Use of ultrasonic Doppler waveforms in the assessment of uterine artery blood flow

by

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INTRODUCTION

A great deal of work has been done in recent years using Doppler continuous wave ultrasound to study blood flow. Blood velocity, measured at some fixed location in a blood vessel, varies cyclically with time even though the mean flow through that vessel may remain constant. A plot of the instantaneous velocity versus time provides the blood velocity waveform. In general, the characteristics of these waveforms depend on several parameters including heart rate, downstream impedance (resistance to flow), physical dimensions of the vessel, and physical characteristics of the vessel such as wall elasticity. In some cases these parameters can be related to certain waveform indices which are obtained from the analysis of the velocity waveform.

These indices can be used for various diagnostic purposes. For example, waveform analysis has been used to diagnose common femoral arterial disease by comparing the characteristics of waveforms collected from normal undiseased arteries to those from arteries that are partially obstructed. The method of analysis and the particular index to be used are not completely agreed upon.

Although a large part of the research related to the use of waveform indices in the study of blood flow has been done to study arterial disease, other uses are possible. In the present study, the potential use of Doppler waveforms for the assessment of blood flow in uterine arteries is investigated. Currently, there are no noninvasive techniques that can be used to routinely obtain this important flow measurement, even though a

knowledge of blood flow is of fundamental importance in the study of reproductive physiology.

One important application is related to early pregnancy detection in cattle. Since it is known that there are marked changes in blood flow through the uterine arteries during the early stages of pregnancy in cattle, it may be possible to determine pregnancy of the animal by detecting these changes through the use of Doppler ultrasound.

Cows are particularly well suited to this investigation since they usually have one gravid and one non-gravid uterine horn during pregnancy. The increases in blood flow to the gravid uterine horn are much larger than the changes to the non-gravid side. Therefore, the waveforms can be recorded from both sides and compared to determine major changes in flow.

Thus, the specific objectives of this study were severalfold:

1) To develop a technique and probe for routinely collecting continuous wave Doppler ultrasound data from the uterine artery of cattle.

2) To develop a data collection system.

3) To develop software for a PDP-11/23 digital computer for processing the data collected and calculating various waveform indices.

4) To collect, process, and analyze data to determine the feasibility of using blood velocity waveform indices to assess uterine artery blood flow.

5) To collect and analyze electromagnetic data to compare mean blood flow to certain waveform indices.

The long term potential for this research involves the possibility for development of a technique for determining pregnancy in cattle as early as

16 days after mating. Currently there is no reliable pregnancy test at less than 30 days of gestation. Other potential uses could be the development of pregnancy tests for other livestock, and the use of Doppler ultrasound to study blood flow in the uterine artery of humans to determine fetal well-being.

This study was performed in conjunction with researchers from the ISU Animal Science Department with the primary responsibility for data collection going to the Animal Science group, and the design and development of hardware, computer software, and data collection system, along with data analysis, going to the Biomedical Engineering group.

LITERATURE REVIEW

Continuous wave Doppler ultrasound is commonly used in clinical and experimental applications to obtain velocity waveforms which can be analyzed to determine useful information. Much of the early work using waveform analysis was of a qualitative nature involving comparisons of basic wave shapes.

Two methods of quantitative analysis are frequently used. One method is based on instantaneous mean velocity flow waveforms obtained with a zero crossing detector. A second method uses multifilter analyzers or fast Fourier transforms (FFT's) to obtain instantaneous maximum velocity waveforms. Both methods of quantitative analysis employ waveform indices which provides a numerical representation of wave shape. The following indices have been used in past studies.

Waveform Indices

The output signal from the continuous wave Doppler ultrasound is a function of beam angle, and the output remains proportional to velocity as the angle of beam varies, although the signal magnitude changes. Normalized indices are dimensionless with respect to velocity (some have dimensions of time) and are independent of beam angle. With these normalized indices a waveform may be used for which absolute values of blood velocity are unknown. The following list describes several possible indices.

Fourier pulsatility index

(Woodcock et al., 1972) The Fourier pulsatility index PI_F is defined

by

$$PI_F = \sum_i^n \frac{V_i^2}{V_o^2}$$

where V_i is the modulus magnitude of the nth Fourier harmonic and V_o is the mean forward flow velocity.

The peak to peak pulsatility index

(Gosling and King, 1974) The peak to peak pulsatility index is probably the most widely used index and has widespread clinical use. This index relates the peak-to-peak amplitude of the velocity waveform to the mean amplitude. It is calculated as follows:

PI = (peak-peak amplitude)/mean amplitude

Another pulsatility index (Skidmore and Woodcock, 1978) which is used is defined by:

$$PI_s = (S-D)/S$$

where S is the peak systolic amplitude and D is the end diastolic amplitude.

Rise time

(Coghlan and Taylor, 1980) The rise time is a commonly used index which is measured as the time between the foot of the wave and the systolic peak.

Acceleration

(Hankner, 1978) This index is simply the rate of change of the blood velocity with respect to time (dV/dt). The specific parameter measured is normally the systolic acceleration. This may be the average systolic

acceleration which can be calculated as

$$A=(V_{pk}-V_{ft})/\text{rise time}$$

where: V_{pk}= maximum pulse velocity

V_{ft}= minimum pulse velocity at beginning of rise

or it may be the maximum systolic acceleration which may be easily computed when the velocity time wave is available in the form of digitized data. Although not dimensionless in this form, acceleration divided by mean or peak amplitude could be used.

Height-width index (HWI)

(Johnston et al., 1984) HWI may be calculated in the following manner:

PI/(duration of systolic peak/ duration cardiac cycle)

Another definition of this index (Bejar et al., 1982) which is used is:

HWI=Peak Width(at half peak amplitude)/peak amplitude

Path length index (PLI)

(Johnston et al., 1984) PLI is a measure of the length of the time/velocity trace. When the data are available in digitized form the PLI may be calculated as follows:

$$PLI=\Sigma_i^n \quad (((f_{i+1}-f_i)^2/f_m^2)-((t_{i+1}-t_i)^2/T))^{0.5}$$

where: n = number of samples

f_m = mean amplitude

T = period of pulse

f_i = amplitude at t_i

t_i = discrete time increment

It should be noted that PLI is dependent on T and therefore is not independent of heart rate.

Percent systole

(McCallum et al., 1978) Percent systole is the percent of the cardiac cycle which is involved in systole and can be calculated as:

(duration of systole/duration of cardiac cycle) X 100

Damping factor

(Johnston et al., 1977) The damping factor is the relationship between a proximal and distal pulsatility index, and therefore can only be determined from waveforms at two locations along a vessel. It is defined as follows:

DF=PI(proximal)/PI(distal)

Diastolic velocity slope

(Bejar et al., 1982) This index is the acceleration (dV/dt) measured on the diastolic slope of the curve. The average slope is used and can be calculated:

DVS=(Vpk-Vft)/peak-foot time

This index is not dimensionless with respect to velocity but could be divided by mean or peak amplitude to be made dimensionless.

Carotid velocity index

(Kreutzer et al., 1982) This index is similar to pulsatility index, but is defined as follows:

CVI=(peak amplitude - end diastolic amplitude)/ peak amplitude

This index appears to be the same as PI_s.

Laplace transform technique

(Skidmore and Woodcock, 1980 a; Johnston et al., 1984) To develop this technique the heart is assumed to produce a unit impulse input. The output is a third order velocity waveform which corresponds to the systems unit impulse response. The recorded wave is digitized, and from the digitized data the Fourier transform and Laplace transforms can be calculated using curve-fitting techniques. The system poles are then plotted and compared to poles in normal subjects.

It has been shown that peripheral resistance affects the one real pole with increased resistance moving the pole farther from the imaginary axis. The other two poles, which occur in the form of a complex conjugate pair, are related to wall stiffness of the vessel. The general form of the Laplace transform is

$$H(s)=1/[(s^2 + 2\delta\omega s+\omega^2)\ (s +\gamma\ )]$$

Principal Components

(Fulton et al., 1983) The method of principal components to analyze blood velocity waveforms has been used. In this method the waveform is approximated by a weighted sum of three component waveforms. The three components are derived statistically from a population of traces.

The first component is the population mean M(t). The other two components A(t) and B(t) are calculated to account for the greatest degree

of deviation by any single wave. The resulting wave can be represented

$$F(t) = M(t) + a\ A(t) + b\ B(t)$$

For each individual waveform the scalar constants a and b are calculated and can be compared to normal values for diagnostic purposes.

Clinical Application of Indices

Johnston et al. (1978) have reported the use of the pulsatility index, PI, and the damping factor, DF, to diagnose arterial occlusive disease. They have concluded that, "The pulsatility index showed an excellent correlation with the severity of atherosclerosis as assessed by arteriography."

Johnston et al. (1984) examined four indices for detecting aortoiliac disease. They included PI, HWI, PLI, and Laplace transform indices. Their conclusion after studying 232 limbs was that pulsatility index, height-width index, path length index, and Laplace transform, "are of approximately equivalent diagnostic accuracy in detecting iliac arterial stenosis." They reported 96, 96, 92, and 89% accuracy, respectively, for pulsatility index, height-width index, path length index, and Laplace transform for iliac disease with > 50% stenosis.

On line analysis of the velocity waveform from the common femoral artery has been used (Fulton et al. 1983). They have used PI, rise time and principal component analysis to clinically assess peripheral arterial insufficiency. Their conclusion was, "Our investigations have indicated that the parameters described correlate well with radiographically demonstrated distribution of disease."

Methods for characterizing fetal blood velocity waveforms have been described by McCallum et al. (1978). They have included PI, percent systole and heart rate as the significant indices in their study. They state that "Large values of pulsatility index can be associated with high placental impedance and complications during pregnancy."

Skidmore and Woodcock (1980 c) have used the Laplace transform technique in the diagnosis of arterial disease. They report using this method to distinguish between proximal arterial disease and mixed proximal and distal disease. For determining peripheral resistance the Laplace transform has no particular advantage over the pulsatility index. The Laplace transform index uses three coefficients which they have found to be related to degree of proximal disease (δ), arterial elasticity (ω), and distal impedance (γ).

Studies by Volpe et al. (1982) and Bejar et al. (1982) show the use of analyzing blood flow velocity waveforms in the anterior cerebral artery of newborn humans. They have specifically discussed the use of the pulsatility index. In both papers $PP_S = (S-D)/S$ has been used, where S is the peak systolic amplitude and D the end diastolic amplitude. Bejar points out, "The pulsatility index gives an estimation of changes in peripheral resistance only if the diastolic and systolic pressure remain constant."

A study by Kreutzer et al. (1982) looked at the use of waveform analysis in determining brain death. They used a continuous wave doppler with a pencil probe and collected data from the common carotid artery. They developed an algorithm which combines diastolic velocity slope,

width/height ratio, carotid velocity index and the kilohertz level of the velocity signal during the reading. They were able to show significant differences in waveform shape for normal, brain damaged, and brain dead patients.

Uterine Blood Flow in Pregnancy

Recent studies have shown that it is feasible to study uterine arterial blood flow in humans (Taylor et al., 1985). Taylor et al. combine real time imaging with pulsed Doppler to obtain waveforms in uterine, ovarian, and iliac arteries. They have discovered waveforms with higher pulsatility indices in non-pregnant women, and changes in uterine artery waveforms in first trimester pregnant women which suggest lower pulsatility index (Campbell et al., 1983).

Campbell et al. (1983) have used gated pulsed Doppler ultrasound to study uterine artery waveforms in second and third trimester pregnant women. They reported high diastolic velocity and low pulsatility in normal pregnancy. In complicated pregnancy about one half of the patients had waveforms which indicated high vascular resistance.

Uterine arterial blood flow has been studied during the oestrous cycle and early pregnancy of bovine (Ford et al., 1979) and porcine (Ford and Christenson, 1979). Ford et al. (1979) have used chronically implanted electromagnetic flowmeters to study mean blood flow in the uterine artery. Daily measurements were taken throughout oestrous and early pregnancy.

In sows the blood flow in the uterine artery of non-pregnant animals varied through the oestrous cycle with the highest flow occurring around

day -5 (oestrous occurs at day Ø) and the lowest flow occurring at approximately day 14 of the oestrous cycle. In pregnant sows the uterine blood flow increased 3-4 fold at approximately 12-13 days after mating.

In cows, measurements were recorded daily in both left and right uterine arteries. Again, the mean uterine blood flow varied with the oestrous cycle. The highest blood flow occurs between day -2 and day 1 of the oestrous cycle. The low blood flow occurs around day 6 and again around day 18. In pregnant cows, the mean blood flow to the gravid uterine horn increased 2-3 fold at between day 14 and day 18 of pregnancy with no corresponding increase in flow in the non-gravid uterine horn.

In summary, a number of waveform indices are listed which can be used in the study of velocity waveform characteristics. Several of these indices have been used in clinical and research applications such as the diagnosis of arterial disease, and the study of placental impedance and complications in pregnancy. Also, recent studies of uterine blood flow during pregnancy of humans, bovine and porcine have shown increased flows and corresponding changes in blood velocity waveforms during pregnancy.

MATERIALS AND PROCEDURES

Probe Design

As stated in the introduction several of the objectives of this investigation were to develop a probe, a data collection system, and software to collect, process, and analyze data. These objectives have been addressed in the following manner.

Criteria

The following criteria were used in specifying requirements for an ultrasound probe to be used in collecting data from the uterine artery of cattle.

Size and shape - The probe must be designed to fit on a finger tip, underneath a rubber glove, and to be small enough to be used in rectal palpation of cows without causing physical damage to the animal.

Reliability - The probe design must be such that it could be reliably used for periods of at least several weeks of data taking without failure. The probe needed to be designed for use in a high humidity, unclean environment with varying temperatures and the possibility of rough handling.

Signal strength - The output should be sufficiently large to be processed by the continuous wave Doppler flowmeter with the chosen design.

Design

The probe design uses two, 2 millimeter by 5 millimeter, 10.0 megahertz, piezoelectric crystals. One crystal acts as a transmitter and the other as a receiver. The two crystals lay side by side in a plastic crystal holder (see Figure 1). Each crystal is connected by two 36 guage

(Ø.ØØ9 inch diameter) stainless steel Cooner wires. In some cases these wires were soldered to the crystals at the factory and epoxy coated. In other instances a conducting epoxy (Econobond Solder 56C) was used to attach the wires to the crystals in the laboratory.

The crystal holders (see Figure 2) are machined on a milling machine from acrylic blocks, and the holder and crystals are mounted on a rubber finger cup which slips over the index finger of the operator. Some earlier model transducers used a velcro strap to hold the probe on the finger. This was acceptable although the finger cup was preferred by the operators involved.

The following procedure was used to build the transducer:

1) Using micro-manipulators, attach one four inch long Cooner wire to each side of two crystals.

2) Fasten two crystals into the crystal holder using Scotch Super Strength adhesive or equivalent. The four wires go through holes in the holder in order to stick out the back.

3) Assemble two 3 foot long cables using Ø.Ø7Ø inch diameter shielded cables (Belden 87ØØ) with RCA phono plugs on one end. Run both cables through a nine inch length of 3/16 inch diameter shrink tubing.

4) Solder the two wires of one crystal to one cable with the upper surface crystal wire attached to the outer cable wire (shield), and the bottom surface wire soldered to the inner copper wire.

5) Repeat the procedure for the second crystal.

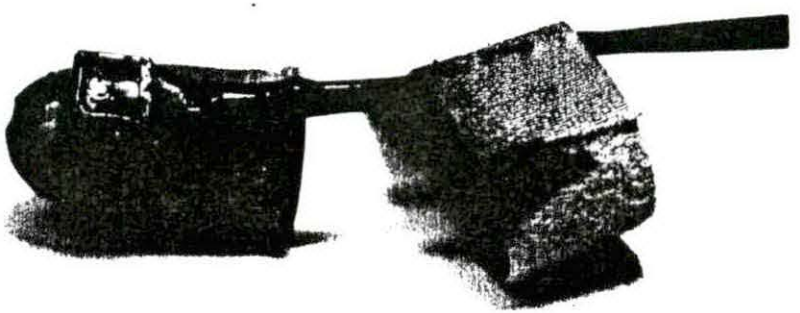


Figure 1. Transducer photograph

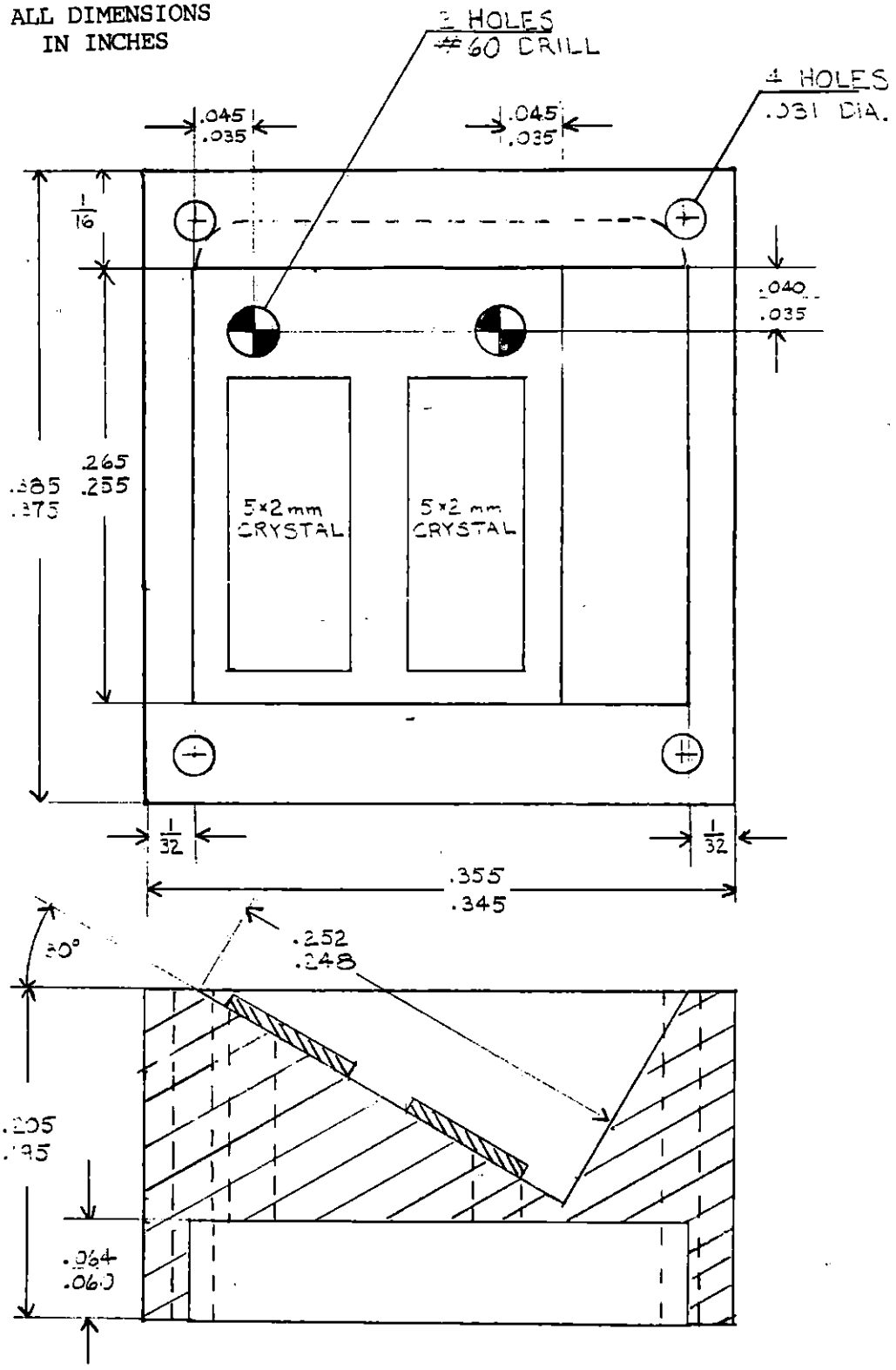


Figure 2. Transducer crystal mounting drawing

6) Coat the soldered joints with a thin coat of a two part quick setting epoxy for electrical insulation.

7) Carefully fold wires back and lay the soldered joints in the back of the crystal holder. Fill in the recess with epoxy to embed the wires.

8) Pull shrink tubing flush with the holder, carefully inserting the loose wires into the shrink tube. Shrink the tubing with a heat gun.

9) Sew the probe to a rubber finger cup using 2/Ø surgical silk.

1Ø) Coat the joints with epoxy, smooth any sharp edges and attach a velcro strap to hold the cable to the finger and to minimize cable flexing.

Potential Errors in Using Continuous Wave Doppler Ultrasound

When using continous wave Doppler ultrasound with a zero crossing detector there are several inherent limitations which can cause significant error (Johnson et al., 1977).

1) Although the output from the continous wave Doppler is often thought to be proportional to the mean velocity this is not strictly true for pulsatile flows with varying velocity profiles. During normal pulsatile arterial flow the velocity profile across the artery varies with time and can cause the Doppler output to vary significantly from a linear response.

2) The effect of noise makes it necessary to set a threshold level when using a Doppler with zero crossing detector. This threshold level can cause low amplitude signals to be completely masked.

3) High amplitude low frequency noise will be present with the use of the continous wave Doppler. These extraneous signals may come from

arterial wall motion, muscle motion, or flow signals from adjacent vessels for example.

4) When blood flows simultaneously in both directions the output of the zero crossing detector may be misleading. This can occur between forward and reverse flow phases of normal velocity waves. This can also be a problem if an artery and a vein are simultaneously insonated.

Data Collection

Cows

The method of collecting data from the uterine artery of cows involved rectal palpation. The operator wearing the finger tip probe palpated the uterine artery. The probe was connected to a Parks Medical model 1Ø1ØLA Doppler continuous wave, dual frequency, bi-directional, flowmeter with a built in strip chart recorder (see Appendix A). This flowmeter has a strip chart output, an audio output and a third output identical to the strip chart input which was connected to a Tandberg series 115 instrumentation tape recorder (see Appendix A). While the first operator searched for the uterine artery and listened to the audio output, a second operator watched the strip chart recorder and operated the tape recorder.

The operators palpated the left and right uterine arteries of each cow and attempted to record approximately twenty seconds of repeatable pulses from each artery. The strip chart recordings were identified and saved along with the magnetic tape recordings.

Dogs

Data were collected from the femoral artery of three dogs (each

weighing approximately 25 kg). The purpose of these experiments was to collect and analyze electromagnetic data to compare mean blood flow to certain waveform indices. A femoral artery cutdown was performed on each dog while under a sodium pentabarbital anesthetic. An electromagnetic flow probe (Invivometric) was placed around the femoral artery. A Biotronex Pulsed Logic model BL610 electromagnetic flowmeter was connected to the probe and the output was sent to a Hewlett-Packard model 7402A oscillograph, and also recorded on magnetic tape using a Hewlett Packard model 3960 or a Tandberg series 115 instrumentation tape recorder.

Initially, a control waveform was recorded using both the electromagnetic flowmeter and the Parks model 909 Doppler flowmeter. The Doppler data were recorded proximal to the electromagnetic flow probe with no significant arterial branches between. Next, the hyperemic response was recorded using the electromagnetic flowmeter only. This was accomplished by clamping the femoral artery for 20 to 30 seconds and then releasing the clamp.

The dog then received acetylcholine administered through a branch of the femoral artery using a Harvard peristaltic pump. After the flow increased due to the acetylcholine, data were collected at the higher flowrates using both electromagnetic and Doppler ultrasound. The flow rate was allowed to return to a steady-state, near normal condition, and one final set of velocity waveforms were recorded using both electromagnetic and Doppler ultrasound flowmeters.

Data Processing

In each case, the data collected were in the form of strip chart

In each case, the data collected were in the form of strip chart recordings and voltages on magnetic tape. The input signals to the magnetic tape varied with signal strength and recorder setting but were on the order of approximately -1 to +3 volts. The output signals from the tape recorder were approximately -.5 to +1.5 volts.

The output from the magnetic tape was digitized at the rate of one data point every 0.01 seconds (100 Hz.) and stored on diskette using a Commodore PET model 2001 computer with analog to digital converter and model 8050 disk drive. The procedure for this analog to digital conversion appears in Appendix B.

The data after being digitized are transferred to a PDP-11/23 computer which is used to process the data. The procedure for transferring data to the PDP-11/23 from the PET appears in Appendix B. The data are stored on a floppy disk by the PDP-11/23.

On the floppy disk the data are in the form of data files. Each file contains from 500 to 2,000 data points which represent from 5 to 20 seconds of data. Each file is then manipulated by a program which arranges the data into a format which can be used by a Fortran program. A copy of this program appears in Appendix C.

When the data file is in its final form it is ready to be processed. The Fortran program which performs this task is shown in flowchart form in Figure 3, and a copy of the program appears in Appendix C.

The processing of data takes place as follows:

1) Each data point is read from the data file by the computer and placed in an array. Each value is assigned a corresponding time value.

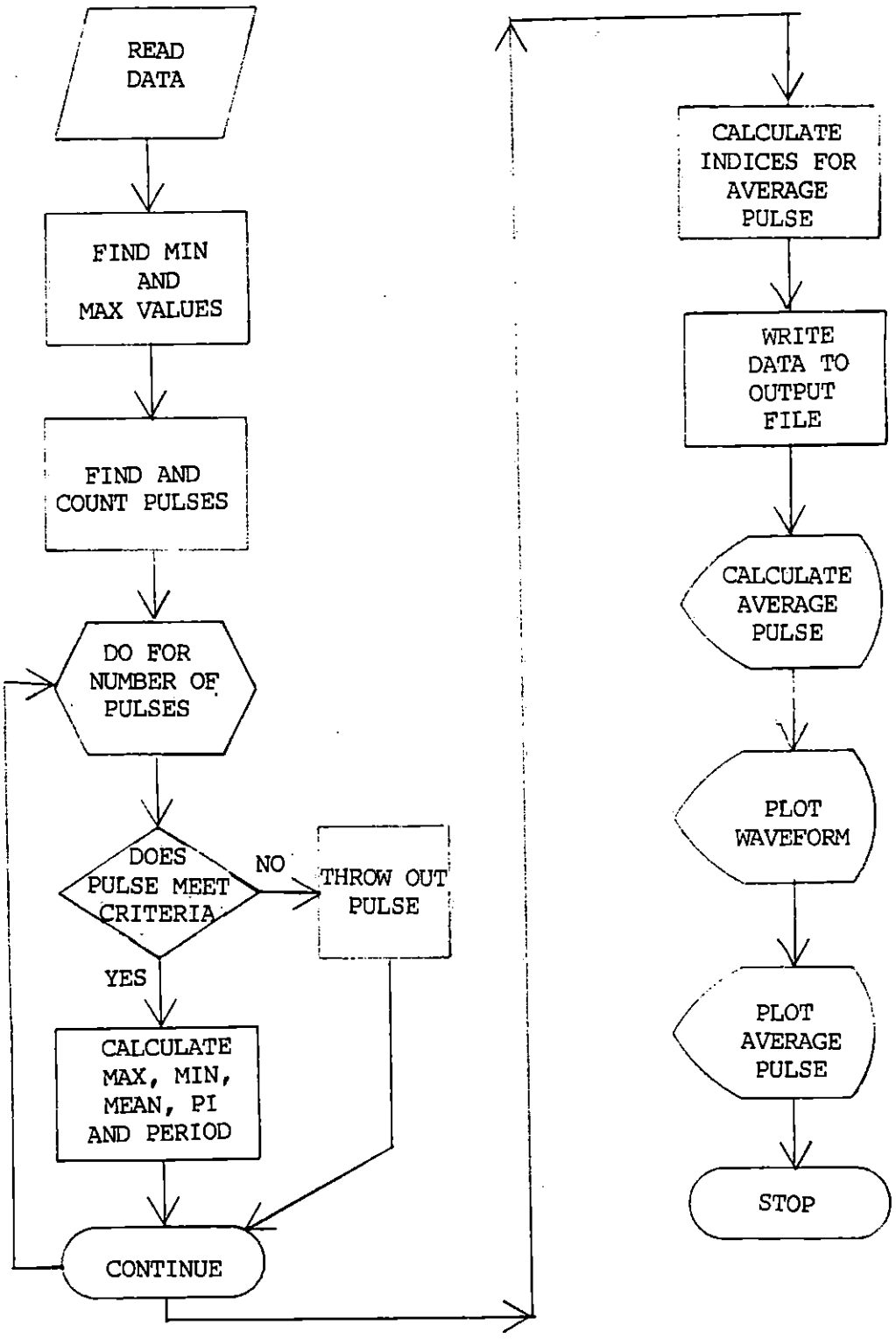


Figure 3. Flowchart for data processing program

Example: R(1)=56. 56 is the value of the data at time t= 1/100 seconds.

2) The computer compares each data point and determines the minimum and maximum value for each set of data.

3) The computer searches for the initial pulse. This occurs when the data value is greater than a percentage (fixed by the operator) of the maximum minus minimum value plus the minimum value (i.e. V > %(max-min)+min).

4) The computer searches for the beginning of that pulse by calculating the slope at the initial point where the pulse was found and performing this calculation for preceding points until the slope of the line changes from positive to negative.

5) Next the location and number of the rest of the pulses are calculated. The procedure is similar to that of finding the initial pulse. The primary difference is that after a point is found which indicates a pulse, a flag is set. No more pulses will be counted until the flag is reset. The flag is reset when the value of the data point falls below some specified percentage of the maximum value minus minimum value plus the minimum value (i.e. V < %(max-min)+min).

6) For each pulse the program calculates the peak, mean and minimum pulse value. The pulsatility index, PI, is calculated for each pulse. A period for each pulse is also calculated.

7) The program compares the period for each pulse to the average period and throws out the bad pulses. This process is iterative and continues until each pulse period is between .7 and 1.5 of the average

period.

8) An output file is opened and the pulsatility index, maximum value, minimum value, and mean value for each pulse is printed.

9) An average pulsatility index is calculated from all of the acceptable pulses.

10) An average pulse is obtained. The program uses an algorithm which normalizes each good pulse so that it has an average period length. Then all of the pulses are added together and divided by the total number of pulses.

11) Values of several waveform indices are calculated and printed for this average pulse.

12) Finally the data are plotted along with a plot of the average pulse.

RESULTS AND DISCUSSION

Measurement of Uterine Artery Blood Flow

Non-pregnant cows

Data were collected from three non-pregnant cows over a period of eight days. Recordings were obtained from both left and right uterine arteries. These data were taken by two different operators.

Two pulsatility indices are calculated for each data set. A mean pulsatility index, $\overline{PI}$ is obtained by determining the peak to peak pulsatility index of each good pulse in a data set and averaging the values. The pulsatility index of the average pulse PI_a is simply calculated from the average pulse data.

Figures 4 and 5 show samples of waveforms which have been recorded on a strip chart recorder along with the same data after they have been digitized and plotted. The values on the ordinate of the computer plots represent a voltage which is proportional to velocity. The values on the abscissa are time in increments of 2.0 seconds. Some samples of average pulses are shown in Figure 6.

Several distinguishing characteristics of uterine artery waveforms should be noted. The pulses normally have a very sharp rise which takes place during approximately ten percent of the period. The diastolic portion of the wave represents approximately ninety percent of the period. Typically, the diastolic portion consists of a steep descending portion followed by a dicrotic notch, a descending portion which is less steep, a small secondary pulse and finally a relatively flat portion.

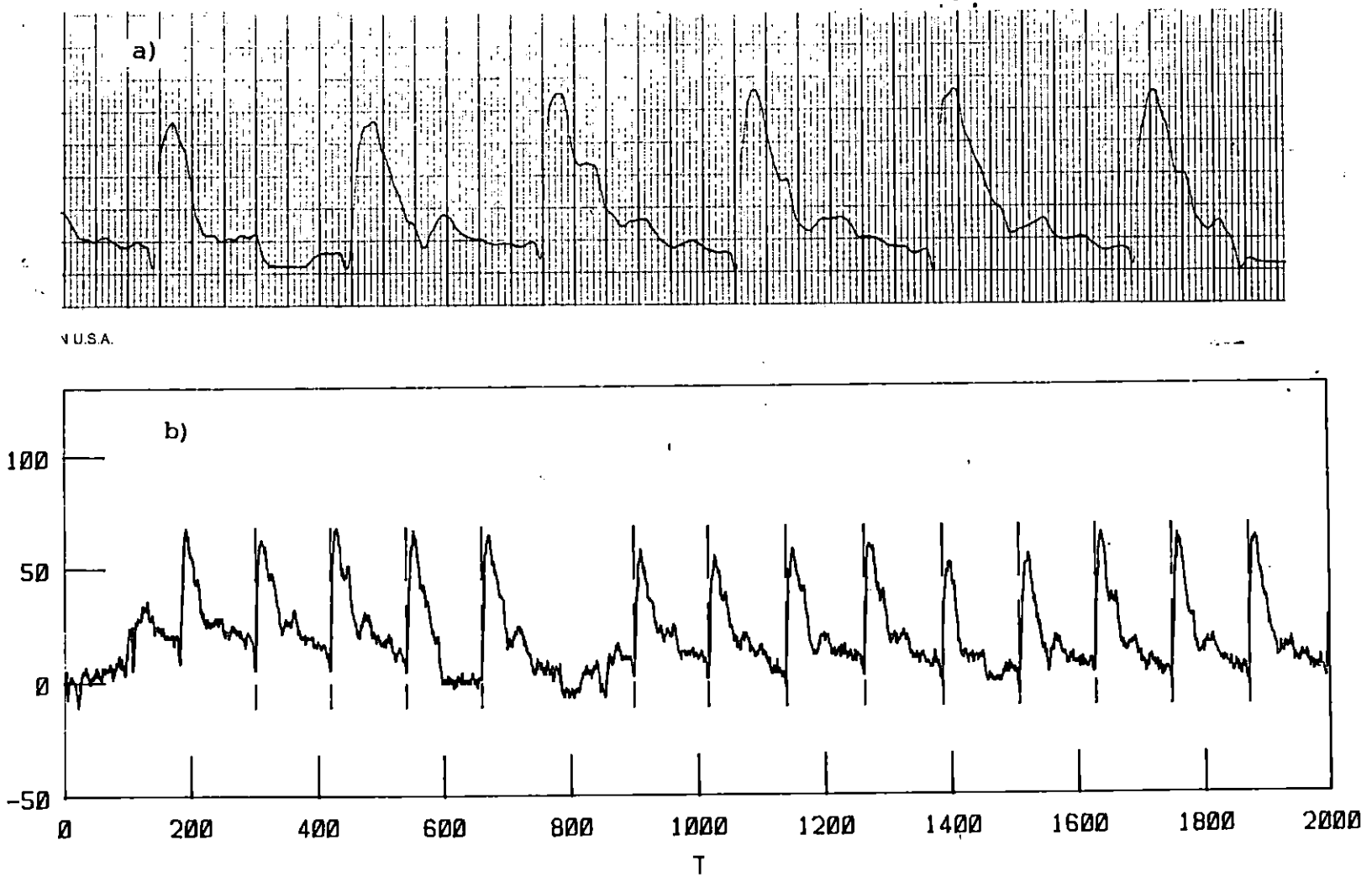


Figure 4. Sample waveform for cow #44, left uterine artery,12/22/84, operator F, from a) strip chart recorder and b) digitized data

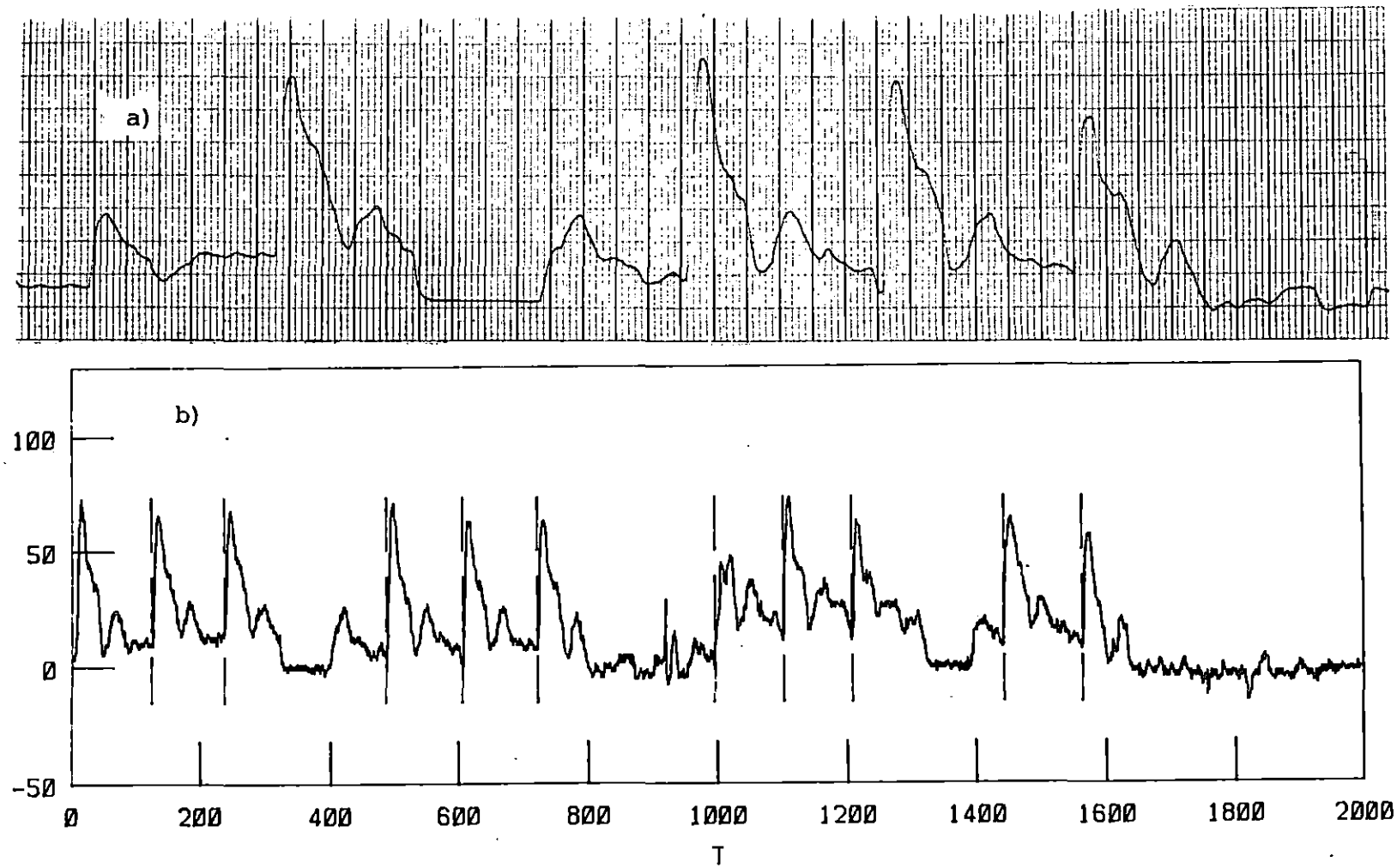
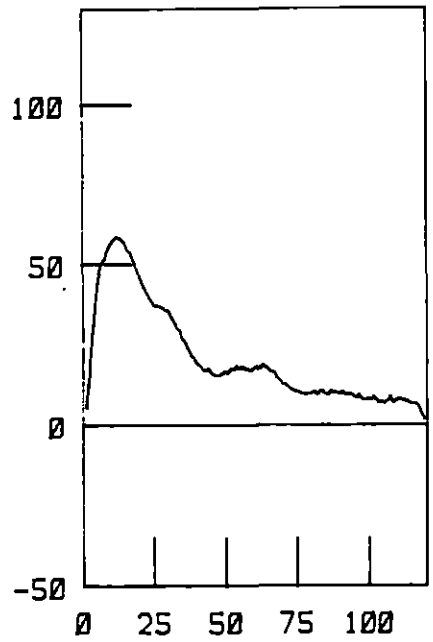
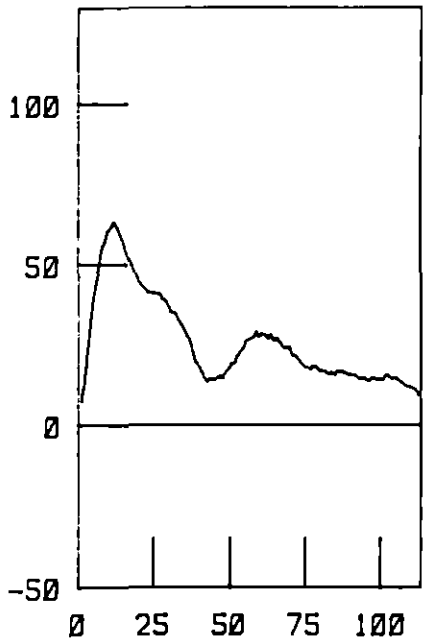


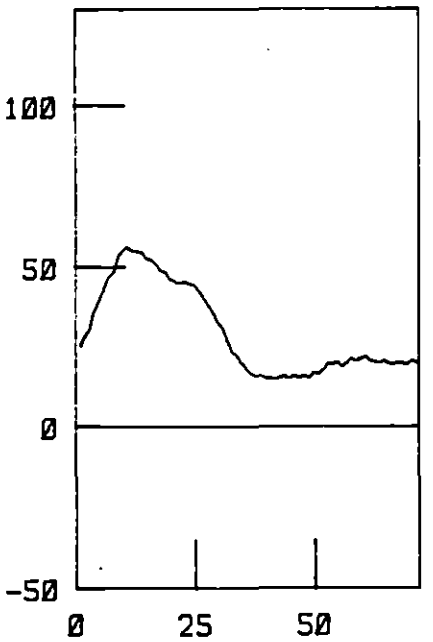
Figure 5. Sample waveform for cow #44, right uterine artery,12/23/84, operator F, from a) strip chart recorder and b) digitized data



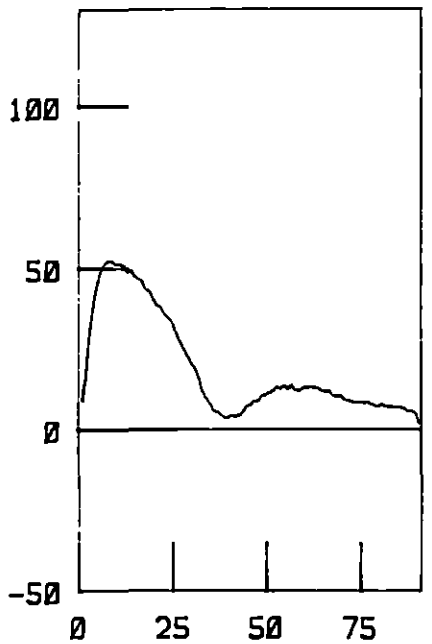
COW 44, LEFT SIDE, 12/22/85



COW 44, RIGHT SIDE, 12/23/85



COW 137, LEFT SIDE, 12/22/85



COW 172, LEFT SIDE, 12/23/85

Figure 6. Averaged pulse samples from bovine uterine arteries

With higher flows the waveforms may be less well defined. They have a more damped appearance and the dicrotic notch and secondary pulse may be unclear or absent (see Figure 6, cow 137). Very little reverse flow is seen in the bovine uterine artery, although it does occur in some instances. In contrast the waveforms from the canine femoral artery (see Figure 28) have a much more sinusoidal appearance with a steeper diastolic slope, large reverse flow, larger secondary pulse and absence of the dicrotic notch.

Figures 7 through 12 show how $\overline{PI}$ varies over a period of 8 days for both left and right uterine arteries. Figures 7, 8, and 9 use data collected by operator F while Figures 10, 11, and 12 show data collected by operator C. In a similar manner PI_a is shown in Figures 13 through 18.

A statistical test can be made to compare the mean value of PI and its variance between left and right arteries in each cow. The values used are tabulated in Tables 1 through 6. The variances can be compared using an F-test (Kennedy and Neville, 1976) with a null hypothesis that states "the variance from the right uterine artery equals the variance from the left uterine artery." The F values for the three cows and the number of degrees of freedom are listed below.

cow 137	F(11,12)=2.54
cow 172	F(11,11)=2.55
cow 44	F(13,11)=1.10

The lowest value of $F_{critical}$ is F(11,11,.05)=2.72 for a 5 percent level of significance. Therefore, in all three cases the null hypothesis cannot be rejected. That is, it cannot be said with a high degree of

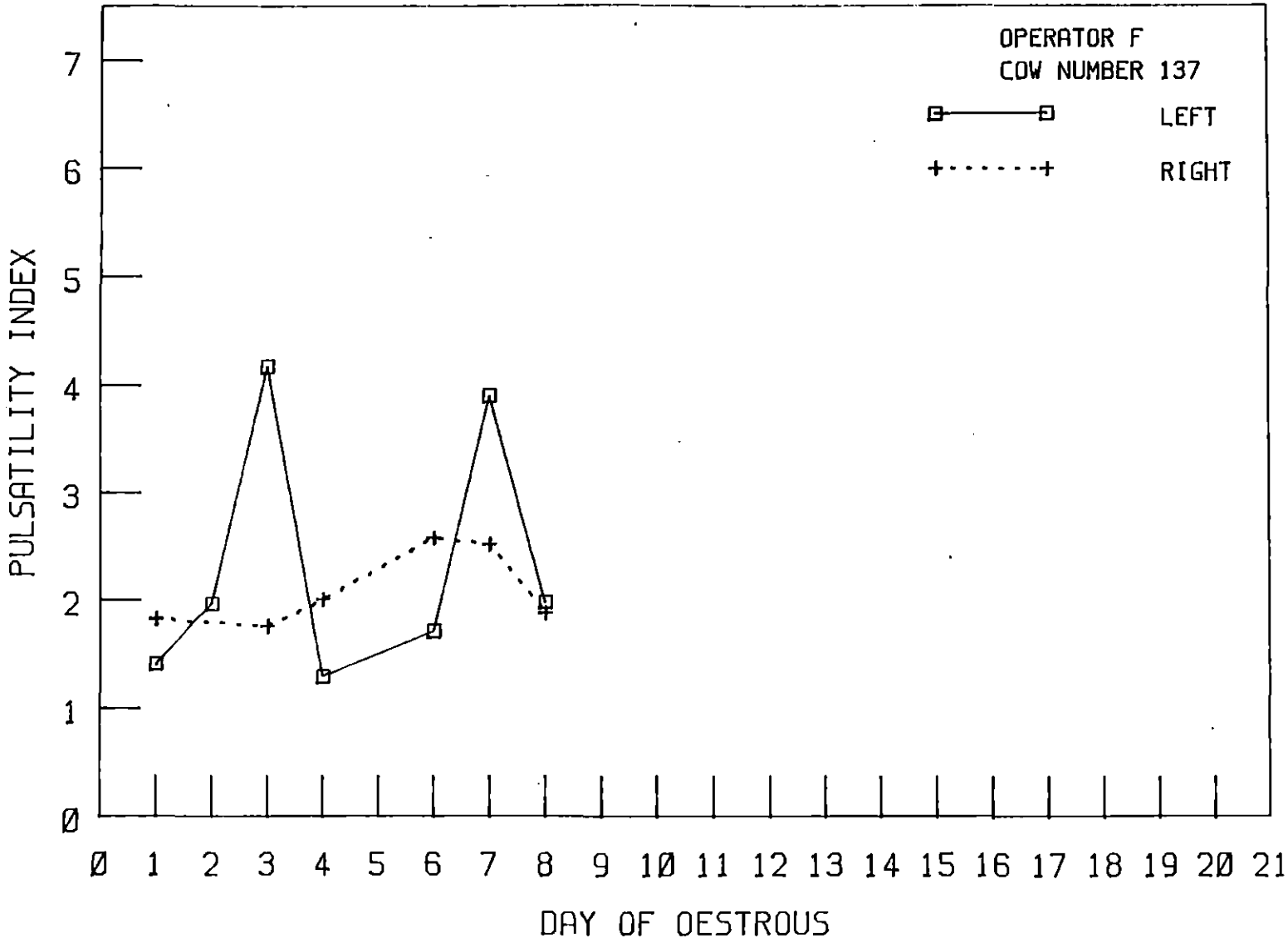


Figure 7. $\overline{PI}$ vs. day (day of oestrous unknown)

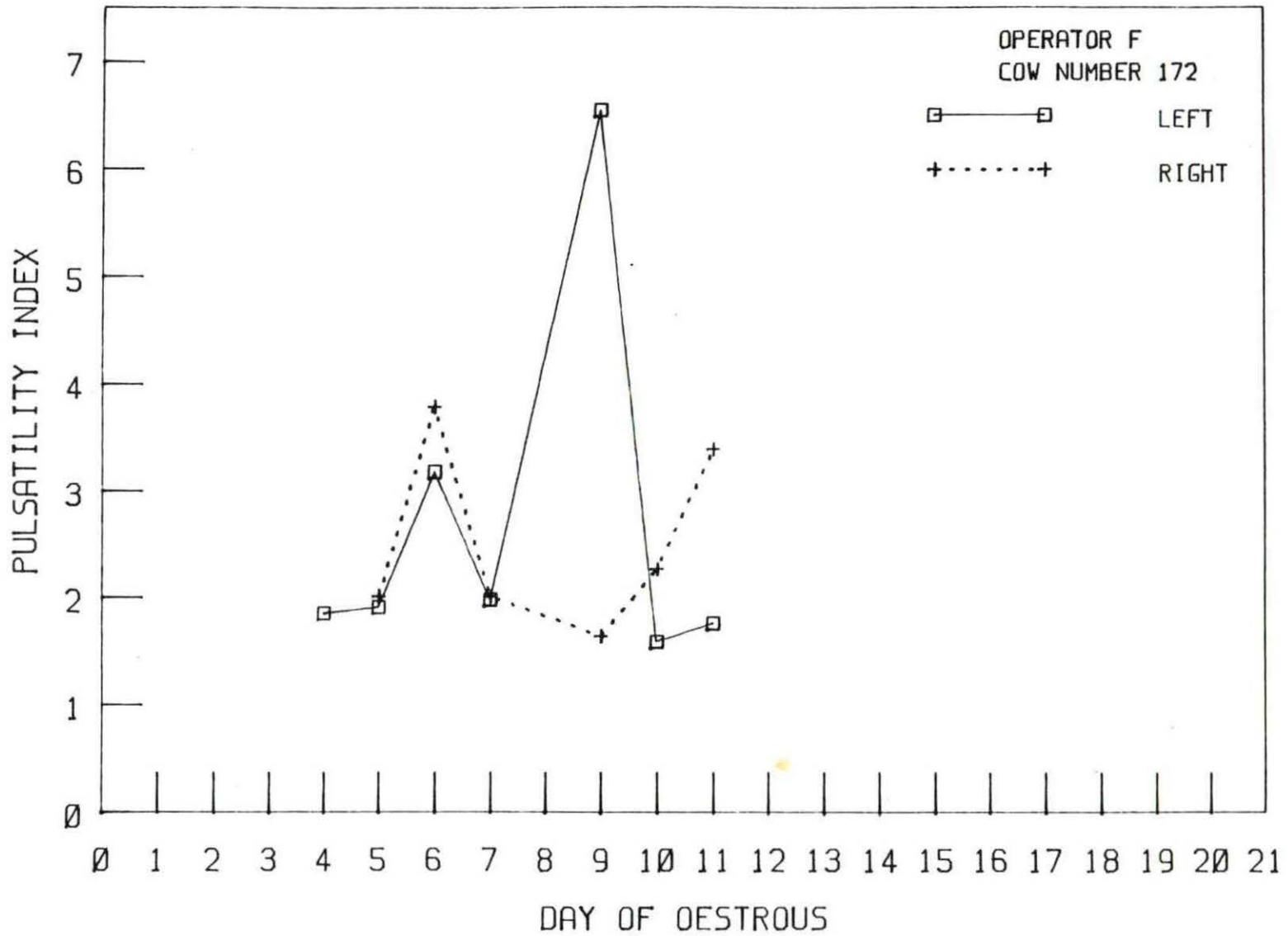


Figure 8. $\overline{PI}$ vs. day of oestrous

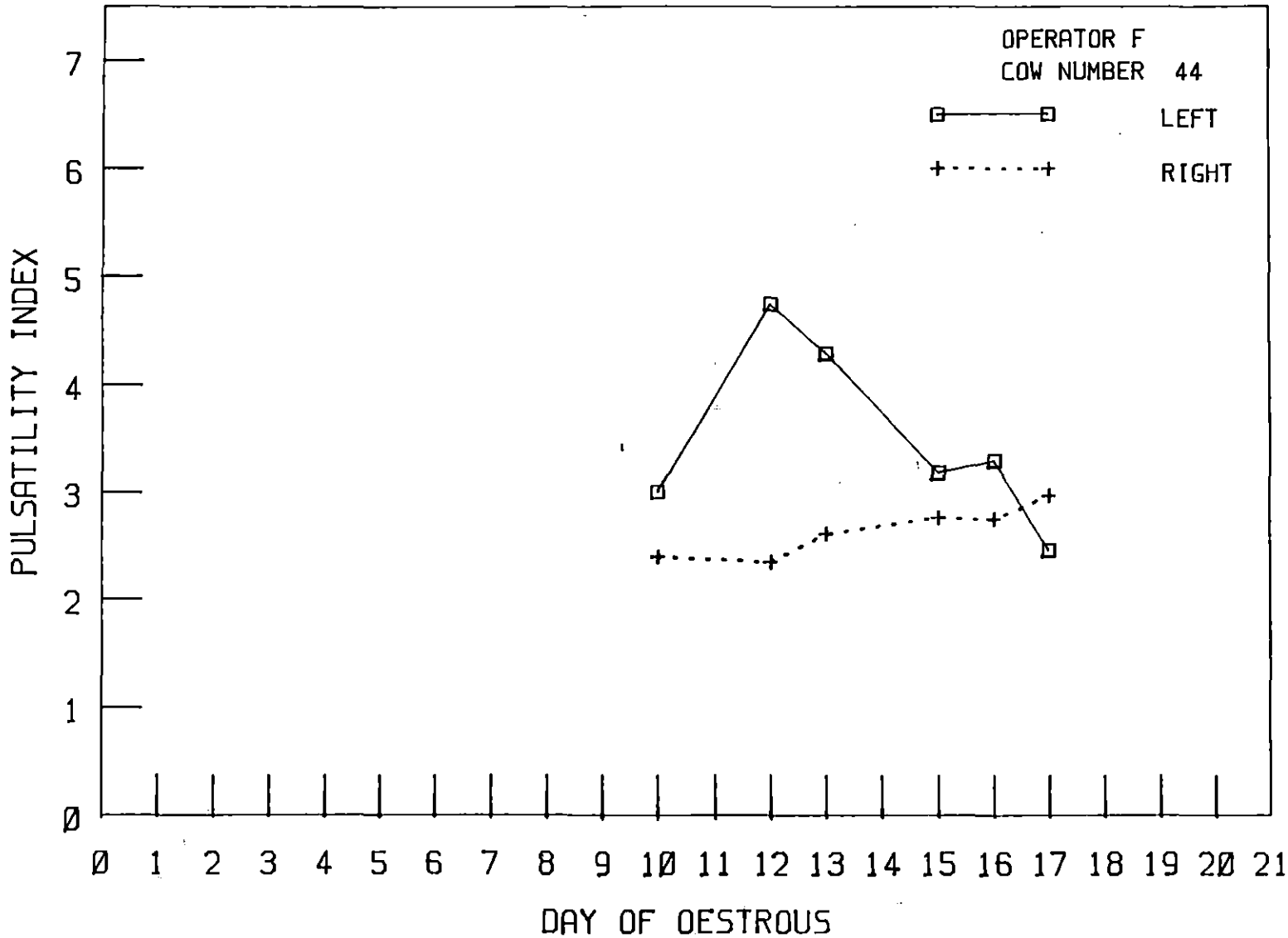


Figure 9. $\overline{PI}$ vs. day of oestrous

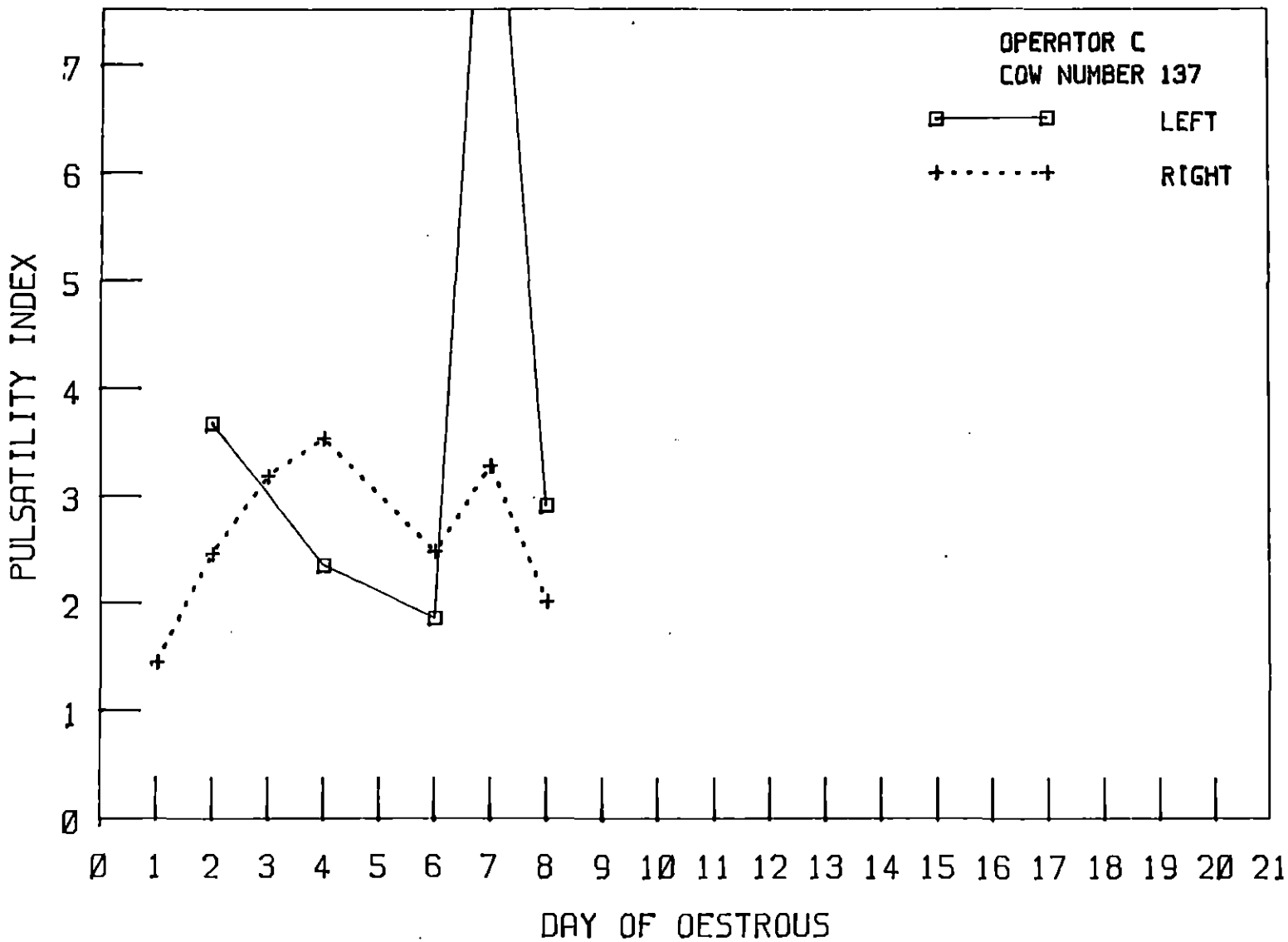


Figure 10. $\overline{PI}$ vs. day (day of oestrous unknown)

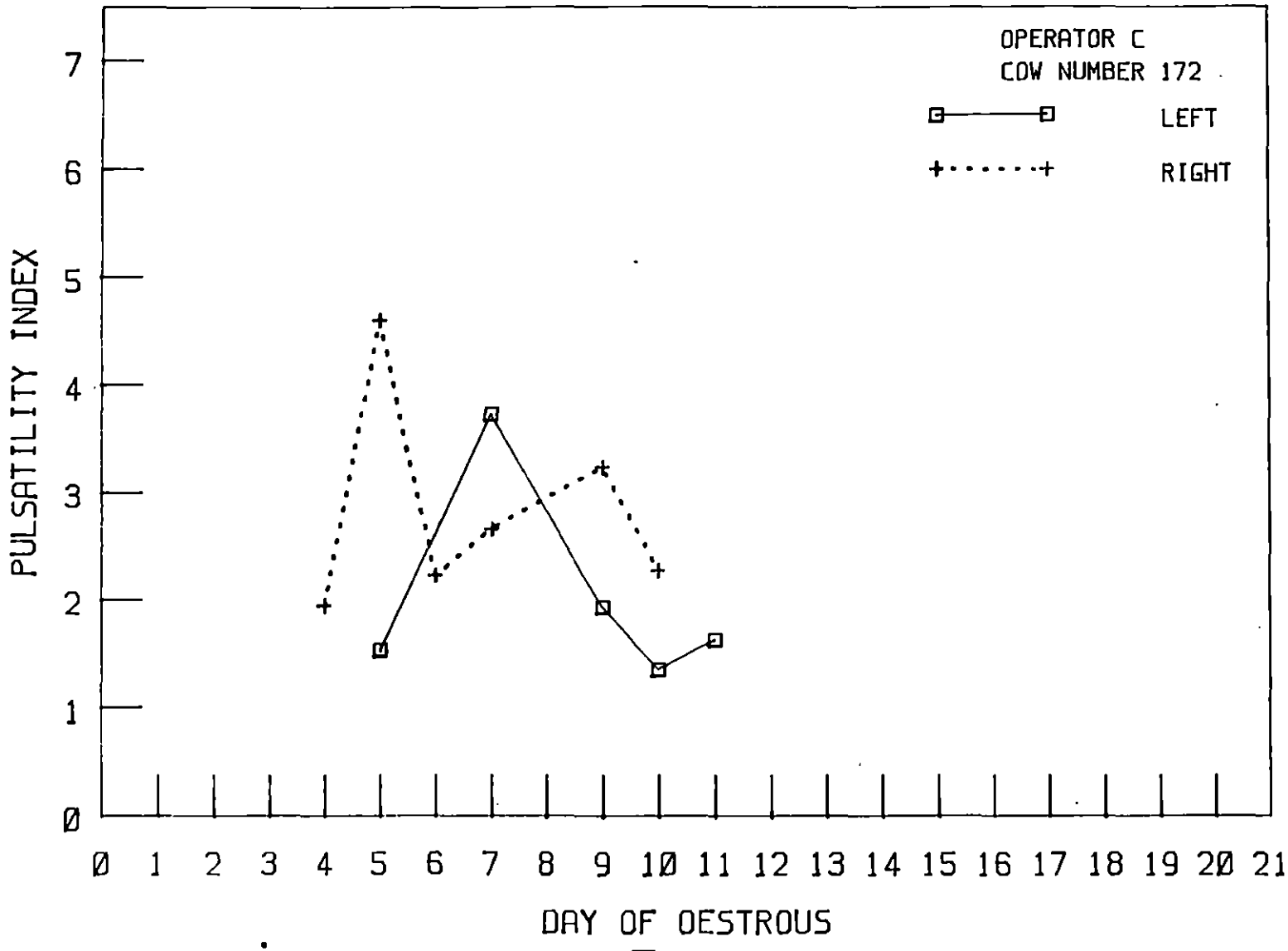


Figure 11. $\overline{PI}$ vs. day of oestrous

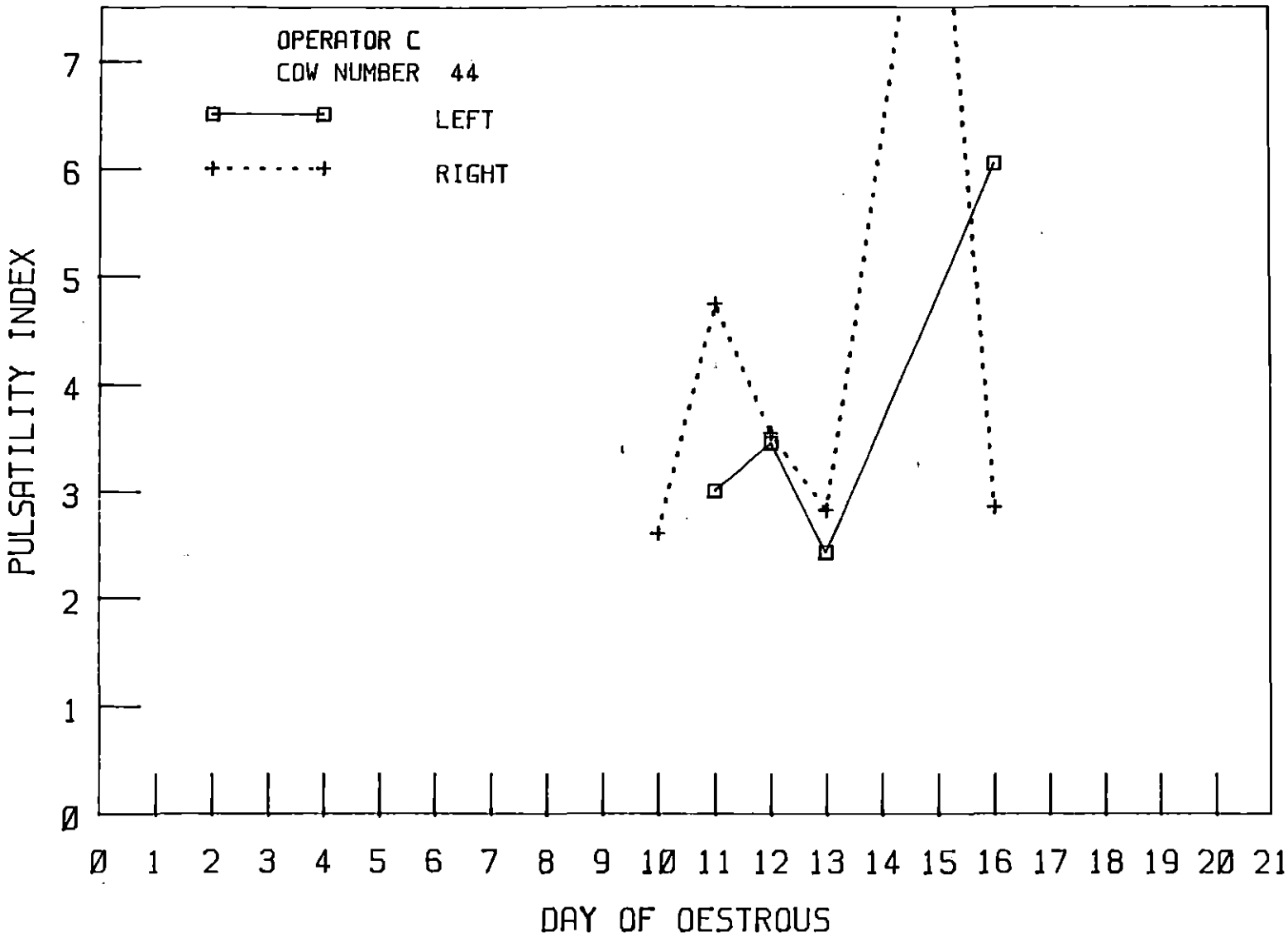


Figure 12. $\overline{PI}$ vs. day of oestrous

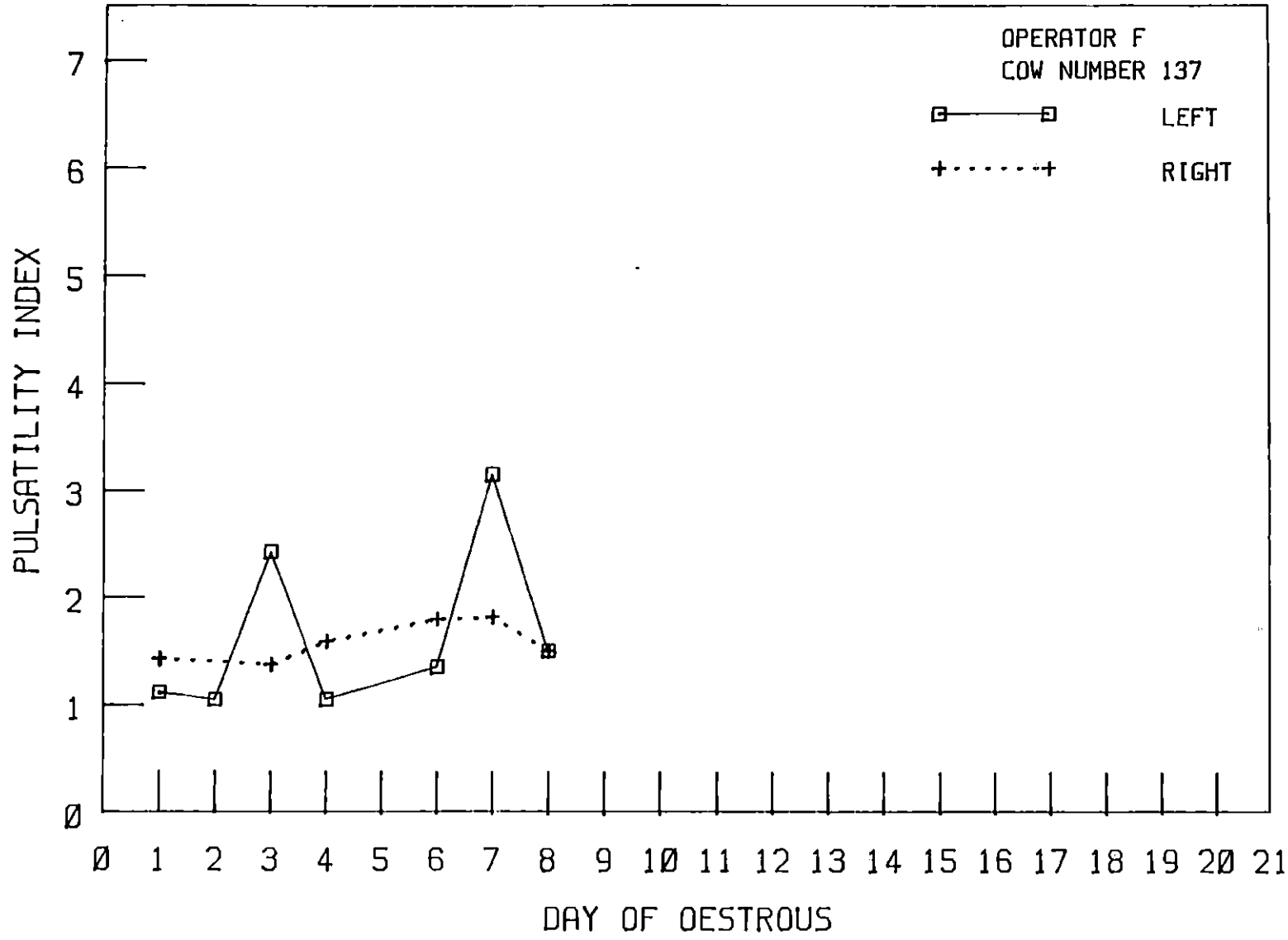


Figure 13. PI_a vs. day (day of oestrous unknown)

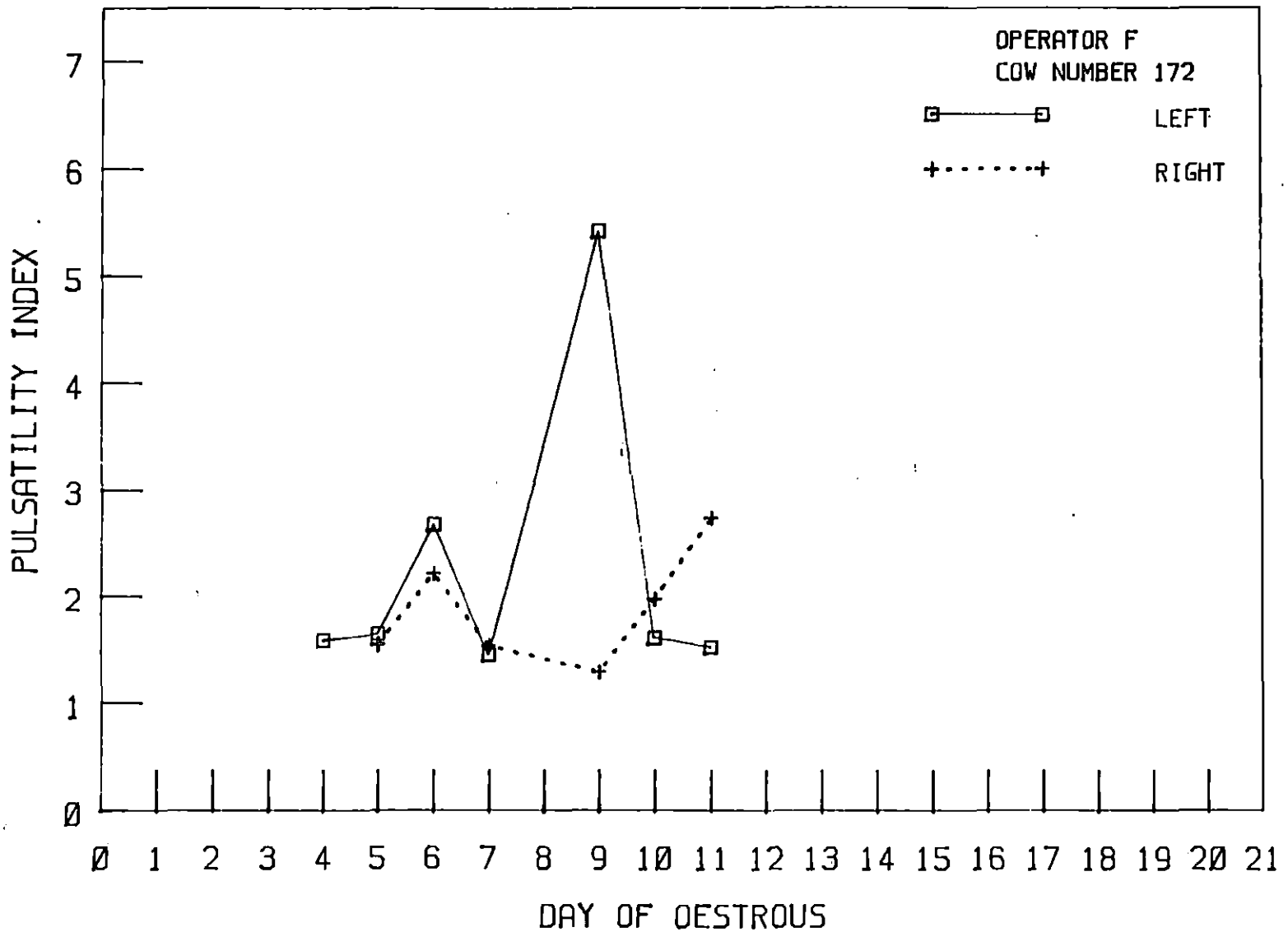


Figure 14. PI_a vs. day of oestrous

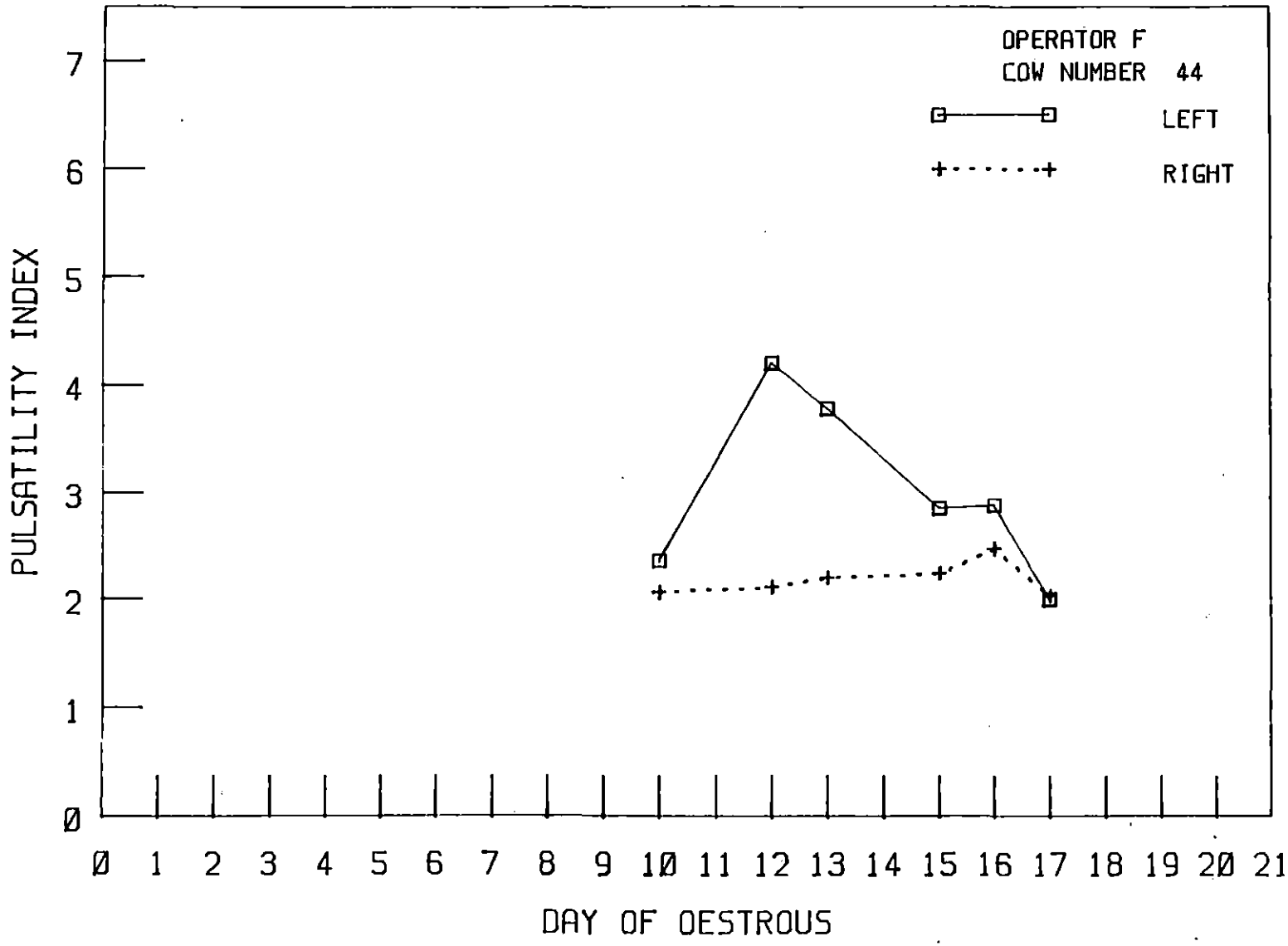


Figure 15. PI_a vs. day of oestrous

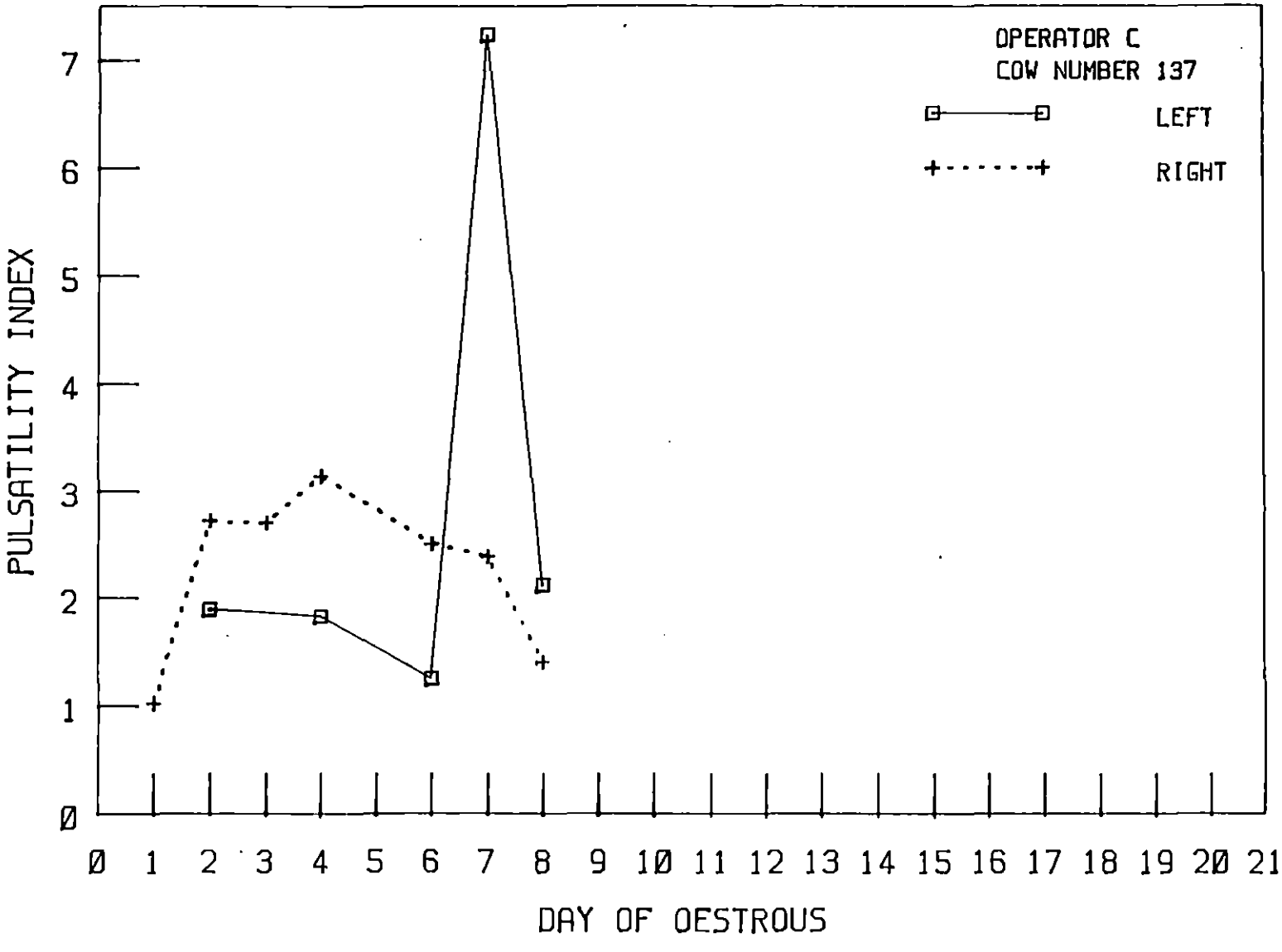


Figure 16. PI_a vs. day (day of oestrous unknown)

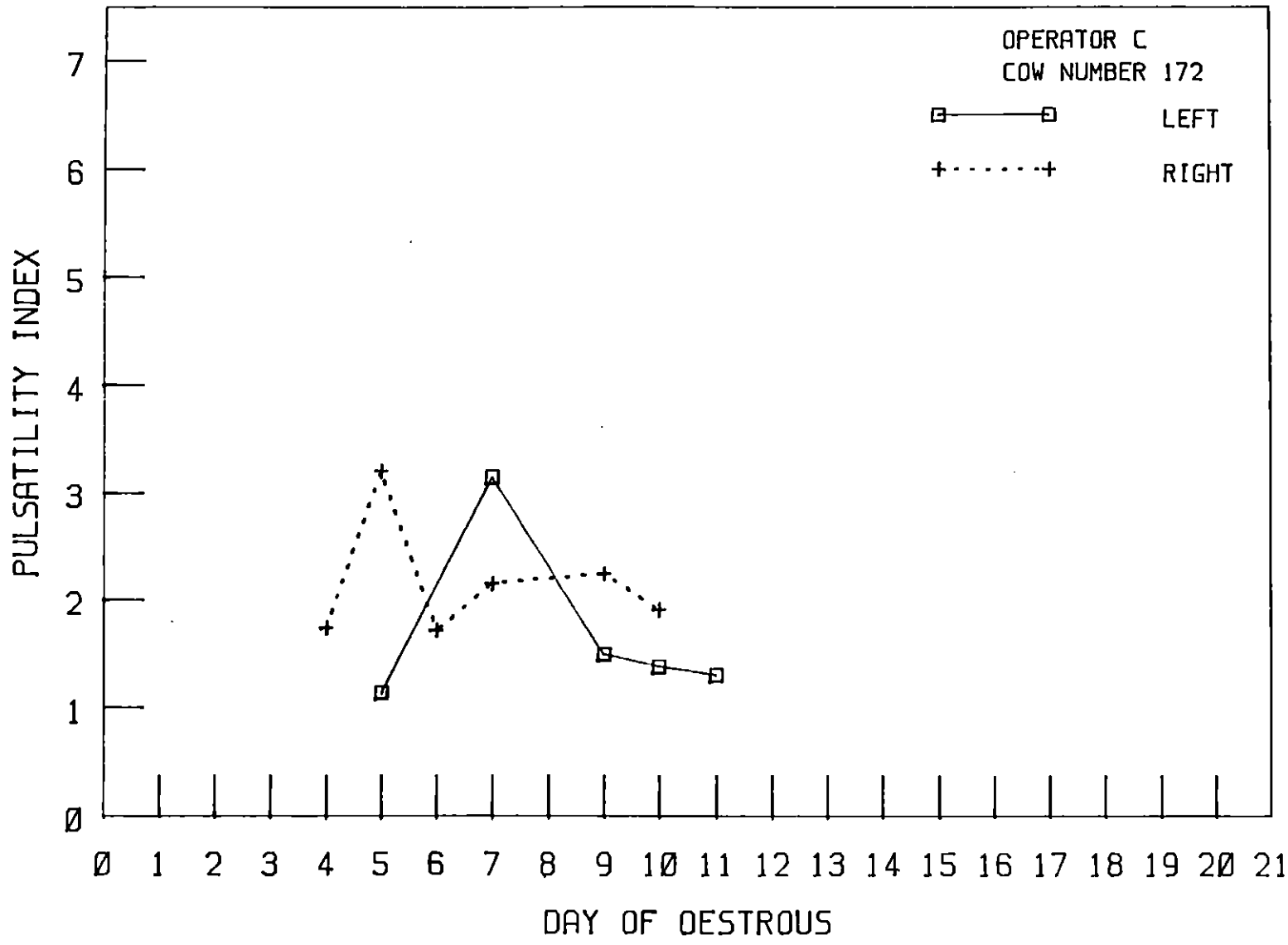


Figure 17. PI_a vs. day of oestrous

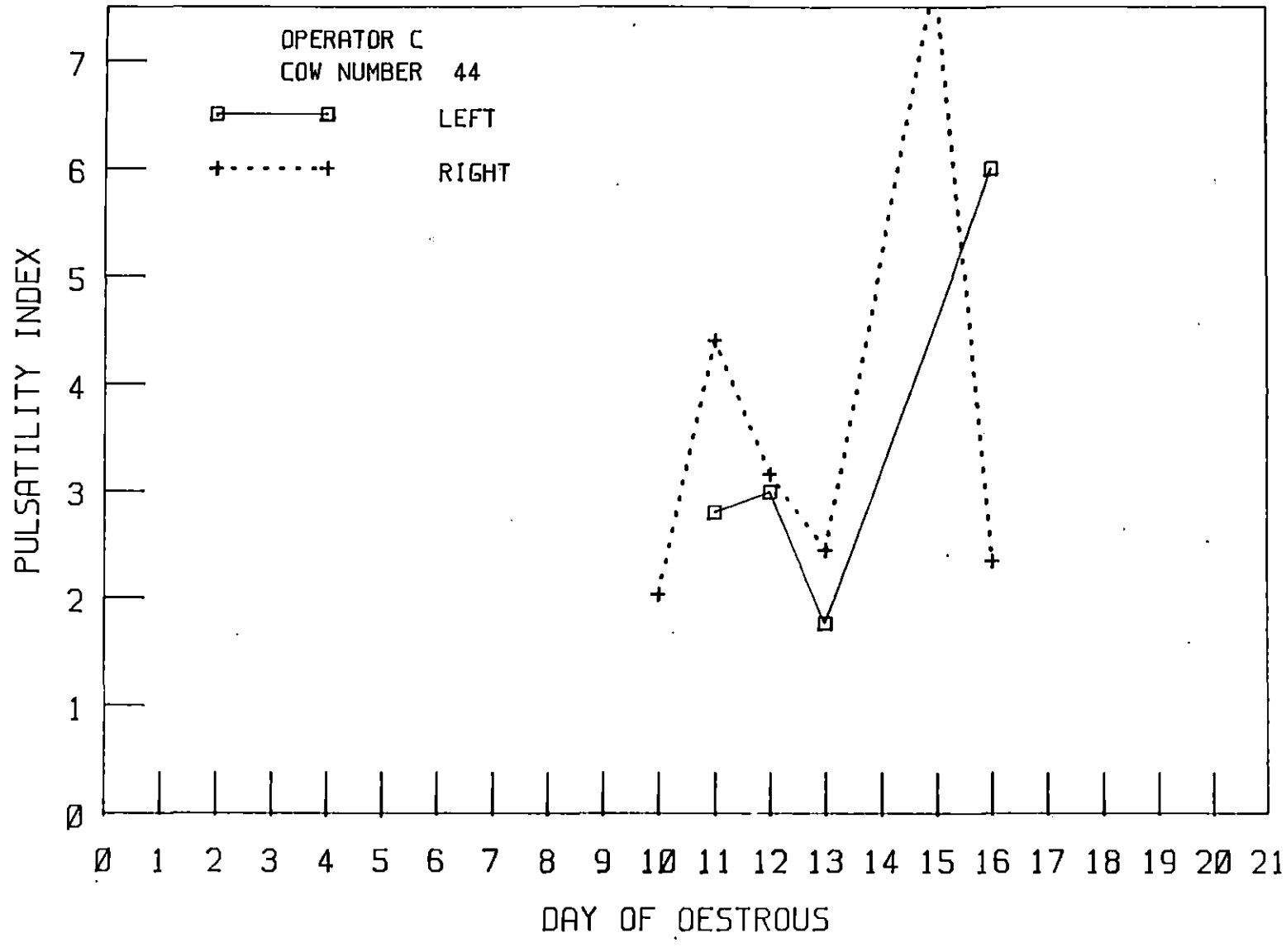


Figure 18. PI_a vs. day of oestrous

Table 1. $\overline{PI}$, PI_a and P-P/PK vs. day for cow 137, operator F

Day*	$\overline{PI}$ L	PI_a L	$\overline{PI}$ R	PI_a R	P-P/PK L	P-P/PK R
1	1.42	1.12	1.83	1.43	Ø.68	Ø.77
2	1.97	1.Ø5	----	----	Ø.62	----
3	4.18	2.43	1.76	1.38	1.ØØ	Ø.76
4	1.3Ø	1.Ø5	2.Ø2	1.6Ø	Ø.61	Ø.82
6	1.72	1.36	2.59	1.81	Ø.79	Ø.85
7	3.9Ø	3.16	2.53	1.82	Ø.99	Ø.82
8	1.99	1.51	1.89	1.51	Ø.76	Ø.81

* Day of oestrous is unknown for cow 137.

Table 2. $\overline{PI}$, PI_a and P-P/PK vs. day for cow 172, operator F

Day	$\overline{PI}$ L	PI_a L	$\overline{PI}$ R	PI_a R	P-P/PK L	P-P/PK R
4	1.85	1.59	----	----	Ø.76	----
5	1.91	1.65	2.Ø2	1.55	Ø.86	Ø.73
6	3.18	2.68	3.79	2.22	Ø.96	Ø.93
7	1.99	1.45	2.Ø2	1.54	Ø.72	Ø.77
9	6.35	5.42	1.64	1.29	1.18	Ø.71
1Ø	1.59	1.61	2.27	1.98	Ø.82	Ø.88
11	1.76	1.52	3.4Ø	2.74	Ø.81	Ø.96

Table 3. $\overline{PI}$, PI_a and P-P/PK vs. day for cow 44, operator F

Day	$\overline{PI}$ L	PI_a L	$\overline{PI}$ R	PI_a R	P-P/PK L	P-P/PK R
1Ø	3.Ø1	2.38	2.4Ø	2.Ø8	Ø.97	Ø.85
11	----	----	----	----	----	----
12	4.75	4.21	2.35	2.12	1.ØØ	Ø.88
13	4.29	3.78	2.62	2.21	1.Ø5	Ø.89
15	3.18	2.86	2.77	2.25	Ø.92	Ø.88
16	3.29	2.88	2.75	2.48	Ø.99	Ø.93
17	2.46	2.ØØ	2.97	2.Ø3	Ø.88	Ø.88

Table 4. $\overline{PI}$, PI_a and P-P/PK vs. day for cow 137, operator C

Day*	$\overline{PI}$ L	PI_a L	$\overline{PI}$ R	PI_a R	P-P/PK L	P-P/PK R
1	----	----	1.47	1.02	----	0.64
2	3.68	1.90	2.48	2.72	0.96	0.98
3	----	----	3.20	2.71	----	0.97
4	2.36	1.83	3.55	3.14	0.90	1.14
6	1.87	1.25	2.50	2.51	0.74	1.06
7	20.02	7.24	3.29	2.39	1.15	0.92
8	2.92	2.12	2.03	1.42	0.95	0.71

*Day of oestrous is unknown for cow 137.

Table 5. $\overline{PI}$, PI_a and P-P/PK vs. day for cow 172, operator C

Day	$\overline{PI}$ L	PI_a L	$\overline{PI}$ R	PI_a R	P-P/PK L	P-P/PK R
4	----	----	1.95	1.74	----	0.79
5	1.53	1.14	4.60	3.20	0.69	1.02
6	----	----	2.23	1.72	----	0.80
7	3.73	3.15	2.67	2.16	1.06	0.95
9	1.93	1.49	3.24	2.25	0.78	0.87
10	1.35	1.38	2.28	1.91	0.80	0.85
11	1.63	1.30	----	----	0.78	----

Table 6. $\overline{PI}$, PI_a and P-P/PK vs. day for cow 44, operator C

Day	$\overline{PI}$ L	PI_a L	$\overline{PI}$ R	PI_a R	P-P/PK L	P-P/PK R
10	----	----	2.61	2.04	----	0.82
11	3.01	2.80	4.75	4.41	1.00	1.25
12	3.45	2.99	3.54	3.16	1.00	0.96
13	2.43	1.76	2.83	2.45	0.98	0.89
15	----	----	9.65	7.77	----	1.20
16	6.05	6.00	2.86	2.35	1.30	0.91
17	8.74	8.39	2.35	1.99	1.25	0.85

confidence that there is a difference in variance between the two arteries.

To compare mean flows between sides over a period of days the data are divided into a high flow side (lower PI_a) and a low flow side for each cow. The high flow sides were the right side for cows 132 and 44 and the left side for cow 172. For the high flow side, the mean value of PI (combined for all three cows, and all days) is 2.75. For the low flow side, it is 2.97. The standard deviation, s, is 2.25 for the high flow side and 1.54 for the low flow side.

Application of the F-test shows an F value of 2.14 while F(40,40,.05)=1.69. This indicates a significantly higher variability on the high flow side. This may be due to the fact that a true mean flow does not exist over a period of 8 days but rather that mean flow varies with time. As this mean flow varies it shows up as greater variance, particularly in the high flow arteries in which the change in mean flow would be more significant.

To compare mean values, a t-test (Kennedy and Neville, 1976) can be applied using a null hypothesis that the mean value of PI for the high flow arteries is equal to the mean value for the low flow arteries. The calculated value, using data from all cows on all days, for t=0.498. The critical value is t(40,.10)=1.684. Therefore the difference in mean values of PI does not appear to be statistically significant.

A comparison of operators can be made using a randomized pairs t-test (Cox, 1983). A total of 31 data pairs exist where the two operators collected data from the same artery, in the same cow, on the same day. For each pair a difference, d, is determined between PI for one operator and PI

for the second. The mean value of d, $\bar{d}$, and the standard deviation of d, s_d, can be calculated. Using a t-test, $\bar{d}$ can be compared to zero. The statistic d is defined as $\overline{PI}$ for operator C minus $\overline{PI}$ for operator F. The value for $\bar{d}$ is 1.197 and the value for s_d is 3.473. The test value t=1.918. For 90 percent confidence and 30 degrees of freedom $t_{critical}$ is 1.697. For 95 percent confidence and 30 degrees of freedom $t_{critical}$ is 2.042.

There is a 93 percent probability that the true value for $\bar{d}$ is not zero. Thus, it can be said with a high degree of confidence that a difference exists for $\overline{PI}$ values between the two operators.

The variance of each operator with respect to PI can be calculated in order to compare values of variance. The test value calculated is 2.99. The value for $F_{critical}$ is F(40,40,.01)=2.11. The probability that the variance is greater with measurements from operator C is greater than 99 percent. Calculated values for standard deviation are 1.05 for operator F and 1.82 for operator C.

The difference in values of $\overline{PI}$ between operators may be a result of procedure. The data were always collected in the same order, with operator F collecting data first followed by operator C. The data were collected within a few minutes of each other, but not simultaneously.

Another index similar to the pulsatility index was calculated for each data set. This index is defined as the peak to peak amplitude divided by the peak amplitude (P-P/PK). It is less sensitive to errors in measuring low mean flow values. Figures 19 through 24 are plots of P-P/PK versus the day of oestrous cycle for the average pulse of each data set. Tables 1

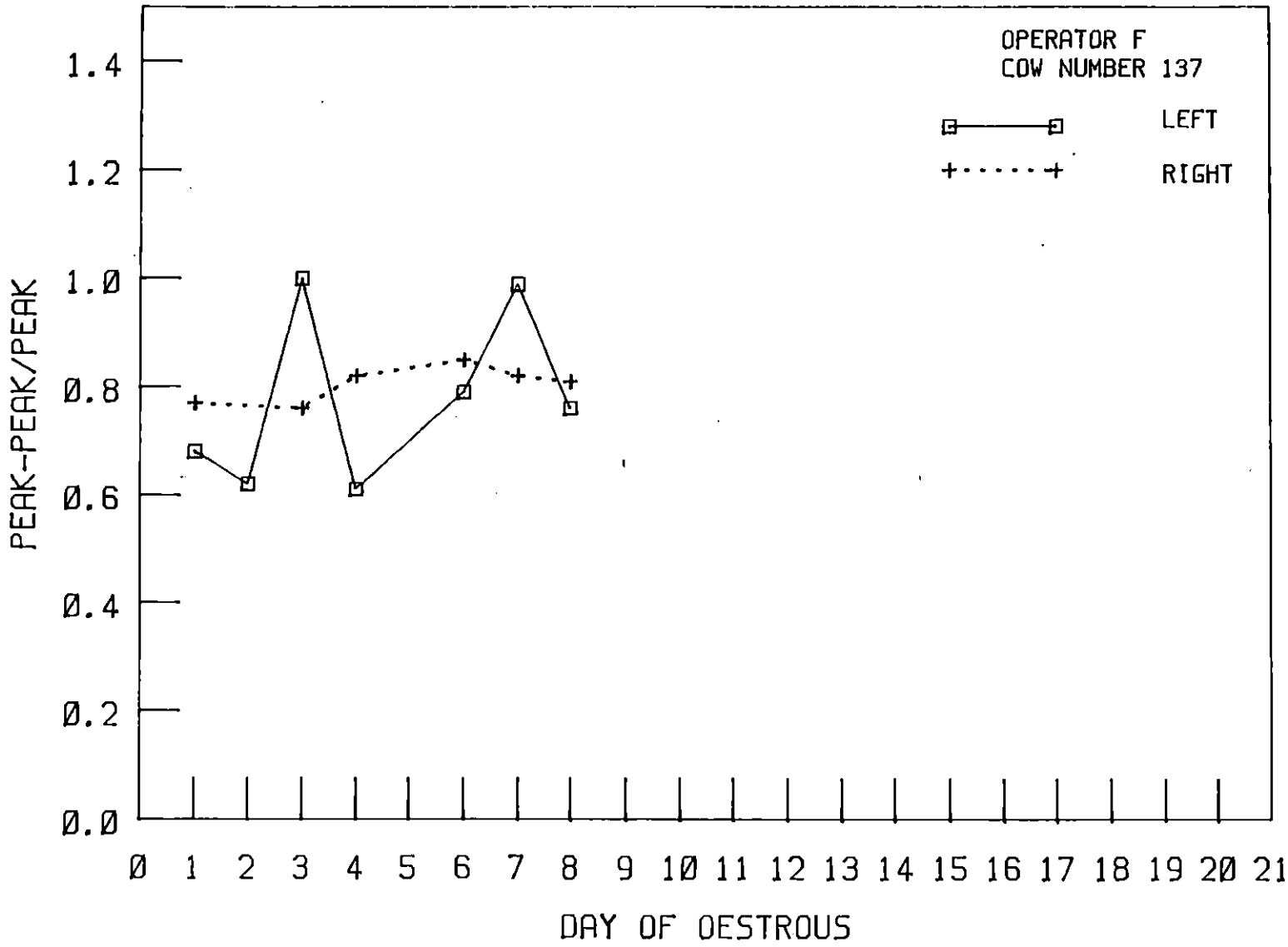


Figure 19. P-P/PK vs. day (day of oestrous unknown)

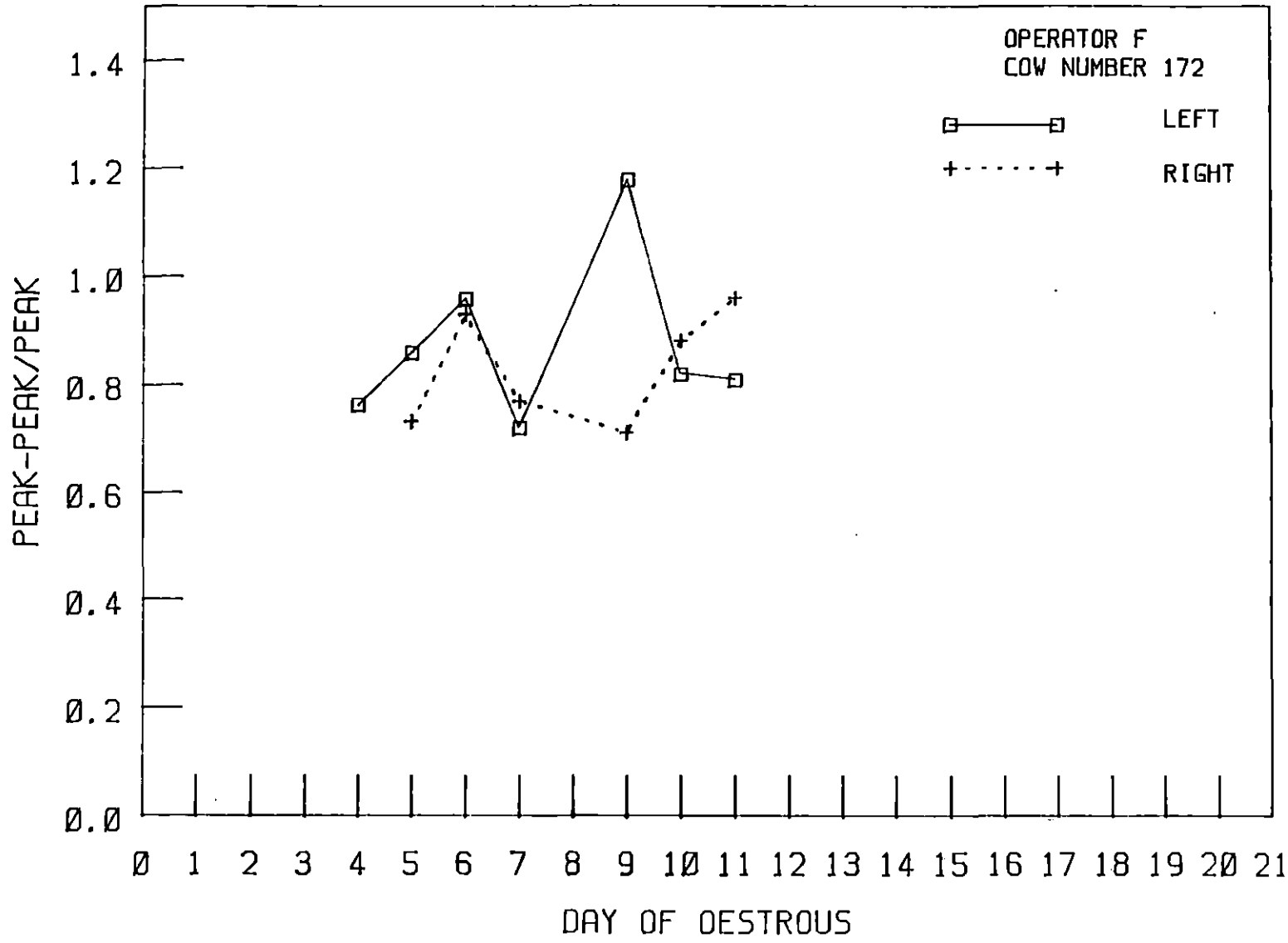


Figure 20. P-P/PK vs. day of oestrous

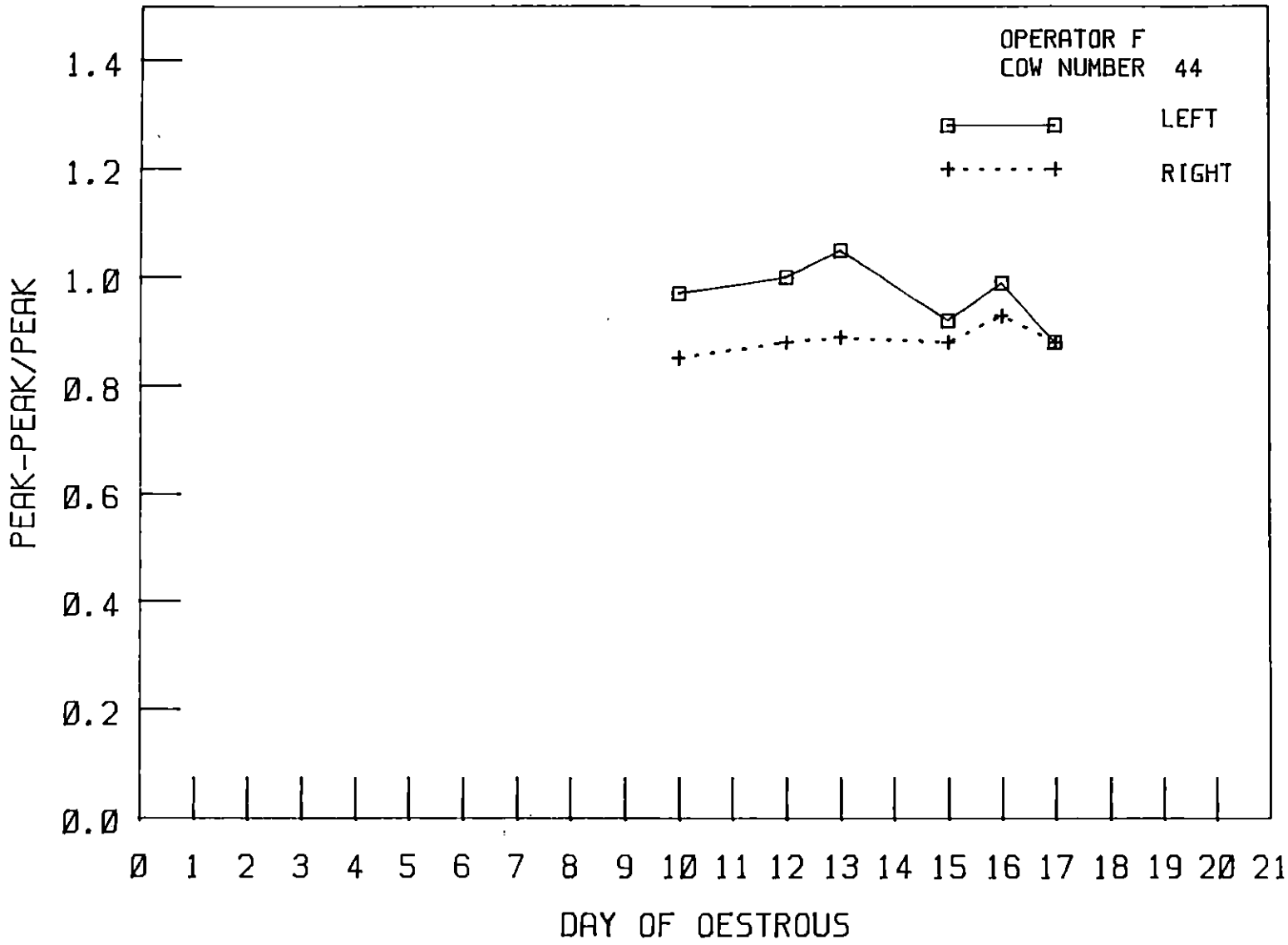


Figure 21. P-P/PK vs. day of oestrous

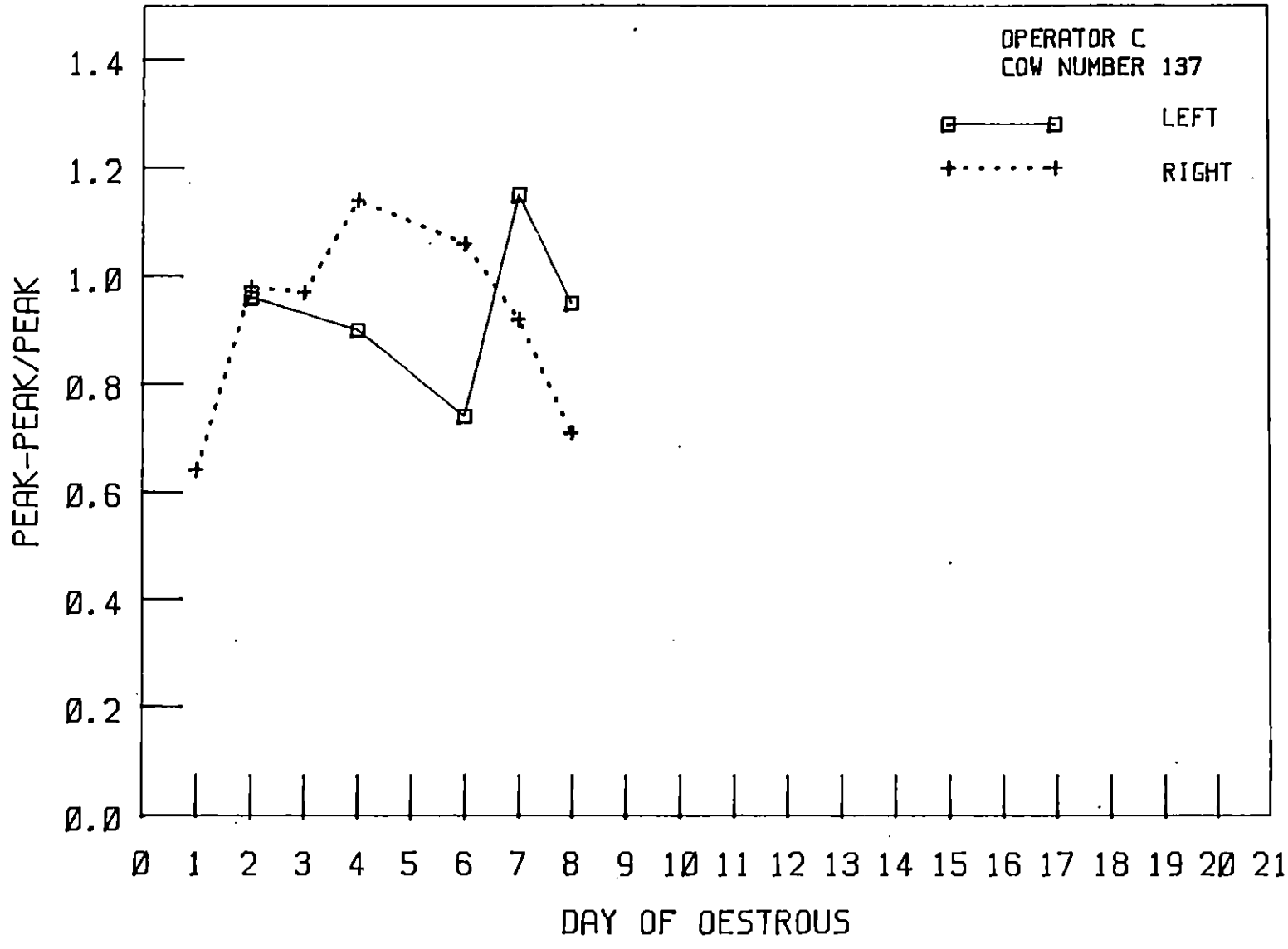


Figure 22. P-P/PK vs. day (day of oestrous unknown)

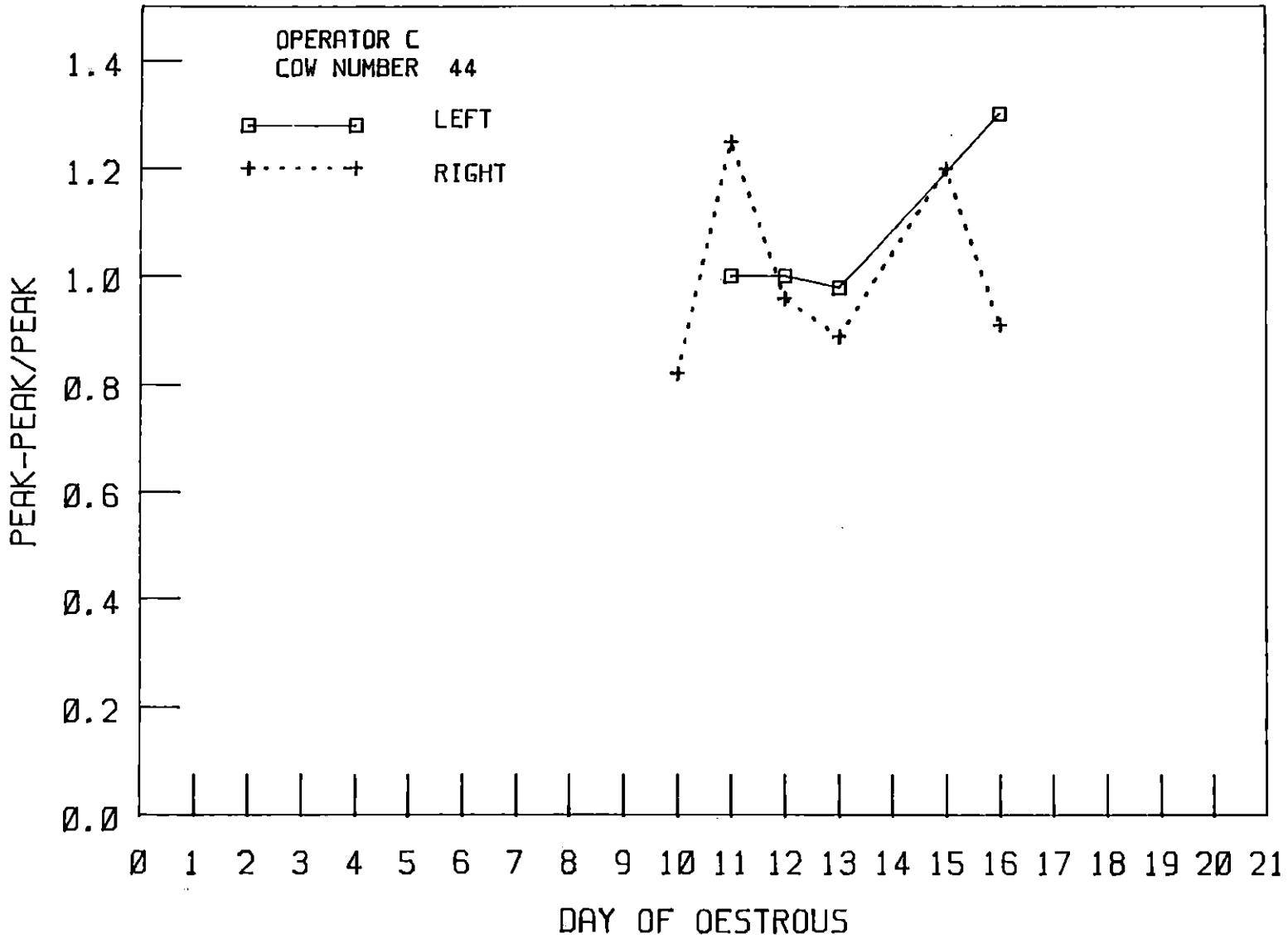


Figure 23. P-P/PK vs. day of oestrous

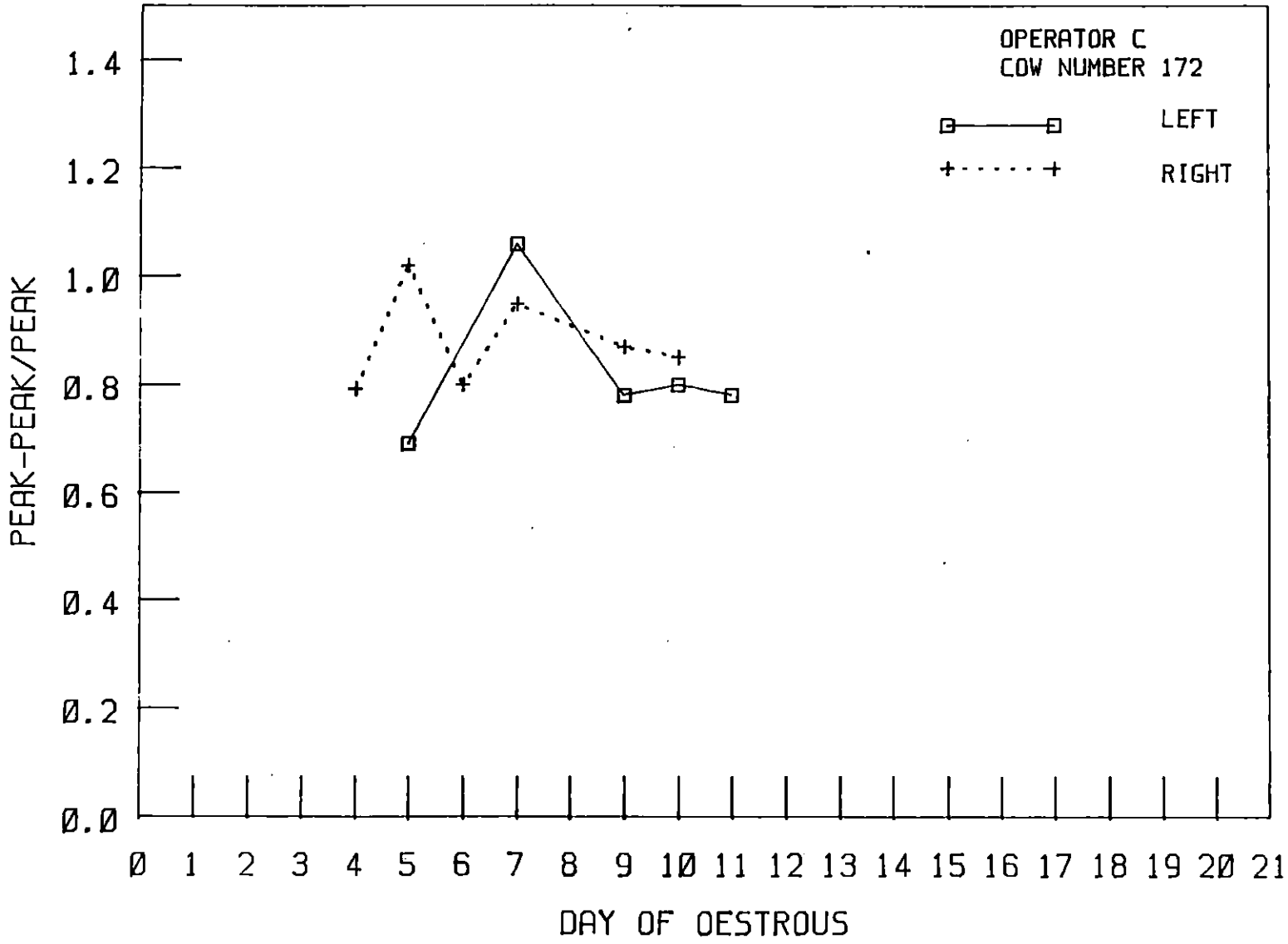


Figure 24. P-P/PK vs. day of oestrous

through 6 show the values used to plot curves in Figures 7 through 24.

If the same comparison for operator difference is made for the P-P/PK index, the same conclusion is reached. The values calculated are d = Ø.Ø86 and s_d = Ø.19Ø. The probability is 97.7 percent that the true mean of d is not zero for the P-P/PK data.

The variance of the three indices can be compared by using the coefficient of variation, V. V is defined as the standard deviation divided by the mean multiplied by 1ØØ (Kennedy and Neville, 1976). The calculated values for V (from all cows, all days) are listed below.

PI.....79.5

PI_a.....6Ø.Ø

P-P/PK.....16.6

The standard deviation for P-P/PK is a much smaller percentage of the mean value than with the other two indices. This fact is particularly important in low flow situations where small errors in mean flow can cause large errors in PI.

Pregnant cow

Flow waveforms were taken from the uterine artery of a cow at day 2Ø5 of gestation. Readings were taken for both the gravid and non-gravid uteri. Figures 25 and 26 show waveforms and average pulses from both arteries. The following values were determined for values of PI, PI_a, and P-P/PK.

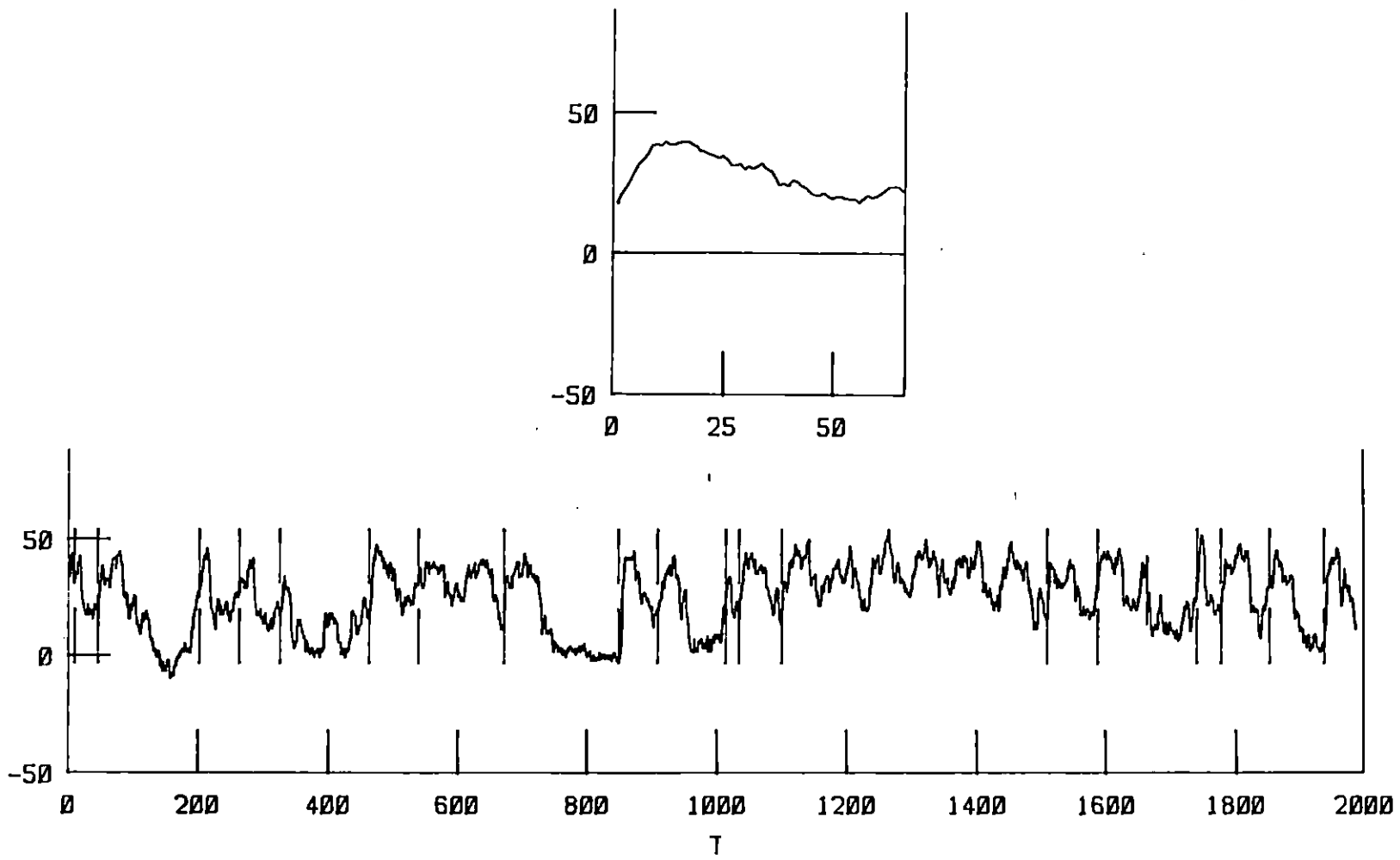


Figure 25. Waveform, uterine artery, pregnant cow 332, gravid uterus 3/3/85, operator F

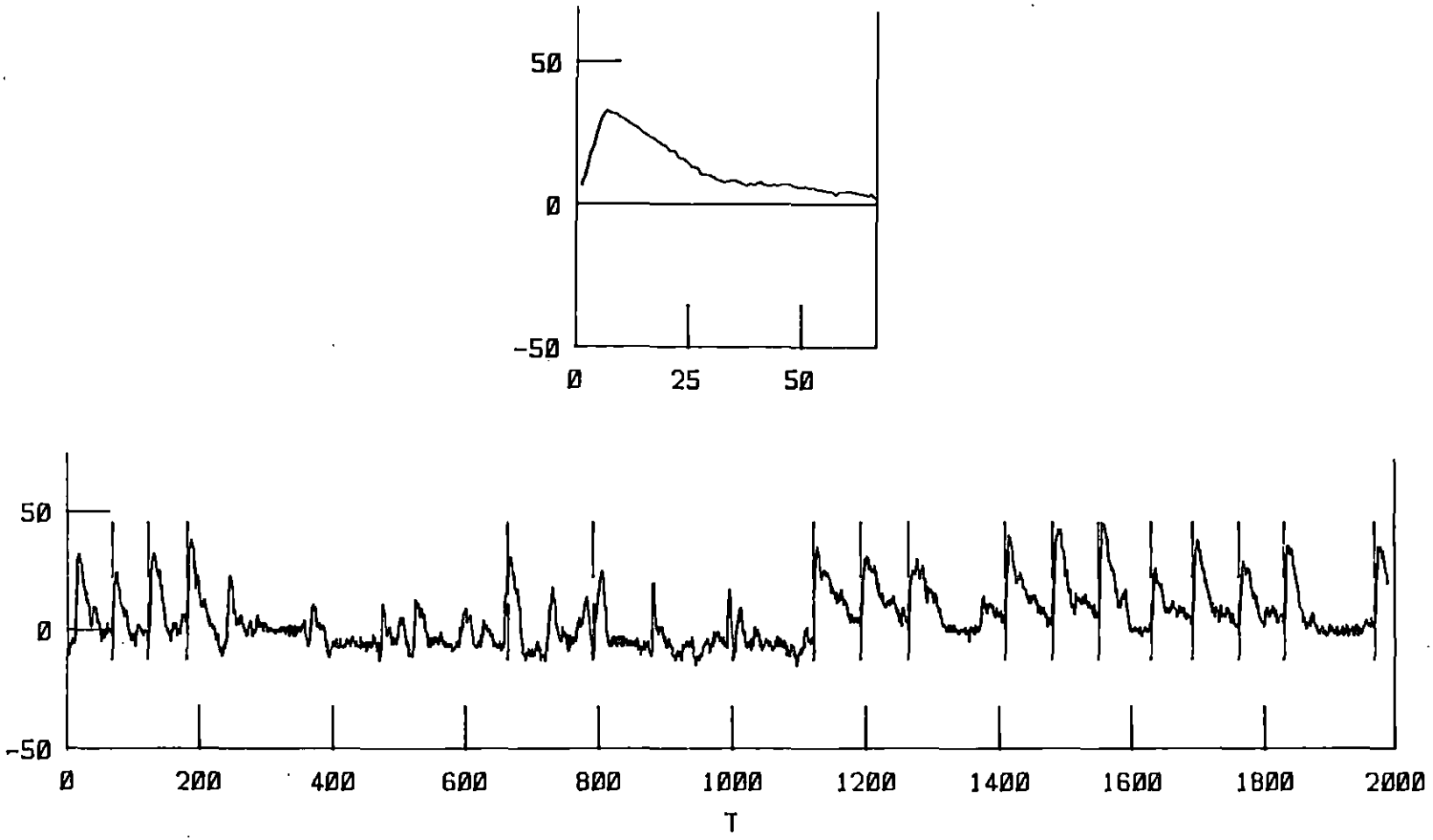


Figure 26. Waveform, uterine artery, pregnant cow 332, non-gravid uterus, 3/3/85, operator F

Table 7. Waveform indices measured in cow 332

	L		R	
Operator	C	F	C	F
PI	Ø.89	1.21	2.8Ø	3.2Ø
PI_a	Ø.9Ø	Ø.78	2.27	2.47
P-P/PK	Ø.64	Ø.55	1.ØØ	Ø.94

In the case of all three indices, values are much lower for the left uterine artery supplying the gravid uterus. This indicates flows in the left artery greater than those in the right artery.

The shape of the waveform shows differences between the arteries on the gravid and the non-gravid side. On the pregnant side the waveform is more highly damped with a less steep systolic slope and higher end diastolic value.

Measurement of Femoral Artery Blood Flow in Dogs

In order to collect and analyze electromagnetic data to compare mean blood flow to certain waveform indices, electromagnetic waveforms were recorded from the femoral artery of three dogs. Figures 27, 28, and 29 show sample recordings of hyperemic response, normal flow, and elevated flow as measured with the electromagnetic flowmeter. Again, the values on the ordinate represent a voltage which is proportional to blood flow velocity, while the values on the abscissa represent time in increments of Ø.Ø1 seconds.

Waveforms were also recorded ultrasonically in two dogs. Normal and elevated waveforms for dog 1 are shown in Figures 3Ø and 31. The hyperemic

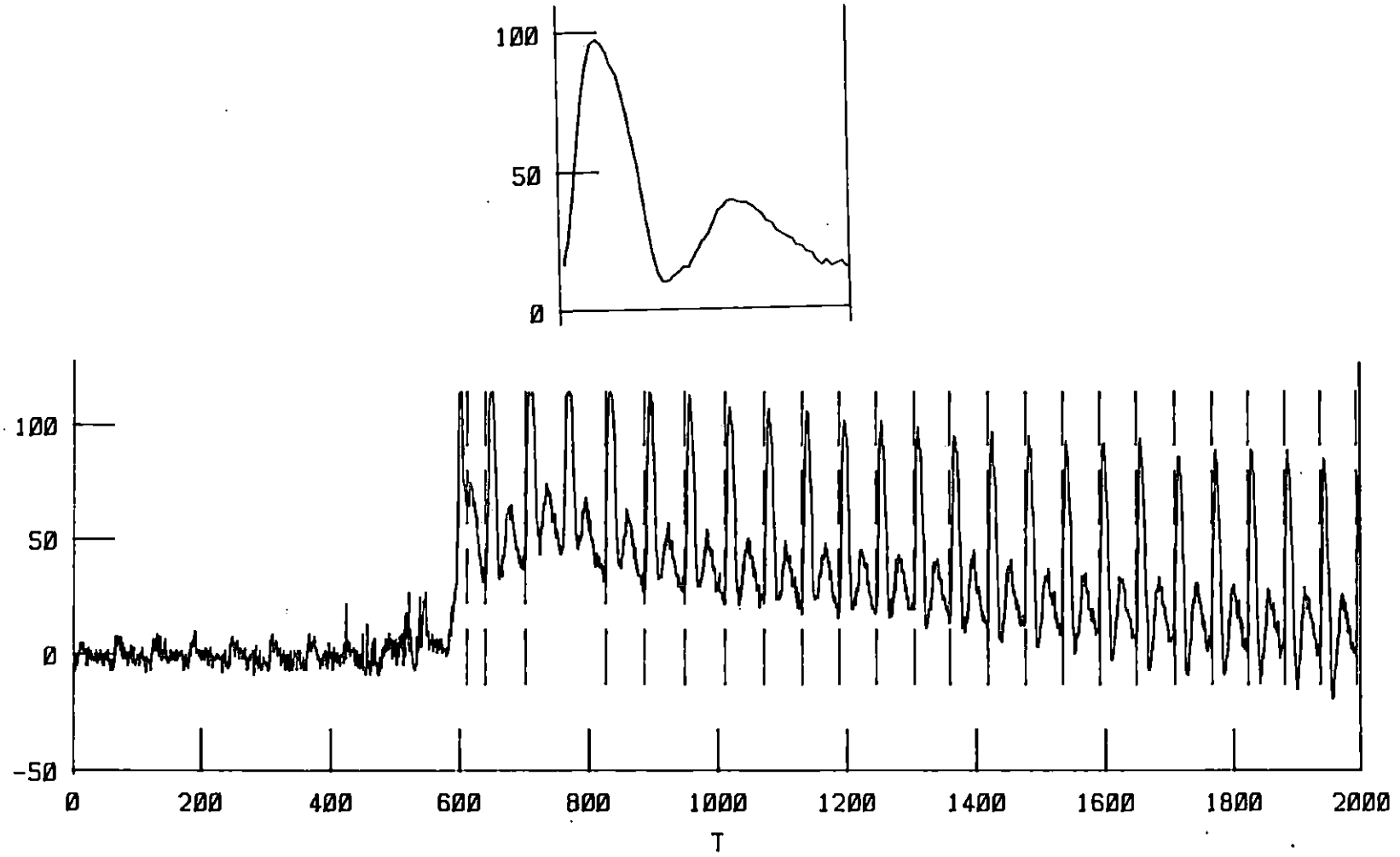


Figure 27. Sample waveforms from dog femoral artery, hyperemic response with electromagnetic flowmeter dog #2

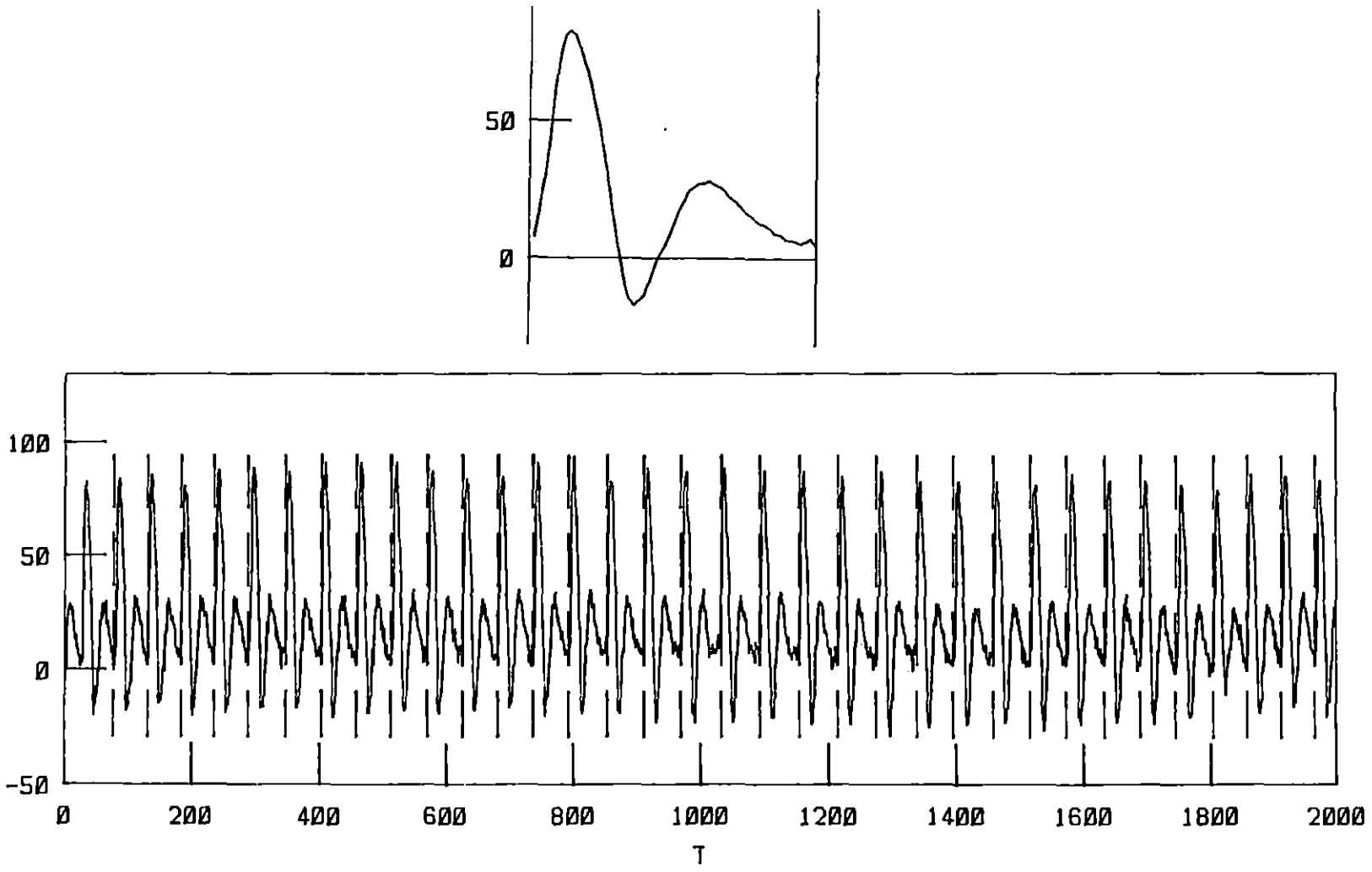


Figure 28. Sample waveforms from dog femoral artery, normal flow, electromagnetic flowmeter dog #2

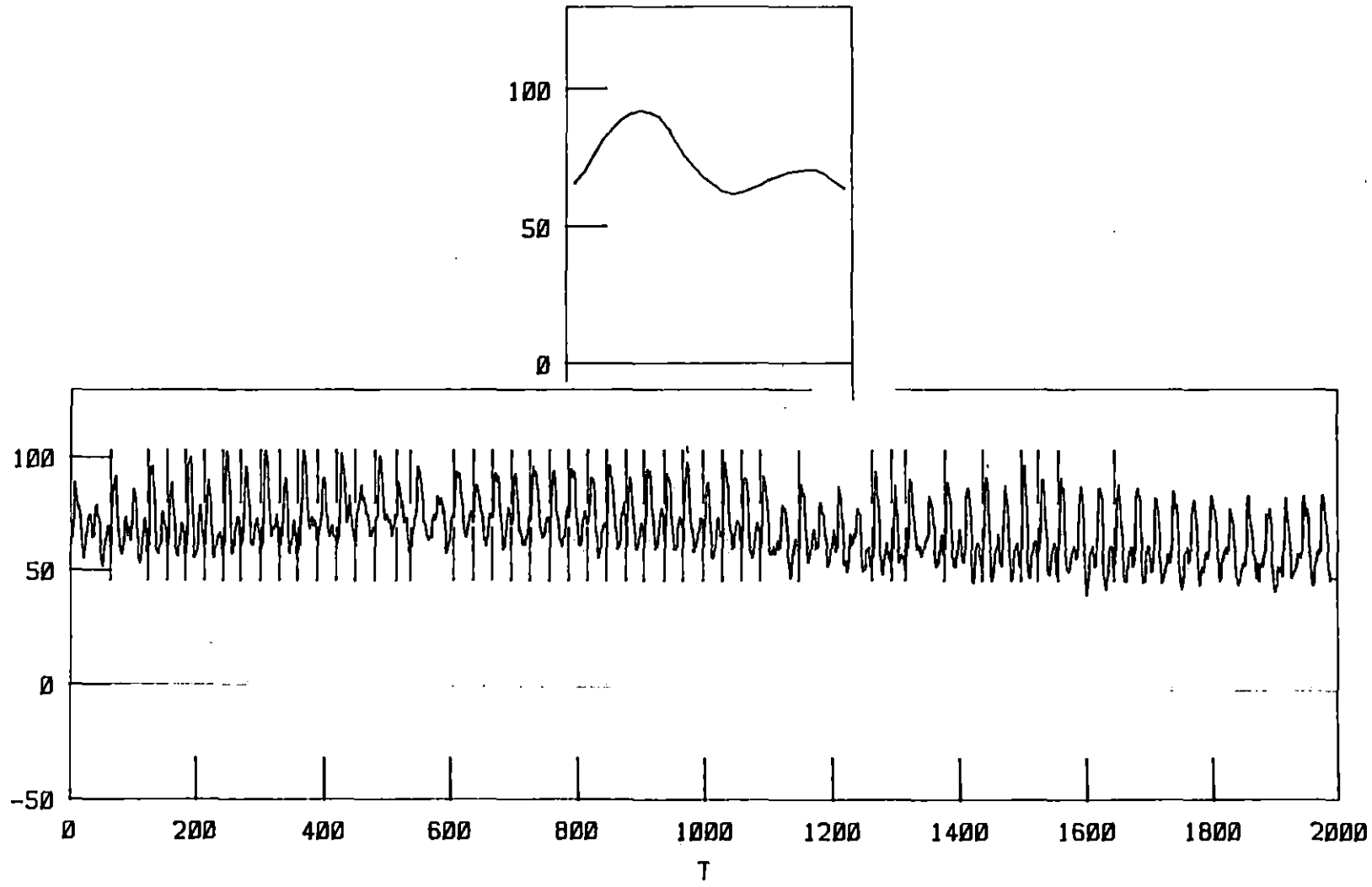


Figure 29. Sample waveforms from dog femoral artery, elevated flow, electromagnetic flowmeter dog #1

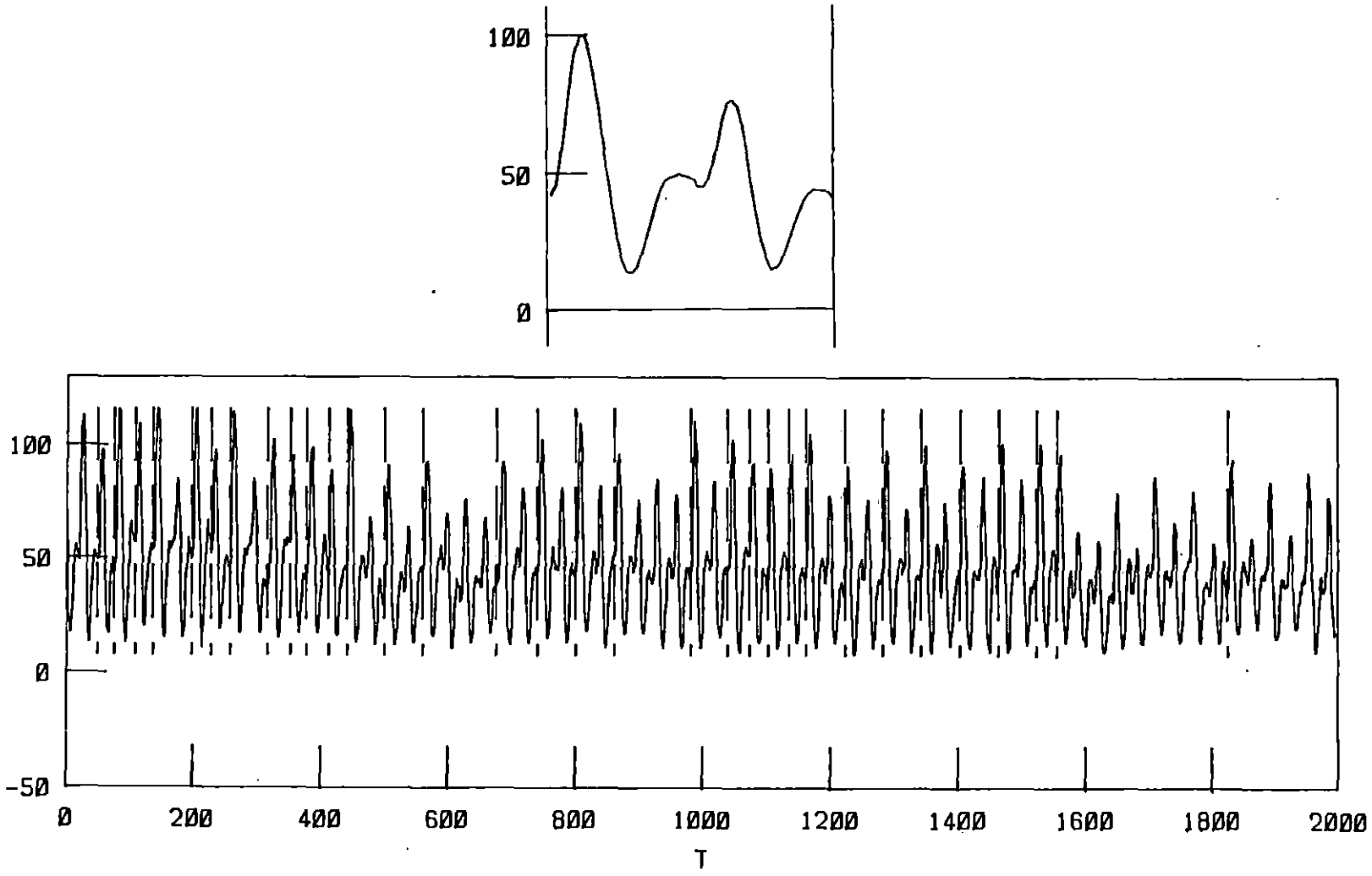


Figure 30. Sample waveforms, dog femoral artery, normal flow, ultrasonic flowmeter dog #1

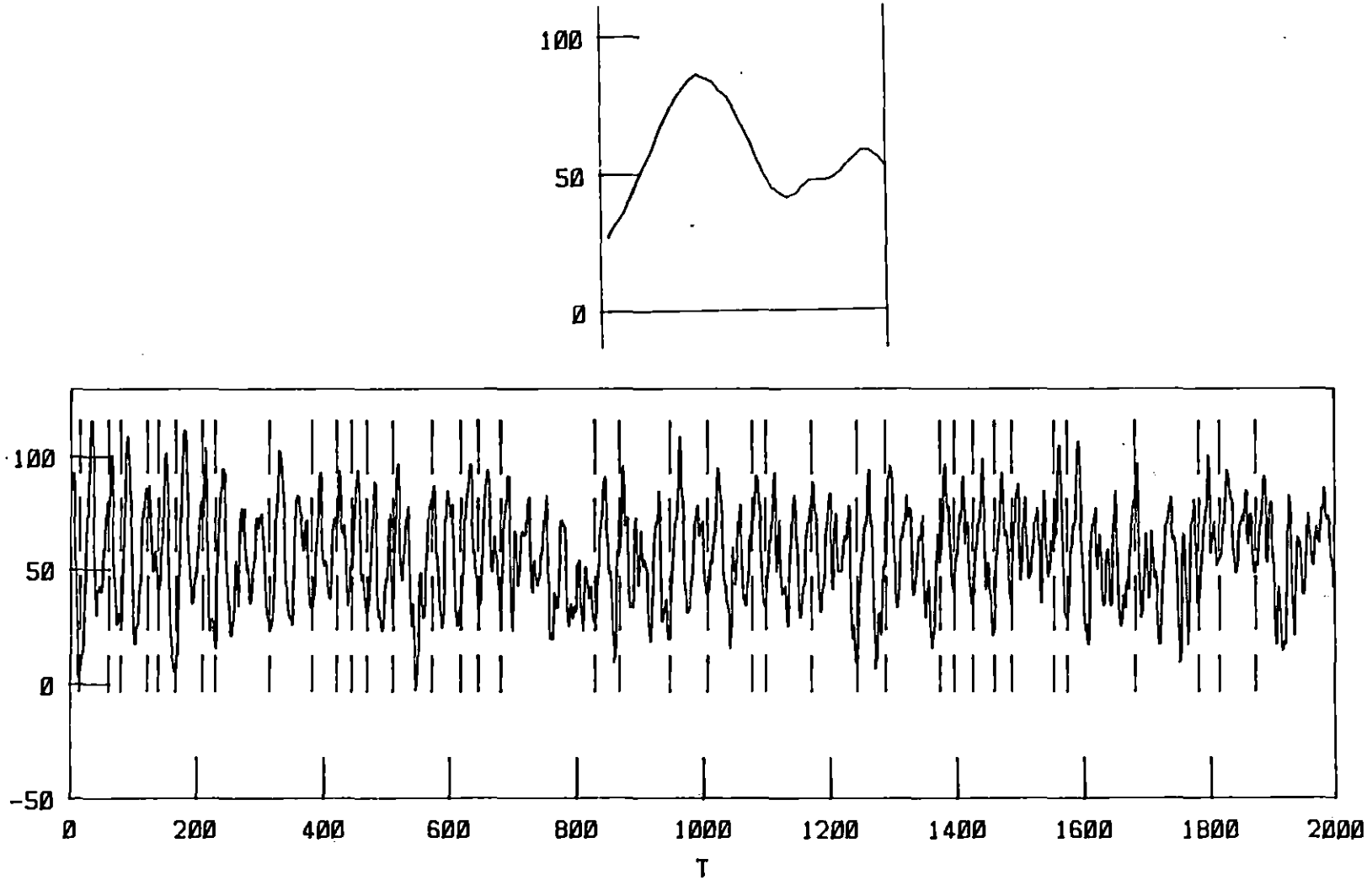


Figure 31. Sample waveforms, dog femoral artery, elevated flow, ultrasonic flowmeter dog #1

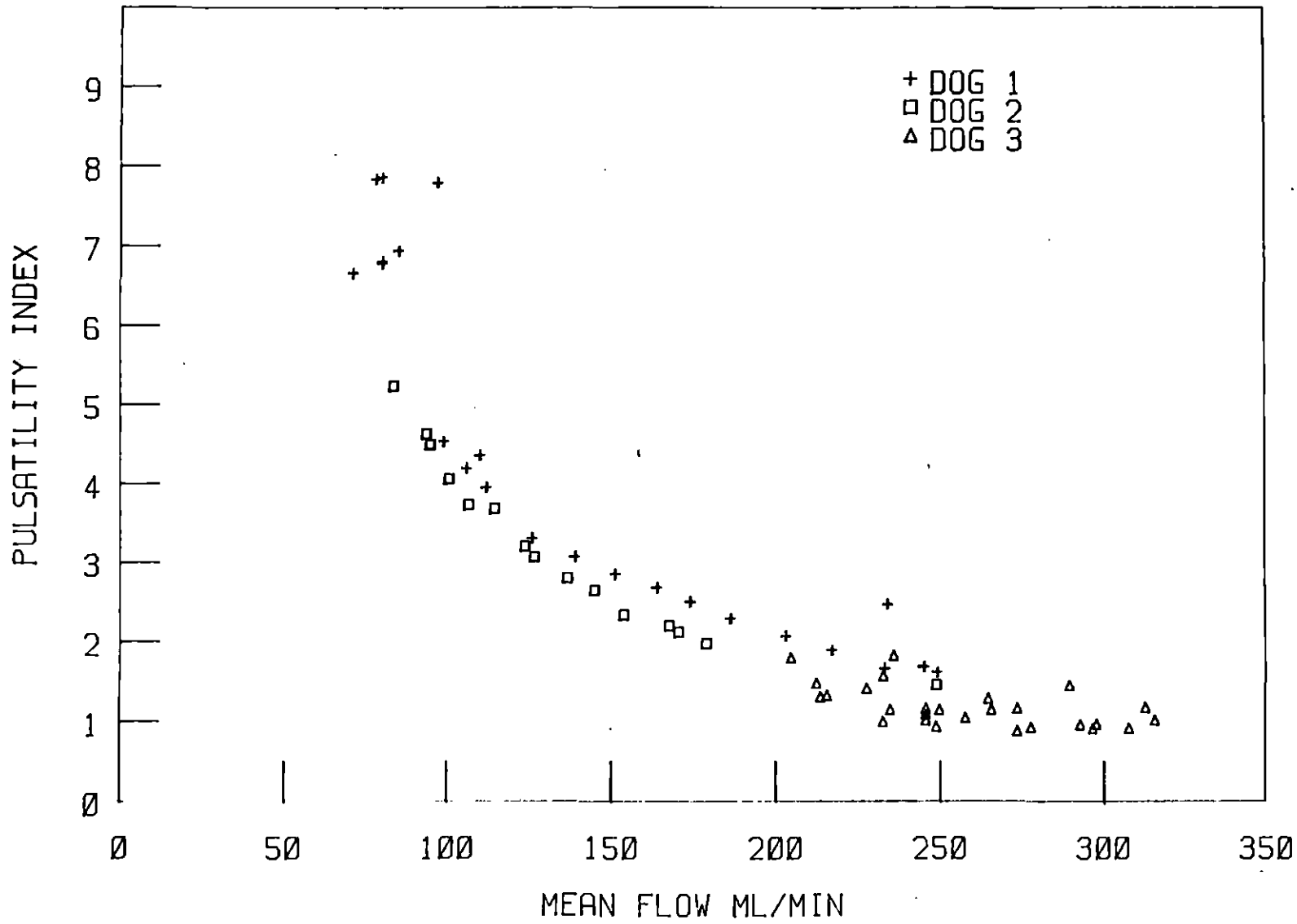


Figure 32. Pulsatility index vs. mean flow

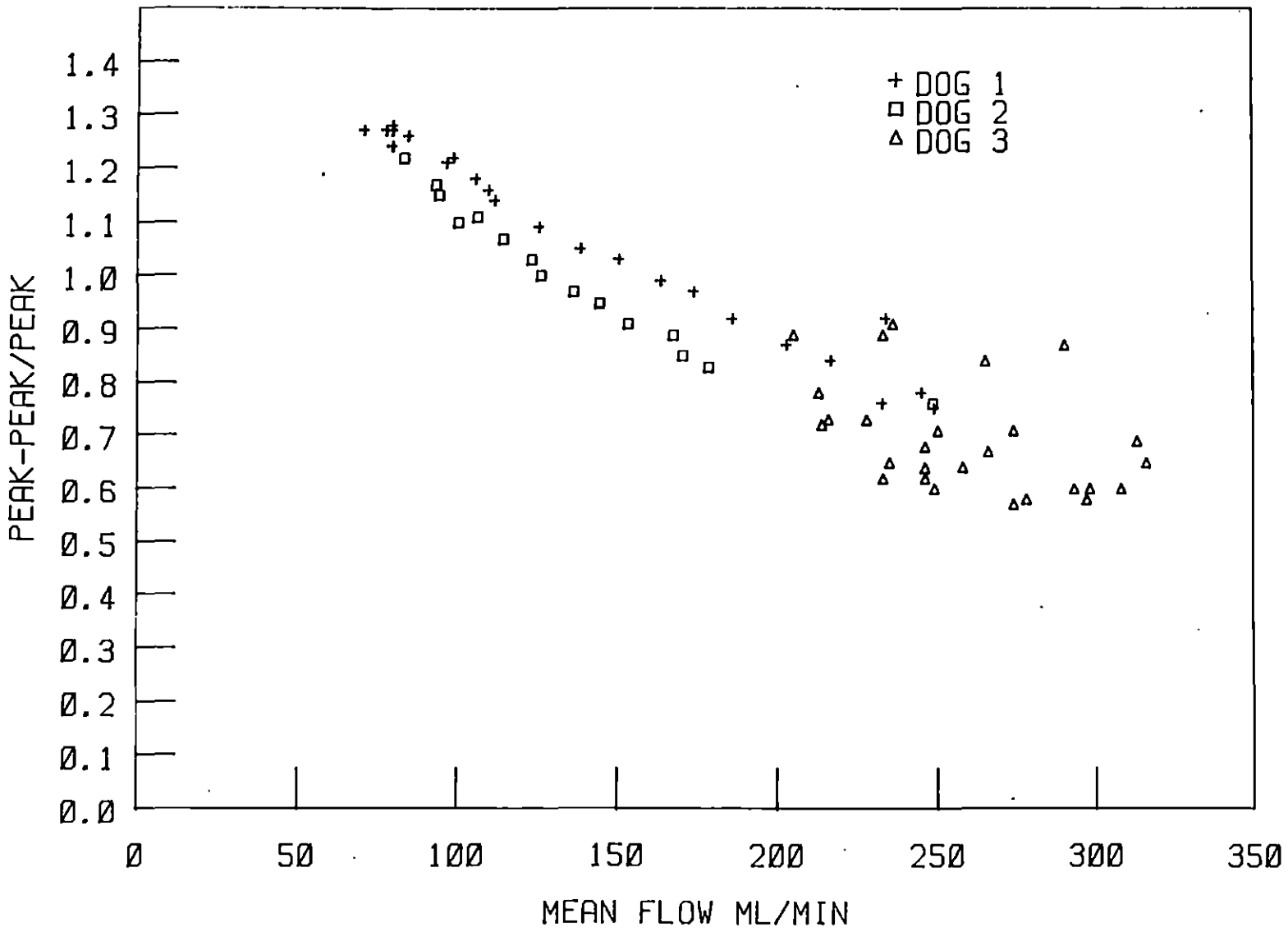


Figure 33. P-P/PK vs. mean flow

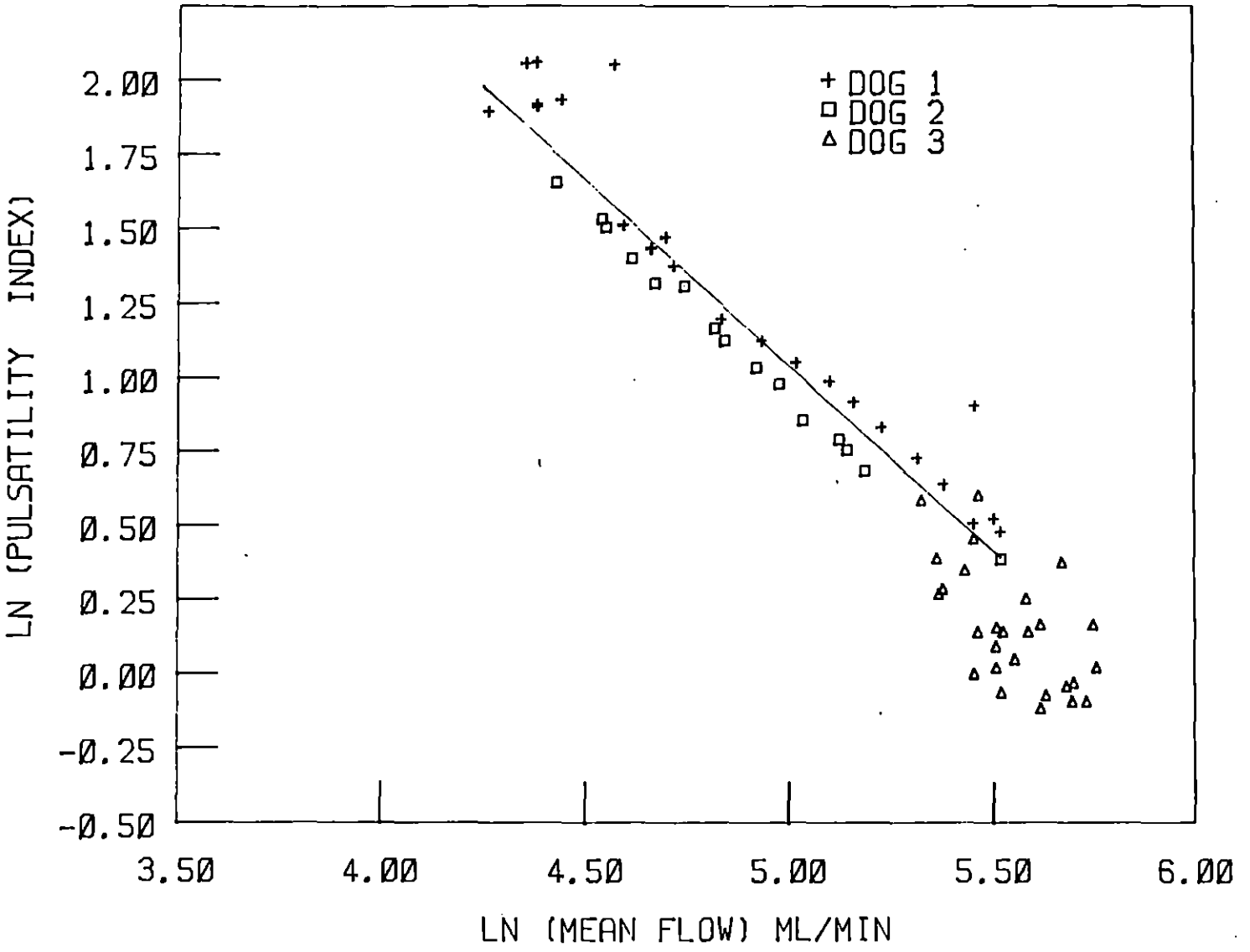


Figure 34. Ln(pulsatility index) vs. ln(mean flow)

Table 8. Mean flow vs. PI and P-P/PK, femoral artery dog 1

MEAN (ml/min)	PI	P-P/PK
234.	2.48	Ø.92
245.	1.69	Ø.78
249.	1.62	Ø.75
233.	1.67	Ø.76
217.	1.9Ø	Ø.84
2Ø3.	2.Ø8	Ø.87
186.	2.3Ø	Ø.92
174.	2.51	Ø.97
164.	2.69	Ø.99
151.	2.86	1.Ø3
139.	3.Ø8	1.Ø5
126.	3.31	1.Ø9
112.	3.96	1.14
11Ø.	4.36	1.16
1Ø6.	4.2Ø	1.18
99.	4.54	1.22
71.	6.65	1.27
97.	7.79	1.21
8Ø.	7.85	1.28
78.	7.83	1.27
85.	6.93	1.26
8Ø.	6.77	1.24
8Ø.	6.8Ø	1.27

Table 9. Mean flow vs. PI and P-P/PK, femoral artery dog 2

MEAN (ml/min)	PI	P-P/PK
249.	1.47	Ø.76
179.	1.99	Ø.83
171.	2.13	Ø.85
168.	2.21	Ø.89
154.	2.35	Ø.91
145.	2.66	Ø.95
137.	2.81	Ø.97
127.	3.Ø8	1.ØØ
124.	3.21	1.Ø3
115.	3.69	1.Ø7
1Ø7.	3.74	1.11
1Ø1.	4.Ø7	1.1Ø
95.	4.5Ø	1.15
94.	4.64	1.17
84.	5.24	1.22

Table 10. Mean flow vs. PI and P-P/PK, femoral artery dog 3

MEAN (ml/min)	PI	P-P/PK
316.	1.02	0.65
313.	1.18	0.69
297.	0.91	0.58
293.	0.96	0.60
308.	0.91	0.60
274.	1.18	0.71
290.	1.46	0.87
265.	1.29	0.84
298.	0.97	0.60
274.	0.89	0.57
258.	1.05	0.64
278.	0.93	0.58
266.	1.15	0.67
250.	1.15	0.71
235.	1.15	0.65
249.	0.94	0.60
246.	1.17	0.68
246.	1.02	0.62
233.	1.00	0.62
246.	1.10	0.64
236.	1.83	0.91
228.	1.42	0.73
233.	1.58	0.89
205.	1.80	0.89
213.	1.48	0.78
214.	1.31	0.72
216.	1.33	0.73

response could not be measured using the ultrasonic flowmeter due to the difficulty of precisely positioning the probe on the artery while clamping the vessel.

Using the data from the hyperemic response curves, the pulsatility index and mean flow can be calculated for a large number of pulses with varying mean flows. Figure 32 is a plot of pulsatility index versus mean flow as measured using an electromagnetic flowmeter. The values for P-P/PK have also been calculated for the same data. The relationship is shown in Figure 33. Tables 8, 9, and 10 include the values used in Figures 32 and 33.

In Figure 34 the natural log of PI, ln(PI), is plotted versus the natural log of mean flow, ln(Q). The data plotted in Figure 34 indicates a linear relationship between ln(PI) and ln(Q) which corresponds to a relationship between PI and mean flow of the form

$$PI = AQ^m$$

where: Q = mean flow

A = constant

m = constant

If the values for ln(PI) and ln(Q) are tabulated and linear regression is performed for each set of data the following values are found for a, m, and the correlation coefficient, r.

	a	m	r
dog 1	1600	-1.247	-0.968
dog 2	1085	-1.207	-0.997
dog 3	295	-0.998	-0.607

An equation relating PI to mean flow can be determined by combining data from dogs 1 and 2. Because of the low value for r the data from dog 3 has not been included. The equation is

$$PI = 1470Q^{-1.25}$$

where Q is in ml/min. The correlation coefficient, r, associated with this equation is -0.96.

An equation for P-P/PK versus mean flow can be determined by using the same procedure. The equation, derived from dog 1 and 2 data only is

$$P-P/PK = 3400Q^{-1.4}$$

The correlation coefficient is -0.965. The low correlation for the dog 3 data may be due to having a large number of points over a relatively small range of mean flow. Some scatter in the data (dog 1) also occurs for low values of mean flow. Although all data from dogs 1 and 2 were used to derive the above equation, from Figure 34 it appears that the above equations are applicable most for mean flows between 100 and 250 ml/min (4.6 to 5.5 on the ln(Q) plot).

A qualitative comparison between the electromagnetic and ultrasound waveforms shown (Figures 27 through 31) does not suggest close correlation between the two sets of waveforms. However, due to the small amount of data no definite conclusion can be drawn. Other studies have shown that waveforms recorded with both flowmeters compare closely (Hankner, 1978).

SUMMARY AND CONCLUSION

The first stated objective of this study was, "To develop a technique and probe for routinely collecting continuous wave Doppler ultrasound data from the uterine artery of cattle." During the eight days of data collection 84 data sets were collected. Of these, 73 contained useable data yielding an 87% success rate. This rate will continue to improve as the technique of each individual operator improves. An ultrasound probe has been designed, built and used which is suitable for rectal palpation of the bovine uterine artery. The design meets the criteria for signal strength and size. The question of reliability/life is still undecided. Some early probes lasted as little as 3-6 data sets (1 day) while some other probes have been used for 1-2 weeks and are still operational.

Objective number two was "To develop a data collection system." A data collection system has been designed. It consists of an ultrasonic flowmeter, an instrumentation tape recorder, an A/D converter and a digital computer.

The third objective of this study was, "To develop software for a PDP-11/23 digital computer for processing the data and calculating various waveform indices." This objective has been fully accomplished. The program processes a file of digitized data and calculates pulsatility index of each pulse, mean pulsatility index, pulsatility index of an average pulse and peak-peak/peak value for an average pulse. This program also plots the data along with an average pulse. Other indices could be readily determined.

The fourth objective was "To collect, process, and analyze data to determine the feasibility of using blood velocity waveform indices to assess uterine artery blood flow." Figures 7 through 24 along with Tables 1 through 6 demonstrate that data can be collected and analyzed on a daily basis. The indices used ($\overline{PI}$, PI_a, and P-P/PK) vary from day to day. The lowest calculated value for PI_a was 1.Ø2 (cow 137, day 2, left side, operator F). For the pregnant cow studied, the highest values of PI_a in the uterine artery of the gravid side was Ø.9Ø. The values in Table 7 for the pregnant cow studied, show values of Ø.89 and 1.21 for the artery supplying the gravid uterus compared to 2.8Ø and 3.2Ø for the non-gravid side. The average $\overline{PI}$ value for the non-gravid side was 3.Ø versus 1.Ø5 for the gravid side.

It should be noted that these data include only one pregnant cow at 2Ø5 days of gestation. The velocity waveforms in the uterine artery may vary significantly from that indicated in Figure 25 at early stages of pregnancy. However, it may be feasible to determine pregnancy by the analysis of blood velocity waveforms if the waveform in early pregnancy has values of PI_a less than 1.Ø or if the values for the pulsatility index are significantly different between the gravid and non-gravid side.

Comparing the three indices, $\overline{PI}$, PI_a, and P-P/PK, showed that the P-P/PK index had much less variance as a percentage of its mean value. This difference among the indices probably results from the variability associated with errors in measuring very low mean flows.

The final objective of this study was, "To collect and analyze electromagnetic data to compare mean blood flow to certain waveform indices." Data were collected from the femoral arteries of three dogs using ultrasonic and electromagnetic flowmeters. Figure 32 shows an inverse relationship between pulsatility index and mean flow, i.e., as mean flow increases the PI decreases. Figure 33 also shows an inverse relationship between mean flow and P-P/PK. An equation for the relationship between PI and mean flow was determined to be of the form

$$PI=1470Q^{-1.25}$$

This equation shows that although PI and mean flow have a nearly inverse relationship, there is not a one-to-one relationship. Instead the PI varies with the -1.25 power of the mean flow.

A number of areas for further work on this project are possible. Since the characteristic waveform in the uterine artery is now known, more work can be done in the area of pattern recognition. Software can be written which will do a more accurate and efficient job of processing data while following a more logical programming sequence.

The relationship between PI and early pregnancy can now be explored by collecting and processing data from cows going through early stages of pregnancy. Further study can be made comparing electromagnetic to ultrasonic waveforms in uterine arteries in cattle.

It would be useful to develop a microprocessor which could digitize and process data at the time and location of data collection. This would eliminate a number of problems associated with data acquisition and provide better feedback for the operators.

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The experimental use of dogs in this project conforms to the "Guiding Principles in the Care and Use of Animals", approved by the Council of the American Physiological Society. Care of dogs prior to experiments were handled by the Laboratory Animal Resources section of the College of Veterinary Medicine. Cattle involved in the project are maintained at the Iowa State University Animal Reproduction Farm.

APPENDIX A: EQUIPMENT SPECIFICATIONS

Parks Model 909 and Model 1010-LA Doppler Flowmeters

1. Oscillator frequency: Nominal 10 Mhz. or 5 Mhz.
2. Power: rechargeable battery - gel cell.
3. Filters: 4 pole low-pass active filters; 12 db per octave cutoff at 3.5, 7, 14, of 28 Hz.

Biotronex Model BL-610

Electromagnetic Blood Flowmeter

1. Input: Differential with no common mode return except through transducer ground.
    a. Impedance: Nominally 10,000 ohms at 1100 cps.
    b. Maximum voltage before distortion at the output of the flowmeter - At least 1×10^{-5} V peak-peak at one tenth amplifier gain using sine-wave generator slightly offset from the carrier frequency.
2. Outputs: Single ended. One output with high response capability for pulsatile blood flow and another output with damped response for mean flow presentation are located on the rear apron of the power supply and console housing.
    a. Output impedance: 2700 ohms.
    b. Output capability: 5.33 volts peak-peak at one tenth amplifier gain

with 1 x 10^{-4}V input connected as in 1.b.

3. Frequency response: At least 100 Hz (-3dB) measured at the phasic output connector with frequency response switch in maximum response setting of 100.

4. Noise: With input shorted to ground and amplifier at one half gain in 100 Hz. frequency response setting, noise is less than .5 x 10^{-6}V.

5. Baseline: Fixed zero reference is presented on the outputs. This will not necessarily be an "electronic zero".

6. Flow polarity: reversible

Tandberg Series 115

Instrumentation Tape Recorder

1. Speed control: Electronic servo controls capstan speed against fixed reference.

2. Tape speeds: 15, 3 3/4, 15/16 ips, electrically switchable. FM carrier frequency and FM reproduce filter bandwidth automatically selected.

3. Input impedance: 40 K ohm/volt, single ended.

4. Frequency range and signal/noise ratio:

Tape speed ips	Center carrier frequency hz	Pass band limits lower	upper	S/N
15	27000	DC	5000	47
3 3/4	6750	DC	1250	45
15/16	1688	DC	312	34

5. Output voltage: ±5 V peak for full deviation.

6 Output impedance: less than 1 ohm single ended.

7. Linearity: Ø.2% departure from best straight line through zero.

Hewlett-Packard

Instrumentation Tape Recorder

1. Tape speed accuracy: ±Ø.2 % .

2. Tape speed: 15, 3 3/4, and 15/15 ips.

3. Input impedance: 5Ø k ohms or greater shunted by 2ØØ pF maximum, single ended.

4. Frequency range and signal/noise ratio.

Tape speed ips	Center carrier frequency hz	Pass band limits lower	upper	S/N
15	27ØØØ	DC	5ØØØ	48
3 3/4	675Ø	DC	125Ø	48
15/16	1688	DC	312	46

5. Output voltage: ± 5 V peak for full deviation.

6. Output impedance: 14Ø ohms maximum.

7. Linearity: ± 1% peak-peak output.

Hewlett-Packard Model 7402A

Oscillograph Recorder

1. Input: single ended.
2. Input impedance: one megaohm (nominal).
3. Input sensitivity range: 20 mV/div - 5 V/div.
4. Gain accuracy: Within 0.75 % of full scale value.
5. Linearity: Within 0.6% of full scale value.
6. Frequency response: Within 2 % flat from DC to 40 Hz (less than 3 dB down at 55 Hz)

APPENDIX B: DATA PROCESSING PROCEDURES

PET A/D CONVERSION

The following document describes the procedure for using the PET personal computer and the A/D converter to collect and digitize data.

Three software programs are needed. They are MEM, ASLOAD, and PDASFC. These programs must be loaded and run in the order shown above. This must be done on a terminal which is specially equipped to handle A/D conversion. Once the programs are loaded and have been run on the proper computer the last program will display questions on the screen. Before going on check the following items: 1) The A/D converter must be hooked up and the A/D converter must be turned on; 2) there must be some signal hooked up to the A/D converter; 3) if using less than 8 channels, use the lowest numbered channels (i.e. for one channel use channel 1, for 3 channels use channels 1, 2, and 3); 4) set the proper input range at the front of the A/D converter.

When the above sequence is complete, the data collection process can be started by answering the questions displayed on the screen. The data will be digitized in a range from Ø to 256. Zero volts corresponds to the number Ø or 128 depending on the range which is chosen. The data which are digitized is stored in the computer memory until a request is made to display it on the screen or on a disk or tape. To display data simply answer the collect/store question with s, for store. Then when the device question appears answer with s, for screen.

After the data have been stored on disk, they can be accessed through a read statement in a basic program.

PET TO BME COMPUTER TRANSFER <PET.DOC>

This document will briefly describe how to transfer files from the PET computer to the BME computer system. This document can be found in account 1,10 (type DOC:pet.doc) on the BME computer system.

The software that allows this type of communication is called TSX-NET, a product of Glenn A. Barber and Associates, Inc., Sherman Oaks, California. Dennis Jensen and Jim Flatten, employees of Ames Laboratory, are responsible for the software support of TSX-NET. Therefore, any technical questions should be directed at them, 294-4823.

Detailed information on TSX-NET can be found on the bookshelf in the room that contains the BME computer system. The same information is also located on a floppy disk in Vol. 1 of a three-ring binder on the bookshelf.

This transfer will work only on PET computers that have the BLUE BOX attached to it. The BLUE BOX has an IEEE 488 cable on one end (compatible with the PET), an IEEE 488 PORT on the side opposite the IEEE 488 cable, and an RS 232 cable (compatible with the PDP-11) on the other end. To begin, DISCONNECT THE PRINTER CABLE from the back of the PET and attach it to the IEEE 488 PORT on the BLUE BOX. Secondly, attach the IEEE 488 cable from the BLUE BOX to the PET at the PRINTER PORT. Lastly, attach the RS 232 cable from the BLUE BOX to the REMOTE DEVICE cable on the PDP-11. The RS 232 cable has female connectors on both ends and is marked "2 & 3 swapped". This connection will now be referred to as the remote line which is connected to the BME computer system. The BME computer system is now connected to the PET computer.

The PET can only be used as a sending terminal when configured in this manner. The logical unit number "4" is assigned to the BLUE BOX in addition to the printer. Therefore, in order to transfer a file from the PET to the PDP-11, a small PROGRAM must be written by the USER that will read in that file (either a "PRG" or "SEQ") from the disk and send it to the printer. If the printer is turned on at the same time the transfer occurs, a hard-copy of the file will be generated simultaneously. At the end of this document, a sample program demonstrating the transfer of a sequential data file is shown.

The BLUE BOX operates at a speed of 300 baud. At boot-strap, the BME computer system is configured to operate at 1200 baud when communicating over the remote line. To change the baud rate of the remote line, log into the 1,9 account and enter the following command :

PET <return>

This command executes a command file that automatically sets the proper baud rate of 300.
This is a privileged command and the 1,9 account can execute privilege commands. Entering the following command will show the status of the remote line :

SET RD SHOW <return>

This following will be printed on the CRT (or something similar):

(C) 1980-82, GABA, Inc. (213)-907-6622
RD.TD2-V2.3: LIC=00000, CSR=175610, Vector=000330, Speed=00300, Retries=00007

Now log into the appropriate account (presumably your account on the BME computer system) where the transfer is going to take place.

1. Enter the following command :

   R FTERM <return>

   After a lengthy printout on the CRT, you'll be staring at :

   FTERM Command:

2. We will now direct FTERM to open a file on the BME computer and be in the receive mode as shown here :

   FTERM Command: R filnam.ext <return> (.DAT for data)

   FTERM Command: <return>

3. Now run the PET program to transfer the file to the BME computer system. When the PET program is running, you'll see the PET file printed on the BME computer system's CRT, while at the sametime FTERM is storing the contents of the PET file into "filnam.ext".

4. When the transfer is complete, enter the following on the BME's CRT :

   <CTRL/P>

   and you'll see the following on the CRT :

   FTERM Command:

   Enter the letter C followed by a <return> to close the file on the BME computer system.

FTERM Command: C <return>

5. Enter the letter E followed by a <return> to exit FTERM.

FTERM Command: E <return>

6. When the transfer session is complete, log into account 1,9 and reset the baud rate back to 1200 on the remote line.

SET RD SPEED=1200 <return>

SAMPLE PROGRAM

This program will perform a transfer of a sequential data file from the PET to the PDP-11. It assumes the data was stored sequentially in a file that represented an array of "I" data points (rows) by "J" data channels (columns). In other words:

```
        CHANNEL--> 1   2   3   4   5   ...   J

TIME       1
   |       2
   |       3
   V       :
           I
```

where channel 1 is heart rate, #2 is arterial pressure, etc., sampled in 1 second intervals.

```
10 PRINT"ENTER DISK DRIVE NUMBER":INPUT N:IF N>1 THEN GOTO 10
20 PRINT"ENTER FILE NAME":INPUT F$
30 OPEN20,8,5,"N:"+F$+",SEQ,R"
40 PRINT"ENTER NUMBER OF DATA POINTS/CHANNEL AND NUMBER OF
CHANNELS (I BY J):INPUT NI,NJ
50 OPEN 1,4
60 FOR I=1 TO NI
70 FOR J=1 TO NJ
80 INPUT#20,X:PRINT X:PRINT#1,X
90 NEXT J
100 NEXT I
110 CLOSE20:CLOSE1
120 END
```

The file which is generated on the PDP-11 is also a sequential file of data. In order to reconstruct the data into the original array, a small program on the PDP-11 must be implemented to do this. If the original array is sent to the PDP-11 intact, the PDP-11 will have difficulty interpreting the data as points and will most likely take each row as a string. This problem can be circumvented by a more experienced programmer by sensing the spaces between the points as delimiters and sending the array intact.

APPENDIX C: COMPUTER PROGRAMS

```
C   VELOCITY WAVEFORM ANALYSIS PROGRAM
C
C This program reads a file of digitized data and plots out a velocity
c versus time graph.  It then calculates heart rate, number of pulses,
c  mean value, and pulsatility index.
c
c INITIALIZE
C
 dimension c(2000),r(2000),CSTRT(90),CBEG(90),RPMX(90),RPMIN(90)
 DIMENSION CPMAX(90),CPMIN(90),MEAN(90),PULS(90),ICST(90),
     C  TPUL(90),CKPUL(90),RTE(90),AR(150),FLAGC(90)
 INTEGER N,I,J,NUMPUL,FLAG,FLAGA,FLAGB,ICST,CKPUL,CT,CKCT,NORMI
     C  ,ITAVG,IAMN,IAMX,IMN,IMX,ITER,FLAGC
 real c,r,MAXR,MAXC,MINR,MINC,D,CSTRT,PK,SUMR,MEAN,PULS,RPMIN
 real MPULS,PH,TPUL,RTE,RSUM,SPUL,RNORM,TAVG,AR,RISE,ACMN,ACMX,ADEL
     C  ,AMEAN,ARMAX,ARMIN,APUL,TCK,CTA,CTB,MXPCT,MNPCT,BPUL,ACMXN,ACMNN
 BYTE FILEN(14),DATE(16)
 SPUL=0.
 RSUM=0.
 CT=0.
 MPULS=0.
 PK=0.
 MAXR=0.
 MAXC=0.
 MINR=256.
 MINC=0.
 D=0.
 NUMPUL=0
 FLAG=0
 FLAGA=0
 FLAGB=0
 DATA ACMN,ACMX,AMEAN,ARMAX,ARMIN,ITER/250.,0.,0.,0.,250.,0/
C
C INPUT DATA ARRAY
C
 WRITE(5,100)
 100 FORMAT('  INPUT FILENAME')
 READ(7,200) nin,FILEN
 200 FORMAT(Q,14A1)
 WRITE(5,250)FILEN
 250 FORMAT(x,14A1)
 WRITE(5,300)
 300 FORMAT('  INPUT NUMBER OF DATA POINTS')
 READ(7,400)N
 400 FORMAT(I4)
 WRITE(5,450)N
 450 FORMAT(X,I4)
```

```
 WRITE(5,22)
 22 FORMAT('  INPUT % OF PEAK TO TRIGGER PULSE, % TO RESET (.65,.45)')
 READ(5,23)MXPCT,MNPCT
 23 FORMAT(F3.2,1X,F3.2)
 WRITE(5,21)MXPCT,MNPCT
 21 FORMAT(5X,F4.2,5X,F4.2)
 WRITE(5,31)
 31 FORMAT('  INPUT DATE; XX/XX/85')
 READ(7,32)DATE
 32 FORMAT(16A1)
 WRITE(5,33)DATE
 33 FORMAT(X,16A1)
 OPEN(UNIT=12,NAME=filen,TYPE='OLD')
 do 500 j=1,N
 D=D+1.0
 C(J)=D
 read(12,600)r(j)
 600 format(f4.0)
 500 continue
 CLOSE(UNIT=12)
C
C FIND MIN AND MAX VALUES
C
 DO 700 J=1,N
 IF(R(J).GT.MINR)GOTO 800
 MINR=R(J)
 MINC=C(J)
 800 IF(R(J).LT.MAXR)GO TO 700
 MAXR=R(J)
 MAXC=C(J)
 700 CONTINUE
C
C FIND FIRST FULL USEABLE PULSE
C
 DO 900 J=1,N
 IF(FLAGB .EQ. 1) GO TO 850
 IF(R(J) .LT. (MAXR-MINR)*MXPCT+MINR) GO TO 900
 FLAGB=1
 PK=PK+1.
 IF(PK .LT. 2.) GO TO 900
 RBEG=R(J)
 CBEG(1)=C(J)
 GO TO 1000
 850 IF(R(J) .GT. (MAXR-MINR)*MXPCT+MINR) GO TO 900
 FLAGB=0
 900 CONTINUE
 WRITE(5,950)
 950 FORMAT('   DID NOT FIND FIRST USEABLE PULSE')
 GO TO 3002
C
```

```
C FIND BEGINNING OF FIRST PULSE
C
 1000 DO 1050 I=J,(J-50),-1
 IF(R(I)-R(I-2)) 1100,1050,1050
 1050 CONTINUE
 1100 CSTRT(1)=C(I)
C
C FIND NUMBER OF OTHER PULSES
C
 DO 1200 J=CSTRT(1),N
 IF (FLAG .EQ. 1) GO TO 1300
 IF (R(J).LT.(MAXR-MINR)*MXPCT+MINR) GO TO 1200
 NUMPUL=NUMPUL+1
 CBEG(NUMPUL)=C(J)
 FLAG=1
 GO TO 1200
 1300 IF (R(J).GT.(MAXR-MINR)*MNPCT+MINR) GO TO 1200
 FLAG=0
 1200 CONTINUE
C
C FIND BEGINNING OF OTHER PULSES
C
 DO 1400 I=2,NUMPUL
  DO 1500 J=CBEG(I),(CBEG(I)-50.),-1
  IF (R(J) .GT. R(J-2)) GO TO 1500
  CSTRT(I)=C(J)
  GO TO 1400
 1500  CONTINUE
 1400 CONTINUE
C
C CHECK FOR BAD PULSES
C
 DO 1450 I=1,NUMPUL-1
 TPUL(I)=(CSTRT(I+1)-CSTRT(I))/100.
 IF (TPUL(I) .EQ. 0.) GO TO 3005
 IF (TPUL(I) .GT. 2. .OR. TPUL(I) .LT. .3) GO TO 1425
 CKPUL(I)=0
 GO TO 1450
 1425 CKPUL(I)=1
 1450 CONTINUE
C
C CALCULATE MEAN, PEAK-TO-PEAK, AND PULSATILITY INDEX FOR EACH  PULSE
C
 DO 20 K=1,90
 RPMX(K)=0.
 RPMIN(K)=256.
 20 CONTINUE
 1404 RSUM=0.
 CT=0.
 DO 1800 I=1,(NUMPUL-1)
```

```
 IF(CKPUL(I) .EQ. 1) GO TO 1800
 IF(FLAGC(I) .EQ. 1) GO TO 1800
 ICST(I)=CSTRT(I)
 ICST(I+1)=CSTRT(I+1)
 CKCT=ICST(I)
 SUMR=0.
  DO 1900 J=ICST(I),ICST(I+1)
  SUMR=SUMR+R(J)
  IF(RPMX(I) .GT. R(J))  GO TO 2000
  CPMAX(I)=C(J)
  RPMX(I)=R(J)
 2000  IF(RPMIN(I) .LT. R(J)) GO TO 1900
  CPMIN(I)=C(J)
  RPMIN(I)=R(J)
 1900  CONTINUE
 MEAN(I)=SUMR/(CSTRT(I+1)-CSTRT(I))
 IF(MEAN(I) .EQ. 0.) GO TO 3006
C
C CHECK FOR BAD START POINTS
C
 IF(R(CKCT) .LT. MEAN(I)+(.25*(RPMX(I)-MEAN(I)))) GO TO 1850
 CKPUL(I)=1
 CKPUL(I-1)=1
 GO TO 1800
C
C CONTINUE IF NO BAD PULSE FOUND OTHERWISE GO TO 1800
C
 1850 PULS(I)=(RPMX(I)-RPMIN(I))/MEAN(I)
 RTE(I)=(60./TPUL(I))
 RSUM=RSUM+RTE(I)
 1800 CONTINUE
C
C COUNT GOOD PULSES
C
 DO 1415 I=1,NUMPUL-1
 IF (CKPUL(I) .EQ. 1) GO TO 1415
 IF (FLAGC(I) .EQ. 1) GO TO 1415
 CT=CT+1
 1415 CONTINUE
 IF(CT .EQ. 0.) GO TO 3007
C
C CHECK PULSES ITERATIVELY AFTER CALCULATING AVERAGE RATE
C
 RATE=RSUM/CT
 IF (RATE .EQ. 0.) GO TO 3008
 TCK=60./RATE
  CTB=CT
  CTA=0.
 DO 1401 I=1,NUMPUL-1
 FLAGC(I)=0
```

```
 IF (CKPUL(I) .EQ. 1) GO TO 1401
 IF (TPUL(I).LT. 1.3*TCK .AND. TPUL(I).GT. .7*TCK)GO TO 1402
 FLAGC(I)=1
  GO TO 1401
 1402 CTA=CTA+1.
 1401 CONTINUE
 WRITE(5,1405)CTA,CTB,CT
 1405 FORMAT(X,F4.0,5X,F4.0,5X,I3)
 IF (CTA .EQ. CTB) GO TO 1403
 CTA=CTB
 ITER=ITER+1
 IF (ITER .GT. 10) GO TO 1403
 GO TO 1404
C
C  SET COUNT AND THROW OUT PULSES THAT ARE TOO SHORT OR TOO LONG
C
 1403 CT=CTA
 IF (CT .GT. 0) GO TO 1416
 WRITE(5,1417)
 1417 FORMAT('   COUNT OF PULSES = 0')
 GO TO 3002
C
C OPEN OUTPUT FILE
C
 1416 OPEN(UNIT=13,NAME='TEST2.TXT',TYPE='NEW')
 WRITE(13,1650)FILEN
 1650 FORMAT(X,///,'  DATA FOR FILE: ',14A1)
C
C CALCULATE HEART RATE
C
 RATE=RSUM/CT
 WRITE(13,1600)RATE
 1600 FORMAT(X,//////,'  HEART RATE=',F5.1,' BEATS PER MINUTE')
 DO 2200 I=1,NUMPUL-1
 IF(CKPUL(I) .EQ. 1) GO TO 2200
 IF(FLAGC(I) .EQ. 1) GO TO 2200
 SPUL=SPUL+PULS(I)
 WRITE(13,2300) I,PULS(I)
 2300 FORMAT(X,//,'  PULSATILITY INDEX(',I2,')=',F5.2)
 WRITE(13,2350)MEAN(I),RPMX(I),RPMIN(I)
 2350 FORMAT(X,/,'  MEAN VALUE=',F6.2,5X,'MAX VALUE=',F6.2,5X,
     C 'MIN VALUE=',F6.2)
 2200 CONTINUE
 MPULS=SPUL/CT
 WRITE(13,2360) MPULS
 2360 FORMAT(X,////,'  MEAN PULSATILITY INDEX=',F5.2)
 TYPE*,CT
C
C AVERAGE PULSE ROUTINE
C
```

```
 WRITE(13,4300)
 4300 FORMAT('1',T20,'AVERAGE PULSE DATA')
 TAVG=(60./RATE)*100.
 ITAVG=INT(TAVG)
 DO 4000 I=1,ITAVG
 AR(I)=0.
  DO 4100 J=1,NUMPUL-1
  IF (CKPUL(J) .EQ. 1)GO TO 4100
  IF (FLAGC(J)  .EQ. 1)GO TO 4100
  RNORM=(FLOAT(I)/TAVG)*(CSTRT(J+1)-CSTRT(J))+CSTRT(J)
  NORMI=INT(RNORM)
  AR(I)=AR(I)+R(NORMI)/FLOAT(CT)
 4100  CONTINUE
 WRITE(13,4200)I,AR(I)
 4200 FORMAT(X,10X,I3,25X,F4.0)
 4000 CONTINUE
 TYPE*,TAVG,ITAVG
C
C CALCULATIONS FOR AVERAGE PULSE
C
 DO 5000 I=1,ITAVG
 IF(ARMAX .GT. AR(I)) GO TO 5001
 ARMAX=AR(I)
 IMX=I
 5001 IF(ARMIN .LT. AR(I)) GO TO 5002
 ARMIN=AR(I)
 IMN=I
 5002 AMEAN=AMEAN+(AR(I)/FLOAT(ITAVG))
 5000 CONTINUE
 IF(AMEAN .EQ. 0.) GO TO 3009
 ADEL=ARMAX-ARMIN
 APUL=ADEL/AMEAN
 BPUL=ADEL/ARMAX
 RISE=FLOAT(IMX)/100
 POUIS=ARMAX/ARMIN
 DO 5100 I=1,ITAVG-1
 ACC=AR(I+1)-AR(I)
 IF(ACMX .GT. ACC)GO TO 5101
 ACMX=ACC
 IAMX=I
 5101 IF(ACMN .LT. ACC)GO TO 5100
 ACMN=ACC
 IAMN=I
 5100 CONTINUE
 ACMXN=ACMX/ARMAX
 ACMNN=ACMN/ARMAX
 WRITE(13,5200)ARMAX,ARMIN,AMEAN,ADEL
 5200 FORMAT('1',///' MAX=',F6.2,5X,'MIN=',F6.2,5X,'MEAN=',F6.2,5X,
     C 'MAX-MIN=',F6.2)
 WRITE(13,5300)APUL,ACMXN,ACMNN
```

```
 5300 FORMAT(X,///,' PULSATILITY=',F5.3,5X,'MAX ACCELERATION/MAX='
     C  ,F5.3,5X,'MAX DECELERATION/MAX=',F7.3)
  WRITE(13,5400)RISE,POUIS,BPUL
 5400 FORMAT(X,///,' RISE TIME=',F5.3,'SEC.',5X,' MAX/MIN=',F7.2,5X,
     C 'P-P/MAX=',F7.3)
C
C CLOSE OUTPUT FILE
C
 CLOSE(UNIT=13)
C
C  PLOTTING ROUTINES
C
 PH=10.*750./D
  CALL INIPLT(13,10.25,7.25)
 call frame(.5,9.75,0,3.0)
 CALL WINDOW(.75,8.5,.5,3.0)
 CALL SCALE(0.,2000.,-50.,130.)
 CALL AXIS(200.,50.,'T',1,1,0,'V',1,1,0)
 CALL LINE(C,R,N,1,0,0,1)
 CALL COLTYP(2)
 CALL MOVETO(0,0,0,0)
 CALL MOVETO(2000.,0,1,0)
 CALL MOVETO(0.,MAXR,0,0)
 CALL MOVETO(D,MAXR,1,6)
 CALL MOVETO(MAXC,MAXR,0,0)
 CALL MOVETO(MAXC,0,1,6)
 CALL MOVETO(CBEG(1),RBEG,0,0)
 CALL MOVETO(CBEG(1),O,1,6)
 DO 1700 I=1,NUMPUL
 CALL MOVETO(CSTRT(I),MAXR,0,0)
 CALL MOVETO(CSTRT(I),MINR,1,6)
 1700 CONTINUE
 DO 2100 I=1,NUMPUL-1
 IF(CKPUL(I) .EQ. 1) GO TO 2100
 IF(FLAGC(I) .EQ. 1) GO TO 2100
 CALL MOVETO(CSTRT(I),RPMX(I),0,0)
 CALL MOVETO(CSTRT(I+1),RPMX(I),1,6)
 CALL MOVETO(CPMAX(I),RPMX(I),0,0)
 CALL MOVETO(CPMAX(I),RPMX(I)-10,1,6)
 CALL MOVETO(CSTRT(I),MEAN(I),0,0)
 CALL MOVETO(CSTRT(I+1),MEAN(I),1,6)
 CALL MOVETO(CSTRT(I),RPMIN(I),0,0)
 CALL MOVETO(CSTRT(I+1),RPMIN(I),1,6)
 2100 CONTINUE
 CALL FRAME(3.,7.,3.25,6.75)
 CALL WINDOW(1.25,3.,.25,3.25)
 call SCALE(0.,TAVG,-50.,130.)
 CALL AXIS (25.,50.,'T',1,1,0,'VEL.',4,1,0)
 CALL MOVETO(0,0,0,0)
 CALL MOVETO(TAVG,0,1,0)
```

```
CALL LINE(C,AR,ITAVG,1,0,0,1)
CALL MOVETO(0,ARMAX,0,0)
CALL MOVETO(TAVG,ARMAX,1,6)
CALL MOVETO(0,ARMIN,0,0)
CALL MOVETO(TAVG,ARMIN,1,6)
CALL MOVETO(0,AMEAN,0,0)
CALL MOVETO(TAVG,AMEAN,1,6)
CALL MOVETO(FLOAT(IAMX)-3.,AR(IAMX),0,0)
CALL MOVETO(FLOAT(IAMX+1)-3.,AR(IAMX+1),1,6)
CALL MOVETO(FLOAT(IAMN)+3.,AR(IAMN),0,0)
CALL MOVETO(FLOAT(IAMN+1)+3.,AR(IAMN+1),1,6)
CALL ENDPLT
OPEN (UNIT=14,NAME='PLT.TXT',TYPE='NEW')
WRITE(14,3001)
3001 FORMAT(' ;:EHEC5V16HOUAL0P11500,1400 D 2000,1400 2000,1100 1500,
    C  1100 1500,1400 U 1520,1300')
WRITE(14,3000)FILEN,DATE
3000 FORMAT(X,'S12       ',14A1,'UALOP11520,1200 S12 LEE WAITE  ',
    C 16A1,'')
write(14,3018) mpuls,apul
3018 format(' U 1520,1000 S12 PI=',F5.2,'U1520,900 S12 PI =',F5.2,
    C 'U 1520,875 S12   aU 1520,1060 S12--')
CLOSE(UNIT=14)
STOP
3005 WRITE (5,3011)I
3011 FORMAT(X,'IN LINE 98 TPUL(',I2,')=0')
GO TO 3002
3006 WRITE(5,3012)I
3012 FORMAT(X,'IN LINE 126 MEAN(',I2,')=0')
GO TO 3002
3007 WRITE(5,3013)
3013 FORMAT(X,'IN LINE 142 CT=0')
GO TO 3002
3008 WRITE(5,3014)
3014 FORMAT(X,'IN LINE 143 RATE=0')
GO TO 3002
3009 WRITE(5,3015)
3015 FORMAT(X,'IN LINE 212 AMEAN=0')
GO TO 3002
3002  CALL INIPLT(11,17.,11.)
call frame(0.,17.,0.,4.25)
CALL WINDOW(1.,15.,1.,3.25)
CALL SCALE(0.,2000.,-50.,250.)
CALL AXIS(200.,50.,'T',1,2,0,'VEL.',4,2,0)
CALL LINE(C,R,N,1,0,0,1)
CALL ENDPLT
OPEN (UNIT=14,NAME='PLT.TXT',TYPE='NEW')
WRITE(14,3016)
3016 FORMAT(' ;:EFEC5V16HOUAL0P11000,900')
WRITE(14,3017)FILEN
```

```
3017 FORMAT(X,'S13 DATA FOR: ',14A1,'PROGRAM DID NOT RUN')
CLOSE(UNIT=14)
stop
end
```

```
C
C  THIS PROGRAM READS A DATA FILE AND ADDS A SPECIFIED NUMBER TO EACH DATA
C  FILE TO SET THE ZERO VALUE.
C
 BYTE FILEN(14),FILEM(14)
 WRITE(5,100)
 100 FORMAT('  INPUT FILENAME TO BE READ FROM')
 READ(7,200)NIN,FILEN
 200 FORMAT(Q,14A1)
 WRITE(5,300)FILEN
 300 FORMAT(X,14A1)
 WRITE(5,400)
 400 FORMAT('  INPUT FILENAME TO BE WRITTEN TO')
 READ(7,500)MIM,FILEM
 500 FORMAT(Q,14A1)
 WRITE(5,600)FILEM
 600 FORMAT(X,14A1)
 WRITE(5,700)
 700 FORMAT('  INPUT NUMBER TO BE ADDED TO DATA;  EXAMPLE 5.')
 READ(7,705)Y
 705 FORMAT(F4.0)
 WRITE(5,710)
 710 FORMAT('  INPUT NUMBER OF DATA POINTS')
 READ(7,720)N
 720 FORMAT(I4)
 OPEN(UNIT=12,NAME=FILEN,TYPE='OLD')
 OPEN(UNIT=13,NAME=FILEM,TYPE='NEW')
 DO 1000 I=1,N
 READ(12,800)X
 800 FORMAT(F4.0)
 X=X+Y
 WRITE(13,900)X
 900 FORMAT(X,F4.0)
 1000 CONTINUE
 CLOSE(UNIT=12)
 CLOSE(UNIT=13)
 STOP
 END
```

```
C
C
C            DATA REVISION PROGRAM FOR ± RANGES
C
C
C THIS PROGRAM READS DATA FROM A FILE WHICH IS CREATED BY THE PET:BASIC
C PROGRAM "PAUL1" AND CONTAINS DIGITIZED DATA TAKEN WITH THE PET A/D
C CONVERTER.  THIS PROGRAM CREATES A NEW FILE IN A FORMAT WHICH CAN
C BE READ BY A FORTRAN PROGRAM.
c
C
 REAL RN
 INTEGER N,NIN,NUM,CT
 BYTE LINE(8),FILEN(14),FILEM(14)
 CT=0
C
C INPUT FILENAME ETC.
C
 WRITE(5,100)
 100 FORMAT(X,'   INPUT FILENAME OF OLD FILE')
 READ(7,200) FILEN
 200 FORMAT(14A1)
 WRITE(5,310)
 310 FORMAT(X,'   INPUT FILENAME TO BE ASSIGNED TO NEW FILE')
 READ(7,320) FILEM
 320 FORMAT(14A1)
 WRITE(5,330) FILEM
 330 FORMAT(X,14A1)
 WRITE(5,340)
 340 FORMAT(X,'    INPUT ZERO VALUE -- 000. TO 256.')
 READ(7,345) ZERO
 345 FORMAT(F4.0)
 WRITE(5,346)ZERO
 346 FORMAT(X,F4.0)
C
C OPEN LOGICAL FILES
C
 OPEN(UNIT=13,NAME=FILEN,TYPE='OLD')
 OPEN(UNIT=14,NAME=FILEM,TYPE='NEW')
C
C BEGIN LOOP TO READ IN DATA
C
 350 READ(13,400,END=1000) NIN,(LINE(I),I=1,NIN)
 400 FORMAT(Q,6A1)
 CT=CT+1
C
C CONVERT EACH DIGIT TO ITS BASE TEN VALUE
C
 DO 500 J=1,NIN
 LINE(J)=LINE(J)-48
```

```
 500 CONTINUE
C
C DETERMINE NUMBER OF DIGITS IN EACH NUMBER AND CALCULATE VALUE
C
 GO TO (600,700,800) NIN-2
 600 N=LINE(2)
 GO TO 2000
 700 N=LINE(2)*10.+LINE(3)
 GO TO 2000
 800 N=LINE(2)*100+LINE(3)*10+LINE(4)
C
C WRITE TO NEW FILE CALLED DATA.DAT
C
 2000  RN=FLOAT(N)-ZERO
  WRITE(14,900)RN
 900 FORMAT(X,F4.0)
 GO TO 350
 1000 WRITE(14,1100)CT
 1100 FORMAT(X,I4)
 CLOSE (UNIT=13)
 CLOSE (UNIT=14)
 STOP
 END
```

```
C
C
C BASIC PROGRAM FOR TRANSFERRING DATA FROM PET TO PDP-11
C
C
10 PRINT"ENTER DISK DRIVE NUMBER"
20 INPUT DR$:D=VAL(DR$)
30 PRINT"ENTER DISK DATA SET NAME"
40  INPUT F$
50 IF D=0 THEN OPEN20,8,5,"0:"+F$+",SEQ,R"
60 IF D=1 THEN OPEN20,8,5,"1:"+F$+",SEQ,R"
61 OPEN 1,4
62 FOR X=1TO3:INPUT 20,Y$:PRINT Y$
63  NEXT X
70 PRINT"ENTER NUMBER OF CHANNELS AND NUMBER OF DATA POINTS PER
 CHANNEL(J,I)"
75  INPUT NC,ND
90  FOR I=1 TO ND
100  FOR J=1TO NC
110  INPUT 20,Q$
114 PRINT 1,VAL(Q$)
120  NEXT J
130 NEXT I
135 CLOSE 20
195 CLOSE1
200 STOP
210 END
```