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Synchronization of oestrous cycles in sable antelope

Katerina V. Thompson[a,b,*], Steven L. Monfort[a]

[a] *Conservation and Research Center, National Zoological Park, Smithsonian Institution, 1500 Remount Road, Front Royal, VA 22630, USA*

[b] *Biological Sciences Program, College of Life Sciences, University of Maryland, 1209 Symons Hall, College Park, MD 20742, USA*

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Abstract

Techniques for manipulating the oestrous cycle of sable antelope, *Hippotragus niger*, were evaluated in a captive population of 24 females maintained at the Smithsonian Institution's Conservation and Research Center in Front Royal, VA, USA. A secondary objective was to demonstrate the effectiveness of fecal steroid monitoring techniques as a non-invasive method of tracking experimental manipulations. Controlled Internal Drug Releasing (CIDR) devices designed for cattle (type B, reduced in length by 5 cm to fit the sable antelope's smaller reproductive tract) were more effective than CIDR devices designed for goats (type G) at delivering progesterone into circulation, and maintained serum progesterone at levels up to $86.1 \pm 7.8\%$ of normal luteal concentrations in females whose spontaneous ovarian activity had been inhibited with melengestrol acetate. Serum progesterone and fecal progestagen measurements were highly correlated ($P < 0.05$). Synchronization treatments of prostaglandin (PG) $F_{2\alpha}$ alone and in combination with modified CIDR-B devices (12-day insertion interval) were both effective in inducing synchronized ovulation, however the $PGF_{2\alpha}$/modified CIDR-B treatment resulted in more precise synchrony and a shorter latency to ovulation than did $PGF_{2\alpha}$ alone. In a separate experiment to characterize the temporal relationship between synchronization treatment, behavioral oestrus and ovulation, onset of behavioral oestrus occurred 34.1 ± 5.7 h following $PGF_{2\alpha}$/modified CIDR-B treatment. Mean duration of the induced oestrus was 24.9 ± 4.3 h. The first detectable rise in fecal progestagens occurred 5.1 ± 1.0 and 4.1 ± 1.0 days following $PGF_{2\alpha}$/modified CIDR-B treatment in groups of females housed with and without an adult male, respectively, indicating that the presence of a male did not accelerate the onset of the induced cycle.

Keywords: Antelope; Oestrous synchronization; CIDR; Fecal steroids

* Corresponding author. Tel.: +1-301-405-2160; fax: +1-301-405-1655; e-mail: kt21@umail.umd.edu

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1. Introduction

Techniques for manipulating ovarian cycles, first developed in domestic livestock species in the 1960's (Jöchle, 1993), were quickly adapted for use in intensively-farmed species such as red deer (*Cervus elaphus*) and fallow deer (*Dama dama*) (Asher et al., 1993). More recently, these techniques have been applied to a variety of non-domestic ungulates (Bartels, 1993; Hodges, 1996; Morrow, 1997; Hosack et al., 1999), but relatively few systematic studies have been conducted to examine the efficacy of oestrous synchronization in wildlife species. The reasons for the success or failure of oestrous synchronization protocols have generally not been documented through the concurrent use of endocrine monitoring techniques (Godfrey et al., 1991; Schiewe et al., 1991).

Oestrous synchronization protocols typically employ one of two strategies: (1) administration of a luteolytic agent such as prostaglandin (PG) $F_{2\alpha}$ or (2) application of a native or synthetic progestagen. Administration of $PGF_{2\alpha}$ analogues induces rapid, premature luteal regression in females with a functional corpus luteum (CL), followed by spontaneous ovulation. This treatment has no effect on females that are in the follicular phase of their oestrous cycles or those who have only recently ovulated, because the CL is refractory to luteolytic agents during its early life (Rowson et al., 1972). To ensure effective luteolysis in females at different stages of the ovarian cycle, two doses of $PGF_{2\alpha}$ are administered 10–11 days apart.

Exogenously administered progestins suppress folliculogenesis through negative feedback inhibition of the hypothalamic–pituitary axis. In ungulates, progestins have been administered intravaginally (e.g., sponges, Controlled Internal Drug Releasing (CIDR) devices and Progesterone Releasing Intravaginal Devices), subcutaneously (e.g., norgestomet and melengestrol acetate implants, MGA) and orally (MGA). During progestin treatment, the CL can be permitted to regress spontaneously or CL regression can be induced by $PGF_{2\alpha}$ administration. Cessation of progestin administration permits resumption of folliculogenesis and subsequent ovulation. Compared to the use of $PGF_{2\alpha}$ alone, the concurrent use of exogenous progestin results in more precise synchronization of oestrus in cattle (Broadbent et al., 1993).

The present study was designed to validate techniques for manipulating the timing of ovulation (and hence, the degree of ovarian synchrony) within social groups of sable antelope (*Hippotragus niger*). Sable antelope are gregarious bovids native to wooded savannas of Southeastern Africa. Although reproduction is seasonal in most wild populations, in captivity sable antelope give birth throughout the year. Captive females are year-round polyoestrous and exhibit an oestrous cycle length of 24.2 ± 0.9 days (Thompson et al., 1998).

Our long-term goal to develop a new experimental model for studying social influences on the timing of reproductive events. Our interest in sable antelope stems from the fact that sable antelope exhibit high rates of flehmen, which suggests that they may be using urinary chemosignals to modulate ovarian synchrony among herdmates (Thompson, 1995; Thompson and Monfort, submitted). Ovarian synchrony is widespread among mammals (Signoret, 1980; McClintock, 1987; Graham, 1991), but the physiological and behavioral mechanisms regulating socially-mediated synchrony are poorly

understood. Experimental investigations of this phenomenon depend upon the ability to reliably manipulate ovulation and ovarian synchrony among herdmates.

A second major objective was to demonstrate the efficacy of fecal steroid monitoring for tracking experimental manipulations of oestrous cyclicity. This approach, if effective, would permit experimental treatment outcomes to be evaluated non-invasively and would make it possible to examine the phenomenon of oestrous cycle adjustment in animals maintained in large naturalistic enclosures that approximate ecological conditions experienced by this species in the wild.

2. Methods

2.1. Animals and management

The study population consisted of 24 captive-born female sable antelope aged 4–14 years (mean liveweight = 183.4 ± 4.2 kg). All individuals were uniquely marked with colored eartags and could be further distinguished through differences in horn morphology. Animals were maintained in groups of 7–12 as necessitated by experimental design and housed on grassy pastures (0.2–8.3 ha). Shelter, ad libitum water and supplemental feed (12.5% protein concentrate, Washington National Zoo Herbivore Maintenance Pellet, Agway, Syracuse, NY, USA) was provided. The barn complex included a drop-floor cradle (The Tamer, Fauna Products, Red Hook, NY, USA), which allowed routine handling of unanesthetized animals for manipulative procedures. All protocols were reviewed and approved by the Conservation and Research Center Institutional Animal Care and Use Committee.

2.2. Steroid hormone extraction and radioimmunoassay (RIA)

Blood samples (10 ml) were collected by jugular veinipuncture during chute restraint, centrifuged (2000 × *g*, 15 min) to obtain serum and stored frozen (−20°C) until analyzed. Fecal samples were collected off the ground immediately after defecation or directly from the rectum during chute restraint and stored frozen (−20°C).

Fecal samples were dried using a Speedvac Rotary Evaporator (Savant Instruments, Forma Scientific, Marietta, OH, USA), pulverized and mixed well. Pulverized feces (0.025 g) were extracted by boiling in 10 ml absolute ethanol for 20 min. After centrifugation (20 min, 2000 × *g*), the supernatant was transferred to a clean tube, evaporated to dryness, reconstituted in 1 ml methanol, and diluted 1:400 in PBS (pH 7.4) for RIA.

RIA of serum (diluted 1:20 in PBS, pH 7.4) and fecal steroid extracts was performed using a broad-spectrum monoclonal antiserum-based progesterone (P) assay developed in our laboratory (Brown et al., 1994; Wasser et al., 1994) and validated for use in sable antelope (Thompson et al., 1998). Inter-assay coefficients of variation were 19.2% ($N = 18$, 38% binding) and 16.9% ($N = 18$, 88% binding) and intra-assay coefficients of variation were < 10%. For each study, all samples from an individual female were

evaluated in a single assay. All fecal progesterone metabolite concentrations are expressed as mass units hormone per g dry feces.

2.3. Study 1: CIDR efficacy

The objectives of Study 1 were to (1) test the capacity of progesterone-containing CIDR (InterAg, Hamilton, New Zealand) devices for elevating serum progesterone to levels comparable to that of a normal luteal phase, (2) determine the duration of progesterone elevation following CIDR device insertion, and (3) establish the utility of fecal progestins for assessing the efficacy of CIDR devices. Two types of CIDR devices were evaluated: one developed for goats (CIDR-G, 0.3 g progesterone) and another designed for cattle (CIDR-B, 1.9 g progesterone, reduced in length by 5 cm to fit the smaller reproductive tract of the sable antelope). The studies were conducted October–December 1994.

The efficacy of CIDR devices for producing a sustained delivery of progesterone is best evaluated in ovariectomized or seasonally anoestrous animals to eliminate potential interference from endogenous progesterone (Macmillan and Peterson, 1993). Captive sable antelope show no evidence of reproductive seasonality (Thompson et al., 1998), and because ovariectomy was not an acceptable option MGA implants were used to suppress spontaneous ovarian activity. Implants (~ 8 g MGA, supplied by E.D. Plotka, Marshfield, WI, USA) were inserted subcutaneously at the scapula under local anesthetic while animals were restrained within the drop-floor chute. Six females received MGA implants and six females served as untreated controls. All individuals were housed together in a 3.6 ha pasture.

Intravaginal CIDR-G devices were inserted into six MGA-implanted females 32 days after MGA implant insertion; CIDR-G devices were removed 21 days later. Progestin concentrations were determined in blood and fecal samples collected during chute restraint on alternate days beginning 2 days before CIDR-device insertion and continuing until 4 days after CIDR-G device withdrawal.

Thirty days following CIDR-G device withdrawal, modified CIDR-B devices were inserted for 21 days. Progestin concentrations were determined in blood and fecal samples collected during chute restraint beginning 2 days before modified CIDR-B device insertion and continuing until 4 days following modified CIDR-B device withdrawal. Preliminary data from the CIDR-G device trial indicated that sampling frequency could be reduced without sacrificing the ability to evaluate treatment efficacy. For comparison to treated subjects, progestin concentrations were evaluated in matched blood and fecal samples collected three to four times a week from the six untreated control females for 8 consecutive weeks using Pearson product–moment correlations.

The effect of CIDR-G and modified CIDR-B devices was evaluated by comparing serum and fecal progestin concentrations immediately before and 24 h following CIDR device insertion and removal using *t*-tests for paired comparisons. To determine whether CIDR devices were effective for elevating serum progesterone to levels approximating that of a normal luteal phase, peak progesterone concentrations during CIDR insertion were compared to peak luteal phase concentrations in untreated controls (determined by averaging the three highest consecutive values for each control female (Morrow, 1997)).

2.4. Study 2: efficacy of oestrous synchronization protocols

Because intravaginal modified CIDR-B devices were effective for elevating serum P to levels approximating normal luteal phase concentrations, they were used for all subsequent trials. Study 2 was conducted April–June 1995. Our objective was to compare the efficacy of oestrous synchronization using either $PGF_{2\alpha}$ alone or in combination with a modified CIDR-B device in eight females that had not previously been subjected to experimental manipulation. Animals were housed in a 3.6 ha grassy pasture and maintained according to standard animal care protocols.

Both oestrous synchronization protocols were tested in succession as follows: (1) 500 μg of $PGF_{2\alpha}$ analog (Estrumate®, Miles Agriculture Division, Shawnee Mission, KS) was injected i.m. on day 1 and 11 (the $PGF_{2\alpha}$ treatment), followed by (2) a third i.m. $PGF_{2\alpha}$ injection and intravaginal insertion of a modified CIDR-B device on day 21 for a 12-day insertion interval (the $PGF_{2\alpha}$/modified CIDR-B combination treatment). Fecal samples were collected three times per week from the day of the first $PGF_{2\alpha}$ injection until 60 days following modified CIDR-B withdrawal.

The timing of the first significant rise in fecal P was determined after the first and second $PGF_{2\alpha}$ injections, and after modified CIDR-B device withdrawal, using a modified version of our standard technique (Thompson et al., 1998). For each female, the lowest daily fecal P values following (1) the first $PGF_{2\alpha}$ injection, (2) second $PGF_{2\alpha}$ injection, and (3) modified CIDR-B device withdrawal were averaged to obtain an estimate of baseline fecal P. Significant increases in fecal P during each putative ovulation were identified by fitting a second-order polynomial equation to the fecal P data for each female and solving for the day on which fecal P reached a criterion value (the female's baseline fecal P + 2 S.D.). This method produced a very good fit to the observed data (Pearson's product–moment correlation, $R > 0.9$) and eliminated any bias caused by our inability to obtain daily samples from each female. The resulting value was corrected for the 16 h time necessary for hormone fluctuations in blood to be reflected in feces (Thompson et al., 1998).

The effects of $PGF_{2\alpha}$ and modified CIDR-B treatments on circulating levels of progesterone was evaluated using *t*-tests for paired comparisons. In addition, the peak fecal P value obtained during modified CIDR-B insertion was compared with the mean of the three highest fecal P consecutive determinations for that female during the oestrous cycle immediately following the synchronization experiment.

2.5. Study 3: timing of behavioral oestrus in relation to oestrous synchronization

Our primary objective in Study 3 was to pinpoint the timing of behavioral oestrus in relation to fluctuations in fecal hormones. This information is essential for accurate interpretation of the relationship between behavioral and hormonal events in future studies of the social regulation of reproduction in this species. Because females show no overt signs of behavioral oestrus in the absence of a male, housing a male with the group was the only available technique for measuring oestrus onset and duration. Introduction of a male to the group could alter the timing of events following synchronization treatment, however, since the presence of a male is known to advance the timing of

oestrus in some ungulates (Knight and Lynch, 1980; Signoret, 1980; McComb, 1987; Verme et al., 1987; Hosack et al., 1999).

To investigate whether male presence affected the timing of ovulation following synchronization treatment, two female herds were studied during April–May 1996. In the first group (Male Presence, $N = 7$ females), a male was introduced immediately following modified CIDR-B device removal and housed with the females for the next 5 days. In the second group (Male Absence, $N = 7$ females), direct male contact was absent.

Both groups were subject to the combined $PGF_{2\alpha}$/modified CIDR-B device synchronization protocol and monitored using fecal steroids (3 × /week). Latency to the first significant rise in fecal progestins in the Male Presence and Male Absence groups was compared using a *t*-test. Continuous behavioral monitoring of the Male Presence group was conducted during the interval 20–96 h after modified CIDR-B device removal. Females were judged to be in oestrus if they stood to be mounted by the male. In two instances, females exhibited lordosis (standing with hind legs apart, tail held up and deflected) in response to anogenital investigation and foreleg kicking by the male but were not subsequently mounted. These females were also considered to be in behavioral oestrus because this posture is indicative of sexual receptivity (Buechner et al., 1974). The association between female dominance rank and mating behavior was evaluated with Spearman's coefficient of rank correlation.

3. Results

3.1. Study 1: CIDR efficacy

Serum and fecal P levels declined to baseline levels within days of MGA implant insertion and remained there until CIDR device insertion in all subjects. This indicated effective suppression of ovarian activity and the absence of crossreactivity of the MGA molecule with our assay system.

Retention of both types of CIDR devices was 100% for the 21-day insertion interval. For both devices, serum P increased significantly ($P < 0.05$) within 24 h of insertion and then declined steadily, but remained elevated for the entire interval (Fig. 1a, b). Serum P declined ($P < 0.05$) by 24 h after withdrawal of the devices. The CIDR-G devices raised serum progesterone levels to 52.6 ± 5.0% of peak luteal phase concentrations in untreated controls within one day of insertion, whereas modified CIDR-B devices elevated serum P to 86.1 ± 7.8% of peak luteal levels in untreated controls (Fig. 1c).

Fecal P concentrations correlated well with serum P levels (Fig. 1a, b) (Pearson product–moment correlation: CIDR-G, 0.44–0.85; CIDR-B, 0.63–0.94). Increases ($P < 0.05$) in fecal P occurred 1 day following insertion for both types of CIDR devices. Fecal P remained elevated throughout the CIDR-B insertion interval and declined ($P < 0.05$) after CIDR-B device removal. In contrast, fecal P declined gradually during the CIDR-G device insertion interval to levels indistinguishable from basal concentrations at the time of CIDR-G device withdrawal.

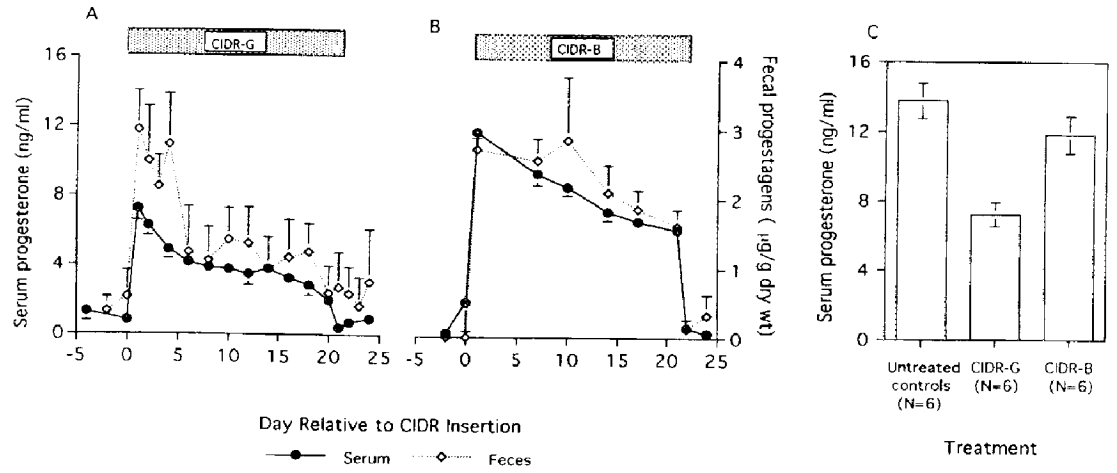

Fig. 1. Serum progesterone and fecal progestagen profiles during insertion of (A) CIDR-G devices and (B) modified CIDR-B devices in female sable antelope ($N = 6$) implanted with melengestrol acetate (MGA). (C) Comparison of peak serum progesterone values obtained during CIDR-G and modified CIDR-B device insertion in MGA implanted females ($N = 6$) and during a normal luteal phase in unmanipulated controls ($N = 6$). Shaded bars indicate the period of CIDR device insertion.

3.2. Study 2: efficacy of oestrous synchronization protocols

Responses of females to synchronization treatments are summarized in Table 1. Both $PGF_{2\alpha}$ alone and $PGF_{2\alpha}$ in combination with the CIDR-B device appeared effective at inducing synchronized ovulation (Fig. 2).

The first $PGF_{2\alpha}$ injection induced luteolysis and subsequent ovulation in females with well-developed CL (Fig. 3), with fecal P declining from pre-injection levels within 2 days of $PGF_{2\alpha}$ administration (mean decline = 9.48 μg/g, $P < 0.001$). At the time of the first $PGF_{2\alpha}$ injection, 5/8 (62.5%) females were in the luteal stage of their oestrous cycle (Table 1), and the luteolytic efficacy of $PGF_{2\alpha}$ was demonstrated by the fact that post-injection fecal P concentrations did not differ ($P > 0.05$) from baseline (Fig. 3); no such decline was observed in females judged to be in the interluteal phase. All females were in the luteal phase of their cycles at the time of the second $PGF_{2\alpha}$ injection and luteolysis was reflected by a rapid decline ($P < 0.05$) in fecal P within 2 days of $PGF_{2\alpha}$

Table 1
Number of days until first detectable rise in fecal P following oestrous synchronization treatments

Treatment	Number of females responding	Mean number of days to increase	Standard deviation*	Range (days)
$PGF_{2\alpha}$ injection #1	5/8	5.63	1.62[a]	3.5–7.3
$PGF_{2\alpha}$ injection #2	8/8	7.10	2.04[a]	4.6–10.5
$PGF_{2\alpha}$ /modified CIDR-B	7/7[+]	3.16	0.66[b]	2.5–4.4

* Values with a different superscript are significantly different at the $P < 0.05$ level by a Bartlett's test.
[+] One female spontaneously expelled the CIDR device prior to planned removal.

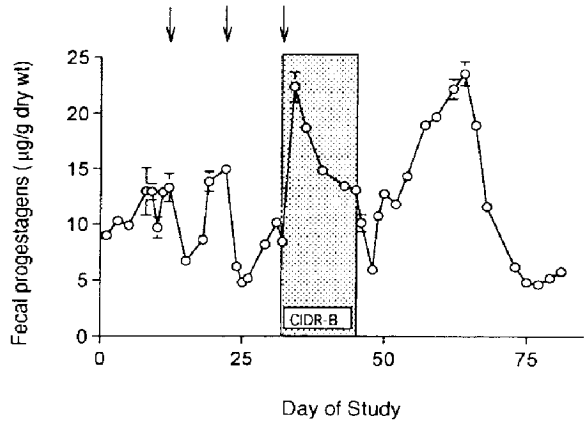

Fig. 2. Fecal progestagen profiles for female sable antelope ($N = 7$) induced to ovulate using prostaglandin $F_{2\alpha}$ (arrows) and CIDR devices. Shaded bar indicates the period of CIDR device insertion.

administration (mean decline = 9.22 µg/g). In all cases where luteolysis was induced, increased fecal P post-treatment confirmed that females subsequently ovulated (Table 1, Fig. 2).

Seven of eight females (87.5%) retained their CIDR-B devices for the entire insertion interval. Fecal P data indicated that one female lost her CIDR-B device 2–5 days before scheduled removal; data for this female were excluded from subsequent analyses. Fecal P increased within 24 h of CIDR-B insertion to levels approximating that of a normal luteal phase (107 ± 11% of peak luteal level, range 70–166%) and remained elevated above baseline for the entire insertion interval (Fig. 2). Following CIDR-B device removal, fecal P fell to baseline levels within 2 days. All females subsequently ovulated, as evidenced by sustained elevations of fecal P. The luteal phase of the induced cycle

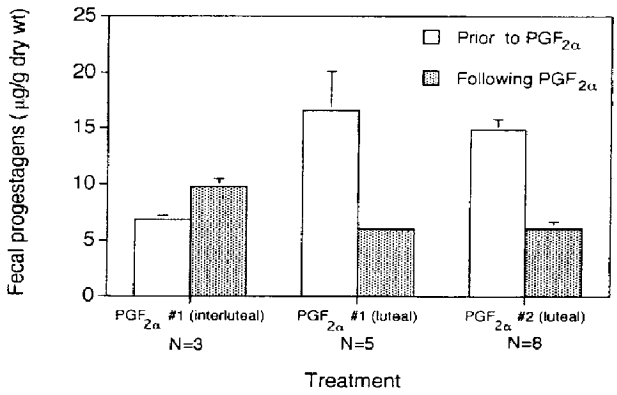

Fig. 3. Fecal progestagen values immediately before and 1 day following prostaglandin $F_{2\alpha}$ administration in female sable antelope ($N = 8$). Treatment consisted of two injections spaced 10 days apart. Females were classified as being in the luteal or interluteal phase of the oestrous cycle at the time of prostaglandin $F_{2\alpha}$ administration based upon fecal progestagen levels.

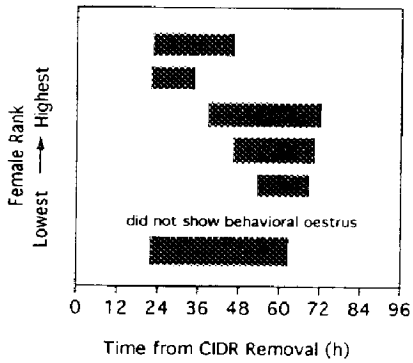

Fig. 4. Onset and duration of behavioral oestrus in sable antelope ($N = 7$) experimentally synchronized with modified CIDR-B devices. Dark bars represent the interval from oestrus onset to the last observed behavioral indication of oestrus.

(21.3 ± 0.9 days, range 17.2–24.5 days) did not differ significantly in duration from that observed in untreated females (18.4 ± 0.9 days; Thompson et al., 1998).

Comparison of the latency to first significant rise in fecal P indicated that the $PGF_{2\alpha}$/CIDR-B combination treatment induced ovulation more rapidly than $PGF_{2\alpha}$ alone, and resulted in significantly greater synchrony of ovulation (Table 1). Based on fecal steroid profiles, females ovulated approximately 4 days sooner following the $PGF_{2\alpha}$/CIDR-B combination treatment than following treatment with $PGF_{2\alpha}$ alone.

3.3. Study 3: timing of behavioral oestrus in relation to oestrous synchronization

Retention of modified CIDR-B devices was 100% and 6/7 (85.7%) females in the Male Presence group exhibited signs of oestrus during the 5 days following modified CIDR-B device withdrawal. The mean time until oestrus onset was 34.1 ± 5.7 h (range = 22.0–53.4 h), and mean oestrus duration was 24.9 ± 4.3 h (range = 15.6–40.5 h). Both the onset of behavioral oestrus (Fig. 4) and the distribution of matings within the period of behavioral oestrus appeared to be influenced by dominance rank. The first-, second- and seventh-ranking females first exhibited signs of oestrus within 15 min

Table 2
Mounts by herd bull during successive 12-h periods of behavioral oestrus
Proportion of total mounts for each female is shown in parentheses.

Female rank	Time from onset of behavioral oestrus				
	0–12 h	13–24 h	25–36 h	> 36 h	Total
1	5 (0.71)	2 (0.29)	–	–	7
2	14 (0.42)	19 (0.58)	–	–	33
3	6 (0.24)	11 (0.44)	8 (0.32)	–	25
4	1 (0.33)	2 (0.67)	–	–	3
5	0 (0)	1 (1.00)	–	–	1
6	–	–	–	–	0
7	1 (0.08)	0 (0)	7 (0.58)	4 (0.33)	12

of one another. Oestrus onset in the remaining females followed dominance rank order (ranks 3–5), except for female rank 6 who failed to exhibit behavioral oestrus. Dominance rank was associated ($P < 0.05$) with timing of mating: dominant females were mated more frequently during the 12 h interval after the onset of behavioral oestrus than were subordinates, while subordinates generally achieved most of their matings during the latter part of oestrus (Table 2).

The mean day on which the first detectable rise in fecal P above baseline following modified CIDR-B device removal was achieved in females housed with (5.1 ± 1.0 days) or without (4.1 ± 1.0 days) a male was not different ($P > 0.05$).

4. Discussion

Both CIDR-G and modified CIDR-B devices were effective in releasing progesterone into blood circulation, but the modified CIDR-B devices produced serum P levels that more closely approximated normal luteal phase concentrations. Maximal serum P concentrations were achieved within one day of CIDR device insertion, whereas serum levels declined gradually thereafter. These progesterone absorption dynamics are very similar to those observed in cattle (Macmillan and Peterson, 1993) and scimitar-horned oryx, *Oryx dammah*, (Morrow, 1997). The overall retention rate for the modified CIDR-B device across all three experiments was 96.4%, which is comparable to retention rates (98–99%) for unmodified CIDR-B devices in cattle (Broadbent et al., 1993; Macmillan and Peterson, 1993). Fluctuations in serum P associated with CIDR device treatment were accurately reflected in feces, indicating that fecal steroid monitoring is a useful technique for assessing treatment efficacy.

Both $PGF_{2\alpha}$ alone, and in combination with modified CIDR-B devices, effectively induced synchronous ovulation in sable antelope. From a comparative standpoint, $PGF_{2\alpha}$ alone, administered in the presence of a mature CL, induced rapid luteolysis in sable antelope in a temporal pattern that was similar to other bovid species (cattle, Rowson et al., 1972; gaur, *Bos gaurus*, Godfrey et al., 1991; addax, *Addax nasomaculatus*, Asa et al., 1996; scimitar-horned oryx, Morrow, 1997). It is noteworthy that CIDR-B induced fecal P concentrations in non-MGA treated females (Study 2) exceeded luteal phase concentrations observed in MGA-treated females (Study 1). Because progesterone absorption from CIDR devices can vary as a result of ovarian activity at the time of CIDR device insertion (Macmillan and Peterson, 1993), these data suggest that concurrent MGA treatment may have inhibited vaginal absorption of progesterone from CIDR devices.

Oestrous synchronization treatments that combine progesterone-containing devices with $PGF_{2\alpha}$ have generally been favored over $PGF_{2\alpha}$ used alone because the combined regimen results in improved predictability, greater response rates, and tighter synchrony. In sable antelope, the $PGF_{2\alpha}$/modified CIDR-B treatment resulted in a shorter time to ovulation (as assessed by the latency to the first detectable rise in fecal P) and tighter synchrony of ovulation than $PGF_{2\alpha}$ alone. And while a two-injection $PGF_{2\alpha}$ regimen also results in imprecise synchrony in cattle (Macmillan and Day, 1982), the same protocol yields extremely tight oestrous synchrony in scimitar-horned oryx (8 h, Morrow, 1997). These results suggest that even closely related species within the family

Bovidae may respond quite differently to the same oestrous synchronization treatment. Nevertheless, combination treatments very similar to those described in this study have been successfully used to induce synchronous ovulation in cattle (Broadbent et al., 1993), zebu, *Bos indicus* (Cavalieri et al., 1997), and ewes (Scudamore et al., 1993).

Although male presence accelerates the onset of oestrous cycling after parturition or seasonal anoestrus in many bovids (McComb, 1987; Verme et al., 1987; Sempéré et al., 1996), male presence had no discernible impact on the timing of ovulation following oestrous synchronization in sable antelope. It is possible that male cues are effective at accelerating the onset of folliculogenesis after periods of ovarian inactivity, but are ineffective at shortening the duration of folliculogenesis itself.

The mean latency to the first detectable rise in fecal P for Study 3 (4.1–5.1 days) was longer than for Study 2 (3.16 days), but oestrous synchrony (as measured by the variances in the time to the first rise in fecal P) did not differ ($P > 0.05$) between studies. The mean time to the first rise in fecal P was consistently shorter ($P < 0.05$) for the $PGF_{2\alpha}$/modified CIDR-B treatment groups compared to females administered $PGF_{2\alpha}$ injections in Study 2 (7.1 days). The sequential design of Study 2 may have contributed to the enhanced synchrony produced by the $PGF_{2\alpha}$/modified CIDR-B combination treatment, because females received an additional $PGF_{2\alpha}$ injection compared to females in Study 3. Multiple $PGF_{2\alpha}$ treatments (i.e., injections in excess of the two necessary to reliably induce ovulation) are known to decrease time to ovulation and produce tighter oestrous synchrony in cattle (Hardin et al., 1980).

The characteristics of the induced oestrus in sable antelope following $PGF_{2\alpha}$/modified CIDR-B treatment were very similar to those described for other bovids. Overall, 85.7% of treated sable antelope exhibited oestrus, as compared to response rates of 76.2% in cattle (Broadbent et al., 1993) and 75% in scimitar-horned oryx (Morrow, 1997). The time to oestrus onset following $PGF_{2\alpha}$/modified CIDR-B treatment (22–53 h) was similar to that reported for ewes (20–36 h; Haresign, 1985; Scudamore et al., 1993), scimitar-horned oryx (33–65 h; Morrow, 1997) and cattle (43.5 h; Broadbent et al., 1993). Duration of oestrus (16–41 h) was longer than that reported for cattle and their congeners, which tend to exhibit oestrus duration of less than 24 h and sometimes as short as 4 h (gaur, Godfrey et al., 1991; cattle, Broadbent et al., 1993), but similar to that reported for scimitar-horned oryx (3–39 h, Morrow, 1997).

A synchronization protocol combining $PGF_{2\alpha}$ with a 12-day CIDR device insertion interval was effective for inducing oestrous synchrony in sable antelope. Although our primary goal was to develop these techniques for studying basic reproductive processes, methods of manipulating the timing of ovulation are a crucial prerequisite for the application of assisted reproduction (i.e., artificial insemination, in vitro fertilization, and embryo transfer). Our results suggest that synchronization of oestrus using $PGF_{2\alpha}$/modified CIDR-B treatments may facilitate the application of assisted reproductive techniques in sable antelope, and possibly other non-domestic bovid species.

5. Conclusions

Modified CIDR-B devices in combination with $PGF_{2\alpha}$ were effective in inducing synchronized oestrus in sable antelope. Fecal progestagens were highly correlated with

serum progesterone and were an effective means of monitoring hormonal fluctuations accompanying experimental manipulations. Responses of sable antelope to oestrous synchronization protocols were similar to those reported for cattle and other bovids, indicating that these techniques may have broad applicability for controlling oestrous cycles in non-domestic ungulates.

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