Attachment accuracy of a novel prototype robotic rotary and investigation of two management strategies for incomplete milked quarters

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Abstract. Throughout 2009 and 2010, FutureDairy (Camden, NSW, Australia) was involved in testing a novel prototype robotic rotary (RR). The commercial version RR is expected to be capable of carrying out 90 milkings per hour. To achieve the high throughput the rotary rotates the cow to the cup attachment robot and then around the platform in a stop–start fashion. The robot does not remain with the cow during the entire milking process. When not all teat cups are attached during a milking session there is an opportunity for cows to be sent back to the waiting yard for a second milking attempt. The study presented here was designed to test whether or not the extension of the interval to a second milking attempt improved milking success of incompletely milked cows. It was expected that with an increased milking interval between the two subsequent milkings the changes to the udder conformation could positively affect the attachment success at the second attempt. The one hour milking interval treatment (**1 h**) simulated cows being drafted directly back to the pre–milking waiting yard, whilst the three hour milking interval treatment (**3 h**) was designed to simulate cows being drafted back after accessing post–milking supplementary feed on a feedpad. The results presented in this manuscript showed no significant difference between the frequencies of successful attachment in the second attempt between the **1 h** and **3 h** treatments indicating that a reasonable level of flexibility exists with management of incompletely milked cows and dairy layout designs. Milk production level affected the probability of success at second attempt, which was about 7.5 times higher in cows with an average milk production level greater than 19.3 kg than those with less than 10.8 kg. When looking at the total proportion of cows successfully milked after two attempts, it was found that successful milking was more likely in multiparous cows compared to primiparous cows.

Additional keywords: success–rate, pasture based, automatic milking system, robotic rotary, dairy

1. Introduction

Whilst automatic milking system (AMS) technology was initially designed for small family farms, more recently (after continuous technological advancement and an increased level of AMS management skills and confidence in the technology) larger farms with more than 500 cows are adopting the system (Svennersten-Sjaunja and Pettersson, 2008). When a teat cup is not attached to an intended teat, the cow can leave the AMS unmilked in that quarter. A study with an average attachment failure rate of 7.6% showed that, when accounting for the effect of an extended milking interval (of the unmilked quarter), milk production for the affected quarter was 26% lower than the yield measured after milking sessions associated with successful teat cup attachment (Bach and Busto, 2005). This impact on yield and the additional impact on system efficiency and udder health, indicate the importance of accurate attachment. Studies around existing indoor AMS have also shown the importance of the design of the automatic milking farm/barn to improve system efficiency, which has importance with regard to both economic and animal welfare needs (Halachmi, 2004; Halachmi et al., 2003).

During 2009 and 2010, a prototype robotic rotary (RR; DeLaval automatic milking rotary—AMR™, Tumba, Sweden; Figure 1) was co-developed, installed, and tested at the Elizabeth Macarthur Agricultural Institute (EMAI), Camden, NSW, Australia. The RR is the world's first reported "high throughput" AMS to be developed. It is expected to be capable of carrying out up to either 900 or 1600 milkings per day depending on the installation (with either two or four robots) and system management.

(Insert Figure 1 here)

The equipment used was a prototype internal, 16 bail, herringbone rotary (DeLaval HBR) with two robotic arms (one teat preparation module and one automatic cup attacher; Figure 1A) fixed to the floor inside the RR platform and whilst the arm has vertical lateral and horizontal planes of movement the footing remains stationary. To enable the RR to achieve such high levels of throughput (compared to a single–box AMS,), the rotary platform rotates the cow around from the entry point to the exit point in a stop–start operation. The fact that the robotic arm does not remain with the cow during the entire milking process means that any unattached or prematurely removed milking cups cannot be (re)attached once the cow has been rotated passed the attachment bail. The configuration of the RR platform is such that cows are positioned at approximately 120° to the robotic arm (the angle of the cow on the platform is 30°). This is a significant change in orientation compared to the positioning in a single–box robot. All existing commercial single– or multi–box AMS have a robot approaching the side of the cow at a 90° angle or from behind. The combined effect, of no opportunity for reattachment and cow orientation in relation to the robotic arm, increases the potential occurrence of incompletely milked cows.

Whilst investigating the feasibility and application of the RR, assessments of the reliability of the RR itself and development of practical working routines is necessary. One particular area of interest is the most suitable management routines for cows which have an “incomplete” milking session. For the purposes of this study an “incomplete” milking is defined as a milking whereby not all teats are attached successfully for milking. When a given milking session is defined as incomplete, there is an opportunity for cows to be granted a second milking attempt. If the appropriate infrastructure exists, the incomplete cow can be drafted directly back to the waiting area for another milking. In a pasture–based system it is not uncommon to have a feedpad for provision of supplementary feed within close vicinity of the dairy. Where such a facility exists there may also be an opportunity to draft cows to the feeding area to extend the interval between the first and second attempt at milking. The subsequent success rate of reattachment in these two scenarios may differ as a direct result of the interval between the two milking sessions (1st and 2nd attempt) due to the impact of interval on the udder and teat conformation. It is known that longer milking intervals between two attempts are associated with a higher level of udder fill (Knight et al. 1994 and Stelwagen et al. 1996) and therefore a change in the likelihood of successful attachment could be expected.

This study was conducted to evaluate success rate of reattachment after an incomplete milking with two management strategies in a pasture–based system. It was hypothesized that the extension of the interval between two attempts for milking would increase the attachment success rate of previously incompletely milked cows. It was expected that with a longer milking interval between the two milking attempts, success of teat cup attachment would be improved through the associated reduced flaccidity and proximity of the teats and udder. The results of this investigation should allow a more informed approach to be taken in proposing suitable management routines and dairy layouts for commercial RR installations.

An additional objective of the study was to quantify and report any trends in attachment success on individual quarters.

2. Materials and methods

2.1. Experimental design

During the four–day trial (May 24–27, 2010) the 155 mixed breed (majority Holstein-Frisian and approximately 10–15% Illawarra) cows were managed and grazed as per recommended practice (Kerrisk, 2010) at Elizabeth Macarthur Agricultural Institute (Camden, NSW, Australia). At the time of the study the cows averaged 174 days in milk (DIM; median = 174), 3.2 lactations (median = 3), and were producing 10 kg milk per milking and 17.5 kg milk per day (7–day average production level) with an average milking frequency of 1.75 milkings/cow per day. Each day the herd was allocated two accurate (12 hour) allocations of feed, one of pasture and one of partial mixed ration (PMR) due to the limited availability of pasture at the time of the trial. The PMR was made available each night on a sacrifice feeding area while the pasture allocation was available during the day. Average feed intake (kg DM/cow.day) during the study period was 8.6 pasture and 12.1 PMR (7 kg DM maize silage, 2.5 kg DM Lucerne hay mix and 2.6 kg pelleted concentrates). In addition, a small amount of pelleted concentrate (~250g) was made available in the RR to entice voluntary cow traffic through the system and encourage correct positioning of the cows at the entry bail. During the trial, cows had voluntary access to two adjacent single–box AMS (DeLaval VMS™, Tumba, Sweden) in the afternoon and night (1400 to 0700 h) and were drafted to the RR in the morning (0700 to 1200 h) for the completion of the RR experimental milking sessions (0800 to 1400 h). Each day approximately 100 cows were milked during the observed milking session; these were not necessarily the same 100 cows each day but 92% of cows had three or more observed milkings and 57% of cows were involved in all four observation sessions (n = 129 different cows recorded during the four–day period).

For the purpose of this study the first observed milkings will be called **first attempt** and any cows that did not have all cups successfully attached at the first attempt will be called **incomplete**; conversely, if all cups were attached the milking is termed **complete**. Normally premature teat cup removal resulting in a low milk yield for any individual quarter would also be classed as an incomplete milking but in this study such cases were avoided by manual intervention to ensure that only completely unmilked teats were contributing to the incomplete records.

All incompletely milked cows at the first milking attempt were returned for a **second attempt** after either **one hour (1 h)** or **three hour (3 h)** waiting periods. During the second attempt the RR (automatically) targeted only the quarter(s) that was/were missed at the first attachment attempt. In other words, quarters milked successfully ("complete quarters") at the first attempt were not remilked at the second attempt. On days 1 and 2, cows were subjected to the **1 h** treatment. A total of 212 milkings were observed during the milking sessions over these two days. Cows were milked in batches of approximately 50 cows at a time to allow staff to return incomplete cows (n = 40 over two day period) back to the system within an hour, simulating an automatic drafting system that could generate a similar result with voluntary cow traffic. On days 3 and 4 cows were subjected to the **3 h** treatment with all cows (216 milkings) receiving their first milking in one batch. The incomplete cows (46 milkings) were drafted to the sacrifice feeding area (otherwise only available at night) to allow them to eat and loaf during the three hour waiting period between first and second attempt. These cows were then returned from the feeding area to the waiting yard at around three hours after milking (minimum milking interval two hours). This treatment was designed to simulate the situation where cows gain access to a feeding area before being drafted back to the waiting yard as they exited the feeding area. To minimize any negative impact on animal welfare, all cows unsuccessfully attached by the teat cup attachment robot at second attempt were attached manually (i.e. with human assistance).

2.2. Statistical analyses

2.2.1. Outcome variables

Two binary outcomes (yes/no) were measured in the presented study: (1) Whether a cow incomplete at *first* attempt was subsequently complete at *second* attempt; and (2) whether a cow was successfully milked *after two* attempts. Electronic data collected by the VMSClient management program (DeLaval, Tumba, Sweden) were used to calculate the milking interval whilst the success of attachment at both the first and second attempts on the RR was recorded through visual observation.

Analyzes were conducted to investigate the effect of individual quarters on the proportion of incompletely milked cows at the first attempt. The four quarters, left back, right back, left front and right front, as well as 'back' (grouped; left back and right back) and 'front' quarters (grouped; left front and right front) were tested for the incidence of attachment failures.

2.2.2. Explanatory or predictor variables

Additional electronic data were collected to investigate the relationship between attachment success and stage of lactation (days in milk; DIM), parity (lactation number), production level (7–day average production), milking interval leading up to first attempt (hours since previous milking) and interval between first and second attempts.

2.2.3. Statistical models

The data were analyzed with GenStat 13th Edition (VSN International, Hertfordshire, UK) with a similar approach used for all binary outcome variables. Initially, contingency tables of explanatory variables were created to make preliminary evaluations of the association of explanatory variables (as described above) with the outcomes. Later, univariable generalized linear mixed models (GLMM) were built to test association of each explanatory variable with outcome variables. Cow ID was included as a random effect in models to take into account the multiple observations from each cow.

The assumption of linearity for quantitative variables was tested by categorizing variables by quartiles for all GLMM analyses. Categorized variables were used for further analyses, if this assumption was invalid. All variables with a P–value < 0.25 in univariable analyses were included in the final GLMM model. Insignificant variables (P > 0.05) were then eliminated using a backward stepwise approach. Odds ratios and their confidence limits from the final model were presented and discussed.

3. Results

The actual interval between first and second attempt averaged 1:03 (max. 2 hours) and 3:30 (h:mm; max. 5 hours) for the 1 h and 3 h treatments, respectively. The descriptive statistics, presented in Table 1, show the attachment success of the first attempt, proportion of successful second attempts and the overall proportion of completely milked cows after two attempts.

(Insert Table 1 here)

3.1. Difference in attachment success on individual quarters

Exploration of the results showed that the probability of incomplete at first attempt was significantly different between individual quarters (Table 2). The probability of incomplete attachment was highest in left back teats as they were 3.3 times less likely to be attached compared with right front teats, which were most likely to be attached at first attempt. When comparing the combined front and back quarters, the front quarters were 2.5 times more likely to be attached successfully at first attempt.

(Insert Table 2 here)

3.2. Successful attachment at second attempt

Probability of success at second attachment was not significantly different between 1 h and 3 h treatment but it was included in the final model as it was the variable of primary interest. Of the other explanatory variables tested, only the average 7–day milk production was significant (see Table 3).

(Insert Table 3 here)

3.3. Successfully milked after two attempts

Parity was significant in the final multivariable model – successful milking after two attempts, whilst the treatment variable (the variable of main interest) was not significant (Table 4).

(Insert Table 4 here)

4. Discussion

There was no significant difference found between the frequency of successful attachment at second attempt in the **1 h** and **3 h** treatments. It is likely that the additional 2.5 hour waiting period (for the **3 h** treatment) was insufficient to cause any dramatic changes in udder conformation that might have otherwise resulted in a treatment effect. However, it was found that cows with a production level higher than 19.3 kg were up to 7 times more likely to result in a successful and complete milking at the second attempt compared to cows producing less than 11 kg. The higher production level would likely be associated with a fuller and more distended udder which may have made it easier for any automatic cup attachment device to locate the teats. The impact of length of post-milking period on cisternal milk volume would be largely dependent on the production level of the cow (Knight et al., 1994). Knight et al. (1994) reported that cisternal milk volume remained low (600g or less) until four hours after milking with two groups of cows producing 28 and 15 litres. A similar study by Stelwagen (1996) reported that whilst the volume remained low until seven or eight hours post milking, the cisternal compartments actually started filling immediately after milking.

The results presented here are particular to pasture–based cows which will have a lower energy intake than cows in an indoor system fed a high energy total mixed ration (TMR). In addition to milking frequency, energy intake has a major effect on production level, as shown in a study by Utsumi (2011). It was shown that when cows were managed on pasture, with the availability of 1 kg concentrate per 4 kg milk in the AMS stall, the limiting factor in milk production was energy intake levels rather than milking frequency. When energy intake is not the limiting factor (during periods of a complete TMR diet) the greatest factor affecting production level was the milking frequency (Utsumi, 2011). Under such circumstances the effect of an extended interval between two attempts could be greater as the udder fills more rapidly.

In agreement with the findings of this study, differences in attachment success between front and back quarters have been recognized (albeit not quantified) in studies with single–box AMS (Capelletti et al., 2004; Hamann et al., 2004). These studies also showed that back quarters were more difficult to attach for an automatic cup attachment robot.

One of the key differences in technology functionality (between the AMS and RR) is that AMS have the opportunity to have several attachment attempts whilst the cow is in the crate for an entire milking session. Conversely, the RR has only one opportunity to attach milking cups per rotation. Each milking cup was collected by the robotic arm only once while the cow was in the attachment bail, after the attachment the cow was rotated to the next position on the rotary.

It could be considered worthwhile to have the robotic cup attachment arm take additional attempts to attach individual cups prior to allowing the cow to rotate to the next bail. Although the impact on throughput and milk harvesting rates would obviously be negatively affected and this needs to be weighed up against the loss in efficiency caused by milking 20% of cows a second time.

The significant impact of only parity on the second outcome variable — proportion of all cows which were successfully milked after two attempts, was somewhat surprising. The impact of parity would likely be largely created by changes in udder conformation and the more difficult shaped (compact and higher) udders often associated with younger cows. Some of the parity effect may have also been attributed to animal behavior. Not surprisingly different udder shapes have been reported to result in variable attachment success in AMS in other studies (Migliorati et al., 2004). This effect requires further investigation as the most suitable management of incompletely milked younger cows could be different to that of older cows.

It is important to mention that, as this study was part of the development of RR, ongoing improvements of the technology prior to full commercialization of the product will undoubtedly result in improved performance of the technology and will likely impact on the absolute incidence of incompletes at first attempt. However, it is anticipated that the trends and treatment differences indentified in the presented work will likely remain unchanged. It is also anticipated that the learnings from the work presented here will continue to have relevance when the layout and cow trafficking routes of new RR installations are being considered, particularly where these include a post-milking feeding area. Whilst the impact on milk yield of effectively extending the interval between milking for the individual quarter(s) that were not successfully attached at first attempt was not measured in this study, it would be likely that a prompter return for the second attempt would be beneficial to short term milk production and udder health.

5. Conclusion

Because this research was conducted on one of just three installations of the prototype RR globally, literature pertaining to operational management with a high throughput RR does not exist, indicating that the findings presented here are invaluable to furthering industry understanding of management with this new milk harvesting technology. The system showed no "attachment success" differences between milking incomplete cows after one hour or three hour intervals. This suggests that there is a level of flexibility available in designing the dairy layout and that no significant advantage or disadvantage (with regard to subsequent success level) exists in drafting cows directly back to the pre-milking yard after an incomplete milking or after visiting a feedpad. The magnitude of incompletely milked cows after two attempts (10%) was biologically significant, suggesting that additional preventive measures will need to be considered to prevent potential cow health issues when operating with a RR dairy.

Acknowledgements

This work was carried out within the FutureDairy program. We wish to acknowledge the investors of the program; Dairy Australia, DeLaval, Department of Primary Industries NSW and The University of Sydney. The investors of FutureDairy had no role in any of the following; study design, the collection, analysis and interpretation of data, writing of the report, and the decision to submit the paper for publication. The authors also gratefully acknowledge Mikael Karttunen for his technical support of the RR and the FutureDairy farm and technical staff for their assistance.

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Table 1: Number of incomplete milkings at a first milking attempt, successful milkings at second milking attempt and complete milkings after two attempts (with proportions between brackets)

Data	**Treatment**	**Total**	**Incomplete at 1st attempt**	**Successfully attached at the 2nd attempt**	**Completely milked after two attempts**
Robotic rotary					
	RR 1 h	212	40 (0.190)	19 (0.48)	191 (0.90)
	RR 3 h	216	46 (0.210)	17 (0.37)	187 (0.87)

Table 2: Univariable results to investigate the association of individual quarters on probability of incomplete at first attempt. Cow ID was included as a random effect in the model (back = left back + right back, front = left front + right front)

Variables	***Categories***	***b***	***SE(b)***	***P–value***	***Odds ratio***	***95% CI****
Teat				<0.001		
	Left back	1.19	0.30		3.27	1.83, 5.84
	Right back	0.98	0.30		2.65	1.49, 4.74
	Left front	0.34	0.30		1.41	0.79, 2.52
	Right front	0				
Front and back quarters combined				<0.001		
	Front teats	0				
	Back teats	0.90	0.21		2.46	1.63, 3.71

* Confidence Interval

Table 3: Final General linear mixed model to investigate the association of treatment and other variables with the outcome variable - proportion of cows incomplete at first attempt which were subsequently complete *at second* attempt. Cow ID was included as a random effect in the model

Variables	***Categories***	***b***	***SE(b)***	***P–value***	***Odds ratio***	***95% CI****
Constant		-0.71	0.63			
Treatment				0.420		
	1 h	0				
	3 h	-0.41	0.51		0.66	0.24, 1.86
Milk yield 7 days				0.038		
	0–10.8	0				
	11.9–14.7	-0.00	0.80		0.99	0.19, 5.14
	14.8–19.2	0.51	0.78		1.66	0.34, 8.14
	≥19.3	2.01	0.79		7.47	1.48, 37.45

* Confidence Interval

Table 4: Final General linear mixed model to investigate the association of treatment and other variables on the second outcome variable - proportion of all cows which were successfully milked *after two* attempts. Cow ID was included as a random effect in the model

Variables	***Categories***	***b***	***SE(b)***	***P–value***	***Odds ratio***	***95% CI****
Constant		1.47	0.41			
Treatment				0.144		
	1 h	0				
	3 h	-0.50	0.34		0.61	0.31, 1.19
Parity				0.003		
	1	0				
	2	0.96	0.43		2.61	1.13, 6.07
	3	1.84	0.43		6.32	2.72, 14.67
	≥ 4	1.82	0.43		6.16	2.65, 14.29

* Confidence Interval

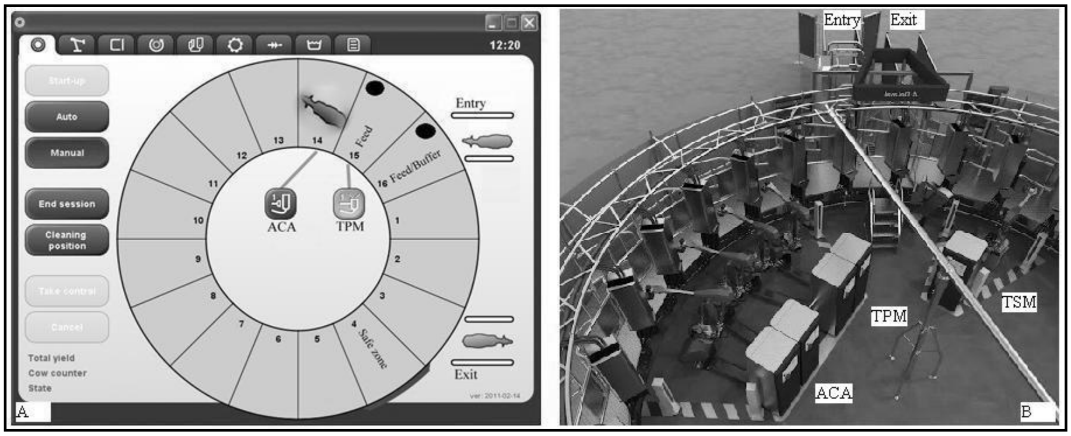

Figure 1: (A); schematic of the16 bail prototype RR showing; the entry to the rotary, one teat preparation module (TPM), one automatic cup attacher (ACA), exit and entry from the rotary platform and the feed available at bails 15 and 16, (feed bin position indicated as black circles); and (B) the commercial internal 24 bail herringbone rotary with two TPM, two ACA and one teat spray module (TSM); (Schematic graphic user interface of AMR™; courtesy of DeLaval)