INTRODUCTION

Immunoglobulins (Igs) are gamma globulin proteins that are found in blood and other body fluids of vertebrates, and are used by the immune system to identify and neutralize foreign objects, such as bacteria and viruses (Korhonen, 2000). For cattle, Igs are grouped into four isotypes, IgG (IgG₁ and IgG₂), IgA, IgM and IgE, based on the heavy chain they possess. Each of these Igs plays different roles and helps direct the appropriate immune response to different types of foreign objects (Butler et al., 1983; Korhonen, 2000). IgG, IgA and IgM are present in high levels in milk, especially in colostrum. Among these Igs, IgG₁ is the most common and abundant, and the milk concentrations of IgG₁, IgA and IgM are highly variable (Grosvenor et al., 1993). One of the main natural functions of Igs is to passively immunize or protect the calf during the early vulnerable stages of life (Bush et al., 1980).

Specific immune milk obtained from cows that are immunized with various intestinal bacterial or viral antigens can prevent the attachment of pathogens to the epithelial lining, which is a critical step in the initiation of infection (Grosvenor et al., 1993). One of the main natural functions of Igs is to passively immunize or protect the calf during the early vulnerable stages of life (Bush et al., 1980).

Bovine Igs in colostrum and milk have the potential to be used as an immunological supplement in infant formula and other hyperimmune food (Lo and Kleiman, 1996; Tawfeek et al., 2006). Hyperimmune collostral or milk preparations directed towards specific diseases may promote human health in the future, when consumed as part of a health-promoting diet or as supplement to medical treatment regimes (Ashraf et al., 2001; Marnila et al., 2003).
et al., 2003). Thus, strategies to increase milk concentrations of Igs are highly sought after.

Numerous researchers have attempted to increase the production of hyperimmune milk or milk levels of Igs. Recently, we have reported a new method using implantation of an Antigen Release Device (ARD) to increase the concentration of specific antibodies against a common antigen (lipoprotein lipase) in serum and whey (Liu et al., 2009). The ARD is a controllable type of antigen transfer system to stimulate the animal to produce Igs (Pearse and Drane, 2004). The core of this ARD is an immunostimulating complex (ISCOM)-based vaccine. The ARD device is coated with different concentrations of biodegradable and biocompatible polylactic acid, also known as polylactide, which can control antigen release. Thus, the ARD should release the antigen gradually and have the same effect as several vaccinations. The objectives of the study were to i) determine the concentrations of Igs in serum and whey after implanting of the ARD, ii) detect the correlation between concentrations of Igs and production parameters, and iii) compare the concentrations of Igs in colostrum and in normal milk.

MATERIALS AND METHODS

Cows and ARD implantation

Twenty healthy second-lactation Chinese Holstein cows in mid-lactation were divided into two groups (test group and control group, n = 10) according to milk yield (26.0±3.5 kg) and lactation period (114±34 d). All cows were housed under the same conditions in Cangdafu farm located in northern China, and fed a TMR ration three times daily.

Immune milk was produced by implanting the ARDs provided by Agri-BIOTECH (Perth, Western Australia). Each capsule of ARD contained 0.76 mg of Pseudomonas lipase and 0.25 mg of Quil A. Three types of ARDs were implanted into each cow of the test group. ARD1 (2.3 mm in diameter and 6.2 mm in length) was not coated with polylactide and thus released its antigen immediately. ARD2 and ARD3 (both are 5.0×10.0 mm) were coated with different concentrations of polylactide and released their antigen at 14 and 28 d, respectively, after implantation. The immunostimulating complex (ISCOM) in the core of the ARDs was made of adjuvant Quil A and Type VIII lipase from a Pseudomonas sp. (Sigma, St. Louis, MO). Each cow of the test group was implanted with the three types of ARDs at the same time in the right iliac lymph node using an implantation gun (Synovex; Fort Dodge, Baulkham Hills, Australia) with a single injection.

Sample collection

The test period lasted for 40 d. Milk production was recorded every 10 d for each cow. Milk samples were collected at d 0, 5, 7, 9, 15, 17, 20, 26, 30 and 40 after ARD implantation. For each animal, duplicate milk samples were collected at 09:00, 16:00 and 22:00 on each sampling day using a robotic system, and mixed in a ratio of 4:3:3 for morning, afternoon, and evening milk by volume. The first aliquot of milk sample (50 ml) from each milking was preserved with bronopol-B2 and subsequently analyzed for fat, protein, lactose, dry matter and somatic cell count (SCC) using a MilkoScan Minor machine (MilkoScan 4000, Foss Electric, Hillerod, Denmark). The second aliquot of milk sample (30 ml) from each individual cow was centrifuged at 1,500 rpm for 15 min at 4°C to remove the fat (Legend Mach 1.6/R, Sorvall, Germany). Then, 5 μl of remin (200 mg ml⁻¹, Sigma) was added to 10 ml of the centrifuged milk. The milk samples were kept at 37°C for 2 h and then were centrifuged at 5,000 rpm for 30 min. The whey samples, collected from the supernatant, were frozen at -80°C. Simultaneously, colostrum samples were collected every day for the first 7 days after parturition from 27 gravid Chinese Holstein cows on the same farm.

Blood samples were taken from the caudal vein of each animal in evacuated tubes containing EDTA (1.8 mg ml⁻¹ of blood) at d 0, 5, 11, 15, 20, 30 and 40 after implantation, and then centrifuged at 3,000 rpm for 30 min to separate serum. The serum samples were frozen at -80°C for further analysis.

Determination of Igs concentrations in whey and serum

Concentrations of IgG1, IgA and IgM were measured by sandwich enzyme-linked immunosorbent assay (ELISA) using the Bovine IgG1/IgA/IgM ELISA Quantitation Kit (Bethyl Laboratories, Inc., Montgomery, TX). The serum samples were diluted to 1:5,000, 1:1,000 and 1:1,000, whereas the whey samples were diluted to 1:1,000, 1:500 and 1:1,000 for IgG1, IgA and IgM assays, respectively. The final absorbance of the samples was measured at 450 nm, using an ELISA plate-reader (Infinite F200; Tecan, Switzerland). The quantification procedures were performed according to the manufacturer’s instruction. Assay precision was defined by determining intra-assay and inter-assay variations. The intra-assay and inter-assay coefficients of variation were 8.9% and 10.3%, respectively.

Statistical analysis

The data was analyzed using the MIXED model of SAS 9.0 (SAS Institute, Cary, NC, USA). The statistical model included cows (individual animals) as a random effect and period and treatment as fixed effects, and significance was assumed at p<0.05. The correlation coefficients among indices were analyzed by Pearson’s correlation coefficient, and significance was assumed at p<0.05. The data on the immunoglobulin concentrations of colostrum was analyzed using Duncan’s multiple range tests and significance was
RESULTS AND DISCUSSION

Variation of Igs concentrations in serum and whey after ARD implantation

The IgG/IgA/IgM production in serum and whey at different days after ARD implantation is shown in Table 1. In serum, the concentrations of IgG1, IgA and IgM increased after ARD implantation, but not significantly. The concentrations of IgM and IgA varied significantly (p<0.05) along with lactation period. Concentration of IgG1 was maintained at a relatively low level during the first 15 d, then increased significantly (p<0.05) to peak at d 20, and remained at that level for the following 20 d. In particular, concentration of serum IgG1 in the test group was significantly (p<0.05) higher than in the control group at d 40 (Figure 1), 12 d after the release of ARD3.

In whey, the concentrations of Igs also increased after ARD implantation, but not significantly (Figure 2). Concentration of IgA in whey decreased slowly until d 15, then increased sharply, and finally decreased again; concentration of IgM showed no significant (p>0.05) changes during the test period. For IgG1, the concentration began to ascend at d 0 after ARD implantation, and then peaked at d 9, 17, 30, which was consistent with the release of the three ARDs. ARD1, ARD2 and ARD3 released their antigens at d 0, 14 and 28, and the concentration of IgG1 increased and persisted for 10 d, 2 d and 1 d, respectively, before dropping gradually. These results clearly demonstrated the stimulatory effect of the antigen on IgG1 production.

ISCOM antigens in the core of the ARD can stimulate humoral response and production of Igs, of which IgG1 is the main antibody involved in the immune response (Caffin et al., 1983). The three releases of ISCOM in the body of the cow were equivalent to primary, secondary, and booster vaccinations, respectively. In dairy cows, almost all milk IgG1 comes from the blood, while milk IgA and IgM comes from both the blood and synthesis by plasmocytes in the mammary gland (Butler, 1998). IgG1 is typically transferred selectively from serum into colostrum or milk by a neonatal Fc receptor (FcRn)-mediated mechanism in the mammary gland secretory epithelium (Kolb, 2002; Vaccaro et al.,

Table 1. The concentrations of IgG1/IgA/IgM in serum and whey (mg ml⁻¹)

<table>
<thead>
<tr>
<th>Samples</th>
<th>Items</th>
<th>Treatment</th>
<th>ANOVA (p&lt;0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Test</td>
<td>Control</td>
</tr>
<tr>
<td>Serum</td>
<td>IgG1</td>
<td>3.186</td>
<td>2.344</td>
</tr>
<tr>
<td></td>
<td>IgA</td>
<td>0.133</td>
<td>0.121</td>
</tr>
<tr>
<td></td>
<td>IgM</td>
<td>2.864</td>
<td>2.454</td>
</tr>
<tr>
<td>Whey</td>
<td>IgG1</td>
<td>0.435</td>
<td>0.311</td>
</tr>
<tr>
<td></td>
<td>IgA</td>
<td>0.159</td>
<td>0.131</td>
</tr>
<tr>
<td></td>
<td>IgM</td>
<td>0.039</td>
<td>0.040</td>
</tr>
</tbody>
</table>

Test = Test group, implanted with 3 types of ARD (n = 10); Control = Control group, without ARD implantation (n = 10). NS = Not significant (p>0.05).

Figure 1. The variations of IgG1 concentration in serum. The values are noted as mean±se. * Denotes levels that are significantly different from those of the control group at the same day (p<0.05). Test group, implanted with 3 types of ARD (n = 10); control group, without ARD implantation (n = 10).
Therefore, the regularity patterns of IgG1 concentrations, but not IgA and IgM, were consistent with the releases of the three ARDs.

In this study, concentrations of IgG1, IgA, and IgM in the serum and the whey were not affected significantly by the ARD implantation, but the serum IgG1 concentration significantly (p<0.05) increased 12 d after the third release of the ARD. The delayed increase in concentration of serum IgG1 suggests that the level of the ISCOM vaccine was inadequate to stimulate a quick immune response. In our previous study, Liu et al. (2008) revealed that specific IgG titer and IgG mass in serum and whey increased significantly (p<0.05) in cows implanted with the same ARD, and the specific IgG titer corresponded well with the releases of the antigen from 3 types of ARD. Cheng et al. (2008) indicated that the implantation of the same ARD did not significantly increase the concentration of lactoferrin in the serum and milk throughout the whole experiment period except on two occasions. The levels of lactoferrin in the milk and serum significantly increased on d 7 and 11 after implantation. In addition, Claerebout and Verheyckx (2000) found that the level of IgG1 against gastrointestinal nematodes (GIN) appeared to be dependent on levels of antigenic stimulation. Therefore, a higher level of ISCOM vaccine or prolonged immune program may be required to significantly increase the concentrations of Igs in milk.

**Correlation between milk Igs concentrations and production parameters**

In this study, we found that the lactation period also affected the concentrations of Igs after the ARD stimulus. To assess whether other production parameters can affect the concentrations of Igs in milk in normal dairy cows, we used the Pearson’s correlation coefficient in comparing the differences between production parameters of dairy cows (including lactation period, dry matter, milk yield, fat, protein, lactose, SCC) and concentrations of Igs in milk (Table 2). There was no significant correlation between the concentrations of Igs and production parameters except for IgA in the whey. The whey concentration of IgA had a significant (p<0.05) correlation with lactation period with a Pearson’s correlation coefficient of 0.76, which corresponded to the above-mentioned results in immune milk and is consistent with results from Korhonen et al.

**Table 2.** Pearson’s correlation coefficients between concentrations of Igs and production parameters of dairy cow

<table>
<thead>
<tr>
<th>Igs</th>
<th>Lactation period</th>
<th>Milk yield</th>
<th>Milk fat</th>
<th>Milk protein</th>
<th>Milk lactose</th>
<th>Dry matter</th>
<th>SCC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Serum</td>
<td>IgG1</td>
<td>0.339</td>
<td>-0.256</td>
<td>0.064</td>
<td>0.073</td>
<td>-0.009</td>
<td>0.072</td>
</tr>
<tr>
<td></td>
<td>IgA</td>
<td>-0.229</td>
<td>-0.223</td>
<td>-0.106</td>
<td>0.103</td>
<td>0.552</td>
<td>0.055</td>
</tr>
<tr>
<td></td>
<td>IgM</td>
<td>-0.498</td>
<td>-0.198</td>
<td>0.079</td>
<td>0.092</td>
<td>0.170</td>
<td>0.132</td>
</tr>
<tr>
<td>Whey</td>
<td>IgG1</td>
<td>-0.390</td>
<td>0.098</td>
<td>0.311</td>
<td>0.354</td>
<td>-0.328</td>
<td>0.303</td>
</tr>
<tr>
<td></td>
<td>IgA</td>
<td>0.76*</td>
<td>0.641</td>
<td>0.165</td>
<td>0.084</td>
<td>0.026</td>
<td>0.177</td>
</tr>
<tr>
<td></td>
<td>IgM</td>
<td>-0.073</td>
<td>0.411</td>
<td>0.336</td>
<td>0.332</td>
<td>0.259</td>
<td>0.337</td>
</tr>
</tbody>
</table>

The data were obtained from milk and serum samples of all the cows in both the test and control groups (n = 20) at d 0 before the ARD implantation.

The data marked with an asterisk (*) indicate significant correlation (p<0.05).

Somatic cell score (SCS) was calculated from the formula: log2(SCC/100,000)+3.
(2000). However, from an analysis of 299 Chinese Holstein cows, Liu et al. (2009) noted that milk IgG₁ concentration was significantly correlated with lactation number, stage of lactation, daily milk production and SCC. Sanchez et al. (2004) also revealed a correlation between lactation period and milk IgG₁ concentration. Other factors, such as maternal age, parity, breed, nutritional status, premature parturition, and time after parturition, were also shown to affect the levels of Igs (McFadden et al., 1997). These conflicting results may arise from small sample numbers, selective transport process in the mammary gland, or varied milk production (Caffin et al., 1983).

**Variation of Igs concentrations in Colostrum**

Figure 3 shows the variation of IgG₁, IgA and IgM in the colostrum sampled from the other 27 gravid dairy cows on the same farm. During the first 3 d, the concentrations of colostral IgG₁, IgA, and IgM all decreased significantly (p<0.05), from 120.81±94.38 to 9.09±8.03 mg ml⁻¹, from 11.69±8.31 to 9.91±0.88 mg ml⁻¹, and from 7.16±0.45 to 0.45±0.37 mg ml⁻¹, respectively. During the remaining 5 d of sampling, the concentrations of IgG₁, IgA and IgM also decreased, but not significantly. However, concentrations of IgG₁, IgA and IgM in normal and immune milk were significantly (p<0.05) lower than in the colostrum samples. Our results are, in general, consistent with previous reports (Quigley et al., 1994; Butler, 1998; Levieux and Ollier 1999), except for a higher colostral IgG₁ concentration (120.81±94.38 mg ml⁻¹) than that (59.8±28.5 mg ml⁻¹) noted by Levieux and Ollier (1999) who used a single radial immunodiffusion assay at d 0. Presumably, this discrepancy can be attributed to the different sampling period and/or the method used. Nevertheless, IgG₁ had the highest concentration compared to other Igs in the colostral samples (Figure 3). As the most abundant Ig in colostrum, the concentration of IgG was approximately 50 to 100 times higher than in normal milk (Mero et al., 1997).

**CONCLUSION**

The present study showed that there were more Igs in colostrum than normal milk, and lactation period could affect the milk IgA concentration. Serum IgG₁ concentration only began to increase significantly after the third ARD release, suggesting that an ISCOM vaccine dose higher than the one used is needed to significantly increase milk concentrations of Igs. The results can be used to design future studies to determine the appropriate doses and/or the number of vaccine releases.

**REFERENCES**


Caffin, J. P., B. Poutrel and P. Rainard. 1983. Physiological and


