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Review: Using artificial insemination *v.* natural service in beef herds

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The aim of this review is to compare the performance of different reproductive programs using natural service, estrus synchronization treatment before natural service (timed natural breeding (TNB)), artificial insemination (AI) following estrus detection and timed artificial insemination (TAI) in beef herds. It is well known that after parturition the beef cow undergoes a period of anestrous, when they do not exhibit estrus, eliminating the opportunity to become pregnant in the early postpartum *by natural mating or by AI after detection of estrus. Hormonal stimulation is already a consistent and well-proven strategy used to overcome* postpartum *anestrus in beef herds. Basically, hormones that normally are produced during the estrous cycle of the cow can be administered in physiological doses to induce cyclicity and to precisely synchronize follicular growth, estrus and ovulation. Furthermore, two options of mating may be used after hormonal stimulation: natural service (i.e. utilization of bull service after synchronization, referred to as TNB) and TAI. These strategies improve the reproductive efficiency of the herds compared with natural service without estrus induction or synchronization. After the first synchronized service, the most common strategy adopted to get non-pregnant cows pregnant soon is the introduction of clean-up bulls until the end of the breeding season. However, methods to resynchronize non-pregnant cows after the first service are already well established and offer a potential tool to reduce the time for subsequent inseminations. Thus, the use of these technologies enable to eliminate the use of bulls by using resynchronization programs (i.e. two, three or four sequential TAI procedures). The dissemination of efficient reproductive procedures, such as TNB, TAI and Resynch programs, either isolated or in combination, enables the production of a greater quantity (obtaining increased pregnancy rates early in the breeding season) and quality (maximization of the use of AI with superior genetic sires) of beef calves. These technologies can contribute to improve the production efficiency, and consequently, improve livestock profitability.*

Keywords: service rate, reproductive performance, cattle planned breeding, hormonal stimulation, bovine

Implications

Artificial insemination (AI) has proven to be a reliable technology for cattle producers to improve genetic progress and control venereal diseases in their herds. However, when the AI program is not adequate to the farm conditions, it can diminish reproductive efficiency by increasing the calving to conception interval and, thus, increasing the calving interval compared with natural service (NS). Hormonal stimulation is already a consistent and well-proven strategy used to improve the reproductive performance in beef herds.

Introduction

High reproductive efficiency is a key requirement in order to ensure sustainable livestock production and satisfactory economic returns for the beef producer. The incorporation of reproductive programs into routine on-farm is one way of optimizing the reproductive outcomes and profitability of beef herds. Despite the widespread adoption of AI globally, NS is the most frequently used method of breeding on beef farms (Thibier and Wagner, 2002; Lamb and Mercadante, 2016). In Brazil, for instance, only 12% of females of reproductive age are inseminated, the remaining 88% being mated to bulls by NS during the breeding season (BS) (Baruselli, 2016).

Artificial insemination has many advantages compared with NS (Lima *et al.*, 2010; Lamb and Mercadante, 2016). It avoids the transmission of venereal diseases (Vishwanath, 2003), enables the use of bulls that are not present on the farm, allows the production of crossbred calves originating from breeds of bulls that are not well adapted to the local environmental conditions (i.e. *Bos taurus* breeds in hot and humid climate), increases calf uniformity, and accelerates genetic gain, resulting in calves that are more productive and

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profitable (Rodgers *et al.*, 2015; Baruselli *et al.*, 2017). The genetic and economic gains are principally achieved through the use of superior genetic bulls. However, the implementation of AI programs based on estrus detection (ED) in beef herds is hampered by factors such as *postpartum* anestrus, ED failure and the practical challenges of ED (i.e. estrus observation at least twice a day in each lot, the large number of animals per lot, the large size of many farms and the labor costs; Bó *et al.*, 2007), reducing the reproductive efficiency of the herd. Because of that, a common perception among cattle producers is that NS is cheaper and easier to implement, overcoming the challenges associated with ED needed for AI (Lima *et al.*, 2010). Thus, aiming to avoid the problems associated with ED and to enable the intensive use of AI programs in beef herds, a variety of strategies have been devised to allow insemination at a predetermined time (timed artificial insemination (TAI)), eliminating the need for ED and allowing insemination of beef cows regardless of cyclic status or season (Lamb *et al.*, 2001; Rhodes *et al.*, 2003b; Baruselli *et al.*, 2004b; Bó *et al.*, 2007). Use of TAI also has the advantage of concentrating the period during which cows become pregnant, this facilitating the organization of the BS, optimizing cattle management and the labor requirements.

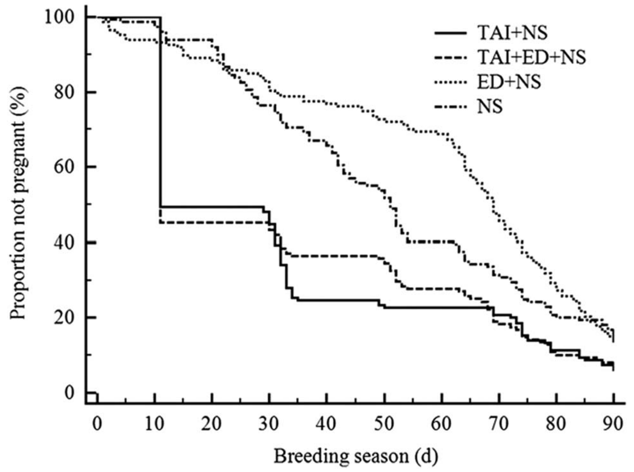

Figure 1 Survival curves for proportion of non-pregnant cows by days of breeding season for various breeding strategies during a 90-day breeding season. TAI + NS ($n = 150$): cows received timed artificial insemination (TAI) on day 11 of the breeding season (BS), followed by natural service (NS) until the end of the BS; TAI + ED + NS ($n = 148$) cows received TAI at day 11, then were observed for estrus twice daily, with AI 12 h after estrus detection (ED) until day 45 of the BS, followed by NS until the end of BS; ED + NS ($n = 147$) cows were bred by AI 12 h after ED during the first 45 days of the BS, followed by NS until the end of BS; NS ($n = 149$) cows were bred by NS throughout the BS. Adapted from Sá Filho *et al.* (2013).

Reproductive programs (artificial insemination v. *natural service)*

As a result of concerns raised regarding the comparative efficiency of NS, insemination based on ED and TAI in getting cows pregnant early in the BS, our group performed two sequential studies to evaluate reproductive performance of *postpartum* beef cows subjected to different reproductive programs (Sá Filho *et al.*, 2013). In the first study, TAI + NS ($n = 150$), TAI + ED + NS ($n = 148$), ED + NS ($n = 147$) and NS ($n = 149$) were evaluated during a 90-day BS. In the second experiment, the use of TAI at the onset of the BS, followed by NS (TAI + NS; $n = 252$) was compared with only NS ($n = 255$) throughout the entire 90-day BS. In brief, in Study 1, the interval to establishment of pregnancy was decreased ($P < 0.001$) for TAI + NS and TAI + ED + NS compared with ED + NS and NS (Figure 1). Also, TAI + NS resulted in a greater ($P = 0.001$) proportion of cows pregnant at 45 days of the BS (75.3%) than TAI + ED + NS (63.5%), which was greater than NS (44.3%) and ED + NS (23.3%). Indeed, ED followed by AI always resulted in a reduction in pregnancy rate compared with natural breeding with a bull, likely due to human failures in ED. At the end of the BS, a greater ($P < 0.01$) proportion of cows were pregnant when TAI was performed (TAI + NS = 92.7% and TAI + ED + NS = 91.9%) compared with ED + NS (85.0%) and NS (83.2%). Thus, using TAI shortens the interval from calving to conception, improves pregnancy rates at 45 days and at the end of the BS, and additionally increases the genetic gain of the herd.

Regarding reproductive efficiency, we conclude that (1) bulls are more efficient than ED followed by AI, and (2) TAI is more efficient than NS. The problem of low ED has been previously reported by others working with suckled beef cows (Stevenson *et al.*, 2000; Baruselli *et al.*, 2002; Bó *et al.*, 2003). Previous studies also demonstrated that TAI increased the number of mounts received, improved estrus synchronization and first service conception rate in suckled Brahman cows (Flores *et al.*, 2006). Also, a greater percentage of *Bos taurus* beef cows bred by TAI (84%) weaned a calf during the subsequent calving season compared with cows bred by NS (78%; Rodgers *et al.*, 2015).

In Study 2 (Sá Filho *et al.*, 2013), TAI + NS resulted in a greater ($P = 0.001$) proportion of cows pregnant at 45 days of the BS than when cows were bred exclusively with NS (63.5% *v.* 46.3%); however, the proportion of cows pregnant at end of the BS was similar (77.0% *v.* 71.0%; $P = 0.31$) between treatments. When the entire BS was evaluated, the likelihood of pregnancy was greater for TAI + NS than NS (adjusted hazard ratio, 1.64; 95% confidence interval, 1.34 to 2.01; $P < 0.0001$; Figure 2), primarily because of pregnancies established by TAI at the beginning of the BS. Indeed, cows subjected to TAI + NS had fewer median days to conception (11 days) than cows exposed exclusively to NS (55 days). In this context, Rodgers *et al.* (2015) reported that a greater percentage of cows bred by TAI calved during the first and second 10-day intervals of the calving season than cows bred exclusively by NS.

These studies clearly demonstrate that using TAI early in the breeding period increases reproductive performance of *postpartum* beef cows maintained on pasture. Cows receiving TAI had greater pregnancy rates at 45 days and at the end of the BS, and reduced number of days from calving to conception. As a consequence, cows exposed to TAI at the beginning of the BS calved earlier, weaning heavier calves

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and had improved probability of re-conception in the subsequent BS.

Timed artificial insemination followed by natural service v. *timed artificial insemination followed by resynchronization*

Typically, the treatment most frequently adopted to achieve pregnancy in early *postpartum* cows which are not pregnant after TAI is the introduction of NS sires until the end of the BS. However, protocols to resynchronize those cows which are not pregnant after the first *postpartum* service are already well established. The main advantage of such protocols is the reduction in time required for subsequent inseminations, thus allowing a more compact BS. Initial studies involved the initiation of resynchronization at the time of pregnancy diagnosis, between 28 and 32 days after TAI (RE30; Stevenson *et al*., 2003; Marques *et al*., 2012 and 2015; Bó *et al*., 2016). Cows diagnosed as non-pregnant on that day were immediately resynchronized for TAI. This Resynch procedure is flexible (it begins at the date chosen for pregnancy diagnosis) and only non-pregnant cows are treated. However, the interval between inseminations may exceeds 38 days which may be considered excessive compared with bull exposure, where mating occurs around 21 days after TAI as cows return to estrus naturally. Although natural mating reduces the interval between two consecutive services, the service rate is dependent on non-pregnant cows returning to estrus ~21 days after TAI (around 50%; Sá Filho *et al*., 2013). The advantage of Resynch programs lies in the reduction of the interval between inseminations, facilitating compaction of the BS, with the benefit of guaranteeing 100% service rate.

To optimize the compactness of the BS, Resynch protocols should start earlier than is typical for pregnancy diagnosis; this means that all cows must be treated. The Resynch22 (RE22) protocol begins 22 days after the previous AI, 8 days before ultrasound pregnancy diagnosis (Sá Filho *et al*., 2014). At the time of pregnancy diagnosis, cows diagnosed as pregnant are excluded from the subsequent treatments while non-pregnant cows continue the resynchronization protocol. Use of RE22 reduces the interval between inseminations to 32 days; however, the first treatment (insertion of progesterone, P4, device and administration of estradiol) must be carried out in all cows and pregnancy diagnosis must be performed on a fixed schedule. In contrast, most farms that use Resynch30 (RE30) have a prescheduled date for pregnancy diagnosis to allow the Resynch protocol to start as soon as possible. This date is not fixed; a new protocol can be initiated in open cows anytime after pregnancy diagnosis). Conversely, for RE22, the date of pregnancy diagnosis is not flexible because the protocol has already been initiated 8 days before.

The reproductive efficiency of the different treatments associated with TAI and resynchronization programs was evaluated for *postpartum* beef cows (Rubin *et al*., 2015). In the first study, cows were subject to: (1) NS ($n=266$); (2) TAI + NS ($n=200$); (3) TAI + RE30 + NS ($n=245$); (4) TAI + RE22 + NS ($n=249$) during a 90-day BS (Figure 3). Within 30 days of the onset of the BS, only 3% of the females submitted to NS were pregnant compared with ~40% for the other groups (TAI + NS = 40.0%, TAI + RE30 + NS = 40.0%, TAI + RE22 + NS = 39.8%; $P<0.001$). At 60 days of the BS, pregnancy rate was higher for cows that were resynchronized and received the second TAI (TAI + RE30 + NS = 69.4% and TAI + RE22 + NS = 66.3%) compared with cows subjected to the other treatments (TAI + NS = 48.0% and NS = 16.9%; $P<0.001$). In addition, cows receiving TAI + NS had greater pregnancy rate than those only

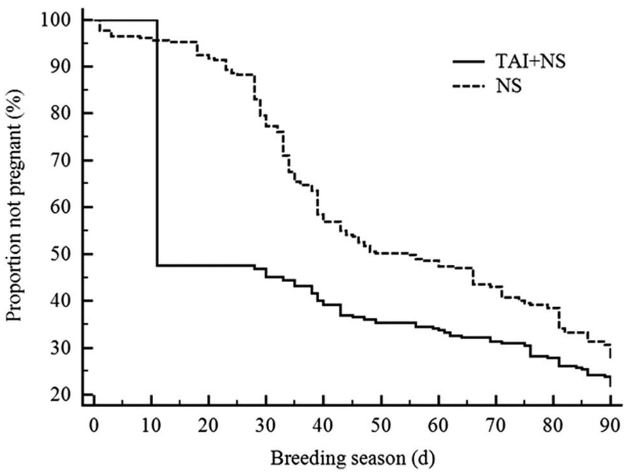

Figure 2 Survival curves for proportion of non-pregnant cows by day 90 of the breeding season (BS) for *postpartum* beef cows bred by natural service (NS; dashed line; $n=255$) or by timed artificial insemination (TAI) at beginning of the breeding season (BS) followed by NS (TAI + NS; solid line; $n=252$) during 90-day BS. Median interval to pregnancy for NS and TAI groups was 55 and 11 days (adjusted hazard ratio, 1.64; 95% confidence interval, 1.34 to 2.01), respectively. Adapted from Sá Filho *et al*. (2013).

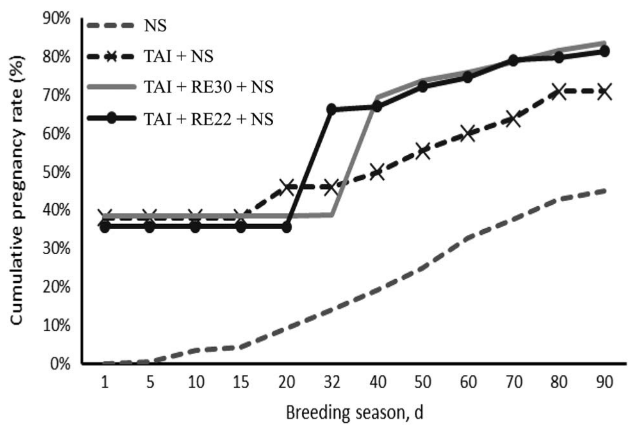

Figure 3 Cumulative pregnancy rate of cows subjected to different reproductive procedures during a 90 day breeding season (BS). Cows under NS were only exposed to bulls' natural service (NS) ($n=266$). Cows under TAI + NS ($n=200$) were subject to timed artificial insemination (TAI) followed by NS until the end of the BS. Cows under TAI + RE30 + NS ($n=245$) received TAI and were resynchronized at the 30 days-pregnancy diagnosis. Cows under TAI + RE22 + NS ($n=249$) received TAI and were resynchronized at unknown pregnancy status 22 days after TAI. Clean-up bulls were introduced 10 days after the last TAI, regardless of the experimental group. Adapted from Rubin *et al.* (2015).

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exposed to NS ($P < 0.001$). At the end of the BS, regardless of the resynchronization schedule, pregnancy rate was greater for cows subjected to TAI + RE30 + NS (83.7%) and TAI + RE22 + NS (81.5%) than for those subjected to TAI + NS (71.0%) or NS (45.1%).

Use of Resynch programs lead to the adoption of management strategies exclusively involving TAI, thus eliminating the need for a clean-up bull(s) on the farm. The reproductive efficiency of using Resynch was evaluated recently by Crepaldi *et al*. (2017). In that study, the use of three consecutive TAI using RE22 (3TAI) resulted in similar pregnancy rates to those achieved using two TAI using RE22 followed by bull exposure (2TAI + bull) and greater pregnancy rate than one TAI followed by bull exposure (1TAI + bull). A cumulative pregnancy rate of 87.4% was achieved at the end of a 64-day BS after three TAI using RE22 (Figure 4).

Use of color Doppler ultrasonography to characterize the vascularization of the corpus luteum (CL) and confirm the lack of an embryonic vesicle in the uterus can be used to diagnose non-pregnancy earlier than can normally be achieved with routine scanning (Siqueira *et al*., 2013; Baruselli *et al*., 2017; Pugliesi *et al*., 2017). This procedure is referred to as Resynch14, as the protocol is initiated 14 days after the previous TAI, followed by pregnancy diagnosis eight days later (i.e. 22 days after TAI) using Doppler ultrasonography (Vieira *et al*., 2014). As before, this protocol requires the initial treatment of all animals (due to unknown pregnancy status at the time of protocol initiation) and a fixed schedule for pregnancy diagnosis. In addition, it requires specific ultrasound equipment and expertise. However, it allows a significant reduction in the interval between AI to 24 days, which is close to what is achieved using clean-up bulls (around 21 days estrus return and rebreeding; Figure 5).

Pregnancy rates after Resynch22 and Resynch14 were recently compared in 244 *postpartum* beef cows (Penteado *et al*., 2016). In that study, following TAI, cows were allocated to one of the two Resynch programs (Resynch22; $n = 126$ or Resynch14; $n = 118$). Resynch22 cows were treated with a P4 device plus 2 mg EB intramuscular (IM) 22 days after the previous AI (day 22). On day 30, the device was removed and pregnancy was diagnosed based on the presence or absence of an embryonic vesicle in the uterus (conventional ultrasonography). Cows diagnosed as non-pregnant were administered prostaglandin $F_{2\alpha}$ (PGF), 1 mg estradiol cypionate and 300 IU equine chorionic gonadotropin (eCG) IM, followed by TAI 48 h later on day 32. Resynch14 cows were treated with a P4 device plus IM administration of 100 mg P4 14 days after the previous AI (day 14). On day 22, pregnancy diagnosis was carried out by the assessment of CL vascularization using color Doppler ultrasonography. Cows with low or absent vascularization were considered non-pregnant and continued the resynchronization treatment (device removal, PGF, estradiol cypionate and eCG IM), and were TAI 48 h later (day 24). Cows with moderate or strong CL vascularity were considered pregnant; in these cows the device was removed and no further treatment was applied. Similar pregnancy per artificial insemination were achieved for Resynch22 and Resynch14 cows following the first AI (48% *v*. 53%; $P = 0.57$) and resynchronization (56% *v*. 51%; $P = 0.37$), respectively. The cumulative pregnancy rates after 32 and 24 days of the BS were also similar ($P = 0.77$) for Resynch22 (77%; 97/126) and Resynch14 cows (75%; 89/118), respectively. In addition, Resynch14 considerably improved the 21-day service rate from 66% to 87.5% compared with Resynch22 (Figure 5).

Collectively, these studies demonstrated that resynchronization programs are feasible and efficient to breed cows during early *postpartum*, reducing the length of the BS and allowing at least similar cumulative pregnancy outcomes as those achieved after bull exposure in a traditional 90-day BS. By increasing the number of cows pregnant by AI, resynchronization/TAI programs facilitate accelerated genetic progress. In addition, the consequent concentration of the calving period early in the season, results in more uniform and improved weaning weights and facilitates the use of young heifers in the subsequent BS.

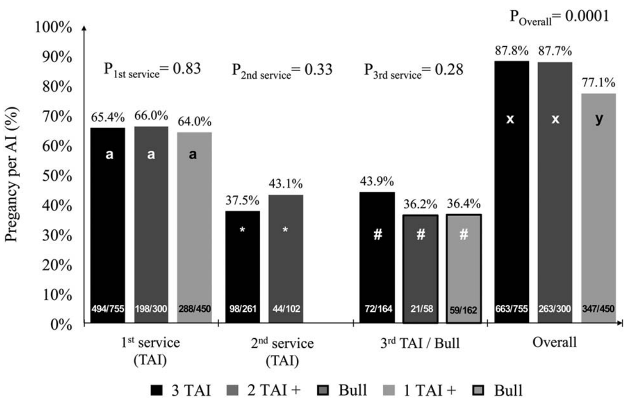

Figure 4 Pregnancy rate in *Bos indicus* beef cows after timed artificial insemination (TAI) with subsequent resynchronization or natural mating. Resynchronization was done using Resynch22 program starting 22 days after the previous TAI. Groups were: 3 TAI (TAI + Resynch22 and TAI + Resynch22 and TAI; $n = 450$); 2 TAI (TAI + Resynch22 and TAI + clean-up bulls; $n = 300$); 1 TAI (TAI + clean-up bulls; $n = 755$). Pregnancy diagnosis of the 3rd TAI and bull mating were done at the end of the breeding season. Adapted from Crepaldi *et al*. (2017). a: $P = 0.83$, *: $P = 0.33$, #: $P = 0.28$, x, y: $P = 0.0001$.

Synchronization treatment previous to natural service

In Brazil, 88% of females of reproductive age are not exposed to an estrus synchronization protocol for TAI and are only exposed to natural breeding (Baruselli, 2016). Similarly, many farms around the world cannot implement applied reproductive technology such as AI upon ED or TAI, because of the absence of adequate animal handling facilities or specialized personnel (Chenoweth, 2002) and the increased management demand (Chenoweth and Lennon, 1984; Chenoweth, 2002). However, after parturition, cows may undergo a prolonged anestrous period, during which they do not show behavioral signs of estrus, which is crucial when reproduction is dependent on bull mating. Delays in the resumption of *postpartum* cyclicity may increase the interval from calving to conception and reduce reproductive efficiency (Diskin and Sreenan, 2000;

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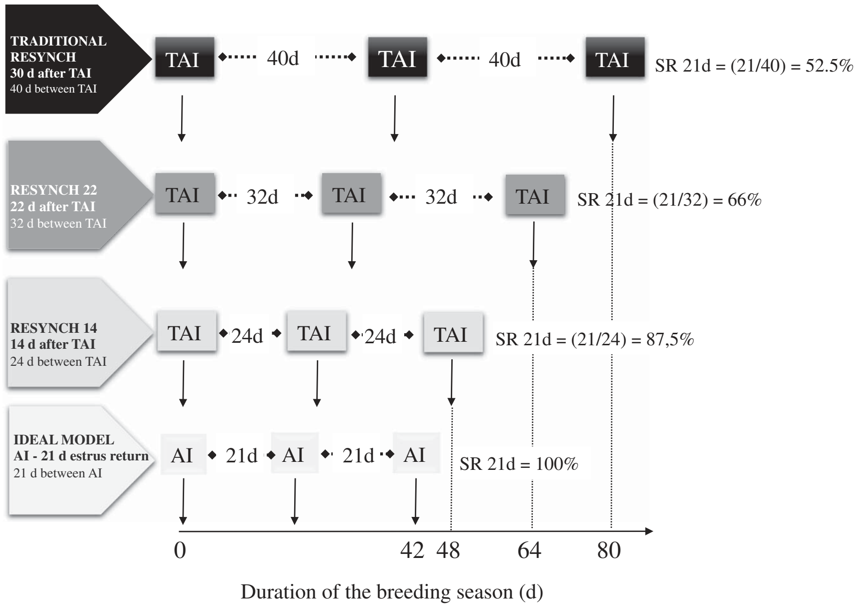

Figure 5 Service rate (SR) and duration of the breeding season after three artificial insemination (AI) for different Resynch programs (ideal model refers to a 21-day interval between AI and SR = 100%): Resynch14 (starts 14 days after previous timed artificial insemination (TAI), with 24-day interval between AI and SR = 87.5%), Resynch22 (starts 22 days after previous TAI, with 32 days interval between AI and SR = 66%) and traditional Resynch (starts after pregnancy diagnosis 30 days after previous TAI, with 40 days interval between AI and SR = 52.5%). Adapted from Baruselli *et al.* (2017).

Baruselli *et al.*, 2004b; Crowe, 2008), which may lead to important economic losses.

Thus, the development of a strategy that allows the early conception of *postpartum* cows exposed to bull mating with satisfactory pregnancy rates is fundamental to enhance the reproductive efficiency. Based on previous experience showing the efficiency of the synchronization of follicular wave emergence and ovulation (as for TAI programs; Stevenson *et al.*, 2000; Baruselli *et al.*, 2002; Bó *et al.*, 2003) and the addition of eCG to overcome *postpartum* anestrus (Baruselli *et al.*, 2004a and 2004b; Sá Filho *et al.*, 2010), our group recently conducted a study to evaluate whether different P4–E2 synchronization treatments (with and without eCG) used before NS, termed timed natural breeding (TNB), are efficient for hastening and improving the pregnancy rates of *postpartum* cows, thereby enhancing their reproductive efficiency during the BS (Ferreira *et al.*, 2018). For that, a total of 350 primiparous Nelore (*Bos indicus*) cows between 35 and 60 days *postpartum* were randomly assigned to one of the three experimental groups: the Control group ($n = 123$; no hormonal treatment); the TNB group ($n = 115$; hormonal protocol with P4 and E2 for TNB without eCG); or the TNB + eCG group ($n = 112$; hormonal protocol with P4 and E2 for TNB with eCG). The treatments are summarized in Figure 6. The bull : cow ratio was 1 : 10 within the first 7 days and 1 : 25 within the next 98 days of the BS. The bulls were removed on day 105.

Pregnancy diagnosis was performed 40, 90, and 140 days after bull exposure. Gestational age was estimated based on an ultrasonographic assessment of the amniotic vesicle and embryo or fetus size (Youngquist and Threlfall, 2007) to predict the date of conception and the number of new gestations every 21-day period (P21, P42, P63, P84 and P105), starting at bull exposure (P21). Pregnancy rate was cumulative and calculated as the number of pregnant cows after bull exposure divided by the total number of cows enrolled per period (P21, P42, P63, P84 and P105).

Control cows were less likely to be pregnant at P21 (5.7%, 7/123) than TNB (30.4%, 35/115) and TNB + eCG (51.8%, 58/112; $P = 0.001$) cows. In the subsequent periods, the pregnancy rate increased for all groups, but differences remained between treatments (Table 1). The TNB + eCG cows achieved more than 50% conception rate within the first 21 days after bull exposure (i.e., the first estrus after treatment), whereas the TNB and Control cows, respectively, took more than 40 and 90 days to achieve a 50% conception rate (Figure 7). At the end of the BS, cows treated with eCG had 21% and 16% more pregnancies than the Control and the treatment without eCG, respectively (Figure 7). Also, the probability of conceiving increased 1.5 fold when cows were treated with the TNB protocol and increased 2.2 fold when eCG was added to the protocol (TNB + eCG). The average interval between the onset of the BS and conception was considerably reduced ($P < 0.0001$) when cows were treated with TNB + eCG (26.5 ± 3.8 days) compared to those treated with TNB without eCG (35.7 ± 4.1 days) and those in the Control (64.7 ± 3.9 days) group. Consequently, the calving to conception interval was also reduced from approximately 120 (Control) to 91 (TNB) and 82 (TNB + eCG) days when cows received the hormonal protocols (the cows started the BS at 55 days *postpartum* on average).

In conclusion, the use of TNB, especially when associated with eCG, efficiently improved the early conception of

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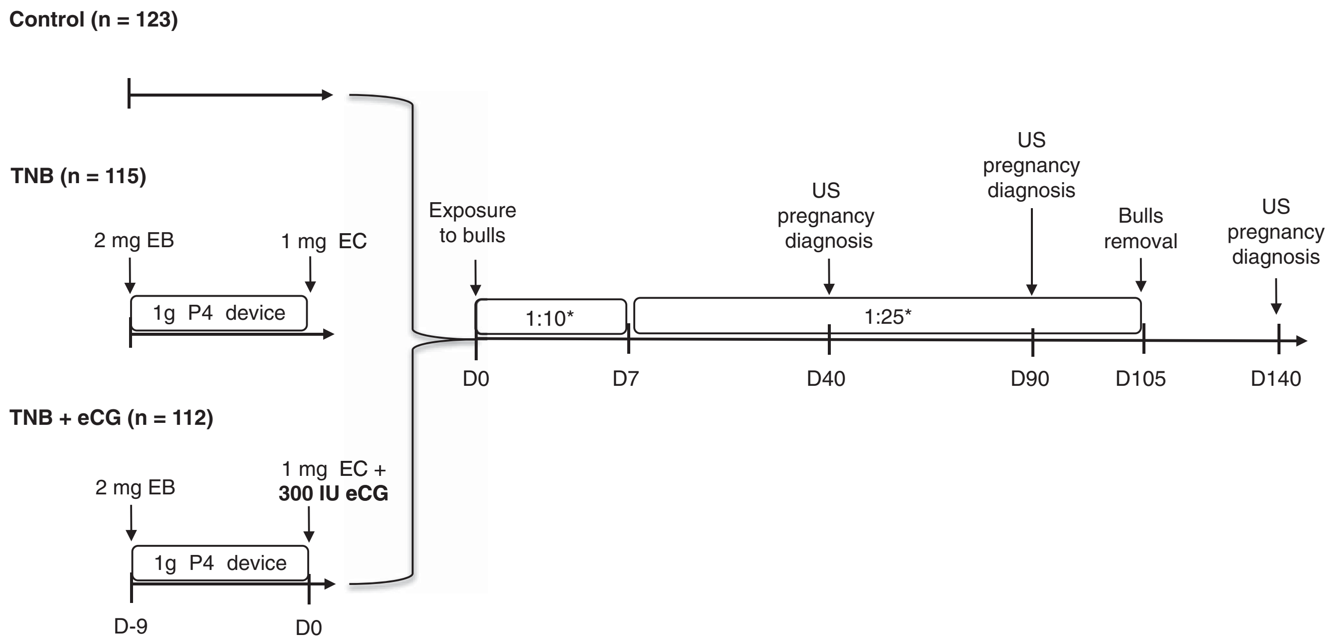

Figure 6 Experimental design used to evaluate the effect of treating *postpartum* primiparous beef cows before exposure to bull natural breeding (NB) on time to conception and pregnancy outcomes during a 140-day breeding season. Control cows received no previous hormonal treatment, TNB (timed NB) cows received a protocol to synchronize follicular wave emergence and ovulation without equine chorionic gonadotropin (eCG), and TNB + eCG cows received a similar treatment as that given to the TNB group with the addition of 300 IU of eCG on day 0. US = transrectal ultrasonographic examination; *bull : cow ratio. Adapted from Ferreira *et al.* (2018).

Table 1 *Cumulative pregnancy rate every 21 days (P21, P42, P63, P84 and P105) of treated and non-treated (control)* postpartum *primiparous beef cows exposed to bull natural breeding (NB) during a 105-day breeding season*

	Control	TNB	TNB + eCG	*P* value
P21 (% (*n*/*n*))	5.7^{c} (7/123)	30.4^{b} (35/115)	51.8^{a} (58/112)	0.001
P42 (% (*n*/*n*))	17.1^{c} (21/123)	42.6^{b} (49/115)	58.9^{a} (66/112)	0.001
P63 (% (*n*/*n*))	27.6^{c} (34/123)	52.2^{b} (60/115)	70.4^{a} (79/112)	0.001
P84 (% (*n*/*n*))	42.3^{c} (52/123)	58.3^{b} (67/115)	74.1^{a} (83/112)	0.001
P105 (% (*n*/*n*))	65.0^{b} (80/123)	68.7^{ab} (79/115)	82.1^{a} (92/112)	0.01

P21, P42, P63, P84 and P105 = cumulative pregnancy rates at 21, 42, 63, 84 and 105 days of the breeding season.
Control cows received no prior hormonal treatment; timed NB (TNB) and TNB + equine chorionic gonadotropin (eCG) cows received a protocol to synchronize follicular wave emergence and ovulation without and with eCG, respectively. Adapted from Ferreira *et al.* (2018).
[a,b,c]Values within a row with different superscript letters differ significantly at the *P* value presented.

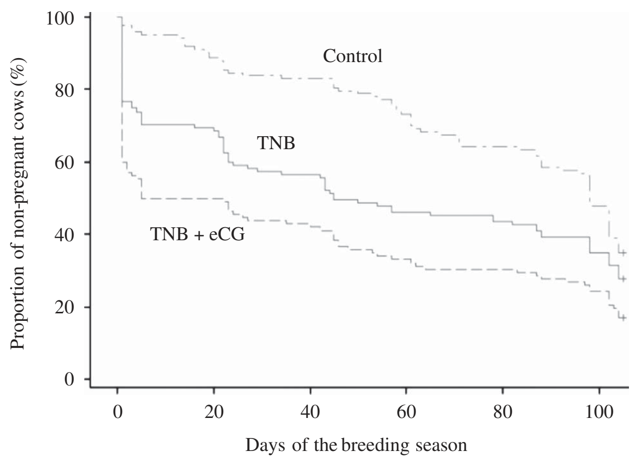

Figure 7 Survival curve illustrating the interval between the onset of the breeding season and conception for *postpartum* primiparous beef cows of the control and treated groups exposed to bull natural breeding (NB). Control cows received no previous hormonal treatment; TNB (timed NB) and TNB + equine chorionic gonadotropin (eCG) cows received a protocol to synchronize follicular wave emergence and ovulation without and with 300 IU of eCG on day 0, respectively. Adapted from Ferreira *et al.* (2018).

postpartum beef cows that were exposed to natural breeding. The use of the treatment for TNB may have increased the LH pulse frequency, anticipating *postpartum* cyclicity and conception (Rhodes *et al*., 2003a). Also, the addition of eCG enhances follicular growth, ovulation and pregnancy after the synchronization protocol (Baruselli *et al*., 2004a and 2004b; Sá Filho *et al*., 2010). The increased number of cows conceiving early in the BS is crucial to improve reproductive efficiency (by reducing the interval between parturitions and increasing the number of pregnant cows at the end of the BS) and farm income.

Economic impact of using reproductive technologies

The use of reproductive technologies such as TAI and TNB can significantly enhance productivity of the herd, culminating in a significant positive economic impact on the entire chain of production. For example, in 2015, it is estimated that TAI generated ~US$ 175 million in Brazil, involving the participation of an estimated 3500 veterinarians (Baruselli, 2016). Timed artificial insemination is currently used on 8.2 million beef cows, generating an 8% increase in calf

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production, which represents ~656 000 more calves per year or an additional income of ~US$ 253 million/year. Timed artificial insemination also increases the genetic merit of herds, generating an average increase of 20 kg in weaning weight, which represents 3.3 million weaned calves with extra 20 kg or an extra US$ 123 million. Also, from weaning to slaughter the TAI calves gain an additional 15 kg of carcass, generating an extra US$ 149 million. Thus, TAI adds more than a half billion dollars per year to the bovine beef chain (Baruselli, 2016).

However, despite the great economic impact of the usage of TAI, many farms do not have adequate animal handling facilities or specialized personnel to implement it, thus, reproductive management of most herds may be flawed. The use of a TNB protocol associated with eCG can accelerate resumption of *postpartum* cyclicity and is a potential tool to improve pregnancy of primiparous cows exposed to bulls, with impact until the end of the BS (Ferreira *et al*., 2018). As only 12% of the Brazilian herd is actually inseminated (Baruselli, 2016), TNB could be applied (depending on farm and animal conditions) to the remaining 88% of the beef national herd (~60.1 million cows and heifers), representing an estimated gain of an extra 4.8 million calves/year or ~US$ 1.9 billion (considering 8% more calves and no genetic gain). This additional income is still underestimated because the anticipation of parturition resulting from the use of TNB was not considered for the calculation.

It is important to note that the technique of TNB should not be used as a substitute for TAI, especially because it does not bring with it the genetic gain that TAI facilitates. However, TNB can organize the BS and improve the reproductive efficiency of herds exposed to bull natural mating. Thus, TNB can be a step forward for farms that, as for now, cannot implement TAI, so that one day they can reach this level of reproductive management.

Summary and conclusions

The high incidence of *postpartum* anestrus and the low efficiency, the prolonged time and great effort required to accomplish ED have limited reproductive efficiency, the widespread application and the success of AI on beef farms. This condition has to be taken into consideration when deciding to begin an AI program. However, the dissemination of efficient reproductive procedures, such as TNB, TAI and Resynch programs described herein, either alone or in combination, enables the production of a greater quantity (getting high pregnancy rate early in the BS) and quality (maximization of the use of AI with superior genetic sires) of beef calves. These technologies can contribute to improve the production efficiency, and consequently, improve livestock profitability.

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Declaration of interest

None.

Ethics statement

None.

Software and data repository resources

None.

References

Baruselli PS 2016. IATF supera dez milhões de procedimentos e amplia o mercado de trabalho. Revista CFMV 69, 57–60.

Baruselli PS, Ferreira RM, Colli MHA and Elliff FM 2017. Timed artificial insemination: current challenges and recent advances in reproductive efficiency in beef and dairy herds in Brazil. Animal Reproduction 14, 558–571.

Baruselli PS, Marques MO, Carvalho NAT, Madureira EH and Campos Filho EP 2002. Effect of different treatments for timed artificial insemination on the reproductive efficiency in lactating beef cows. Revista Brasileira de Reprodução Animal 26, 218–221.

Baruselli PS, Reis EL, Carvalho NAT and Carvalho JBP 2004a. eCG increase ovulation rate and plasma progesterone concentration in Nelore (Bos indicus) heifers treated with progesterone releasing device. In XVI International Congress on Animal Reproduction, p. 117 (abstract). Porto Seguro, Brazil.

Baruselli PS, Reis EL, Marques MO, Nasser LF and Bó GA 2004b. The use of hormonal treatments to improve reproductive performance of anestrous beef cattle in tropical climates. Animal Reproduction Science 82–83, 479–486.

Bó GA, Baruselli PS and Martínez MF 2003. Pattern and manipulation of follicular development in Bos indicus cattle. Animal Reproduction Science 78, 307–326.

Bó GA, Cutaia L, Peres LC, Pincinato D, Maraña D and Baruselli PS 2007. Technologies for fixed-time artificial insemination and their influence on reproductive performance of Bos indicus cattle. Society of Reproduction and Fertility Supplement 64, 223–236.

Bó GA, de la Mata JJ, Baruselli PS and Menchaca A 2016. Alternative programs for synchronizing and resynchronizing ovulation in beef cattle. Theriogenology 86, 388–396.

Chenoweth P 2002. Use of Bulls with estrus synchronization ‘Bull-Sync.’ In Proceedings of the applied reproductive strategies in beef cattle workshop, Manhattan, Kansas, pp. 132–136.

Chenoweth PJ and Lennon PE 1984. Natural breeding trials in beef cattle employing oestrus synchronisation and biostimulation. Animal Production in Australia 15, 293–296.

Crepaldi GA, Freitas BG, Mingoti RD, Colli MHA, Gonçales Junior WA, Ferreira RM and Baruselli PS 2017. Reproductive efficiency of Nelore cows submitted to three different reproductive strategies in a 64 days breeding season. Animal Reproduction 14, 698 (abstract).

Crowe MA 2008. Resumption of ovarian cyclicity in post-partum beef and dairy cows. Reproduction in Domestic Animals 43, 20–28. (Review).

Diskin MG and Sreenan JM 2000. Expression and detection of oestrus in cattle. Reproduction, Nutrition, Development 40, 481–491.

Ferreira RM, Conti TL, Gonçalves RL, Souto LA, Sales JNS, Sá Filho MF, Elliff FM and Baruselli PS 2018. Synchronization treatments previous to natural breeding anticipate and improve the pregnancy rate of postpartum primiparous beef cows. Theriogenology (accepted for publication).

Flores R, Looper ML, Kreider DL, Post NM and Rosenkrans CF Jr 2006. Estrous behavior and initiation of estrous cycles in postpartum Brahman influenced cows after treatment with progesterone and prostaglandin F2alpha. Journal of Animal Science 84, 1916–1925.

Lamb GC and Mercadante VRG 2016. Synchronization and artificial insemination strategies in beef cattle. Veterinary Clinics: Food Animal Practice 32, 335–334.

Lamb GC, Stevenson JS, Kesler DJ, Garverick HA, Brown DR and Salfen BE 2001. Inclusion of an intravaginal progesterone insert plus GnRH and prostaglandin F2α for ovulation control in postpartum suckled beef cows. Journal of Animal Science 79, 2253–2259.

https://doi.org/10.1017/S175173111800054X Published online by Cambridge University Press

Lima FS, Vries ADE, Risco CA, Santos JEP and Thatcher WW 2010. Economic comparison of natural service and timed artificial insemination breeding programs in dairy cattle. Journal of Dairy Science 93, 4404–4413.

Marques MDO, Morotti F, da Silva CB, Ribeiro Júnior M, da Silva RCP, Baruselli PS and Seneda MM 2015. Influence of category – heifers, primiparous and multiparous lactating cows – in a large-scale resynchronization fixed-time artificial insemination program. Journal of Veterinary Science 16, 367–371.

Marques MO, Ribeiro Júnior M, Silva RCP, Sá Filho MF, Vieira LM and Baruselli PS 2012. Ressincronização em bovinos de corte. In 5º Simpósio Internacional de Reprodução Animal Aplicada (pp. 82–92. SIRAA, Londrina, PR, Brazil.

Penteado L, Rezende RG, Mingoti RD, Colli MHA, Sá Filho MF, Santos FB, Lemos Motta JC, Bayeux BM, Vieira LM and Baruselli PS 2016. Pregnancy rate of Nelore cows submitted to resynchronization starting 14 or 22 days after prior FTAI. Animal Reproduction 13, 450. (abstract).

Pugliesi G, Rezende RG, Silva JCB, Lopes E, Nishimura TK, Baruselli PS, Madureira EH and Binelli M 2017. Uso da ultrassonografia Doppler em programas de IATF e TETF em bovinos. Revista Brasileira de Reprodução Animal 41, 140–150.

Rhodes FM, McDougall S, Burke CR, Verkerk GA and Macmillan KL 2003a. Invited review: treatment of cows with an extended postpartum anestrous interval. Journal of Dairy Science 86, 1876–1894.

Rhodes FM, McDougall S, Burke CR, Verkerk GA and Macmillan KL 2003b. Treatment of cows with an extended postpartum anestrous interval. Journal of Dairy Science 86, 1876–1894.

Rodgers JC, Bird SL, Larson JE, DiLorenzo N, Dahlen CR, DiCostanzo A and Lam GC 2015. An economic evaluation of estrous synchronization and timed artificial insemination in suckled beef cows. Journal of Animal Science 10, 1297–1308.

Rubin MIB, Martini AP, Simões DF, Oliveira JAR, Trentin JM, Sá Filho MF, Baruselli PS and Pessoa GA 2015. Resynchronization protocols improve reproductive efficiency of suckled beef cows subjected to a breeding season during autumn-winter. Animal Reproduction 12, 659. (abstract).

Sá Filho MF, Ayres H, Ferreira RM, Marques MO, Reis EL, Silva RCP, Rodrigues CA, Madureira EH, Bó GA and Baruselli PS 2010. Equine chorionic gonadotropin and gonadotropin-releasing hormone enhance fertility in a norgestomet-based, timed artificial insemination protocol in suckled Nelore (Bos indicus) cows. Theriogenology 73, 651–658.

Sá Filho MF, Marques MO, Girotto R, Santos FA, Sala RV, Barbuio JP and Baruselli PS 2014. Resynchronization with unknown pregnancy status using progestin-based timed artificial insemination protocol in beef cattle. Theriogenology 81, 284–290.

Sá Filho MF, Penteado L, Reis EL, Reis TANPS, Galvão KN and Baruselli PS 2013. Timed artificial insemination early in the breeding season improves the reproductive performance of suckled beef cows. Theriogenology 79, 625–632.

Siqueira LG, Areas VS, Ghetti AM, Fonseca JF, Palhao MP, Fernandes CA and Viana JH 2013. Color Doppler flow imaging for the early detection of non-pregnant cattle at 20 days after timed artificial insemination. Journal of Dairy Science 96, 6461–6472.

Stevenson JS, Cartmill JA, Hensley BA and El-zarkouny SZ 2003. Conception rates of dairy cows following early not-pregnant diagnosis by ultrasonography and subsequent treatments with shortened Ovsynch protocol. Theriogenology 60, 475–483.

Stevenson JS, Thompson KE, Forbes WL, Lamb GC, Grieger DM and Corah LR 2000. Synchronizing estrus and(or) ovulation in beef cows after combinations of GnRH, norgestomet, and prostaglandin F2α with or without timed insemination. Journal of Animal Science 78, 1747–1758.

Thibier M and Wagner HG 2002. World statistics for artificial insemination in cattle. Livestock Production Science 74, 203–212.

Vieira LM, Sá Filho MF, Pugliesi G, Guerreiro BM, Cristaldo MA, Batista EOS, Freitas BG, Carvalho FJ, Guimaraes LHC and Baruselli PS 2014. Resynchronization in dairy cows 13 days after TAI followed by pregnancy diagnosis based on corpus luteum vascularization by color Doppler. Animal Reproduction 11, 378. (abstract).

Vishwanath R 2003. Artificial insemination: the state of the art. Theriogenology 59, 571–584.

Youngquist RS and Threlfall WR 2007. Current therapy in large animal. Theriogenology, 2nd edition, pp. 298–299. EUA, Philadelphia, PA, USA.

https://doi.org/10.1017/S175173111800054X Published online by Cambridge University Press