total body calcium, which requires less of ^{47}Ca for meaningful measurement in each experiment and permits the use of more animals.

METHODS

Of the six dairy goats used in this study through the course of 34 experiments lasting two years, one Toggenburg (No. 6) passed through one pregnancy, parturition and lactation, whereas two Nubians (Nos. 7 and 14) completed two pregnancies parturitions and subsequent lactations each. Two other Nubian goats (Nos. 4 and 16) and a Saenen (No. 1) were never pregnant throughout the study.

On day 0 of each experiment, the goats were injected via the jugular vein with approximately 15 μCi of ^{47}Ca . Blood samples (25 ml) were drawn within an hour post-injection and in the initial experiments at the following times up to about 150 hours: 14-16, 21-24, 27-30, 35-39, 44-48, 52-55, 58-62, 78-82, 98-102, 122-128 and 140-150. In subsequent experiments, samples were taken only to about 70 hours post-injection because later samples were unnecessary for calculating the parameters of the RECaP (see below).

Blood samples were centrifuged at room temperature for 30 minutes at 1800 rpm and 10 ml of the resulting plasma of each sample was placed in a vial for ^{47}Ca scintillation counting in a 3" x 3" NaI(Tl) well-type crystal which was connected to a combined pulse-height analyzer and scaler and to an automatic sample changer (Model 4218, Nuclear-Chicago, Chicago). Detection of radioactivity in samples was always compared to a 10 ml standard volume prepared from the original dosing solution in order to correct for physical decay of ^{47}Ca and any variations in instrument operation. After counting, total calcium in the plasma was measured by photometric titration using sodium ethylenediamine tetraacetic acid and Eriochrome blue-black (Calcon) indicator (9).

Plasma specific activity, percent of the injected dose (I.D.) of ^{47}Ca per gm of total Ca in a given volume of plasma, of each sample was calculated and its logarithm was plotted as a function of time in hours (linear) post-injection. In Figure 1 is an example of a specific activity curve of a mature non-pregnant non-lactating goat (No. 4). Since the curves were multi-exponential, data points within an arbitrary portion of the curve from 20 to 64 hrs post-injection, which appeared fairly linear, were selected for a linear regression analysis by the method of least squares by computer. This best-fit line was extrapolated back to the y-axis intercept at 0 time, which gave a value of 14.5% of I.D./gm Ca. When this number is divided into 100% of the injected dose, whose radioactivity at 0 time is assumed to be distributed uniformly if mixing at injection had been instantaneous, a value of 6.9 gm results. This value represents the size, E, in gm of the RECaP. It should be emphasized that E is a measure based on an arbitrary selection of a portion of the specific activity curve from 20 to 64 hr, but it is a highly useful tool for relative comparison of different animals or the same animal under different physiological conditions.

The biological half-life, $T_{1/2}$, in hours of the RECaP is calculated by determining by use of the regression line the time it takes for 14.5% I.D./gm to decrease by a factor of two to 7.25 of I.D./gm. In Fig. 1, by extrapolation down from the regression line to the y-axis, the $T_{1/2}$ is found to be 33.0 hr. All calculations were processed by computer.

Another parameter of the RECaP, transfer rate or TR, can be calculated from the values obtained for E and $T_{1/2}$ and it serves as an index of the turnover rate of this pool. Transfer rate in gm/hr is calculated as follows:

$$TR = E \times \frac{0.693}{T_{1/2}} \quad \text{and in this example was } 0.14 \text{ gm/hr.}$$

The term $0.693/T_{1/2}$ is the decay constant, k , of the pool. As can be seen, if E increases, TR increases; if $T_{1/2}$ increases, TR decreases; and if E increases and $T_{1/2}$ decreases, TR increases according to the relative contributions of each term. An understanding of the changes in TR of the RECaP is necessary for an appreciation of the physiological changes influencing this pool during pregnancy and lactation.

All goats were offered adequate amounts of loose hay and grain and water ad libitum. They were housed along with other goats in spacious pens that provided outside runs as well as inside protection. Their health was good and the periods of pregnancy parturition and lactation were uneventful except for a brief period of mastitis in goat No. 7.

In addition to determinations of blood plasma radioactivity and Ca, milk samples were collected and similarly analyzed. The goats were also measured for their total body activity by a 4" x 5" NaI (Tl) crystal detector in a shielded vault (ILLASCO) and associated electronic components similar to those described above. These data will be published at a later time.

A detailed discussion of the method of measurement of calcium kinetics in dairy cows is presented elsewhere (13).

RESULTS

Figure 2 illustrates the experiment-to-experiment fluctuations in E and $T_{1/2}$ of the RECaP of a goat (No. 4) never pregnant during this study. Values of E ranged from about 5 to 10 gm over the two year period, whereas $T_{1/2}$ bounced around from roughly 20 to 35 hr. Excursions of $T_{1/2}$ are always considerably greater than of E , which may reflect physiological, dietary or environment variations. Plots of E and $T_{1/2}$ of other non-pregnant non-lactating goats as a function of time were similar (for a plot of goat No. 1, see ref. 13). In these three goats the constancy of these values occurred irregardless of seasonal variation.

In the next three illustrations are presented the dynamic patterns of E and $T_{1/2}$ of the RECaP from goats going through one or two pregnancies and subsequent lactations. Shortly after goat No. 6 (Fig. 3) became pregnant $T_{1/2}$ steadily but dramatically fell from 34 to 18 hr, whereas E rose only slightly in the latter part of gestation from about 5 to 8 gm. The marked change in TR of the RECaP from beginning (i) to end (e) of pregnancy can be seen as follows:

$$TR_i = 5 \text{ gm} \times \frac{0.693}{34 \text{ hr}} = 0.1 \text{ gm/hr.}$$

$$TR_e = 8 \text{ gm} \times \frac{0.693}{18 \text{ hr}} = 0.3 \text{ gm/hr.}$$

A listing of TR values of each goat as a function of time is given in Table I. For the first experiment post-partum TR declined to a value of 0.2 gm/hr because E fell sharply to 3 gm even though $T_{1/2}$ continued its plummet to 10 hr, a greater than three-fold decrease from

its pre-gestation value. However, as lactation proceeded a new pattern emerged of synchronously increasing or decreasing values of E and $T_{1/2}$. In one experiment, the values of E and $T_{1/2}$ were nearly identical at 15. TR at this time in early lactation was about 0.7 gm/hr, a maximum for this goat. Such high transfer rates have only been observed during lactation. Toward the end of lactation, $T_{1/2}$ increased and E fell to their pre-gestation values.

Figures 4 and 5 show the widely fluctuating patterns of E and $T_{1/2}$ of two goats continuously pregnant or lactating. Lactational output by these two goats was greater than by goat No. 6. As in goat No. 6 (Fig. 3) E increased in the latter part of gestation, whereas $T_{1/2}$ had already fallen when the experiments were initiated. In goat No. 7 (Fig. 4) a flareup of mastitis persisted for only a brief period in early lactation; otherwise lactation was normal with respect to milk production and length of time. E and $T_{1/2}$ declined after normal lactation was resumed; then E increased from about 5 to 10 gm and subsequently returned gradually to a level of 7, whereas $T_{1/2}$ plateaued earlier at a value of around 18 hr. Neither the onset of the second pregnancy nor the cessation of milking had much effect on these two parameters and, hence, on TR of the RECaP. However, just after second kidding, E rose very steeply from 7 to 20 gm while $T_{1/2}$ remained constant. Then during lactation, the pattern of synchronous declines or rises in E and $T_{1/2}$ occurred as in goat No. 6.

Figure 5 depicts the patterns of changes of the parameters E and $T_{1/2}$ of goat No. 14 through two pregnancies and lactations. The findings are similar to those of goat No. 7 (Fig. 4) except that the extremely large increases in E after each parturition to values of around 25 gm are remarkable. During the first lactation E remained high at around 20, but it fell rapidly

and then rose gradually to about 7 to 8 gm after initiation of the second pregnancy. The synchronous rises and falls in E and T $1/2$ were present during both lactations as in goats No. 6 and 7, but the apparently overcompensatory extremes of E resulted in large TR values of the order of 1 gm/hr. These large TRs reflect the very high turnover of the RECaP requisite to the demand for Ca in milk production.

The first maximum in pool size during the second lactations of goats No. 7 and 14 and the only lactation of goat No. 6 (Figs. 3 to 5) coincided with maximum daily milk production (Table II) and might reflect the large quantity of calcium in the mammary glands.

Blood specific activity curves were mirrored by the milk specific activity curves when allowance was made for the lag time in milk production and collection. Typical blood and milk specific activities as a function of time are presented for one goat (No. 14) in Fig. 6.

It should be noted in Fig. 2 that E decreased from about 6 to 3 gm and T $1/2$ increased from around 25 to 35 hr as a function of time of the experiments. Calculations of TR revealed that it changed from almost 0.2 gm/hr to 0.06 gm/hr over a period of two years.

This finding showed that turnover of the RECaP decreases with increasing age, a result which was confirmed using several goats first injected as kids and followed to maturity (Fig. 7). The plot of decreasing transfer rate as a function of age reflects the increase in E to a maximum at about 11 months of age and then its subsequent decrease to maturity. In the mature goats, E values of 3 to 9 gm represent about 0.4 to 1.2% of total body Ca or from approximately 0.06 to 0.2 gm Ca/Kg body weight.

In Table III are collected the mean plasma calcium concentrations ($\pm$ 1SD) of goats during pregnancy and lactation and of goats which never were pregnant or lactating during these experiments. Note that calcium decreased only slightly during the pregnancy of goat No. 6 but fell greatly during lactation of all lactating goats. No change in calcium concentration was observed in goats never pregnant as a function of age.

DISCUSSION

Dramatic changes in E, $T_{1/2}$ and TR of the RECaP have been shown to occur during periods of gestation and milk production. Whereas, TR of this pool fluctuates over a relatively narrow range in non-pregnant, non-lactating periods, it changes abruptly to meet the calcium requirements of the developing fetus and, particularly in the last day or so pre-partum, of colostrum production during gestation and of subsequent lactation post-partum (See Table I). The increased turnover of the RECaP during pregnancy is attributed to a sharp fall in $T_{1/2}$ after the onset of and a rise in $T_{1/2}$ near the end of gestation. (See Figs. 3-5).

Although direct measurements of these parameters of the RECaP are not available at parturition, they have been made within a week of partum (Table I) and they suggest that E continues its rise from late gestation through parturition before abruptly falling during early lactation in parallel with A falling $T_{1/2}$. Subsequently, both E and $T_{1/2}$ rise steeply in synchronous fashion, as if orchestrated, to fulfill the demand for calcium of the mammary glands. In the case of goat No. 7 during its second lactation (Fig. 4) TR values were as follows: about 0.8 gm/hr at the maximum of the first excursion; about 0.2 gm/hr at the minimum of the second; about 0.5 gm/hr at the maximum of the third; and again about 0.2 gm/hr at the minimum of the fourth and last excursion before the E and $T_{1/2}$ returned to approximately normal pre-gestation values about 9 months after parturition. Thus, the decreased transfer rate reflected the reduced need of calcium from the RECaP as milk output decreased. However, it is not clear why pool size is largest during maximal milk production about one to two months post-partum, although the quantity of calcium in the goat's udder may have been maximal during this time (Table II).

It appears from the kinetic data presented here that mobilization of the RECaP is a direct result of the physiological stresses on calcium homeostasis related to gestation and lactation. Whether turnover of this calcium pool is influenced strictly by rapidly acting physico-chemical mechanisms, including dissolution and exchange requisite to maintaining a constant blood calcium concentration or by parathyroid hormone in response to hypocalcemia or by a combination of these two types of actions is not possible to state with any certainty at this time. Further experiments, particularly during late pregnancy and early lactation, will be necessary to try to elucidate the influences impinging on the RECaP. However, this problem is of considerable interest because knowledge of the mechanisms of bone turnover including the RECaP peri-partum may aid in unravelling the etiology of parturient hypocalcemia and paresis which occurs most commonly in high producing dairy cows as a result, perhaps, of a breakdown in these calcium mobilizing mechanisms.

FIGURE LEGENDS

- Fig. 1. Semilogarithmic plot of blood plasma specific activity (percent injected dose of ^{47}Ca per gm of calcium) as a function of time of goat No. 14. The linear portion of the curve between 20 and 68 hours post-injection is used for calculating the size (E), biological half-life ($T_{1/2}$), and transfer rate (TR) of the readily exchangeable calcium pool (RECaP). See text for detailed discussion.
- Fig. 2. Plot of the kinetic parameters, pool size and half-life of the RECaP of goat No. 4 as a function of time. This goat was neither pregnant nor lactating during the course of study.
- Fig. 3. Changes in E and $T_{1/2}$ as a function of pregnancy, parturition and lactation of goat No. 6. Note the precipitous fall of $T_{1/2}$ prior to parturition and the wide fluctuations of $T_{1/2}$ and E during lactation. (This figure was also published in reference 13 and is used here with permission of the publisher, Academic Press).
- Fig. 4. Changes in E and $T_{1/2}$ of goat No. 7 through two gestations and subsequent lactations. Lactation and pregnancy were concurrent in the second gestation, after which time $T_{1/2}$ and E fell and rose in synchrony. (This figure was also published in reference 13 and is used here with permission of the publisher, Academic Press).
- Fig. 5. Changes in E and $T_{1/2}$ of goat No. 14 through two gestations and subsequent lactations also. The fluctuations in E and $T_{1/2}$ are similar to those observed in goat No. 7 (Fig. 4), but the upward excursions of E after each parturition are extremely large. These changes reflect a very high turnover of the RECaP requisite to the Ca demands of lactation.

Fig. 6. Semi-logarithmic plot of ^{47}Ca plasma and milk specific activity as a function of time of goat No.14 during one experiment (32).

Fig. 7. Plot of ^{47}Ca transfer rate as a function of age of 7 goats. The three youngest goats ($\odot$) were injected at eight months and measurements of kinetic parameters of the readily exchangeable calcium pool were made of the goats up to two and a half years of age. The other four goats ($\boxdot$) were eleven months at the beginning and 17 months of age at the conclusion of measurements.

ACKNOWLEDGEMENTS

Appreciation is expressed to Dr. John H. Marshall of Argonne National Laboratory for a fruitful discussion concerning selection of an arbitrary time-specific portion of the specific activity curve for analysis. Also, we gratefully acknowledge the technical assistance of Mrs. Mary Cupp and Mr. Richard W. Anderson, and the advice and help of Dr. Timothy G. Lohman.

TABLE I

Mean Values of Transfer Rate in Grams Per Hour of the Readily Exchangeable Calcium Pool of Goats

Goat No.	Breed	Age at Start*	Mean Transfer Rate			
			<u>Normal</u>	<u>During Pregnancy</u>	<u>Post- Partum</u>	<u>During Lactation</u>
<u>Non-Pregnant Non-Lactating</u>						
1	Saanen	5 yr.	0.10 $\pm$.02	--	--	--
4	Nubian	2 yr.	0.18 $\pm$.04	--	--	--
16	Nubian	2 yr.	0.21 $\pm$.07	--	--	--
<u>One Pregnancy and Lactation</u>						
6	Toggenburg	5 yr.	0.15 $\pm$.04	0.16 $\pm$.06	--	0.40 $\pm$.21
<u>Two Pregnancies and Lactations</u>						
7	Nubian	2 yr.	--	(1) 0.22 $\pm$.06	0.47	0.29 $\pm$.03
				(2) 0.29 $\pm$.03***	0.73	0.41 $\pm$.19
14	Nubian	2 yr.	--	(1) 0.38 $\pm$.05	--	0.48 $\pm$.05
				(2) 0.48 $\pm$.05***	0.42	0.66 $\pm$.26

* January 1966

** Started April, 1967

† Within one week of parturition (one experiment)

†† Standard Deviation

*** Value same as for first lactation of same goat

TABLE II

Mean Daily Milk Production in Grams of Lactating Goats on a Per Month Basis

<u>Date</u>	<u>Goat No. 7</u>	<u>Goat No. 14</u>	<u>Date</u>	<u>Goat No. 7</u>	<u>Goat No. 14</u>	<u>Goat No. 6</u>
4/13/66		Birth	3/26/67	Dry	Birth	
4/27	Birth	Nursing	4/-	Dry	3395	
5/4	Nursing	Nursing	5/12	Birth	3210	
5/-	650	1420	5/-	Nursing	3445	
6/-	835	2210	6/-	3060	2910	
7/-	1145	2320	7/7	2840	2595	Birth
8/-	1180	2330	7/-	2850	2490	2780
9/-	1270	1950	8/-	2320	1950	2800
10/-	950	1785	9/-	1810	1865	2370
11/-	875	1525	10/-	1410	1215	1615
12/-	975	1580	11/-	1110	800	1095
1/-/67	925	1055	12/-	1345	1040	1270
2/-	1020	Dry	12/11	Dry	Dry	Dry
3/-	Dry	Dry				

TABLE III.

Mean Plasma Calcium Concentration in Mg Percent of Goats
During Periods of Pregnancy Lactation and Non-Pregnancy and Non-Lactation

<u>Goat</u>	<u>Experiment</u>	<u>Period</u>	<u>N</u>	<u>Mean Mg % Ca</u>	<u>S.D.</u>
1	4-37	Non-Preg	32	9.2	0.42
4	4-37	Non-Preg	32	10.4	.51
16	27-37	Non-Preg	9	9.8	.54
6	4-23	Non-Preg	20	10.7	.40
	24-31	Preg	6	10.6	.68
	32-37	Lact.	6	9.6	.38
7	4-9	Preg. 1	6	10.3	.04
	26-28	Preg. 2	3	10.0	.20
	22-25	Preg. 2 & & Lact. 1	4	10.0	.35
	10-21	Lact. 1	12	9.3	.49
	29-37	Lact. 2	9	8.7	.30
14	4-9	Preg. 1	6	10.6	.23
	24-25	Preg. 2	2	10.5	.25
	20-23	Preg. 2 & Lact. 1	4	10.0	.31
	10-19	Lact. 1	10	9.7	.29
	26-37	Lact. 2	12	9.4	.48

REFERENCES

1. Anderson, J. J. B., ed. 1969. Parturient Hypocalcemia. Academic Press, New York (in press).
2. Anderson, J. J. B., Crackel, W. C. and Twardock, A. R. Calcium-47 Kinetics in Cattle as a Function of Age. Submitted for publication in J. Dairy Sci.
3. Anderson, J. J. B., Kuo, Y.-H., Crackel, W. C. and Twardock, A. R. 1969. Effects of High and Low Dietary Calcium on the Size and Half-Life of the Readily Exchangeable Calcium Pool in Female Goats Under Two Different Feeding Conditions. In: Parturient Hypocalcemia, J. J. B. Anderson, ed. Academic Press, New York (in press).
4. Hansard, S. L., Comar, C. L., and Davis, G. K. 1954. Effects of Age upon the Physiological Behavior of Calcium in Cattle. Am. J. Physiol., 177:383.
5. Hansard, S. L., Comar, C. L., and Plumlee, M. P. 1954. The Effects of Age upon Calcium Utilization and Maintenance Requirements in the Bovine. J. Animal Sci., 13:25.
6. Kronfeld, D. S., chairman. 1968. Eighth Annual Ruminant Nutrition Conference. Fed. Proc., 27:137-161.
7. Kronfeld, D. S. 1968. Introduction and Hypothesis. Fed. Proc., 27:137.
8. Luick, J. R., Boda, J. M., and Kleiber, M. 1957. Some Biokinetic Aspects of Calcium Metabolism in Dairy Cows. Am. J. Physiol., 189: 483.
9. Malmstadt, M. V., and Hadjiioannou, T. P. 1959. Automatic titration a of Calcium or magnesium in blood serum. Clin. Chem., 5:50.
10. Mayer, G. P., Ramberg, C. F., Jr., and Kronfeld, D. S. 1969. Calcium Homeostasis in the Cow. Clin. Orthoped., No. 62:79.
11. Nurmio, P. 1968. On Plasma Calcium Regulation in Paresis Puerperalis Hypocalcemia in Cattle. Acta Vet. Scand., Suppl. 26, 100 pp.
12. Payne, J. M. 1964. Recent Advances in Our Knowledge of Milk Fever. Vet. Res., 76:1275.
13. Twardock, A. R., Kuo, Y.-H., Crackel, W. C., and Anderson, J. J. B. 1969. Measurement of Calcium Kinetics in Dairy Goats. In: Parturient Hypocalcemia, J. J. B. Anderson, ed. Academic Press, New York (in press).
14. Ward, G. M., Blosser, T. H., and Adams, M. F. 1952. The Relation of Prepartal and Postpartal Mineral Balances to the Occurence of Parturient Paresis in Dairy Cows. J. Dairy Sci., 35:587.

Fig. 1

Method for Determining the Readily Exchangeable Calcium Pool Size (E), Biological Half-Life ($T_{1/2}$), and Transfer Rate (TR) using Calcium-47. (Goat #1, Experiment 22)

Intercept at zero time = 14.5 % Dose/Gm Ca

$$E = \frac{100}{14.5} = 6.88 \text{ Gms Ca}$$

$$T_{1/2} = 33.0 \text{ Hours}$$

$$TR = \frac{.693 \times E}{T_{1/2}} = 0.14 \text{ Gms Ca/Hour}$$

Fig. 6

Fig. 7