



Bovine pestivirus infection: a cause of ovulatory disturbance in dairy cows

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ABSTRACT

Twelve (Experiment I) and four (Experiment II) multiparous dairy cows seronegative to pestivirus were selected and randomly assigned to either a control group which did not become infected or a treatment group in which all cows became infected following intranasal inoculation 9 days before AI. The experimental induction of infection was carried out with 2 ml of non-cytopathic pestivirus (BVD virus) suspension containing 5 log₁₀ TCID₅₀/ml (Experiment I) and 4.5 log₁₀ TCID₅₀/ml (Experiment II). In both experiments, the cows were superovulated on day 10±2 of the cycle using the standard procedures. The cows in Experiment I were artificially inseminated at 12 and 24 h after the onset of estrus and a non-surgical ova/embryo collection was performed 7 days after AI. In Experiment II, the cows were slaughtered on day 8 after superovulation-induced estrus and the ovaries submitted for gross and histopathological examination including immunohistochemistry. Mean (±SE) number of ovulatory sized follicles on day of AI and corpora lutea palpated on day 7 after AI were significantly (p<0.05) higher in control un-infected cows compared to that of the pestivirus infected cows (17.1±2.6 vs. 9.2±1.1 and 12.2±2.7 vs. 2.8±0.9), respectively. On histopathological examinations, the mean (±SE) number of unovulated lutenised follicles (≥ 9mm in diameter) present on the ovaries of the control cows on day 8 after estrus was 6.8±4.9 compared to 12.5±5.4 for the infected cows. Further, many corpora lutea in the ovaries of infected cows had a hypoplastic or atrophic wall. In conclusion, the present study demonstrated that pestivirus infection during the period of final growth of preovulatory follicles results in a disturbance in ovulation and development of corpus luteum leading to a poor superovulatory response in multiparous dairy cows.

Keywords: Pestivirus infection, Superovulation, Immunohistochemistry, Ovary, Dairy cows

INTRODUCTION

Non-cytopathic type 1 bovine pestivirus infection is prevalent in the cattle populations of many countries

(Kafi 1988). In Iran, the prevalence of seropositive cows to pestivirus infection was reported between 50 to 70 percent (Sedigi-Nezhad 1996). Cattle undergoing pre- or postnatal infections are associated with a variety of disease syndromes that

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include immune suppression, congenital defects, abortion, and mucosal disease and, importantly, disruption of reproductive functions (Kafi 2001).

It has been demonstrated that spontaneously infected (Virakul *et al* 1988) or experimentally (McGowan *et al* 1993a) induced pestivirus infection at approximately the time of artificial insemination (AI) significantly lower conception rate in dairy cattle. Field studies (McGowan *et al* 1993b; Rufenacht *et al* 2001) have also shown that pestivirus infection is a cause of reproductive loss in dairy cows. The adverse effect of bovine pestivirus infection on the final growth of ovulatory follicles was initially reported in superovulated Holstein heifers by Kafi *et al* (1997). Later, it was shown that acute pestivirus infection disturb follicular development (Grooms *et al* 1998) and corpus luteum development (Fray *et al* 2001 and McGowan *et al* 2003) following experimental infection of seronegative cattle with a non-cytopathic bovine pestivirus.

The aims of the present study were to determine the superovulatory response of dairy multiparous Holstein cows experimentally infected with a non-cytopathic isolate of bovine pestivirus (Experiment I), the morphologic changes and the distribution of pestivirus antigens in ovarian structures of the infected cows were evaluated using gross and histopathological examinations including immuno-histochemistry (Experiment II).

MATERIALS AND METHODS

Experiment I

Twelve multiparous Holstein cows, aged 4 to 6 years, were selected from a brucellosis free herd. To confirm that they are pestivirus antibody-free, all cows were bled before commencing the experiment. The cows were checked to determine their body condition scores (based on 1 to 8), all animals were in a range of 4 to 5 of condition score two weeks before breeding. After a general examination, the

cows were randomly divided into two control and treatment groups, and placed in two paddocks. The cows were being fed by good quality pasture grass and supplemented based on the pasture condition.

Experimental infection. Inocula were prepared shortly before use by adding 31 ml of bovine serum to 0.15 ml of virus culture media containing 6.5 log TCID/ml to adjust final inoculum to 5 log TCID/ml of non-cytopathogenic pestivirus. The serum inoculum contained an Australian strain of non-cytopathogenic bovine pestivirus (BVD-type 1) isolated from a persistently virus carrier Angus cow (McGowan *et al* 1993a). All cows in the treatment group were infected by intranasal installation of 2 mls of the inoculum (one ml in each nostril) 8 days prior to AI. Shortly before inoculation, each cow was isolated from the remaining un-inoculated cows. This way of experimental infection was previously shown to have a high reliability and further the magnitude and duration of viremia-induced is similar to that observed following natural infection (Cook *et al* 1990).

Sample collection. All cows were blood sampled 14 days before and immediately prior to virus inoculation. Also, blood sampling was carried out every second day until day 9 after virus inoculation, and then on days 13, 16, 30 after virus inoculation. Blood samples were kept chilled and after clot formation, the sera were separated and stored frozen at -20 °C until assayed for detection of pestivirus or antibody to pestivirus. All unfertilized and degenerate embryo were stored in straws and frozen in order to examine for isolation of virus or virus-associated antigens. The above-mentioned specimens were shipped to the veterinary laboratory of Camden (N.S.W.) for serology and virus isolation.

Serological examination. The sera samples were examined by Gel Diffusion Precipitin (GDP) test to detect antibody to pestivirus. Also, ELISA test was carried out to confirm the GDP test results (Kirkland *et al* 1997).

Virus isolation. It was carried out on 0.5 ml of

each serum sample collected 2, 4, 6, 8 days after inoculation to identify the approximate time of onset of viraemia. A second quantitative examination of serum samples was attempted to measure the titer of virus in the serum samples (Kirkland *et al* 1997). In addition, the unfertilized and degenerate embryos were examined for pestivirus.

Oestrus synchronization and superovulation.

Oestrus synchronization was performed by using syncromate (SMB) implant (Intervet, The Netherlands) containing 3 mg of progestagen norgestomet. After rectal palpation, those cows that had an active corpus luteum, were injected with 500 µg of cloprostenol (Prostaglandin F_{2α} analogue) intramuscularly to be prepared for a synchronization programme. Thus, at the time of SMB implant insertion, most cows were in luteal phase based on the findings of rectal palpation. One SMB implant was inserted on the outer surface of the ear of each cow by using the applicator (this was concomitant with intranasal inoculation of the virus in the treatment group). On day 7 after SMB insertion, the implants were removed and at the same time all cows received 500 µg cloprostenol intramuscularly to have more precise oestrus synchronization. At the time of removing the implants, the animals were tail painted to aid heat detection. The cows were observed for oestrus behaviour from 24 hours after removing the implants and the cloprostenol injection. Using one injection of equine chorionic gonadotrophin (eCG) was considered less stressful to the cows than handling and injecting them eight times, if FSH was used. All cows received 2500 IU eCG intramuscularly on day 10 after the induced oestrus, 4 days after using SMB implant, followed 48 hours later by an injection of 500 µg cloprostenol i.m. to cause regression of the mid-cycle corpora lutea and induce oestrus.

Artificial insemination. Prior to AI, the amount of paint loss was scored and recorded. Approximately 48 and 56 hours after removing the implants and cloprostenol injection, all animals were

artificially inseminated twice (at 8 hours intervals). The frozen thawed semen used for insemination was from a Holstein pestivirus free bull of high fertility. It was examined to be free of pestivirus by seronegative sheep that was inoculated with whole blood from the bull. The sheep was then serially bled to monitor the occurrence of seroconversion. Further, whole blood from the bull was submitted for pestivirus antigen capture ELISA testing (Kirkland *et al* 1997).

Ultrasonic examination of ovaries. Immediately prior to AI, each cow was scanned to visualize the ovarian structures using a B-mode ultrasound machine equipped with a 5 MHz linear array transrectal transducer (SSD, 500 V, Aloka Co., Tokyo, Japan). The number of follicles (≥ 10 mm) on the right and left ovary were determined.

Embryo collection and evaluation. On day 7 after AI, a transcervical ova/embryo collection was performed. Shortly before ova/embryo collection, the number of corpora lutea on the ovaries of each cow was determined via rectal palpation. The flushing medium used was phosphate-buffered saline (PBS) supplemented with 1% fetal calf serum (FCS) and 100 µg streptomycin per milliliter and 25 µg of fungizone. Immediately after each collection, the flushed media was searched to find ova/embryos. They were then identified, counted and evaluated by gross morphological criteria (Elsden 1980).

Embryo culture. All good quality embryos were held in the culture media at 37 °C prior to culture. Then, the embryos were cultured in Hams-F10 medium (CSL, Commonwealth, Australia) supplemented with 20% fetal calf serum in 35 mm plastic dishes in an atmosphere of 5% CO₂, 5% O₂, 90% N₂. The temperature and relative humidity of incubator were 38.5 °C and 95%, respectively. The embryos were morphologically evaluated 48 h. after the commencement of culture and their developmental stages were recorded.

Experiment II

Four Jersey cows aged 4-6 years were used in this

experiment. Two days prior to commencement of the experiment the cows were blood sampled via coccygeal vein and serum or the whole blood submitted for pestivirus serology and virus isolation. Then, two seropositive cows were assigned to the control group and two seronegative non-viremic cows to the infected group. The method and the timing of experimental infection for each cow in the infected group were similar to that described in Experiment I. Then, the cows in either group were treated for synchronization of oestrus and superovulation as previously described (Kafi *et al* 1997). As the cows were to be slaughtered on day 18 post-inoculation, infection was confirmed by virus isolation from plasma collected on days 4 to 10 post-inoculation. The procedure for virus isolation has been previously described (Kirkland *et al* 1997). The cows in the control and infected groups were all slaughtered on day 18 post-inoculation (8 days after superovulatory-induced oestrus). The ovaries of the slaughtered cows were then collected and several longitudinal slices (4-5mm thickness) of tissue from each ovary were placed in 10% buffered formaldehyde. The ovarian slices contained both follicular and luteal structures. The ovarian slices were subsequently embedded in paraffin and 5 μ m sections initially stained with haematoxylin and eosin.

Immunohistochemistry. Paraffin - embedded sections of the ovaries each cow was immunolabelled according to Swasdipan *et al* (2001). Briefly, formaldehyde-fixed paraffin-embedded tissues were immunolabeled for bovine pestivirus using the bovine pestivirus-specific monoclonal antibody 15C5. Cytospin preparations of bovine pestivirus-infected and noninfected bovine tracheal cells functioned as positive and negative controls, respectively. Other controls comprised substitution of specific antibodies with nonreactive antibodies (specific for alphaviruses) and omission of reagents.

Statistical analysis. The differences in the mean number of ovulatory-sized follicles on day of AI, mean number of corpora lutea on day 7 after AI,

mean number of recovered ova/embryos, mean number of fertilized ova and mean number of transferable embryos for each group in Experiment I were compared using a t-test. Fischer exact test was used to analyse statistically the proportions for the results of the embryo culture. All statistical analyses were carried out using SAS programs package (SAS Inc., 1988, Cary, NC, USA). The level of significance was set at $p < 0.05$.

RESULTS

Clinical observations. During the whole period of the present study, none of the cows showed any clinical signs of disease. Further, no sign of diarrhea, increased nasal or lacrimal discharge, or other signs related to BVD/MD were not observed following the virus inoculation.

Experimental infection. In Experiment I, of 6 cows in the control group, 3 cows were seropositive and 3 cows were identified seronegative before commencing the experiment. Therefore, all these 6 cows were considered eligible for inclusion in the control group based on their serology results. All cows in the treatment group were also diagnosed as seronegative before commencing the experiment based on the results of the GDP test. Of 6 cows in the treatment group, 5 cows became infected (83.33%), as indicated by seroconversion within 29 days. Therefore the data of the cow that did not become infected was excluded from the statistical analyses. The mean time from intranasal inoculation to seroconversion was 23.4 ± 3.4 days ($n=5$). Of 5 seroconverted cows, three showed seroconversion in the fifteenth day after exposure and two cows had seroconverted by the twenty-ninth day after exposure.

Virus isolation was carried out on the sera samples on the second, fourth, sixth, eighth days after virus inoculation. The virus was isolated from 2 cows on day 6 after inoculation with a peak viraemia of 3 log TCID₅₀/ml of serum and the titer of the virus in the 3

remaining cows were not detectable. In addition, no virus was isolated from the frozen unfertilized and degenerate embryos. In Experiment II, the two inoculated cows had a detectable viremia ($\geq 0.5 \log_{10}$ TCID₅₀/ml) between days 4 and 2 prior to the day of superovulatory-induced oestrus.

Experiment I

Superovulatory response. All cows except two (one in the control and one in the treatment) showed oestrus behaviour at the time of first AI, as indicated by the degree of paint loss (83.33%, n=12). By the second AI on the same day (8 h. interval), all cows (100%, n=12) were in heat as detected by the degree of paint loss and secondary signs of oestrus. A composite summary of the superovulatory response is given in Table 1.

Table 1. Comparison of the superovulatory response of the cows infected with pestivirus 9 days prior to AI and the uninfected control group

	Control (n=6)	Infected (n=5) [#]
Follicles* ≥ 10 mm	17.1 \pm 2.6 ^a	9.2 \pm 1.1 ^b
Corpora lutea**	12.2 \pm 2.7 ^c	2.8 \pm 0.9 ^d
Recovered ova/emb	3.5 \pm 1.9	1.6 \pm 1.0
Fertilized ova	2.8 \pm 1.0	1.6 \pm 1.0
Transferable emb	2.0 \pm 1.2	1.4 \pm 1.0

* scanned by ultrasonography on day of oestrus.

** Counted via rectal palpation. # one cow failed to become infected. a, b, c, d; Means with different superscripts between columns show a significant difference ($p < 0.05$).

The mean (\pm SE) number of observed follicles (≥ 10 mm) on the day of AI for control and infected groups was 17.1 \pm 2.6 and 9.2 \pm 1.1, respectively ($p < 0.05$). Cows in the control group, had 73 corpora lutea (detected by rectal palpation), with a mean (\pm SE) number of 12.2 \pm 2.7 and a range of 1 to 20 corpora lutea, whereas cows in the infected group had a total number of 14 corpora lutea on their ovaries on day 7 after AI, with a mean (\pm SE) number of 2.8 \pm 0.9 and a range of 1 to 6 corpora lutea. The total of transferable embryos collected from the

control and pestivirus infected cows was 12 and 7, respectively.

Embryo culture. Of 12 morphologically normal morula/blastocysts in the control group, 6 (50%) were developed to hatched blastocyst after 48 h. culture while of seven embryos in the infected group, only two embryos hatched (28.5%) after 48 h culture.

Experiment II

Histopathological evaluation of the ovaries. On slaughterhouse inspection (day 8 after superovulatory-induced oestrus), the proportion of grossly normal corpora lutea was significantly ($p < 0.05$) greater in the control cows (59%; n=44) than in the infected cows (28%; n=53). The mean (\pm SE) number of unovulated follicles ≥ 9 mm in diameter present on the ovaries of the control cows were 6.8 \pm 4.9 compared to 12.5 \pm 5.4 for the infected cows. The ovaries of the infected cows contained fewer normally developed corpora lutea (crown ≥ 15 mm) and a greater number of unovulated follicles, many of which were partially luteinized (Figure 1). Histologically the corpora lutea in the ovaries of the control cows slaughtered on day 8 after oestrus were normal, composed of solid luteal tissue. However, many corpora lutea in the ovaries of infected cows had a hypoplastic or atrophic wall and a comparatively large fluid filled central cavity. Even the relatively normal corpora lutea in the infected cows were smaller with a thinner layer of luteal cells and a larger central cavity compared to the corpora lutea in the ovaries of the control cows. Infiltration by mononuclear cells was evident in the wall of some of the unovulated luteinised follicles but minimal or absent in the others.

Immunohistochemistry findings. In sections from the infected cows, bovine pestivirus antigen was detected focally in the granulosa cells of apparently intact mature Graafian follicles as well as more uniformly in granulosa cells and infiltrating macrophage in follicles with obvious pathological changes. Antigen positive follicles with or without

apparent lesions were often found adjacent to antigen negative follicles (Figure 2). No antigen was detected in any of the sections from the control cow ovaries.

A: Control No. 90



B: Infected No. 50



Figure 1. Cross sectional appearance of the superovulated ovaries of a control (A) and a pestivirus infected cow (B) slaughtered on day 8 after superovulatory induced oestrus. Note the well formed corpora lutea in the control cow's ovaries and the thin walled corpora lutea in the ovaries of the pestivirus infected cow. Also, the diameter of corpora lutea in the infected cows is smaller than in the control cows's ovaries.

DISCUSSION

The superovulation procedure used in the present study maximized the number of follicles at risk of pestivirus infection. Data obtained from the present study concerning effectiveness of intranasal inoculation are comparable with the findings of Cook *et al* (1990) in that the intranasal inoculation can be considered as one of the effective methods of experimental induction of pestivirus infection.

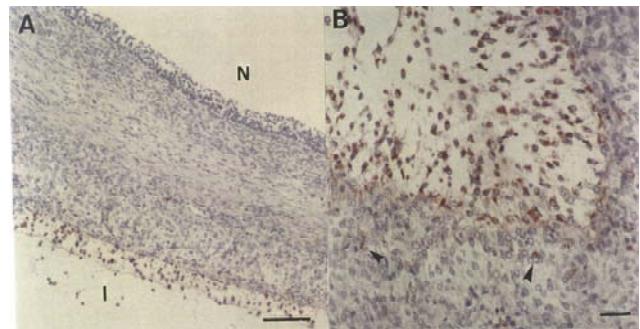


Figure 2. Immunohistochemical demonstration of bovine pestivirus antigen in ovarian follicles. Infected follicles with or without apparent lesions were often found adjacent to uninfected follicles (A). Virus antigen was present in degenerate, necrotic and detached granulosa cells (A, B) as well as in mononuclear cells, mainly monocyte-macrophages, infiltrating the interstitial parenchyma (arrow heads) as well as the follicles (B). Formaldehyde-fixed, paraffin-embedded tissue sections were labeled with a monoclonal antibody specific for nonstructural protein 3 (NS3). The reaction was visualised using AEC-substrate (red label), and counterstained with hematoxyline. N= normal uninfected follicle, I= bovine pestivirus infected follicle. Bar=20µm in A and 1µm in B.

The results of the current study show a significantly higher mean number of the ovulatory sized-follicles (≥ 10 mm in diameter) in un-infected control cows on day of AI comparing to that of the pestivirus-infected cows on the corresponding day. Similarly, a lower mean number of ovulatory-sized follicles was observed in superovulated Holstein heifers when underwent an intranasal infection during the period of final growth of preovulatory follicles compared to uninfected control Holstein heifers (Kafi *et al* 1997). Further, Grooms *et al* (1998) reported that the maximum diameter and growth rate of dominant ovulatory follicles were significantly reduced during the two oestrous cycles subsequent to infection of seronegative cattle with a non-cytopathic bovine pestivirus isolate. A lower plasma oestradiol-17 β concentration was observed in the period of the first dominant follicle of post-oestrus in pestivirus infected cows (Fray *et al* 1999). The results of the current study and the above-mentioned studies show that pestivirus infection

adversely affects on normal development of preovulatory follicles in Holstein heifers as well as dairy cows.

A significantly lower number of ova/embryos recovered from the pestivirus infected cows comparing to that of the control cows in the current study. This could be attributed to the lower number of ovulatory-sized follicles on day of AI in the infected cows. The ovulatory-sized follicles in the infected cows either did not ovulate and then regressed or became luteinised-unovulated follicles by day 7 after AI. This explanation is strengthened considering the results of our previous studies that showed an ovulatory disturbance (Kafi *et al* 1997) associated with a disturbance in preovulatory LH surge (McGowan *et al* 2003) in pestivirus infected heifers comparing to that of the uninfected control heifers. The reason for a low number of transferable embryos recovered from the control cows in the current study could be the long half-life of eCG in blood (Boland *et al* 1991). This has been shown to produce a highly oestrogenic uterine environment which this, in turn, may adversely affect the quality of developing embryos (Schams *et al* 1978, Boland *et al* 1991).

The results of the embryo culture in the present study showed a significantly lower percentage of hatched blastocyst of the embryos collected from pestivirus infected cows compared to that of the embryos collected from the uninfected control cows. Although it has been shown that blastomeres are permissive to pestivirus infection (Vanroose *et al* 1998), there is no compelling evidence to indicate that blastomeres from in vivo-derived, zona pellucida-intact embryos can be infected with non-cytopathogenic BVDV. Studies in vitro have failed to show conclusively that non-cytopathogenic BVDV compromises embryo development directly (Zurovac *et al* 1994; Stringfellow *et al* 2000). Although the number of morula/blastocysts cultured in Experiment I of the present study was not high enough to make a strong conclusion however, the

lower hatching rate in the embryos recovered from the pestivirus infected cows compared to that of the uninfected control cows shows that bovine pestivirus may adversely affect the normal development of the embryos. Bielanski and Dubuc (1995) reported a lower in vitro developmental competence in the oocytes collected from experimentally pestivirus infected heifers.

The results obtained from experiment II of the present study could help to explain the lower ovulation rate in pestivirus infected cattle. Pestivirus antigen was detected in granulosa cells and infiltrating macrophages in follicles between 11 and 17 days after inoculation. Interestingly, there were follicles with extensive virus infection accompanied by destruction of granulosa cells next to non-infected and intact follicles. This finding was similarly observed by Brownlie *et al* (1997) in the ovaries of persistently infected cattle. There is no clear explanation for this peculiar histopathological feature.

In conclusion, the present study demonstrated that pestivirus infection during the period of final growth of preovulatory follicles results in a disturbance in ovulation leading to abnormal development of corpus luteum in multiparous dairy cows. Further, results of embryo culture of the present study showed that superovulated dairy cows infected with pestivirus during the period of final growth of preovulatory follicles may produce embryos that are not developmentally competent.

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References

- Bielanski, A. and Dubuc, C. (1995). In vitro fertilization of ova from cows experimentally infected with a non-cytopathic strain of bovine viral diarrhoea virus. *Animal Reproduction Science* 38: 215-221.
- Boland, M.P., Goulding, D. and Roche, J.F. (1991). Alternative gonadotrophins for superovulation in cattle. *Theriogenology* 35: 5-14.
- Brownlie, J. Booth P.J, Stevens D.A. and Collins M.E. (1997). Expression of non-cytopathogenic bovine viral diarrhoea virus (BVDV) in oocytes and follicles of persistently infected cattle. *Veterinary Records* 141: 335-337.
- Cook, L.G., Littlejohns, I.R. and Jessep, T.M. (1990). Induced seroconversion in heifers with a field strain of bovine pestivirus. *Australian Veterinary Journal* 67: 393-395.
- Elsden R.P. (1980). Bovine embryo transfer. In: Proceedings of Annual Meeting of Society of Theriogenology. Omaha, USA, Pp: 101.
- Fray, M.D., Mann, G.E., Clark, M.C. and Charleston, B. (1999). Bovine viral diarrhoea virus: its effects on estradiol, progesterone, and prostaglandin secretion in the cow. *Theriogenology* 51: 1533-1546.
- Fray, M.D., Mann, G.E., Bleach, E.C.L., Knight, P.G. Clark, M.C. and Charleston, B. (2001). Modulation of sex hormone secretion in cows by acute infection with bovine viral diarrhoea virus. *Reproduction* 123: 281-289.
- Grooms, D.L., Brock, K.V., Pate, J.L. and Day, M.L. (1998). Changes in ovarian follicles following acute infection with bovine viral diarrhoea virus. *Theriogenology* 49: 595-605.
- Kafi, M., McGowan, M.R., Kirkland, P.D. and Jillella, D. (1997). The effect of bovine pestivirus infection on the superovulatory response of Friesian heifers. *Theriogenology* 48: 985-996.
- Kafi, M. (1998). An Update on current concepts of the epidemiology of bovine pestivirus infection in cattle. *Archives of Razi Institute* 49: 53-64.
- Kafi, M. (2001). Recent findings and current hypotheses on the pathogenesis of low fertility in cattle associated with pestivirus infection around the time of artificial insemination: a review. *Journal of Tehran Veterinary Faculty* 56: 113-117.
- Kirkland, P.D., McGowan, M.R., Mackintosh, S. and Moyle, A. (1997). Insemination of cattle with semen from bulls transiently infected with pestivirus. *Veterinary Record* 140: 124-127.
- McGowan, M.R., Kirkland, P.D., Richards, S.D. and Littlejohns, I.R. (1993a). Increased reproductive losses in cattle infected with bovine pestivirus around the time of insemination. *Veterinary Record* 133: 39-43.
- McGowan, M.R., Kirkland, P.D., Rodwell, B. J., Kerr, D. and Carroll, C.L. (1993b). A field investigation of the effects of bovine viral diarrhoea virus infection around the time of insemination on the reproductive performance of cattle. *Theriogenology* 39: 443-449.
- McGowan, M.R., Kafi, M., Kirkland, P.D., Kelly, R., Bielefeldt-Ohmann, H. Occhio, M.D. and Jillella, D. (2003). Studies of the pathogenesis of bovine-pestivirus induced ovarian dysfunction in superovulated dairy cattle. *Theriogenology* 59: 1051-1066.
- Rufenacht, J. Rofenacht, Z. P., Schaller, L. Audige, B., Knutti, U. Kopfer and Peterhans E. (2001). The effect of infection with bovine viral diarrhoea virus on the fertility of Swiss dairy cattle. *Theriogenology* 15: 199-210.
- Schams, D., Menzer, E. Schallenberger, B., Hoffman, J. and Hann, R. (1978). Some studies on PMSG and endocrine response after application for superovulation in cattle. In: Control of reproduction in the cow. Pp: 122.
- Sedigi-Nezhad, S. (1996). A survey on BVD-MD in Iran. *Research and Reconstruction* 30: 128-131.
- Stringfellow, D.A., Ridderl, K.P., Galik, P.K., Damiani, P., Bishop, M.D. and Wright, J.C. (2000). Quality control for bovine viral diarrhoea virus-free IVF embryos. *Theriogenology* 53: 827-839.
- Swasdipan, S., Bielefeldt-Ohmann, H. Philips, N., Kirkland, P.D. and McGowan, M.R. (2001). Rapid transplacental Infection with Bovine Pestivirus following Intranasal inoculation of ewes in early pregnancy. *Veterinary Pathology* 38: 275-280.
- Vanroose G, Nauwynck H, Van Soom A, Vanopdenbosch E. and de Kruif, A. (1998). Replication of cytopathic and non-cytopathic bovine viral diarrhoea virus in zona-pellucida free and zona-intact in vitro-produced bovine embryos and the effects on embryo quality. *Biology of Reproduction* 58: 857-866.
- Virakul, P., Fahning, M.L., Joo, H.S. and Zemianis, R., (1988). Fertility of cows challenged with a cytopathic strain of bovine viral diarrhoea virus during an outbreak of spontaneous infection with a noncytopathic strain. *Theriogenology* 29: 441-449.
- Zurovac, O.V., Stringfellow, D.A., Brock K.V. Riddel, M.G. and Wright, J.C. (1994). Noncytopathic bovine viral diarrhoea virus in a system for in vitro production of bovine embryos. *Theriogenology* 41: 841-853.