THE USE OF OXYTOCIN AND CARBETOCIN IN FARROWING SOWS AND ITS EFFECT ON THE DURATION OF PARTURITION

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Contents

Abstract

Stillbirth in swine production farms remains a major problem despite the use of drugs during parturition and account for 5-8% mortality in normal farrowings (Friend et al., 1962; Randall, 1972a,b; Zaleski and Hacker, 1993; Herpin et al., 1996; Trujillo-Ortega et al., 2007). A short duration of farrowing is important for piglet survival (Randall, 1972b). Pigs have a short survival time when they are exposed to asphyxia; irreversible brain damage occurs within 5 minutes (Miller and Miller, 1965 In: Curtis, 1974; Curtis, 1974). Approximately 82% of the intra-partum deaths occur in piglets born in the last third of the litter (Randall, 1972b).
Oxytocin is the most commonly used drug worldwide to accelerate parturition in sows and reduces the expulsion interval between piglets (Muhner et al., 1955 In: Cole and Foxcroft, 1982; Mota-Rojas et al., 2002; Alonso-Spilsbury et al., 2004). There are side effects reported; oxytocin administered intramuscular results in a higher number of ruptured umbilical cords, more intra-partum deaths and more meconium-stained piglets (Mota-Rojas et al., 2002b; Alonso-Spilsbury et al., 2004). Carbetocin is a synthetic octapeptide analogue of the hormone oxytocin (Barth et al., 1975 In: Hunter et al., 1992; Hunter et al., 1992; Engstrøm et al., 1998; Schramme et al., 2008). Carbetocin might be a safe and more effective alternative to oxytocin (Kirkden et al., 2013); accelerates the parturition with possible better fetal outcomes (Hühn et al., 2004; Udluft, 2004 In: Scramme et al., 2008).
The purpose of this research was to evaluate the use oxytocin and carbetocin in farrowing sows and its effect on the duration of parturition. This study was performed at two commercial swine farms from November 2012 to January 2013 and the set up was triple blinded. Per farm sows were randomly arranged into three groups of 50 sows; first group received 1 ml (10 IU) oxytocin (Oxytocin®, Dechra) by intramuscular injection in the neck region after the fourth piglet was born, second group received 1 ml (0,07 mg) carbetocin (Longacton®, Dechra) by intramuscular injection in the neck region after expulsion of the fourth piglet, third group received no injection and were only observed. To study the duration of the delivery, total farrowing duration (in minutes) and expulsion interval between piglets (time in minutes between two born piglets) were collected. Also parity, gestation length and litter size of each sow were recorded. In addition other variables of the piglets born were noted, head or breech presentation, aspect of the umbilical cord, sex and weight. In the context of animal welfare according to the Committee on Animal Experiments of Utrecht (DEC), behaviour of the sows was included in this study. Factors affecting the total farrowing duration (TFD), Farrowing Duration after the fourth piglet (FD4+) and four Farrowing Duration (FD) intervals were analysed with a General Linear Model (GLM)procedure; factorial ANOVA. Behaviour of the sows was analysed with a logistic regression. No differences were found between the treatment groups on the behaviour of the sows during the farrowing process; treatment did not affect the welfare of the sows ($P>0.05$). The amount of intervention was significant in all models; birth assistance prolonged the duration of farrowing compared to sows without birth assistance ($P<0.05$). There were no differences found between the carbetocin and control group on the duration of farrowing ($P>0.05$). Treatment with oxytocin was significant compared to the control group; oxytocin prolonged the last part of the farrowing process (interval 4) in sows with litters larger than 12 piglets ($P<0.05$).
A recommendation for farmers is that sows should be regularly monitored during the farrowing process whether they are treated with uterotonic drugs or not; prolonged birth intervals between piglets can be an indicator for farrowing problems.

1. Introduction

Selection for higher litter size in the intensive pig farming industry has been effective but has also contributed to an increased number of stillborn piglets (Johnson et al., 1999). Stillbirth in swine production farms remains a major problem despite the use of drugs during parturition and account for approximately 5-8% mortality in normal farrowings (Friend et al., 1962; Randall, 1972a,b; Zaleski and Hacker, 1993; Herpin et al., 1996; Trujillo-Ortega et al., 2007). A high number of stillborn piglets means an economical loss and can be seen as an animal welfare issue (van Dijk et al., 2005).

Previous studies reported that prolonged duration of farrowing has a great influence on the amount of stillborn piglets in a litter (Friend et al., 1962; Randall, 1972b; van Dijk et al., 2005). Borges et al. (2005) reported that sows with a duration of farrowing longer than 3 h had 2 times greater probability of stillbirth than those with a shorter duration of farrowing. Anoxia or asphyxia is probably the most common cause of intra-partum mortality during farrowing (Randell 1972b; Edwards, 1977 In: Alonso-Spilsbury et al., 2004; Hughes, 1992 In: Alonso-Spilsbury et al., 2004). A short duration of farrowing is important for piglet survival (Randall, 1972a,b). Pigs have a short survival time when they are exposed to asphyxia; irreversible brain damage occurs within 5 minutes (Miller and Miller, 1965 In: Curtis, 1974; Curtis, 1974). According to Glastonbury (1977), 75% of the stillborn piglets dies during parturition.
The probability of a piglet being stillborn is related to a longer birth interval, to later position in the birth order and a large litter size (Randall 1972b; De Roth and Downie, 1976; Zaleski and Hacker, 1993; Canario et al., 2006). Normally, piglets are born with an average interval of approximately 16 minutes between piglets and birth interval varies from 13.3-19.6 minutes (Randall 1972b; De Roth and Downie, 1976; Zaleski and Hacker, 1993; van Dijk et al., 2005; Mota-Rojas et al., 2005a). Birth interval between two live born piglets is significantly shorter than the interval between live born and stillborn piglets (van Dijk et al., 2005). The birth interval of stillborn piglets was more than 3 times the birth interval of live born piglets (Randall, 1972b; Alonso-Spilsbury et al., 2004). More stillborn piglets with an increased birth interval ultimately prolonged the duration of farrowing. Approximately 82% of the intra-partum deaths occur in piglets born in the last third of the litter (Randall, 1972b). Piglets born at the end of the litter have a greater risk of asphyxia, damage or rupture of the umbilical cord and detachment of the placenta because they are more exposed to the accumulative effects of uterine contractions (Randall, 1972a,b; English and Wilkinson, 1982). The presence of ruptured umbilical cords increased during parturition and 51.1% of the umbilical cords were broken in the last third of the parturition (Randal, 1972b).
Larger litters are associated with a longer duration of farrowing (Fahmy and Friend, 1981; De Roth and Downie 1976) and shorter birth intervals (Stanton et al., 1973). According Zaleski and Hacker (1993) the probability of stillbirth is associated with the number of piglets in the litter. Many other factors can also negatively influence the duration of farrowing such as individual weight of piglets, high parity, length of gestation, birth presentation and some breeds. Heavy piglets have increased difficulties to pass the vaginal birth canal and have greater risk of dying during the farrowing process (Fahmy et al., 1978 In: Canario et al., 2006). Some authors have mentioned that as the parity increased, the duration of farrowing increased gradually (Pejsak, 1984; Cutler et al., 1992). There was also reported that changes in the reproduction tract of sows and poor muscle tone might lead to a less efficient farrowing process (Pejsak, 1984). According to Fahmy and Friend (1981) the duration of farrowing increased linearly with the increase in gestation length. Van Dijk et al. (2005) reported that piglets with a posterior presentation were born after a longer birth interval but the number of anterior or posterior presentations in a litter did not affect the duration of farrowing. There are breed differences found in the literature. Meishan sows have been compared to other breeds; they have a shorter duration of farrowing and birth interval per piglet, a larger litter size, less stillborn

piglets and the mean birth weight is lower (Meunier-Saläun et al., 1991 In: Farmer and Robert, 2002; Farmer and Robert, 2002; van Dijk et al., 2005; Canario et al., 2006a).

Oxytocin

Oxytocin is the most commonly used drug worldwide to control parturition. Several authors described the benefits of using oxytocin in sows during parturition; it reduces the farrowing duration in sows and the expulsion interval between piglets (Muhner et al., 1955 In: Cole and Foxcroft, 1982; Mota-Rojas et al., 2002, 2006, 2007; Alonso-Spilsbury et al., 2004). Despite the use of uterotonic drugs the amount of stillborn piglets remains a problem; stillbirth rate remains the same since the 1960-1970s. The frequency, intensity and duration of myometrial contractions increased in sows which were treated with oxtyocin (1 IU/6 kg IM after the birth of the first piglet) compared to the control group (Mota-Rojas et al., 2005b, 2006). Uterine contractions decrease blood flow and interrupts the supply of oxygen to the fetus in the uterus (Tucker and Hauth, 1990). A significant decrease in fetal cardiac frequency was seen in sows which were treated with oxytocin compared to the control group (Mota-Rojas et al., 2005b). There are also other side effects reported; intramuscular treatment with oxytocin (20-50 IU) after the expulsion of the first piglet resulted in an increased number of hemorrhagic or premature ruptured umbilical cords, a higher number of stillborn piglets and more meconium-stained piglets compared with the control group (Mota-Rojas et al., 2002). Alonso-Spilsbury et al. (2004) showed that the number of sows with dystocia was greater in the oxytocin treated groups (20-40 IU oxytocin at onset of fetal expulsion) compared to the control sows and the need for birth assistance increased in the treated groups.

In a dose minimisation study of Mota-Rojas et al. (2005a), it was recommend to administer oxytocin IM to sows after the expulsion of the first piglet in the lowest possible dose which still decreases the duration of farrowing; 0.083 IU/kg. Oxytocin (0.083 IU/kg) decreased the intra-partum mortality significantly and less meconium-stained piglets were born compared to higher doses; 0.111 or 0.167 IU/kg (Rota-mojas et al., 2005a). Fetal anoxia in utero results in increased peristalsis with relaxation of the anal sphincter and the expulsion of meconium into the amniotic fluid (Penny and Randall, 1967). Severe anoxia leads to deep inspiration efforts and inhalation of amniotic fluid with meconium debris (Penny and Randall, 1967). The presence of meconium staining on the skin and in the respiration tract are indicators of fetal distress and anoxia (Penny and Randall, 1967; Randall, 1972b).

Routes of oxytocin administration were compared in the research of Mota-Rojas et al. (2006). 3 control groups received 0.9% Saline solution intramuscular (IM), intravulvular (IVU) or intravenous (IV) after the expulsion of the first piglet. Other groups received; 40 IU oxytocin by IM or by IVA injection or 20 IU oxytocin IV after the expulsion of the first piglet. Oxytocin administrated IV had a shorter period of action (IV-group 9.34 min, IVU-group 19.58 min and IM group 31.36 min) and a longer duration of farrowing compared to the other oxytocin groups (Mota-Rojas et al., 2006). The duration of contraction was different between the oxytocin groups; respectively 16.14 s in the IM-group, 14.92 s in the IVA-group and 15.74 in the IV-group (Mota-Rojas et al., 2006). More stillborn piglets, more stillborn piglets with ruptured umbilical cords and more stillborn piglets with severe meconium staining were seen in the oxytocin groups compared with the control groups, but was less in the IM-group than in the IV and IVU groups (Mota-Rojas et al., 2006).

The time of administration with oxytocin in sows during parturition was researched by Mota-Rojas et al. (2007). 3 groups received intramuscular a dosage of 0.083 IU/kg oxytocin after the birth of the first, fourth or eight piglet. Administration of oxytocin to sows after the eight piglet resulted in milder uterotonic effects with better fetal outcomes compared to the administration of oxytocin after the expulsion of the first or fourth piglet (Mota-Rojas et al., 2007). Difference between the control group and the oxytocin group that received oxytocin after eight piglets (O-8 group) were seen; less meconium-stained piglets and less intra-partum death were reported in the O-8 group after the eight piglet compared to the control group (Mota-Rojas et al., 2007).

Oxytocin is posterior pituitary hormone which is synthesized as an inactive precursor in the hypothalamus along with its neurophysin (Zeeman et al., 1997). The activated oxytocin and its neurophysin are packaged into neurosecretory granules and transported axonally to the nerve endings in the neurohypophysis where they were released by exocytosis into the bloodstream (Zeeman et al., 1997). Oxytocin circulates in the blood as a free peptide (Zeeman et al., 1997) and the biological half-life is 3-4 minutes in pregnant women (Ryden and Sjoholm, 1969). Oxytocin induces uterus contractions during parturition and milk ejection during lactation (Zingg and Laporte, 2003).
According to Shmygol et al. (2006) the effect of oxytocin on human uterine smooth muscle can be divided into three components: 1. increase in frequency of the contractions, 2. initial transient increase of base tone, 3. increase in amplitude and duration of contractions for a longer period of time.
The expression of oxytocin receptors is upregulated during the gestation and this leads to a strong increase of uterine sensitivity towards oxytocin (Soloff et al., 1979; Zing and Laporte, 2003). Before the onset of parturition an increase of oxytocin receptors occurs in the myometrium; greatest levels are reached during parturition and declines to baseline levels postpartum (Soloff et al., 1979; Kitazawa et al., 2001).

The release of oxytocin is of importance for effective uterine contractions and rapid birth of the piglets (Taverne et al., 1979). Oxytocin plasma concentrations are low during late gestation (Forsling et al., 1979). Between 9-4 hours before the birth of the first piglet, the uterine myometrial activity changed into more regular and synchronous pattern (Taverne et al., 1979). The frequency of myometrial activity increased further during farrowing (Taverne et al., 1979). The increase in myometrial activity coincides with elevated plasma concentrations of oxytocin and reached the highest levels during parturition (Taverne et al., 1979).
Oxytocin is released in a pulsatile pattern (Gilbert et al., 1994). Baseline levels of oxytocin increase to 10 fmol/l just before farrowing, rise to 45 fmol/l at 3 h after the start of farrowing and decreases to a normal value of 5-6 fmol/l (Castrén et al., 1993b In: Algers and Uvnas-Moberg, 2007). After the expulsion of each piglet, in the minute following the appearance of piglets is a significant elevation of oxytocin secretion detectable (Gilbert et al., 1994). According to Castrén et al. (1993b) only about 50% of the piglets were born during an oxytocin peak and the first piglets in a litter were born at much lower oxytocin levels than dose later born in the litter (Castrén et al., 1993b In: Algers and Uvnas-Moberg, 2007). Also low oxytocin levels may cause prolonged duration of farrowing in sows (Castrén et al., 1993b In: Algers and Uvnas-Moberg, 2007).

Carbetocin
Carbetocin is a synthetic octapeptide analogue of the hormone oxytocin (Barth et al., 1975 In: Hunter et al., 1975; Hunter et al., 1992; Schramme et al., 2008). Carbetocin has similar clinical and pharmacological properties to those of oxytocin (Su et al., 2012). Oxytocin and carbetocin bind with a similar affinity to the oxytocin receptors in the myometrium (Atke and Vilhardt, 1987). Binding results in an increased frequency of contractions and tonus of the uterus (Su et al., 2012). There are some structural differences reported between the molecules oxytocin and carbetocin (figure 1) (Schramme et al., 2008). The alterations mentioned in figure 1 give the molecule carbetocin more stability and avoid early decomposition (Schramme et al., 2008).

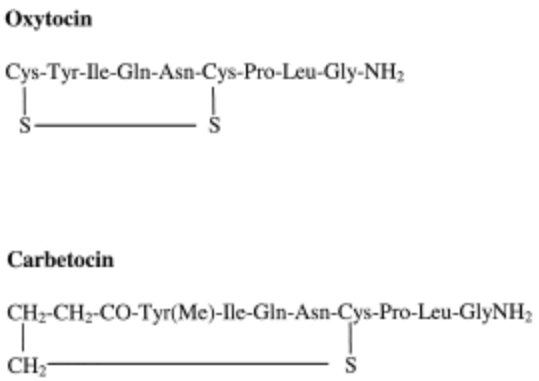

Figure 1 Structures of oxytocin and carbetocin (Hunter at al., 1992; Engstrøm et al., 1998)
The 1-6 disulfide bridge is replaced by a methylene group which protects carbetocin from the disulphidase cleavage and the N-terminal desamination protects carbetocin from the aminopeptidase cleavage (Hunter et al., 1992).

According to Knaggs (1967) the half-life of oxytocin is less than a minute when it is administered intravenously in sows. The half-live of carbetocin in sows is 85-100 minutes (Cort et al., 1981 In: Engstrom et al., 1998; Schramme et al., 2008). In food-producing animals the activity of carbetocin is 3 times longer in the uterus and the frequency of the contractions is 25% greater compared to the use of oxytocin (Schramme et al., 2008). Carbetocin has in vivo only one-tenth of the potency of oxytocin (Barth et al., 1975 and Cort et al., 1979, 1982 In: Hunter et al., 1992). The use of carbetocin in sows seems to accelerate the parturition by reducing the birth interval between the piglets (Cort et al.1979 In: Schramme et al., 2008). The prolonged activity of carbetocin is not only caused by the biological halve-life but lipophilic properties probably cause a longer half-life at the receptor (Atke and Vilhardt, 1987). Carbetocin might be a safe and more effective alternative to oxytocin (Kirkden et al., 2013); accelerates the parturition with possible better fetal outcomes (Hühn et al., 2004; Udluft, 2004 In: Scramme et al., 2008).

Carbetocin has a half-live of approximately 40 min in women when administrated intravenously (Sweeney et al., 1990 In: Rath, 2009 and Cordovani et al., 2012). This is approximately 10 times longer than de half-life of oxytocin reported in the research of Ryden and Sjoholm (1969). In humans carbetocin is indicated for prevention of uterine atony after delivery by caesarean section (Su et al., 2012). Oxytocin is currently the uterotonic drug of first choice and has proven to decrease the incidence of postpartum haemorrhage (PPH) in women (Holleboom et al., 2013). According to Boucher et al. (1998), a single injection carbetocin was as least as effective as a continuous infusion of oxytocin in preventing haemorrhage during caesarean section. Carbetocin is not approved by the Food and Drug Administration (FDA) for vaginal births in women (Su et al., 2012).
Carbetocin and oxytocin both have a rapid onset of action (Hunter et al., 1992). According to hunter et al. (1992), a single intramuscular injection of 10-70 µg carbetocin in women 24-48 h postpartum resulted in tetanic contraction in less than 2 minutes, lasting for 11 minutes and followed by rhytmic contractions for 119 minutes. Intramuscular administration of carbetocin has a prolonged uterine activity compared to intravenous carbetocin (119 vs. 60 minutes) (Hunter et al., 1992). The duration of uterine activity appears to be dose dependent (Hunter et al., 1992). Because of the long lasting effect, carbetocin can be administered as a single dose in woman rather than as a continuous intravenous infusion that is usually required for oxytocin (Cordovani et al., 2012). Only minimal side effects were reported when different doses of carbetocin were used intramuscular or intravenous in women (Hunter et al., 1992). Most patients experienced mild or moderate cramping in this research (Hunter et al., 1992).

Oxytocin is used to accelerate the parturition in sows but can have a negative influence on the number of stillborn piglets. It has been reported that carbetocin also accelerates parturition in sows. Other benefits of carbetocin are claimed; a longer duration of action and less potent with fewer adverse effects on the piglets. Although carbetocin is veterinary registered, a comparative study between the use of oxytocin and carbetocin on the duration of parturition has not been done before. The purpose of this research was to evaluate the use oxytocin and carbetocin in farrowing sows and its effect on the duration of parturition. Oxytocin and carbetocin were compared with a control group without treatment.

Two students have worked on this research project. The use of oxytocin and carbetocin in farrowing sows and its effect on the duration of parturition was evaluated in the present study. The effects on the vitality of the piglets were evaluated by another student and published elsewhere.

2. Materials & methods

2.1 Number of animals

This study is performed at two commercial swine farms from November 2012 to January 2013. Farm 1 is located in the central area and farm 2 in the east area of The Netherlands. Two students observed 75 births on farm 1 or 75 births on farm 2. Camborough 29 sows on farm 1 were fed three times daily with commercial lactation feed and had ad libitum access to water. Topic 30 sows on farm 2 were fed three times daily with commercial lactation liquid feed and had ad libitum access to water. Sows on both farms were moved into individual farrowing crates one week before the expected farrowing date and remained there until weaning. Approximately 100 sows littered on farm 1 in a three weeks schedule and 50 sows littered on farm 2 every week. Farm 2 induced delivery by injection of 1 ml (0,0875 mg) cloprostenol (Planate®, Essex Animal Health Friesoythe) into the vulva every Thursday morning to sows, that had not given birth at 116 days of gestation. Cloprostenol injected sows farrowing within 24 h were excluded from this experiment due to possible influence on the parturition process. Delivery on farm 1 was not induced. Sows with less than 8 live born piglets were also excluded from this experiment.

2.2 Procedures

Per farm sows were randomly arranged into three groups. So, in the end, each group included 50 sows. The oxytocin group received 1 ml (10 IU) oxytocin (Oxytocin®, Dechra) by intramuscular injection in the neck region, behind the base of the ear in the muscle mass between ear and shoulder, after the fourth piglet was born. The carbetocin group received 1 ml (0,07 mg) carbetocin (Longacton®, Dechra) by intramuscular injection in the neck region, as advised in leaflet of Dechra also after expulsion of the fourth piglet. The control group received no injection, but were only observed. The study was set up triple blinded, the observers nor the statistician knew the contents of the bottles.

During the farrowing process were observing sows and piglets minimal assisted. To minimise the number of stillborn piglets we used the guideline for vaginal palpation based on Randall, 1972b and Alonso-Spilsbury et al. (2004). The interval to perform a vaginal palpation was 45 minutes, almost three times the average found in the literature for birth interval (13.3-19.6 minutes, Randall 1972b; De Roth and Downie, 1976; Zaleski and Hacker, 1993; van Dijk et al., 2005; Mota-Rojas et al., 2005), or occasionally earlier when intrauterine piglets were thought to have serious distress; vaginal palpation was carried out when previously born piglets were not breathing, had a low heart rate and died after stimulation within several minutes. Piglets born inside the membranes and weak piglets were assisted in respiration when needed and in suckling after 60 minutes.

The study was approved by the Committee on Animal Experiments of Utrecht (DEC); registration number 2012.III.09.087.

2.3 Experimental design

In this study, 150 end of gestation sows were involved to observe parturition. Oxytocin and carbetocin solutions were injected after the birth of the fourth piglet in the neck region of sows. Directly after birth, weight and sex of piglets were determined. Subsequently live born piglets were wiped dry on their backs with tissues and a symbol for identifying individual piglets was painted on their back with brushes. After this procedure, piglets were placed back in the farrowing crates on the same place from where they were taken. At last permanent earmarks were given after the piglet had suckled for the first time or after 60 minutes.

2.3.1 Farrowing duration

To study the parturition, duration of farrowing (total expulsion time in minutes from the first piglet up to and including the last piglet) and birth interval between piglets (expulsion time in minutes between two born piglets) were collected. The exact time in minutes of each born piglet was noted on a protocol (Appendix I). Also parity, gestation length and litter size of each sow were recorded. In addition other variables of the piglets born were noted, head or breech presentation, sex, weight and aspect of the umbilical cord: rupture (broken), adhered different (included oedematous, hemorrhagic, knot in the umbilical cord) or adhered normal.

2.3.2. Live born and stillborn piglets

In this study each born piglet was registered whether they were born alive or dead. Stillbirths can influence the farrowing process (Randall, 1972b) and can be divided into two groups. Type I stillbirths contains death before parturition starts (pre-partum), often because of infectious causes (Randall and Penny, 1967; Sprecher et al., 1974). Type II stillbirths contains death during parturition (intra-partum) and is often caused by non-infectious causes for example anoxia and dystocia (Sprecher et al., 1974; Alonso-Spilsbury, 2004; Mota-Rojas, 2002). To classify stillbirth type I and stillbirth type II mortality criteria from Mota-Rojas et al. (2006) was used, based on previous studies by Randall and Penny (1967), Randall (1972b), Sprecher et al. (1974), Mota-Rojas et al. (2002, 2005b). Type I stillbirths have characteristic oedematous and hemorrhagic appearance and can be coloured gray or brown because of autolysis and beginning mummification (Mota-Rojas et al., 2006). Type II stillbirths can be recognized because they have a similar appearance as their normal littermates but without breathing and these pigs die of oxygen starvation during the parturition (Leman, 1985 In: Mota-Rojas et al., 2006). Type I stillbirths were only analyzed on time born and head or breech presentation if seen. Type II stillbirths were evaluated on time born, head or breech presentation, umbilical cord appearance, skin staining with meconium, sex and weight.

2.3.3 Sow behaviour

The behaviour of the sow during parturition was observed in this experiment. Urination, defecation and general behaviour of the sow (kicking with the legs towards the abdomen during the parturition and delivery speed of the individual piglets) was noted on the protocol. After the experiment was finished, behaviour was classified for further investigation. In the context of animal welfare according to the DEC, behaviour of the sows was included in this study to investigate whether there is a difference in behaviour between the different treatment groups.

2.4 Statistical analysis

For the investigation of the effect of treatment on the farrowing process we analysed three different outcome parameters: total farrowing duration (TFD), farrowing duration after the fourth piglet (FD4+) and 4 time intervals of farrowing duration. This involved the following intervals; farrowing duration (FD) interval 1 (time in minutes between the birth of piglet 1-4), farrowing duration (FD) interval 2 (piglet 5-8), farrowing duration (FD) interval 3 (piglet 9-12) or farrowing duration (FD) interval 4 (piglet 13 up to and including the last piglet). The total farrowing duration, farrowing duration after the fourth piglet and farrowing duration intervals were Ln transformed to normalise their distribution. Factors affecting the TFD, FD4+ and FD intervals were analysed with a General Linear Model (GLM) procedure; factorial (Univariate) ANOVA.

Next to treatment, the factors analysed were farm, length of gestation, parity, intervention (birth assistance), mean birth weight per litter, number of live born piglets, aspect of the umbilical cord per litter, number of breech positions (posterior presentation) per litter and type II stillborn piglets per litter. The factors were adapted, as can be seen in table 1. The adapted factors of the farrowing duration after piglet four (FD4+) and the four intervals of the farrowing duration are published in Appendix II.

In another analysis, the behaviour of the sows was investigated. The behaviour of the sows was grouped in the following categories; 0= quiet/calm behaviour and 1= restless behaviour. The data was analysed with a logistic regression.

Total Farrowing Duration (TFD)	
Farm	Farm was divided into two groups: 1 = Farm 1 2 = Farm 2
Treatment	Treatment was divided into three groups: 1 = carbetocin 2 = oxtocin 3 = control
Gestation (Gest_new)	Gestation was adapted to farm average for gestation length: 2,00 = mean gestation. Gestation length = average. 1,00 = > mean gestation. Gestation length was longer than the average. 0,00 = < mean gestation. Gestation length was shorter than the average.
Parity (Parity_new)	Parity was divided into three groups: 2,00 = 2-5 1,00 = ≥ 6 0,00 = 1
Intervention (Intervention_new)	Intervention was divided into three groups: 2,00 = no intervention. No birth assistance during farrowing was necessary. 1,00 = 1 intervention. One intervention means that there was birth assistance used for the birth of 1 piglet of a litter. 0,00 = ≥ 2 interventions. ≥ 2 intervention means that there was birth assistance used for the birth of 1 piglet of a litter.
Mean weight	Mean weight of a litter (litter = live born piglets + type II stillborn piglets).
Type II Stillbirths per litter (Type2Litter)	The amount of type II stillborn piglets per litter (litter = live born piglets + type II stillbirths).
Live Born Piglets (LBPtotal)	The amount of Live Born Piglets (LBP) of a sow per litter.
Normal umbilical cords per litter (Normal UC_new)	The amount of normal umbilical cord per litter (litter = live born piglets + type II stillborn piglets).The variable is expressed as a number between 0 and 1. For example; 0.35 of piglets born in a litter are born with an umbilical cord that a normal appearance.
Breech positions per litter (BreechLitter)	The amount of breech positions per litter (litter = live born piglets + type II stillborn piglets).The variable is expressed as a number between 0 and 1. For example; 0.35 of piglets born in a litter are born in a breech position.

Table 1 Factors used for analyzing the TFD

Based on the results of the analyses, non-significant variables (P>0.05) were excluded from the GLM-factorial (Univariate) ANOVA. After a stepwise elimination process the final models were generated. Because data originated from two different farm, the variable farm and treatment were forced in the analysis even if non-significant. The behaviour of the sows was analysed with a logistic regression and the same P-value was used for non-significant (P>0.05). The statistical analyses were performed with SPSS version 18.0; SPSS Inc. Released 2009. PASW Statistics for Windows, Version 18.0. Chicago: SPSS Inc.

3. Results

The descriptive statistics are presented in tables 2-7. Baseline tables of the variables between treatment groups and farms are presented in table 4 and 5. The results of the total farrowing duration (TFD), farrowing duration after the fourth piglet (FD4+), mean birth interval and farrowing duration intervals (FD interval 1, 2, 3 and 4) between treatment groups and farms are presented in table 6 and 7. The results of the mean birth intervals during parturition are presented in figures 2, 3 and 4.

	Total number of live born piglets	Total number of stillborn piglets	Type I stillborn piglets	Type II stillborn piglets
Overall	2121 (92,06%)	183 (7,94%)	41 (1,78%)	142 (6,16%)
Farm 1	1150 (91,65%)	96 (8,35%)	26 (2,26%)	70 (6,09%)
Farm 2	1154 (92,46%)	87 (7,54%)	15 (1,30%)	72 (6,24%)

Table 2 Born piglets

	Presentation of the live born piglets and type II stillborn piglets
Anterior	1381 (61.03%)
Posterior	670 (29.60%)
Unknown	212 (9.37%)

Table 3 Presentation of the piglets

Variable	Carbetocin		Oxytocin		Control		P
	Mean± SD	Range	Mean ± SD	Range	Mean ± SD	Range	
Total Duration of Farrowing	211,38± 96,370	74-500	215,54± 96,002	69-518	232,26± 98,277	75-578	0,523
Gestation length	115,66 ± 1.154	113-118	115,48 ± 1,182	113-118	115,90 ± 0,931	114-117	0,161
Parity	4,32± 2,094	1-9	4,52± 2,451	1-10	4,34± 2,370	1-11	0,893
Intervention (birth assistence)	1,2600± 2,23890	0-11	1,2000± 2,02031	0-10	1,0200± 1,49134	0-6	0,813
Mean Weight	1300,6771± 260,60003	841,18 - 2074,00	1312,1766± 192,64417	880,39 - 1670,67	1316,7075± 188,27541	905,07 - 1907,50	0,930
Litter size	15,26± 3,269	8-25	15,02± 3,236	9-22	14,98± 3,133	8-23	0,895
Total number of Life Born Piglets (LBP)	14,02± 3,087	8-23	14,20± 2,828	9-20	14,20± 2,695	8-19	0,937
Type II stillbirths per Litter	,0748± 0,10207	,00 - ,42	,0493± ,06719	,00 - ,23	,0459± ,07109	,00 - ,31	0,156
Breech positions per Litter	0,2944± ,11650	,06 - ,53	,2982± ,16747	,00 - ,75	,2894± ,14549	,00 - ,69	0,955
Normal umbilical cords per Litter	,7658± ,17144	,27 – 1,00	,7876± ,14764	,41 – 1,00	,8163± ,13091	,50 – 1,00	0,240

Table 4 Differences in variables between treatment groups

Variable	Overall		Farm 1		Farm 2		P
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD		
Total Duration of Parturition	219,73 ± 96,661	69-578	202,61± 88,785	69-578	236,84± 101,668	74-518	0,030
Gestation length	115,68± 1,101	113-118	115,08 ± ,926	113-117	116,28 ± ,924	114-118	0,000
Parity	4,39± 2,296	1-11	4,40 ± 1,945	1-10	4,39 ± 2,614	1-11	0,972
Intervention (birth assistence)	1,1600± 1,93200	0-11	,7867 ± 1,54477	0-10	1,5333 ± 2,20156	0-11	0,017
Mean Weight	1309,8537± 215,03779	841,18-2074,00	1314,8797 ± 211,09127	898,30 - 2074,00	1304,8277 ± 220,21956	841,18 - 2014,75	0,776
Litter size	15,09± 3,194	8-25	14,99± 2,859	9-23	15,19± 3,513	8-25	0,703
Total number of Life Born Piglets (LBP)	14,14± 2,857	8-23	14,05± 2,487	9-20	14,23± 3,199	8-23	0,712
Type II stillbirths per Litter	,0567± ,08210	,00-,42	,0572± ,07169	,00-,35	,0561± ,09183	,00-,42	0,939
Breech positions per Litter	,2940± ,14374	,00-,75	,2850± ,14468	,00-,55	,3030± ,14319	,00-,75	0,443
Normal umbilical cords per Litter	,7899± ,14959	,27-1,00	,7695± ,16683	,27-1,00	,8104± ,12797	,50-1,00	0,094

Table 5 Differences in variables between farms

Variable	Carbetocin		Oxytocin		Control	
	Mean± SD	Range	Mean ± SD	Range	Mean ± SD	Range
Total Duration of Farrowing	211,38± 96,370	74-500	215,54± 96,002	69-518	232,26± 98,277	75-578
Duration of farrowing after the fourth piglet (FD4+)	134,70± 74,999	40-390	138,62± 67,920	46-319	159,88± 86,251	54-524
Mean birth interval between piglets	14,8868 ± 5,84147	4,89-35,71	15,6329 ± 6,16943	6,90-32,69	17,2021 ± 7,79534	6,25-44,46
FD interval 1 (piglet 1-4)	25,8467± 17,19505	2,33-66,33	26,4167± 19,07380	3,33-107,33	24,8067± 13,51045	5,33-72,33
FD interval 2 (piglet 5-8)	12,4550± 8,29659	2,75-42,00	10,9600± 6,96096	2,50-36,50	13,3250± 6,65633	2,25-30,50
FD interval 3 (piglet 9-12)	10,9796± 8,89396	1,75-43,00	10,8367± 7,51695	1,75-31,00	14,5391± 12,00328	1,75-49,67
FD interval 4 (piglet ≥ 13)	13,8436± 10,84339	1,50-49,00	18,0007± 11,71669	4,25-47,00	19,0280± 26,92623	,00-152,50

Table 6 Results in TFD, FD4+ and FD intervals between treatment groups

Variable	Overall		Farm 1		Farm 2	
	Mean± SD	Range	Mean ± SD	Range	Mean ± SD	Range
TFD	219,73 ± 96,661	69-578	202,61± 88,785	69-578	236,84± 101,668	74-518
FD4+	144,40± 77,049	40-524	129,36± 73,008	46-524	159,44± 78,515	40-390
Mean birth interval	15,9073 ± 6,68280	4,89-44,46	14,7824 ± 6,31682	4,89-44,46	17,0321 ± 6,88885	6,25-38,60
FD interval 1 (piglet 1-4)	25,6900 ± 16,65384	2,33-107,33	25,4044 ± 16,75952	2,33-107,33	25,9756 ± 16,65539	3,33-74,67
○ **Carbetocin**	25,8467 ±17,19505	2,33-66,33	27,3333 ± 17,50661	2,33-60,00	24,3600 ± 17,10478	5,33-66,33
○ **Oxytocin**	26,4167 ±19,07380	3,33-107,33	27,2267 ± 20,77341	6,33-107,33	25,6067 ± 17,60332	3,33-74,67
○ **Control**	24,8067 ±13,51045	5,33-72,33	21,6533 ± 10,29776	5,67-44,00	27,9600 ± 15,68153	5,33-72,33
FD interval 2 (piglet 5-8)	12,2467 ± 7,35543	2,25-42,00	11,7633 ± 6,35983	3,00-36,50	12,7300 ± 8,24711	2,25-42,00
○ **Carbetocin**	12,4550 ±8,29659	2,75-42,00	12,5400 ± 6,66368	4,50-31,00	12,3700 ± 9,80384	2,75-42,00
○ **Oxytocin**	10,9600 ±6,96096	2,50-36,50	10,2700 ± 6,69807	3,00-36,50	11,6500 ± 7,28512	2,50-28,50
○ **Control**	13,3250 ±6,65633	2,25-30,50	12,4800 ± 5,65313	5,25-24,75	14,1700 ± 7,55077	2,25-30,50
FD interval 3 (piglet 9-12)	12,1098 ± 9,72906	1,75-49,67	11,2122 ± 8,45051	1,75-43,50	13,0320 ± 10,87001	1,75-49,67
○ **Carbetocin**	10,9796 ±8,89396	1,75-43,00	9,8967 ± 6,46542	1,75-24,50	12,1076 ± 10,90239	3,25-43,00
○ **Oxytocin**	10,8367 ±7,51695	1,75-31,00	10,6633 ± 8,68106	2,50-31,00	11,0100 ± 6,31981	1,75-26,00
○ **Control**	14,5391 ±12,00328	1,15-49,67	13,0767 ± 9,86327	3,50-43,50	16,0625 ± 13,94367	1,75-49,67
FD interval 4 (piglet ≥ 13)	17,0174 ± 18,29143	0,00-152,50	15,7928 ± 22,01411	0,00-152,50	18,3042 ± 13,38850	0,00-63,60
○ **Carbetocin**	13,8436 ±10,84339	1,50-49,00	11,2774 ± 7,13107	1,50-31,25	16,5448 ± 13,39875	1,80-49,00
○ **Oxytocin**	18,00 ±11,71669	4,25-47,00	14,9325 ± 10,65057	5,00-41,00	21,0689 ± 12,18745	4,25-47,00
○ **Control**	19,0280 ±26,92623	0,00-152,50	20,6799 ± 34,84142	,00-152,50	17,2110 ± 14,70306	0,00-63,60

Table 7 Results in TFD, FD4+ and FD intervals between farms

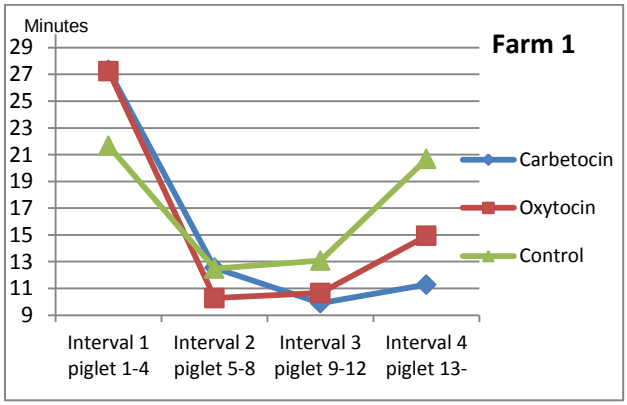

Figure 2 Results of the mean birth intervals during parturition; Farm 1.

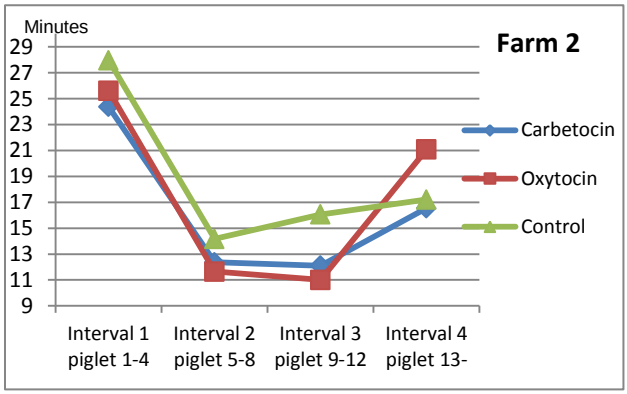

Figure 3 Results of the mean birth intervals during parturition; Farm 2.

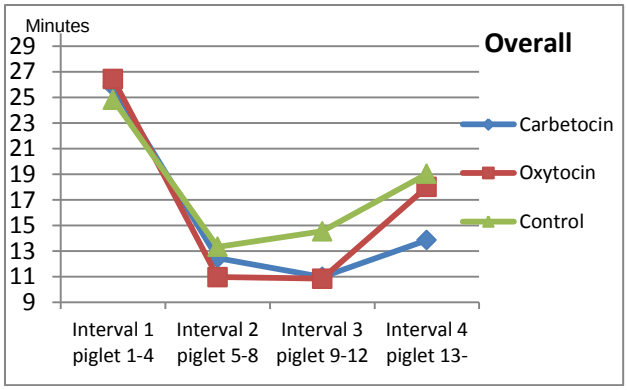

Figure 4 Results of the mean birth intervals during parturition; Overall.

3.1 Total Farrowing Duration (TFD)

The non-significant variables (P>0.05) were excluded from the General Linear Model (GLM)-factorial ANOVA after stepwise elimination and are reported in table 8.

Variables	TFD
	P
Intervention (birth assistance)* Treatment	0.837
Intervention * Farm	0.765
Farm * Parity	0.446
Farm * Treatment	0.694
Gestation * Parity	0.420
Parity * Treatment	0.375
Intervention * Parity	0.208
Gestation * Treatment	0.546
Normal umbilical cords per litter	0.532
Parity	0.332
Breech positions per litter	0.206
Gestation * Farm	0.063
Weight	0.107
Type II stillbirths per litter	0.134
Treatment	***0.157***

Table 8 GLM-factorial TFD

In the GLM-factorial ANOVA treatment and farm were not significant (Appendix III). There were no differences found between the different treatment groups and treatment had no influence on the total duration of farrowing (P>0.05). Farm had also no influence on the total duration of farrowing (P>0.05). Several factors were significantly affecting the farrowing process and are reported in Appendix III. The number of live born piglets influenced the TFD; more live born piglets resulted in a longer duration of farrowing (P<0.05). 1 or ≥ 2 interventions during the farrowing process prolonged the total duration of farrowing (P<0.05 and figure 5). According the results, a prolonged gestation had a negative influence on the farrowing process and resulted in a prolonged duration of farrowing (P<0.05). After re-parameterisation, it was clear in the results that the interaction between gestation length and intervention had a negative effect on the duration of farrowing (P<0.05). A shorter and prolonged gestation in combination with more interventions resulted in a prolonged duration of the farrowing.

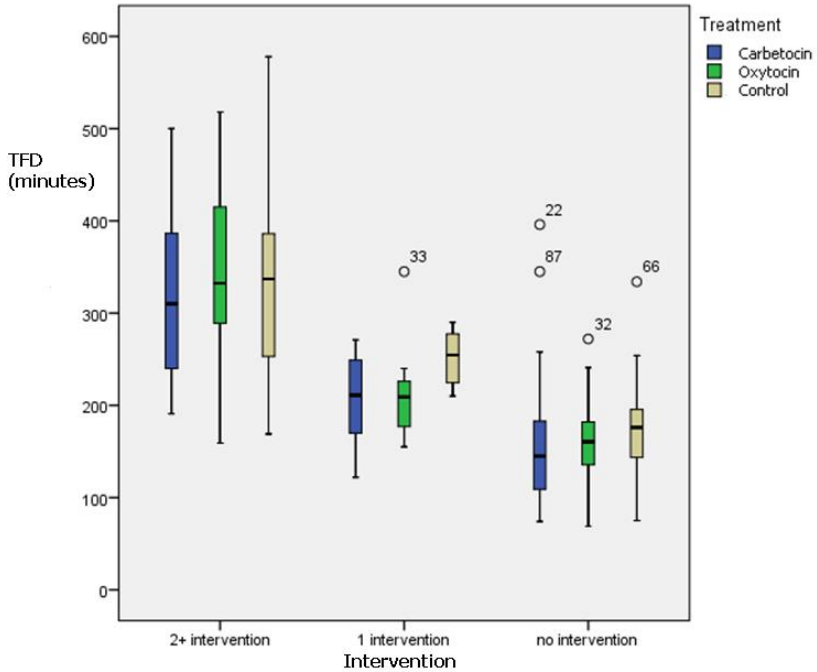

Figure 5 Total Farrowing Duration vs. Amount of intervention (birth assistance)

3.2 Farrowing Duration after the fourth piglet (FD4+)

The non-significant variables (P>0.05) were excluded from the GLM-factorial ANOVA after stepwise elimination and are reported in table 9.

Variables	FD4+
	P
Treatment * Intervention (birth assistance)	0.854
Farm * Treatment	0.951
Treatment * Parity	0.472
Gestation * Parity	0.953
Farm * Parity	0.635
Treatment * Gestation	0.301
Farm * Gestation	0.157
Weight	0.889
Farm * Intervention	0.354
Gestation * Intervention	0.353
Parity * Intervention	0.225
Parity	0.524
Gestation	0.250
Farrowing Duration part1	0.101
Normal umbilical cords per litter after treatment	0.107
Breech positions per litter after treatment	0.051
Treatment	***0.061***

Table 9 GLM-factorial FD4+

In the GLM-factorial ANOVA treatment and farm were not significant (Appendix IV). There were no differences found between the different treatment groups and treatment had no influence on the duration of farrowing after the fourth piglet (P>0.05). Farm had also no influence on the FD4+ (P>0.05). Several factors were significantly affecting the farrowing process and are reported in Appendix IV. The number of live born piglets influenced the duration of farrowing after the fourth piglet; more live born piglets resulted in a longer duration of farrowing (P<0.05). 1 or ≥ 2 interventions during the farrowing process resulted in a prolonged duration of the farrowing after the fourth piglet (P<0.05 and figure 6). The factor type II stillborn piglets per litter resulted in a prolonged duration of the farrowing after the fourth piglet (P<0.05).

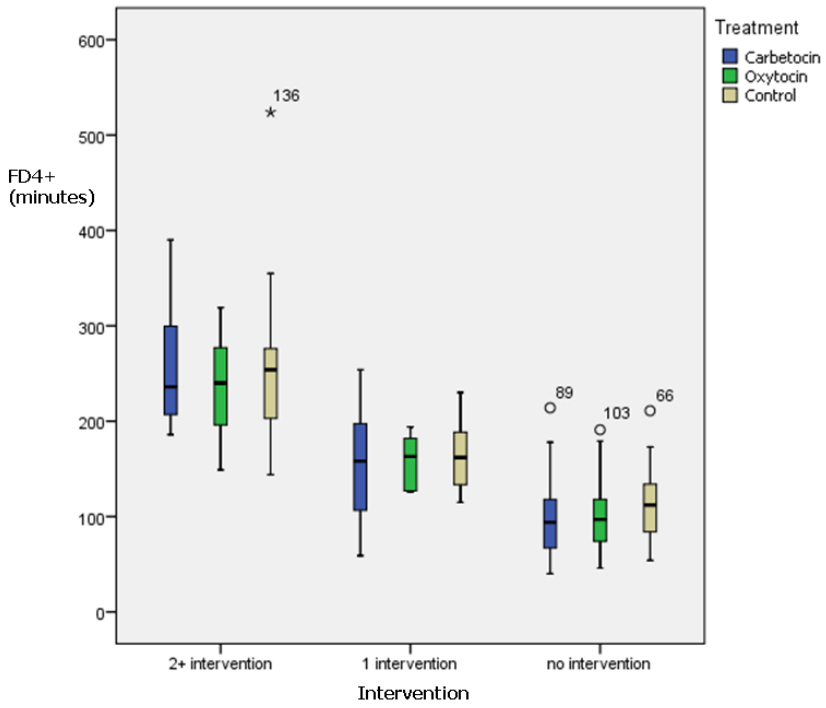

Figure 6 Farrowing Duration after the fourth piglet vs. Amount of intervention (birth assistance)

3.3 Farrowing Duration (FD) intervals

The non-significant variables (P>0.05) were excluded from the GLM-factorial ANOVA after stepwise elimination and were reported in table 10.

Variables	FD interval 1		Variables	FD interval 2		Variables	FD interval 3		Variables	FD interval 4
	P			**P**			**P**			**P**
Gestation * Parity	0.947		Farm * Parity	0.928		Farm * Treatment	0.968		Type II stillbirths per litter	0.977
Treatment * Intervention in interval 1	0.887		Normal umbilical cords per litter	0.879		Treatment * Intervention in interval 3	0.920		Gestation * Intervention in interval 4	0.909
Farm * Treatment	0.868		Farm * Gestation	0.851		Parity * Intervention in interval 3	0.946		Gestation * Parity	0.957
Farm * Intervention in interval 1	0.565		Gestation * Intervention in interval 2	0.552		Farm * Parity	0.627		Treatment * Intervention in interval 4	0.852
Type II stillbirths per litter	0.758		Type II stillbirths per litter	0.832		Treatment * Gestation	0.538		Farm * Gestation	0.256
Treatment * Gestation	0.677		Gestation * Parity	0.645		Breech positions per litter	0.737		Normal umbilical cords per litter	0.968
Gestation * Intervention in interval 1	0.690		Treatment * Gestation	0.163		Treatment * Parity	0.319		Treatment * Gestation	0.164
Breech positions per litter	0.704		Gestation	0.637		Farm * Intervention in interval 3	0.631		Gestation	0.642
Live born piglets per litter	0.453		Parity * Intervention in interval 2	0.455		Gestation * Intervention in interval 3	0.580		Treatment * Parity	0.394
Farm * Parity	0.247		Treatment * Parity	0.071		Farm * Gestation	0.210		Part3 Farrowing Duration	0.455
Farm * Gestation	0.325		Farm * Treatment	0.637		Weight	0.725		Farm * Intervention in interval 4	0.222
Normal umbilical cords per litter	0.361		Treatment * Intervention in interval 1	0.414		Part2 Farrowing Duration	0.544		Farm * Parity	0.059
Treatment * Parity	0.114		Parity	0.638		Gestation * Parity	0.317		Farm * Treatment	0.143
Parity * Intervention in interval 1	0.227		Farm * Intervention in interval 1	0.567		Gestation	0.556		Breech positions per litter	0.116
Parity	0.825		Live born piglets per litter	0.212		Parity	0.135		***Treatment***	***0.006 included***
Weight	0.082		Breech positions per litter	0.168		***Treatment***	***0.392***			
Treatment	***0.055***		Part1 Farrowing Duration	0.059						
			Treatment	***0.215***						

Table 10 GLM-factorial Farrowing Duration interval 1, 2, 3 and 4

Farrowing Duration (FD) interval 1

In the GLM-factorial ANOVA treatment and farm were not significant (Appendix V). There were no differences found between the different treatment groups and treatment had no influence on the duration of farrowing in interval 1 (P>0.05). Farm had also no influence on the farrowing process (P>0.05).

Several factors were significantly affecting the farrowing process and are reported in Appendix V. Gestation was significant this model but between the gestation groups were no differences found on the duration of farrowing (P<0.05). 1 or ≥ 2 interventions during the farrowing process resulted in a prolonged duration of the farrowing (P<0.05).

Farrowing Duration (FD) interval 2

In the GLM-factorial ANOVA treatment and farm were not significant (Appendix V). There were no differences found between the different treatment groups and treatment had no influence on the duration of farrowing in interval 2 (P>0.05). Farm had also no influence on the duration of farrowing (P>0.05). Several factors were significantly affecting the farrowing process and are reported in Appendix V. 1 or ≥ 2 interventions during the farrowing process resulted in a prolonged duration of the farrowing (P<0.05). Although the factor weight was significant in this model (P<0.05), according to the results it was not clinically relevant (Appendix V).

Farrowing Duration (FD) interval 3

In the GLM-factorial ANOVA treatment and farm were not significant (Appendix V). There were no differences found between the different treatment groups and treatment had no influence on the farrowing duration in interval 3 (P>0.05). Farm had also no influence on the duration of farrowing (P>0.05). Several factors were significantly affecting the farrowing process and are reported in Appendix V. 1 or ≥ 2 interventions during the farrowing process resulted in a prolonged duration of the farrowing (P<0.05). The factor normal umbilical cords per litter resulted in a prolonged duration of the farrowing (P<0.05). According the results, the factor type II stillborn piglets per litter and live born piglets resulted in a reduced duration of farrowing (P<0.05).

Farrowing Duration (FD) interval 4

In the GLM-factorial ANOVA farm was not significant (P>0.05) and had no influence on the duration of farrowing in interval 4 (Appendix V).

Several factors were significantly affecting the farrowing process and are reported in Appendix V. Treatment was included in this model (treatment P=0.006). The difference in the duration of farrowing between the carbetocin and control group was not significant (P>0.05). Treatment with oxytocin was significant compared to the control group; oxytocin prolonged the last part of the farrowing process (interval 4) in sows with litters larger than 12 piglets (P<0.05).

1 or ≥ 2 interventions during the farrowing process resulted in a prolonged duration of the farrowing (P<0.05). According the results, the factor type II stillborn piglets per litter resulted in a prolonged duration of the farrowing (P<0.05). Although the factor weight was significant in this model (P<0.05), according the results it was not clinically relevant. The factor live born piglets resulted in a reduced duration of farrowing (P<0.05). To interpret the interaction between parity and intervention, re-parameterisation of the results was necessary. The interaction parity ≥ 6 * intervention ≥ 2 was significant and resulted in a reduced duration of farrowing (P<0.05). In this model, the coincidence increases because the effect of the individual sows becomes larger at the end of the farrowing process (table 11).

	FD interval 1	FD interval 2	FD interval 3	FD interval 4
Frequencies	Carbetocin 50 Oxytocin 50 Control 50	Carbetocin 50 Oxytocin 50 Control 50	Carbetocin 49 Oxytocin 50 Control 49	Carbetocin 39 Oxytocin 40 Control 42

Table 11 Frequencies of sows

Prior to the analysis of the models in this study, mean birth intervals were published in figures 2-4. The factor farm was not significant in all used analyses. Because there were no differences found between the farms, figure 4 represents the most accurate image of the mean birth intervals during parturition.

3.4 Sow behaviour

Prior to treatment 32% of the sows were restless compared to 16% after treatment (table 12). There was no relation found between the behaviour of the sow and treatment (treatment P=0.359) (Appendix VI). If the behaviour of the sows before treatment was restless, it was almost four times more likely that sows were restless after treatment regardless of the type of treatment they received during the farrowing process (odds ratio = 3.788) (Appendix VI).

Behaviour	Quiet/calm	Restless
Before treatment	102	48
After treatment	126	24

Table 12 Sow Behaviour

4. Discussion

The mean gestation length of 115 days on Farm 1 and 116 days on Farm 2 were in range with the mean values reported in recent literature (van Dijk et al., 2005; Vanderhaeghe et al., 2010; Oliviero et al., 2010). The differences found between the gestation length on the two farms was significant. In this study the gestation length was adapted for each farm prior to the analysis of the statistical models. A possible explanation might be due to the fact there is a 24 hour waiting period after the injection with cloprostenol to a portion of the sows which ultimately can prolong the mean gestation length on farm 2.

In this research the total stillbirth rate is 7.94% and is in range with findings in the literature, range from 5-8% (Friend et al., 1962; Randall, 1972a,b; Zaleski and Hacker, 1993; Herpin et al., 1996; Trujillo-Ortega et al., 2007). When the total stillbirth rate is further divided, we found 6.16% were stillborn piglets type II and 1.78% stillborn piglets type I. The values found in this research are more or less consistent with the values published by Hacker and Zaleski (1993); 7.8% type II and 1.2% type I stillbirths.

The mean duration of farrowing in the control group (232.26 minutes) and mean birth interval (17.92 minutes) were in the range with values reported in the literature. The mean duration of farrowing varies between 156-316 minutes for normal farrowings or control groups in previous research (156 min. Randall, 1972a; 186 min. De Roth and Downie, 1976; 288 min. Fahmy and Friend, 1981; 316 min. Mota-Rojas et al., 2002; 240 min. Alonso-Spilsbury et al., 2004; 166 min. van Dijk et al., 2005; 194 min. Mota-Rojas et al., 2005a; 209 min. Mota-Rojas et al., 2005b; 301 min. Oliviero et al., 2010 316 min. Mota-Rojas et al., 2002). The mean birth interval between piglets varies between 13.3-19.6 minutes (13.3 min. Randall 1972b; 16 min. De Roth and Downie, 1976; 15.3 min. Zaleski and Hacker, 1993; 15.7 min. van Dijk et al., 2005; 19.6 min. Mota-Rojas et al., 2005; 18 min. Mota-Rojas et al., 2007). The mean duration of farrowing was respectively 211.38 minutes for the carbetocin group and 215.54 minutes for the oxytocin group. The mean birth interval of the carbetocin group was 15.81 minutes and was 16.56 minutes for the oxytocin group. These values for mean duration of farrowing and average birth interval found in this study were also within the literature values.

Experimental design

In this study, according figure 2,3, 4 and table 8, the mean birth interval was prolonged at the beginning (piglet 1-4) and at the end of the farrowing process (piglet 13 until the last piglet). Also piglets born in the middle rank of the litter were born with the shortest mean birth interval. This was in accordance with previous found literature (Randall, 1972a; Stanton et al., 1973; van Dijk et al., 2005). The short birth intervals might be caused by a tremendous rise of oxytocin under expulsion of the piglets (Ellendorff et al., 1979) due to a positive feedback reflex release of oxytocin. Towards the end of the farrowing process, birth intervals between piglets start to rise and this might be the moment to interfere by administering a drug to stimulate contractions of the uterus. According to our results it might be better to use oxytocin and carbetocin after piglet eight because the mean litter size was 14-15 live born piglets in this study. This suggestion was also supported by research of van Dijk et al., (2005) and Mota-Rojas et al., (2007). According to Mota-Rojas et al (2007) it is likely that oxytocin administered in a later phase of parturition sufficiently stimulates the uterus even when the muscles were fatigue.

In this research 10 IU of oxytocin was administrated intramuscular after the delivery of the fourth piglet, this was well within the dose mentioned by Mota-Rojas et al., (2002b and 2007); 0.083 IU/kg. 20 IU of oxytocin was more in line with the research of Mota-Rojas et al. (2002) and Alonso-Spilsbury et al. (2004) but they used a more weight-dependent administration of oxytocin; range 20-50 IU. The

leaflet of Dechra advised to use 2-4 ml for a sow; this corresponds to 20-40 IU oxytocin per animal. The lower dose of 10 IU oxytocin per sow used in this experiment might have influenced the results. Sows were administered 0.07 mg carbetocin intramuscularly; the recommended dosage for acceleration of parturition according to the leaflet of Dechra. According to Anon (1996) the action of 1 mg carbetocin is equivalent to 50 IU oxytocin; the used dose of 0.07 mg carbetocin was equivalent to 3.5 IU oxytocin (Anon, 1996 In: Schramme et al.,2008). The differences in the dosage between the used drugs in this research might have influenced the results.

The 45 minutes guideline for vaginal palpation was not always achievable. Sometimes researchers could not feel a piglet in birth canal and the sow was checked later again which eventually prolonged the farrowing process. On the other hand vaginal palpation could have influenced the farrowing process due to pressure in the pelvis which can cause the release of oxytocin. It has been generally accepted that peripheral stimuli such as stretching of the cervix, stimulation of the vagina and nipple causes a release in oxytocin which stimulates contractions by neurohumeral reflex. The presence of a reflex secretion of oxytocin after vaginal and cervical dilatation was first described by Ferguson (1941).

In this study was decided to follow four parturitions at the same time and to continue under certain conditions. Occasionally head or breech position was missed during parturition, because it was not easy to follow multiple sows at the same time. The time of the birth of these piglets was still listed and there was a note made on the protocol that the birth position of the piglet was unknown. Other parameters were usually still to interpret when head or breech position was missed. Sometimes more piglets were born in several minutes and the weight of the piglets was determined at a later time during the parturition but piglets were always marked for identification. Due to this guideline and the intensive monitoring of the farrowing process, there was virtually no data missed from individual piglets and for this reason it was not necessary to exclude sows from this study.

Occasionally problems with aggression and biting towards the piglets were seen in mainly first parity sows. This might be related to distress during the parturition and the painful experience of uterine contractions during the delivery of the piglets. According to Randall (1972a) this behaviour ceased once one or two piglets found the teat and suckling started. The piglets of aggressive sows in this research were kept in a warm box with sawdust until the parturition was finished and slowly introduced with their mother. It was not necessary to remove sows from this study.

On farm 2, a portion of the sows were induced with cloprostenol to synchronise the moment of farrowing. Cloprostenol is an prostaglandine F2α (PGF2α) analogue and is used in sows for the induction of farrowing. More than 80% of the sows will farrow within 36 h after an intramuscular injection given at 112-114 days of gestation (Hammond and Matty, 1980, Holtz et bal., 1983, Guthrie, 1985 In: Kaeoket, 2006). The luteolytic effect of PGF2α can terminate pregnancy during the progesterone phase by inducing uterine contractions (Wenkoff, 1975). Because of the direct effects of PGF2α, there was decided to incorporate a 24 h waiting period. Whether this induction influenced the duration of farrowing has not been researched yet in this study. According to most studies, there was no effect of prostaglandins on duration of farrowing reported (Černe, 1978; Jainudeen and Brandenburg, 1980; Martin et al., 1985; Kaeoket, 2006). Occasionally a longer duration of farrowing was reported when prostaglandins were used for induction (Smith et al., 1982).

All Models (GLM-factorial ANOVAs)
In the models TFD, TFD4+ and FD intervals, the factors; farm, intervention, parity, mean birth weight and breech position had a similar outcome and were discussed here.

During the procedure farm (environment, management and breed differences) was excluded from all models for farrowing duration. This was entirely in line with expectations, there were no significant differences found between the two farms.

1 or ≥2 intervention(s) clearly prolonged the duration of farrowing in this research study and was a bit expected because intervention (birth assistance) was given when farrowing problems occur. According to Holm et al. (2004) the duration of farrowing and the need for birth assistance are highly correlated. Previous studies demonstrated that supervising the farrowing process can reduce the amount of stillborn piglets (White et al., 1996; Le Cozler et al., 2002). Other researchers reported a positive association between vaginal palpation during parturition and stillborn piglets (Holm et al., 2004; Canario et al., 2006a; VanderHaeghe et al., 2010). However it remains unclear in this study if intervention is a causative factor for stillborn piglets and this should be further investigated.

The classification for the factor parity was based on our research results and previous literature of van Dijk et al. (2005), Oliviero et al. (2010) and Vanderhaeghe et al. (2010). Parity of the sow had no effect on the duration of farrowing in all models. This was in accordance with findings by Fahmy and Friend (1981), van Dijk et al. (2005), but in contrast with other researchers (Pejsak, 1984; Cutler et al., 1992). They found that an increasing parity gradually prolonged the duration of farrowing due to changes in the reproduction tract of older sows.

Mean birth weight had no clinical relevance on duration of farrowing in all the models. In the literature there were no references found about a relation between mean birth weight and farrowing duration or the birth interval between piglets. Literature only described the relation between birth weight and stillbirth (Quiniou et al., 2002; Canario et al., 2006). The relation between individual birth weight of the piglets and birth interval has not been researched.

Breech position (amount of breech positions per litter) had no effect on the duration of farrowing in all models. This was in accordance with findings published by van Dijk et al. (2005). Randall (1972a) also mentioned that the presentation of the piglet had no obvious influence on the farrowing process. In previous literature, birth presentation was described; 36% of the piglets were born with a posterior presentation (Dziuk and Harmon, 1969), 44.6% had a posterior presentation (Randall, 1972a) and 43% had a posterior presentation in the research of van Dijk (2005). In this research study less piglets had a posterior (breech) presentation (29.60%) and 9.37% of the piglets were born with an unknown position. According to van Dijk et al. (2005) the number of posterior presentations in a litter did not affect the duration of farrowing because anterior and posterior presentations are more or less equally divided. At individual pig level posteriorly presented piglets were born after longer birth intervals than anteriorly presented littermates (van Dijk et al., 2005). Whether individual piglets with a posterior presentation were born with a significant longer birth interval has not been researched in this study.

Total Farrowing Duration (TFD)

The factor treatment in this model was not significant; between the treatment groups (Oxytocin, Carbetocin or Control) no differences were found on the duration of farrowing.

The number of live born piglets was significant; more live born piglets resulted in a longer duration of farrowing. According to the literature, larger litters were related to longer duration of farrowing (Friend et al., 1962; De Roth and Downie, 1976). Fahmy and Friend (1981) also found that the farrowing time was less in smaller litters than in larger litters. A linear relationship between the duration of farrowing and the number of piglets born was found; each additional piglet in the litter required 10.4 minutes increase in duration of farrowing (Fahmy and Friend, 1981).

A shorter or longer gestation time prolonged the duration of farrowing in this study. In the literature was only found that a longer gestation time prolonged the duration of farrowing (Friend et al., 1962;

Fahmy and Friend, 1981). According to Fahmy and friend (1981), there was calculated that each day of delay can expect an increase of 15 min in duration of farrowing.

Farrowing Duration after the fourth piglet (FD4+)
In this model treatment was also not significant; between the treatment groups (Oxytocin, Carbetocin or Control) no differences were found on the duration of farrowing.
The factor live born piglets significantly prolonged the farrowing process and this factor was explained earlier in the TFD model.
The amount of type II stillborn piglets per litter influenced the farrowing process negatively. Previous studies also reported an association between stillbirths and duration of farrowing (Friend et al., 1962; Randall, 1972b; van Dijk et al., 2005; Canario et al., 2006a). According Friend et al. (1962) and Randall (1972b) the stillbirth rate was higher in prolonged farrowings. Also Randall (1972b) reported that stillborn type II piglets were born after a longer birth interval compared to live born littermates. According to van Dijk et al. (2005) the duration of farrowing increased with an increasing number of stillborn piglets per litter. It remains unclear whether the prolonged duration of farrowing is the causative factor or the result of piglet mortality. Prolonged birth interval is responsible for the dead of the piglet; intrapartum deaths are a result of anoxia experienced during parturition (Randall, 1972a,b;). An explanation for a prolonged birth interval according van Dijk et al. (2005) is that a dead piglet cannot participate with its movements to enter the birth canal correctly and subsequent delivery. From the literature it is known that piglets actively participate in the birth process by frequently turning prior to the expulsion (Taverne et al., 1977 In: Ellendorff et al., 1979). The relation between individual birth interval of the piglets and type II stillbirths has not been researched in this study. In future studies this should be further investigated.
The farrowing time between the first and fourth piglet was excluded from this model, it means that there were no differences observed between the different treatment groups. This implies that all groups were equal before the treatment was applied.

Farrowing Duration (FD) interval 1 and 2
In both models treatment was not significant; between the treatment groups (Oxytocin, Carbetocin or Control) no differences were found on the duration of farrowing.
In model FD interval 2 farrowing time between the first and fourth piglet was not significant. This also implies that all groups were equal on duration of farrowing before the treatment was applied.

Farrowing Duration (FD) interval 3
In this model treatment was also not significant; between the treatment groups (Oxytocin, Carbetocin or Control) no differences were found on the duration of farrowing.
The farrowing time between the first and eight piglet was not significant and all treatment groups were equal on duration of farrowing.
The amount of normal umbilical cords per litter was significant and prolonged the duration of farrowing. In the literature there were no references found about the duration of farrowing in combination with umbilical cord appearance. Although previous literature reported negative side effects on umbilical cords after treatment with oxytocin (Alonso-Spilsbury et al., 2004; Rota-Mojas et al., 2002, 2006), it is yet unknown in this study whether there are negative side effects on the umbilical cord at individual piglet level and therefore is further investigation required.
In this model, the amount of type II stillborn piglets per litter and live born piglets resulted in a reduced duration of farrowing. It is possible that there was a kind of three-way interaction with intervention, because intervention provides live born and dead piglets and so consequently reducing the duration of farrowing.

Farrowing Duration (FD) interval 4
In the last model treatment was significant. There were no differences found between the carbetocin and control group on the duration of farrowing. Treatment with oxytocin was significant compared to the control group; oxytocin prolonged the last part of the farrowing process in sows with large litters (more than 12 piglets). Possible explanation might be that the short acting and potent effect of oxytocin caused saturation of myometrial receptors by large concentrations of oxytocin after the fourth piglet and this ultimately disrupts the last part of the farrowing process (Dial et al., 1987 In: Lundin-Schiller et al., 1996). Myometrial receptor loss was mentioned as a cause of decreased uterine contraction response because high doses of oxytocin might decrease its receptor concentration (down-regulation) with its effect dependent on the dose and duration of treatment (Bossmar et al., 1994 In: Zeeman et al., 1997; Adachi and Oku, 1995 In: Zeeman et al., 1997; Mota-Rojas et al., 2006). According to Pejsak (1984) the uterine reactivity of oxytocin gradually decreases as parturition progresses.

The amount of stillborn piglets type II per litter prolonged the farrowing process significantly and was explained earlier in model FD4+.
In this model the amount of live born piglets reduced the duration of farrowing. It is possible that in the last part of the farrowing process a kind of interaction was created with intervention. Intervention shortens the birth interval between piglets immediately and ensures the birth of live born piglets. In previous literature no references were found on this subject.
The interaction between intervention ≥ 2 * parity ≥ 6 significantly reduced the duration of farrowing. Earlier was mentioned that parity was not significant in all used models. The influence of the individual sows on the farrowing process in FD interval 4 was increased, caused by the current division into intervals. A possible explanation is yet unknown because the factor ≥ 2 interventions (birth assistance) on its own resulted in a prolonged duration of farrowing.

Sow behaviour
There were differences found between the treatment groups on the behaviour of the sows during the farrowing process and so treatment did not affect the welfare of the sows during this study. First the behaviour was recorded by collecting objective observations; urinating, defecating before and after treatment. Because the lack of these observations, the behaviour of each sow during farrowing process was described by the amount of stress. The amount of stress was primarily a subjective perception of the researcher.

Recommendations
After completion of this study, there are a number of recommendations for further research. Not all models were optimally performed. The models of the farrowing duration intervals should be optimized by adjusting several factors per interval; amount of live born piglets, amount of type II stillborn piglets, amount of breech positions, amount of normal umbilical cords and mean birth weight. Farrowing duration interval 4 (piglet ≥ 13) can still be divided into two groups (piglet 13-16 and piglet 17 up to and including the last born piglet) for further investigation. In addition, research at the individual pig level is advisable to find out what kind of side effects there are for the individual piglets when treatment with carbetocin or oxytocin is used in sows during parturition. According to this research, oxytocin administered after the birth of the fourth piglet should not be used in sows with litters larger than 12 piglets because it causes a delay at the end of the farrowing process. It might be possible that treating sows with oxytocin in a later phase during the farrowing process has a positive effect on the parturition compared to the carbetocin and control group. This should be further investigated because other researchers did report a reduced duration of farrowing after treatment with oxytocin but used a slightly higher, more weight-dependent dosage (Mota-Rojas et al., 2002b; Alonso-Spilsbury et al., 2004; Rota-Mojas et al., 2007). Further research on the time of administration during parturition and dosage of oxytocin and carbetocin is recommended. A recommendation for farmers is that sows should be regularly monitored during the farrowing

process whether they are treated with uterotonic drugs or not; prolonged birth intervals between the piglets can be an indicator for farrowing problems in sows.

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Appendices

I . Protocol

Farm and date :
Sow number :
Parity :
Days of gestation :
Manure consistence during farrowing : /after fourth piglet
Behavior during farrowing : /after fourth piglet
Behavior on injection :
Litter size :

- 1
- 2
- 3 (Control)

Piglet .... died because of ..... date: time:
Piglet .... died because of ..... date: time:
Piglet .... died because of ..... date: time:
Piglet .... died because of ..... date: time:
Piglet .... died because of ..... date: time:
Piglet .... died because of ..... date: time:

Pig	Symbool	Time * Born	*Ant/ post	*Umb. cord B	*Umb. cord Adh d	*Umb. cord Adh n	Time First breath >60	First breath 16-60	First breath <15	* Stillbirth I	* Stillbirth II	Skin color Cy	Skin color Pa	Skin color Pi	*Meconium Sev	*Meconium Mil	*Meconium Abs	Time First standing >5	First standing 1-5	First standing <1	Teat contact >60	Teat contact 30-60	Teat contact <30	Sex m	Sex f	Weight gram (..,1)	Comments
1	2																										
2	7																										
3	8																										
4	X																										
5	•																										
6	••																										
7	•••																										
8	—																										
9	—																										
10	•/•																										
11	|																									
12	||																									

Pig	Symbool	Time * Born	*Ant/ post	*Umb. cord B	*Umb. cord Adh d	*Umb. cord Adh n	Time First breath >60	First breath 16-60	First breath <15	* Stillbirth I	* Stillbirth II	Skin color Cy	Skin color Pa	Skin color Pi	*Meconium Sev	*Meconium Mil	*Meconium Abs	Time First standing >5	First standing 1-5	First standing <1	Teat contact >60	Teat contact 30-60	Teat contact <30	Sex m	Sex f	Weight gram (..,1)	Comments
13																											
14	A																										
15	#																										
16	2 N																										
17	7 X																										
18	8 •																										
19																											
20																											

Explanation of the variables:

- Farrowing duration (total expulsion time from the first up to and including the last piglet in minutes)
- Expulsion time between two successive piglets, live or stillborn piglets (birth interval in minutes)
- Gestation (days)
- Parity of the sow (number)
- Litter size (the number of live born piglets, type I or II stillborn piglets)
- Anterior/posterior
  - breech presentation
  - unknown
  - head presentation
- Umbilical cord
  - broken
  - adhered different (included oedematous, hemorrhagic, knot in the umbilical cord)
  - adhered normal
- Stillbirth
  - type I
  - type II
- Weight (in grams)

- *First breath**
  - *> 60 seconds*
  - *16-60 seconds*
  - *< 15 seconds*
- *Skin color**
  - *cyanotic*
  - *pale*
  - *pink*
- *Meconium**
  - *severe*
  - *mild*
  - *absent*
- *First standing**
  - *> 5 minutes*
  - *1-5 minutes*
  - *< 1 minutes*
- *Teat contact**
  - *> 60 minutes*
  - *30-60 minutes*
  - *< 30 minutes*
- *Sex**
  - *male*
  - *female*

**The vitality factors were not used in this study but have been published elsewhere.*

II. Adapted factors for statistical analysis

Farrowing Duration after the fourth piglet (FD4+)	
Farm	Farm was divided into two groups: 1 = Farm 1 2 = Farm 2
Treatment	Treatment was divided into three groups: 1 = carbetocin 2 = oxtocin 3 = control
Gestation (Gest_new)	Gestation was adapted to farm average for gestation length: 2,00 = mean gestation 1,00 = > mean gestation 0,00 = < mean gestation
Parity (Parity_new)	Parity was divided into three groups: 2,00 = 2-5 1,00 = ≥ 6 0,00 = 1
Intervantion (Interv_new)	The amount of interventions after the treatment (≥ 5 piglet). Intervention was divided into three groups: 2,00 = no intervention 1,00 = 1 intervention 0,00 = ≥ 2 interventions
Weight	Mean weight of a litter (litter = live born piglets + type II stillborn piglets).
Type II Stillbirths per litter after treatment (T2Litter)	The amount of type II stillborn piglets per litter after treatment (after the fourth piglet). (litter = live born piglets + type II stillbirths).
Live Born Piglets after treatment (LBPnew)	The amount of Live Born Piglets (LBP) of a sow after treatment (after the fourth piglet).
Normal umbilical cords per litter (NormalUClitter)	The amount of normal umbilical cord per litter after treatment (after the fourth piglet). (litter after treatment = live born piglets after treatment + type II stillborn piglets after treatment).The variable is expressed as a number between 0 and 1. For example; 0:35 of piglets born in a litter are born with an umbilical cord that a normal appearance.
Breech positions per litter (Breechlitter)	The amount of breech positions per litter after treatment (after the fourth piglet). (litter = live born piglets + type II stillborn piglets).The variable is expressed as a number between 0 and 1. For example; 0:35 of piglets born in a litter are born in a breech position.
Part1 Farrowing Duration (Pdpart1)	Farrowing time in minutes between the first and fourth piglet (before treatment). Pdpart1 = Total farrowing time – farrowing time between fifth up to and including the last born piglet.

Table 13 Factors used for analyzing the FD4+

Farrowing Duration (FD) intervals	
Farm	Farm was divided into two groups: 1 = Farm 1 2 = Farm 2
Treatment	Treatment was divided into three groups: 1 = carbetocin 2 = oxtocin 3 = control
Gestation (Gest_new)	Gestation was adapted to farm average for gestation length: 2,00 = mean gestation 1,00 = > mean gestation 0,00 = < mean gestation
Parity (Parity_new)	Parity was divided into three groups: 2,00 = 2-5 1,00 = ≥ 6 0,00 = 1
Intervention Part 1,2,3 or 4. (IntervPart1,2,3 or 4)	The amount of interventions during a part of the farrowing (interval 1 = farrowing time between piglet 1-4, interval 2 = farrowing time between piglet 5-8, interval 3 = farrowing time between piglet 5-8 and interval 4 = farrowing time piglet ≥ 13 until the last born piglet). Intervention was divided into three groups: 2,00 = no intervention 1,00 = 1 intervention 0,00 = ≥ 2 interventions
Weight	Mean weight of a litter (litter = live born piglets + type II stillborn piglets).
Type II Stillbirths per litter (Type2Litter)	The amount of type 2 stillborn piglets per litter (litter = live born piglets + type II stillbirths).
Live Born Piglets per litter (LBPtotal)	The amount of Live Born Piglets (LBP) of a sow per litter.
Normal umbilical cords per litter (NormalUCLitter)	The amount of normal umbilical cord per litter (litter = live born piglets + type II stillborn piglets).The variable is expressed as a number between 0 and 1. For example; 0.35 of piglets born in a litter are born with an umbilical cord that a normal appearance.
Breech positions per litter (BreechLitter)	The amount of breech positions per litter (litter = live born piglets + type II stillborn piglets).The variable is expressed as a number between 0 and 1. For example; 0.35 of piglets born in a litter are born in a breech position.
Part1,2, 3 or 4 Farrowing Duration (PD Part1,2 or 3 PD)	Part1 Farrowing Duration = farrowing time between the first and fourth piglet. PD Part1 is used for the analysis of farrowing duration interval 2 (piglet5-8). Part2 Farrowing Duration = farrowing time between the first and eight piglet. PD Part2 is used for the analysis of farrowing duration interval 3 (piglet 9-12). Part3 Farrowing Duration = farrowing time between the first and twelfth piglet. PD Part3 is used for the analysis of farrowing duration interval 4 (piglet≥ 13 up to and including the last born piglet).

Table 14 Factors used for analyzing the FD intervals

III. SPSS results Total Farrowing Duration (TFD)

TFD

Levene's Test 0.883

Tests of Between-Subjects Effects					
Dependent Variable: LNpd					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	15,333[a]	12	1,278	15,182	,000
Intercept	134,447	1	134,447	1597,503	,000
Gestation (gest_new)	,288	2	,144	1,709	,185
Intervention (Interv_new)	11,451	2	5,725	68,029	,000
Farm	1,768E-005	1	1,768E-005	,000	,988
Treatment	,315	2	,158	1,874	,157
Live Born Piglets per litter (LBPtotal)	,878	1	,878	10,436	,002
Gestation* Intervention (gest_new * Interv_new)	,965	4	,241	2,866	,026
Error	11,530	137	,084		
Total	4245,163	150			
Corrected Total	26,863	149			
a. R Squared = ,571 (Adjusted R Squared = ,533)					

Table 15 Result LN transformation TFD GLM-factorial ANOVA

Parameter	Bexp	Sig.	95% Confidence Interval	
			Lower Bound	Upper Bound
Intercept geom mean	97,514	0,000	73,774	128,766
< mean gestation = [gest_new=,0]	1,044	0,625	0,876	1,245
> mean gestation = [gest_new=1,0]	1,347	0,000	1,155	1,573
mean gestation = [gest_new=2,0]	1	.	.	.
≥ 2 interventions = [Interv_new=,00]	2,192	0,000	1,779	2,705
1 intervention = [Interv_new=1,00]	1,699	0,000	1,412	2,042
no intervention = [Interv_new=2,00]	1	.	.	.
Farm 1 = [Farm=1]	0,999	0,988	0,905	1,104
Farm 2 = [Farm=2]	1	.	.	.
Carbetocin = [Treatment=1]	0,898	0,069	0,798	1,009
Oxytocin = [Treatment=2]	0,978	0,722	0,868	1,103
Control = [Treatment=3]	1	.	.	.
Live born piglets per litter = LBPtotal	1,027	0,002	1,011	1,045
< mean gestation * ≥2 interventions = [gest_new=,0] * [Interv_new=,00]	1,051	0,755	0,765	1,446
< mean gestation * 1 intervention = [gest_new=,0] * [Interv_new=1,00]	0,761	0,088	0,555	1,042
< mean gestation * no intervention = [gest_new=,0] * [Interv_new=2,00]	1	.	.	.
> mean gestation * ≥2 interventions = [gest_new=1,0] * [Interv_new=,00]	0,760	0,044	0,583	0,993
> mean gestation * 1 intervention = [gest_new=1,0] * [Interv_new=1,00]	0,705	0,020	0,526	0,946
> mean gestation * no intervention = [gest_new=1,0] * [Interv_new=2,00]	1	.	.	.
mean gestation * ≥2 interventions = [gest_new=2,0] * [Interv_new=,00]	1	.	.	.
mean gestation * 1 intervention = [gest_new=2,0] * [Interv_new=1,00]	1	.	.	.
mean gestation * no intervention = [gest_new=2,0] * [Interv_new=2,00]	1	.	.	.

Table 16 Result Parameters TFD GLM-factorial ANOVA

SPSS Results re-parametrisation Total Farrowing Duration (TFD)

Levene's Test 0.833 , Gestation excluded

Tests of Between-Subjects Effects					
Dependent Variable: LNpd					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	15,333[a]	12	1,278	15,182	,000
Intercept	134,447	1	134,447	1597,503	,000
Gestation* Intervention (gest_new * Interv_new)	1,752	6	,292	3,469	,003
Intervention (Interv_new)	11,451	2	5,725	68,029	,000
Treatment	,315	2	,158	1,874	,157
Live Born Piglets per litter (LBPtotal)	,878	1	,878	10,436	,002
Farm	1,768E-005	1	1,768E-005	,000	,988
Error	11,530	137	,084		
Total	4245,163	150			
Corrected Total	26,863	149			
a. R Squared = ,571 (Adjusted R Squared = ,533)					

Table 17 Result LN transformation re-parametrisation TFD GLM-factorial ANOVA

Parameter	Bexp	Sig.	95% Confidence Interval	
			Lower Bound	Upper Bound
Interceptgeom mean	97,514	0,000	73,774	128,766
< mean gestation * ≥ 2 interventions = [gest_new=,0] * [Interv_new=,00]	2,408	0,000	1,893	3,065
< mean gestation * 1 intervention = [gest_new=,0] * [Interv_new=1,00]	1,350	0,018	1,053	1,728
< mean gestation * no intervention = [gest_new=,0] * [Interv_new=2,00]	1,044	0,625	0,876	1,245
> mean gestation * ≥ 2 interventions = [gest_new=1,0] * [Interv_new=,00]	2,248	0,000	1,861	2,716
> mean gestation * 1 intervention = [gest_new=1,0] * [Interv_new=1,00]	1,614	0,000	1,271	2,050
> mean gestation * no intervention = [gest_new=1,0] * [Interv_new=2,00]	1,347	0,000	1,155	1,573
mean gestation * ≥ 2 interventions = gest_new=2,0] * [Interv_new=,00]	2,192	0,000	1,779	2,705
mean gestation * 1 intervention = [gest_new=2,0] * [Interv_new=1,00]	1,699	0,000	1,412	2,042
mean gestation * no intervention = [gest_new=2,0] * [Interv_new=2,00]	1,000	.	.	.
≥ 2 interventions = [Interv_new=,00]	1,000	.	.	.
1 intervention = [Interv_new=1,00]	1,000	.	.	.
no intervention = [Interv_new=2,00]	1,000	.	.	.
Carbetocin = [Treatment=1]	0,898	0,069	0,798	1,009
Oxytocin = [Treatment=2]	0,978	0,722	0,868	1,103
Control = [Treatment=3]	1,000	.	.	.
Live born piglets per litter = LBPtotal	1,027	0,002	1,011	1,045
Farm 1 = [Farm=1]	0,999	0,988	0,905	1,104
Farm 2 = [Farm=2]	1,000	.	.	.

Table 18 Result Parameters re-parametrisation TFD GLM-factorial ANOVA

IV. SPSS results Farrowing Duration after the fourth piglet (FD4+)

FD4+

Levene's Test 0.883

Tests of Between-Subjects Effects					
Dependent Variable: LNpdPart_2					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	22,693[a]	7	3,242	31,331	,000
Intercept	176,383	1	176,383	1704,644	,000
Farm	,007	1	,007	,063	,801
Treatment	,591	2	,295	2,854	,061
Intervention (interv_new)	10,184	2	5,092	49,212	,000
Type II stillbirths per litter after treatment (T2litter)	,629	1	,629	6,079	,015
Live Born Piglets after treatment (LBPnew)	1,732	1	1,732	16,737	,000
Error	14,693	142	,103		
Total	3560,771	150			
Corrected Total	37,386	149			
a. R Squared = ,607 (Adjusted R Squared = ,588)					

Table 19 Result LN transformation FD4+ GLM-factorial ANOVA

Parameter	Bexp	Sig.	95% Confidence Interval	
			Lower Bound	Upper Bound
Intercept geom mean	71,522	0,000	57,340	89,211
Farm 1 = [Farm=1]	0,986	0,801	0,884	1,100
Farm 2 = [Farm=2]	1	.	.	.
Carbetocin = [Treatment=1]	0,856	0,020	0,751	0,975
Oxytocin = [Treatment=2]	0,906	0,126	0,797	1,028
[Control = Treatment=3]	1	.	.	.
≥ 2 interventions = [interv_new=,00]	2,181	0,000	1,859	2,560
1 intervention = [interv_new=1,00]	1,467	0,000	1,264	1,701
no intervention = [interv_new=2,00]	1	.	.	.
Type II stillbirths per litter after treatment (after the fourth piglet) = T2litter	2,077	0,015	1,156	3,736
Live born piglets of a sow after treatment (after the fourth piglet) = LBPnew	1,039	0,000	1,020	1,059

Table 20 Result Parameters FD4+ GLM-factorial ANOVA

V. SPSS results Farrowing Duration (FD) intervals

FD interval 1 (piglet 1-4)

Levene's Test 0.919

Tests of Between-Subjects Effects					
Dependent Variable: LNinterv1					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	22,415[a]	7	3,202	9,844	,000
Intercept	565,594	1	565,594	1738,816	,000
Farm	,074	1	,074	,229	,633
Treatment	1,920	2	,960	2,952	,055
Gestation (gest_new)	2,114	2	1,057	3,249	,042
Intervention in interval 1 (IntervPart1_new)	20,117	2	10,058	30,923	,000
Error	46,189	142	,325		
Total	1451,869	150			
Corrected Total	68,604	149			
a. R Squared = ,327 (Adjusted R Squared = ,294)					

Table 21 Result LN transformation FD interval 1 GLM-factorial ANOVA

Parameter	Bexp	Sig.	95% Confidence Interval	
			Lower Bound	Upper Bound
Intercept geom mean	20,045	0,000	15,705	25,585
Farm 1 = [Farm=1]	0,956	0,633	0,793	1,153
Farm 2 = [Farm=2]	1	.	.	.
Carbetocin = [Treatment=1]	0,770	0,030	0,610	0,974
Oxytocin = [Treatment=2]	0,972	0,814	0,771	1,228
Control = [Treatment=3]	1	.	.	.
< mean gestation = [gest_new=,0]	0,806	0,085	0,630	1,030
> mean gestation = [gest_new=1,0]	1,100	0,397	0,881	1,373
mean gestation = [gest_new=2,0]	1	.	.	.
≥ 2 interventions in FD interval 1 = [IntervPart1_new=,00]	3,725	0,000	2,452	5,658
1 intervention in FD interval 1 = [IntervPart1_new=1,00]	2,307	0,000	1,713	3,108
no intervention in FD interval 1 = [IntervPart1_new=2,00]	1	.	.	.

Table 22 Result Parameters FD interval 1 GLM-factorial ANOVA

FD interval 2 (piglet 5-8)

Levene's Test 0.412

Tests of Between-Subjects Effects					
Dependent Variable: LNinterv2					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	17,561[a]	6	2,927	12,505	,000
Intercept	16,627	1	16,627	71,040	,000
Farm	,038	1	,038	,163	,687
Treatment	,728	2	,364	1,555	,215
Intervention in interval 2 (IntervPart2_new)	15,217	2	7,608	32,508	,000
Weight	1,379	1	1,379	5,891	,016
Error	33,469	143	,234		
Total	872,817	150			
Corrected Total	51,030	149			
a. R Squared = ,344 (Adjusted R Squared = ,317)					

Table 23 Result LN transformation FD interval 2 GLM-factorial ANOVA

Parameter	Bexp	Sig.	95% Confidence Interval	
			Lower Bound	Upper Bound
Intercept geom mean	5,507	0,000	3,313	9,152
Farm 1 = [Farm=1]	1,033	0,687	0,882	1,208
Farm 2 = [Farm=2]	1	.	.	.
Carbetocin = [Treatment=1]	0,912	0,345	0,754	1,105
Oxytocin = [Treatment=2]	0,843	0,080	0,696	1,021
Control = [Treatment=3]	1	.	.	.
≥ 2 interventions in FD interval 2 = [IntervPart2_new=,00]	2,158	0,007	1,232	3,773
1 intervention in FD interval 2 = [IntervPart2_new=1,00]	2,790	0,000	2,145	3,629
no intervention in FD interval 2 = [IntervPart2_new=2,00]	1	.	.	.
Mean weight of a litter = Weight	1,000	0,016	1,000	1,001

Table 24 Result Parameters FD interval 2 GLM-factorial ANOVA

FD interval 3 (piglet 9-12)

Levene's Test 0.330

Tests of Between-Subjects Effects					
Dependent Variable: LNinterv3					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	36,432[a]	8	4,554	13,993	,000
Intercept	22,645	1	22,645	69,582	,000
Farm	,344	1	,344	1,058	,306
Treatment	,613	2	,307	,942	,392
Intervention in interval 3 (IntervPart3_new)	20,156	2	10,078	30,967	,000
Normal umbilical cords per litter (NormalUCLitter)	1,487	1	1,487	4,568	,034
Type II Stillbirths per litter (Type2litter)	1,357	1	1,357	4,169	,043
Live Born Piglets per litter (LBPtotal)	5,212	1	5,212	16,015	,000
Error	45,237	139	,325		
Total	810,374	148			
Corrected Total	81,669	147			
a. R Squared = ,446 (Adjusted R Squared = ,414)					

Table 25 Result LN transformation FD interval 3 GLM-factorial ANOVA

Parameter	Bexp	Sig.	95% Confidence Interval	
			Lower Bound	Upper Bound
Intercept geom mean	15,090	0,000	6,560	34,744
Farm 1 = [Farm=1]	0,907	0,306	0,751	1,095
Farm 2 = [Farm=2]	1	.	.	.
Carbetocin = [Treatment=1]	0,875	0,258	0,692	1,104
Oxytocin = [Treatment=2]	0,867	0,218	0,690	1,089
Control = [Treatment=3]	1	.	.	.
≥ 2 interventions in FD interval 3 = [IntervPart3_new=,00]	3,740	0,000	2,375	5,888
1 intervention in FD interval 3 = [IntervPart3_new=1,00]	2,743	0,000	1,964	3,831
no intervention in FD interval 3 = [IntervPart3_new=2,00]	1	.	.	.
Normal umbilical cords per litter = NormalUCLitter	2,032	0,034	1,054	3,916
Type II Stillbirths per litter = Type2litter	0,255	0,043	0,068	0,958
Live Born Piglets per litter = LBPtotal	0,932	0,000	0,900	0,965

Table 26 Result Parameters FD interval 3 GLM-factorial ANOVA

FD interval 4 (piglet 13 up to and including the last born piglet)

Levene's Test 0.465

Tests of Between-Subjects Effects					
Dependent Variable: LNinterv4					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	39,334[a]	13	3,026	7,984	,000
Intercept	6,671	1	6,671	17,603	,000
Farm	,019	1	,019	,050	,824
Treatment	4,013	2	2,007	5,295	,006
Parity (Parity_new)	,085	2	,043	,112	,894
Intervention in interval 4 (IntervPart4_new)	9,139	2	4,570	12,058	,000
Weight (Mean weight of a litter)	3,582	1	3,582	9,453	,003
Live Born Piglets per litter (LBPtotal)	3,054	1	3,054	8,059	,005
Parity* Intervention in interval 4 (Parity_new * IntervPart4_new)	3,769	4	,942	2,487	,048
Error	39,791	105	,379		
Total	830,503	119			
Corrected Total	79,125	118			
a. R Squared = ,497 (Adjusted R Squared = ,435)					

Table 27 Result LN transformation FD interval 4 GLM-factorial ANOVA

Parameter	Bexp	Sig.	95% Confidence Interval	
			Lower Bound	Upper Bound
Intercept geom mean	6,495	0,005	1,791	23,547
Farm 1 = [Farm=1]	0,972	0,824	0,758	1,247
Farm 2 = [Farm=2]	1	.	.	.
Carbetocin = [Treatment=1]	0,849	0,253	0,640	1,126
Oxytocin = [Treatment=2]	1,363	0,042	1,012	1,837
Control = [Treatment=3]	1	.	.	.
Parity 1 [Parity_new=,00]	1,102	0,643	0,729	1,665
Parity ≥ 6 = [Parity_new=1,00]	1,355	0,097	0,946	1,943
Parity 2-5 =[Parity_new=2,00]	1	.	.	.
≥ 2 interventions in FD interval 4 = [IntervPart4_new=,00]	4,179	0,000	2,620	6,666
1 intervention in FD interval 4 = [IntervPart4_new=1,00]	2,323	0,002	1,366	3,951
no intervention in FD interval 4 = [IntervPart4_new=2,00]	1	.	.	.
Mean weight of a litter = Weight	1,001	0,003	1,000	1,002
Live Born Piglets per litter = LBPtotal	0,931	0,005	0,885	0,978
Parity 1 * ≥ 2 interventions = [Parity_new=,00] * [IntervPart4_new=,00]	0,534	0,360	0,138	2,069
Parity 1 * 1 intervention = [Parity_new=,00] * [IntervPart4_new=1,00]	1,097	0,895	0,274	4,393
Parity 1 * no intervention = [Parity_new=,00] * [IntervPart4_new=2,00]	1	.	.	.
Parity ≥ 6 * ≥ 2 interventions = [Parity_new=1,00] * [IntervPart4_new=,00]	0,376	0,006	0,188	0,748
Parity ≥ 6 * 1 intervention = [Parity_new=1,00] * [IntervPart4_new=1,00]	1,247	0,559	0,590	2,635
Parity ≥ 6 * no intervention = Parity_new=1,00] * [IntervPart4_new=2,00]	1	.	.	.
Parity 2-5 * ≥ 2 interventions = [Parity_new=2,00] * [IntervPart4_new=,00]	1	.	.	.
Parity 2-5 * 1 intervention = [Parity_new=2,00] * [IntervPart4_new=1,00]	1	.	.	.
Parity 2-5 * no intervention = [Parity_new=2,00] * [IntervPart4_new=2,00]	1	.	.	.

Table 28 Result Parameters FD interval 4 GLM-factorial ANOVA

SPSS results re-parametrisation Farrowing Duration interval 4 (piglet 13 up to and including the last born piglet)

Levene's Test 0.065
Parity excluded

Tests of Between-Subjects Effects

Dependent Variable: LNinterv4

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	39,334[a]	13	3,026	7,984	,000
Intercept	6,671	1	6,671	17,603	,000
Farm	,019	1	,019	,050	,824
Treatment	4,013	2	2,007	5,295	,006
Intervention in interval 4 (IntervPart4_new)	9,139	2	4,570	12,058	,000
Weight (Mean weight of a litter)	3,582	1	3,582	9,453	,003
Live Born Piglets per litter (LBPtotal)	3,054	1	3,054	8,059	,005
Intervention in interval 4* Parity (IntervPart4_new * Parity_new)	4,056	6	,676	1,784	,109
Error	39,791	105	,379		
Total	830,503	119			
Corrected Total	79,125	118			

a. R Squared = ,497 (Adjusted R Squared = ,435)

Table 29 Result LN transformation re-parametrisation FD interval 4 GLM-factorial ANOVA

Parameter	Bexp	Sig.	95% Confidence Interval	
			Lower Bound	Upper Bound
Intercept	6,495	0,005	1,791	23,547
[Farm=1]	0,972	0,824	0,758	1,247
[Farm=2]	1,000	.	.	.
[Treatment=1] = carbetocin	0,849	0,253	0,640	1,126
[Treatment=2] = oxytocin	1,363	0,042	1,012	1,837
[Treatment=3] = control	1,000	.	.	.
2 interventions in FD interval 4 = [IntervPart4_new=,00]	4,179	0,000	2,620	6,666
1 intervention in FD interval 4 = [IntervPart4_new=1,00]	2,323	0,002	1,366	3,951
no intervention in FD interval 4 = [IntervPart4_new=2,00]	1,000	.	.	.
Mean weight of a litter = Weight	1,001	0,003	1,000	1,002
Live Born Piglets per litter = LBPtotal	0,931	0,005	0,885	0,978
≥ 2 interventions * parity 1 = [IntervPart4_new=,00] * [Parity_new=,00]	0,587	0,417	0,161	2,140
≥ 2 interventions * parity ≥ 6 = [IntervPart4_new=,00] * [Parity_new=1,00]	0,509	0,023	0,285	0,909
≥ 2 interventions * parity 2-5 = [IntervPart4_new=,00] * [Parity_new=2,00]	1,000	.	.	.
1 intervention * parity 1 = [IntervPart4_new=1,00] * [Parity_new=,00]	1,208	0,780	0,317	4,604
1 intervention * parity ≥ 6 = [IntervPart4_new=1,00] * [Parity_new=1,00]	1,690	0,115	0,877	3,254
1 intervention * parity 2-5 = [IntervPart4_new=1,00] * [Parity_new=2,00]	1,000	.	.	.
no intervention * parity 1 = [IntervPart4_new=2,00] * [Parity_new=,00]	1,102	0,643	0,729	1,665
no intervention * parity ≥ 6 = [IntervPart4_new=2,00] * [Parity_new=1,00]	1,355	0,097	0,946	1,943
no intervention * parity 2-5 = [IntervPart4_new=2,00] * [Parity_new=2,00]	1,000	.	.	.

Table 30 Result Parameters re-parametrisation FD interval 4 GLM-factorial ANOVA

VI. SPSS results Sow behaviour

Logistic regression

Variables in the Equation							
		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	Treatment			2,048	2	,359	
	Treatment(1)	,873	,645	1,833	1	,176	2,393
	Treatment(2)	,817	,651	1,577	1	,209	2,265
	Behaviour1-4piglet(1)	-1,208	,473	6,534	1	,011	,299
	Constant	-1,628	,246	43,660	1	,000	,196
a. Variable(s) entered on step 1: Treatment, Behaviour14piglet.							

Table 30 Result Logistic regression P-value

Variables in the Equation							
		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	Behaviour1-4piglet(1)	1,332	,460	8,379	1	,004	3,788
	Constant	-2,219	,333	44,420	1	,000	,109
a. Variable(s) entered on step 1: Behaviour14piglet.							

Table 31 Result Logistic regression odds ratio