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Expected pregnancy rate in recipient cattle, sheep and goats derived using a model incorporating embryo and maternal contributions to embryo survival

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ABSTRACT

Pregnancy rate to term after embryo transfer (ET) in cattle ranges from 30-50%. A model is proposed which partitions embryo survival into independent and binomial embryo and maternal components. Parameters for these two components can be used to calculate expected pregnancy rates. In 35 out of 36 sets of data in which pregnancy data were recorded following contemporary single and twin ET, or single and twin ovulation, expected pregnancy rate was either within 5 percentage units or one standard deviation of observed pregnancy rate. Pregnancy rate changes in single ET recipients or single ovulating females are equally sensitive to changes in the embryo and maternal components. In contrast, pregnancy rate changes in twin ET recipients or twin ovulating females are more sensitive to changes in the maternal component. In conclusion, these data suggest that the model adequately describes embryo survival and pregnancy rates. Accordingly, research to improve the maternal component seems warranted in order to improve reproductive success.

Keywords: cattle, recipients; pregnancy rate; embryo; maternal; modelling.

INTRODUCTION

The efficiency of beef production (Davis *et al.,* 1983 and 1984) and dairy production (Peters and Ball, 1987) is closely related to reproductive rate. A major component of reproductive rate is embryo survival rate to term. For most practical purposes, embryo survival rate is synonymous with pregnancy rate. Pregnancy rate to term following artificial insemination is of the order of 60 - 70% in well-managed herds (Zavy, 1994).

Embryo transfer (ET) in cattle has been commercially available for over two decades. In most instances, single embryos have been transferred and pregnancy rates have been taken as reflecting embryo survival rate. In large-scale commercial bovine embryo transfer programmes, pregnancy rates of between 40 and 70% have been reported (Hasler *et al.,* 1987, 1995). Embryo transfer-induced twin calving has been attempted in many studies and pregnancy rates of 40 - 70% can be achieved (McMillan, 1996a).

The reasons for high post-transfer loss of in vitro-produced bovine embryos are unknown. However, our results (McMillan *et al.,* 1997) show that a model of independent binomial embryo and recipient effects adequately explains embryo loss. To effectively partition embryo loss into embryo and recipient contributions requires analysis of the results from experiments involving transfer of single and twin embryos (McMillan, 1997b).

The aims of this study were to determine:

- the extent to which expected pregnancy rate, based on this model, was similar to observed pregnancy rate
- the relative contributions of the embryo and maternal component in determining expected pregnancy rate

MATERIALS AND METHODS

Assumptions used in the model, and the methodology for estimating the two relevant parameters (e for embryo component and r for maternal (or recipient) component) have been presented elsewhere (McMillan, 1996b). The term e can be interpreted as the expected embryo survival rate when all females are fully competent at sustaining a pregnancy (i.e., r = 1.0). Similarly, r can be interpreted as the expected pregnancy rate in single ET recipients when all embryos are fully competent to survive (i.e., e = 1.0). Expected pregnancy rate in single ET recipients is $e \times r$, and for twin ET recipients, $e \times r \times (2 - e)$ (McMillan, 1996b). Eighteen sets of data were used to compare observed and expected pregnancy rate for the 18 estimated values of e and r as described below. Firstly, observed distributions of recipient cattle with either 0, 1 or 2 calves born from either contemporary single or twin ET in 5 published studies were used to estimate pregnancy rate (Heyman *et al.,* 1995; Reichenbach *et al.,* 1992; Sinclair *et al.,* 1995; Takada *et al.,* 1991; Van Soom *et al.,* 1994). Secondly, some recently published data in recipient cattle in which pregnancy rate was determined between Day 14 and Day 60 of pregnancy (McMillan *et al.,* 1997). And finally, 8 sets of data from cattle, sheep and goats that were previously used to compare observed and expected incidences of partial failure of multiple ovulation (McMillan, 1996b). Differences were established using contingency table analysis with correction for continuity (Snedecor and Cochran, 1967). The sensitivity of the pregnancy rate changes of single compared with twin ET recipients, respectively, to changes in e or r was calculated by substituting changes in e and r into the respective equations, pregnancy rate = $e \times r$ and pregnancy rate = $e \times r \times (2 - e)$. In addition, the proportion of variation amongst studies in either observed or expected twin pregnancy rate that was due to variation in either *e* or *r* was examined using a simple linear regression approach including all 36 data points from this study.

RESULTS

In recipient cattle which received *in vitro* produced embryos the observed pregnancy rate to term ranged from 15 ± 5% to 47 ± 13% for those receiving a single embryo (Table 1). Observed pregnancy rates were similar for four of the five studies (mean = 37 ± 3%, χ^2 = 1.36, 3 d.f., N.S.), and these were higher than recorded in the study by Heyman *et al.*, 1995 (37 ± 3% vs. 15 ± 5%, χ^2 = 9.15, 1 d.f., P<0.01). With one exception (Takada *et al.,* 1991), the expected pregnancy rate of single ET recipients was within 5 percentage units of those observed (Table 1). In this exceptional case, the difference was 15 percentage units, although this difference was of similar magnitude to the standard deviation (Table 1). Observed pregnancy rates for those recipients receiving two embryos ranged from 33 ± 8% to 57 ± 7% (Table 1) and were not different amongst the five studies (mean = 42 ± 3%, χ^2 = 4.17, 4 d.f., N.S.). In all five instances, the expected pregnancy rate of twin ET recipients was within 5 percentage units and one standard deviation of those observed (Table 1).

In recipient cattle which received *in vitro* produced embryos the observed pregnancy rate up to the 60th day of pregnancy ranged from 32 ± 8% to 61 ± 9% for those receiving a single embryo (Table 2), and were not different amongst the five estimates (mean = 44 ± 4%, χ^2 = 3.96, 4 d.f., N.S.). In all five instances, the expected pregnancy rate of single ET recipients was well within one standard deviation unit of observed pregnancy rates (Table 2). Observed pregnancy rates for those recipients receiving two embryos ranged from 54 ± 7% to 88 ± 12% (Table 2) and were not different amongst the five estimates (mean = 63 ± 4%, χ^2 = 4.85, 4 d.f., N.S.). In all five instances, the expected pregnancy rate of twin ET recipients was within one standard deviation unit of observed pregnancy rates (Table 2). Recipients receiving two embryos had a higher pregnancy rate than those receiving one embryo (63 ± 4% vs. 44 ± 4%, χ^2 = 10.24, 1 d.f., P<0.01).

In the four very large sets of sheep data on ovulation and lambing (Kelly and Johnstone, 1983, Table 3), observed pregnancy rates to lambing were higher (P<0.001) for twin compared with single ovulating ewes. Furthermore, the expected pregnancy rates were no more than 2 percentage units different from observed pregnancy rates (Table 3). In the smallest set of sheep data (Smith and McGowan, 1986, Table 3), expected pregnancy rates to lambing were no more than one standard deviation different for both single and twin ovulating ewes (Table 3). However, in the remaining set of sheep data (Kelly and Allison, 1976), expected pregnancy rate to lambing in single ovulating ewes was more than three standard deviations lower than that observed (Table 3), although in twin ovulating ewes the predicted pregnancy rate was within two percentage units of the observed pregnancy rate (Table 3).

In spontaneously ovulating cattle (Echternkamp *et al,* 1990), observed pregnancy rate was similar in single compared with twin ovulating cattle (68 ± 3 vs. 77 ± 3, χ^2= 3.46, 1 d.f., N.S.). Expected pregnancy rate in these two subgroups of cattle were within three percentage units of the observed pregnancy rates (Table 3). In recipient goats (Armstrong *et al.,* 1983), observed pregnancy rates to term were lower in single compared with twin ET recipients

TABLE 1: Comparison of observed and expected pregnancy rates to term in recipient cattle in 5 studies.

Study	Single ET			Twin ET		
	No. Recipients	Observed Pregnancy Rate (%)	Expected Pregnancy Rate (%)	No. Recipients	Observed Pregnancy Rate (%)	Expected Pregnancy Rate (%)
Heyman *et al.,* 1995	54	15 ± 5	20 ± 5	36	33 ± 8	28 ± 7
Reichenbach *et al.,* 1992	129	38 ± 4	33 ± 4	149	41 ± 4	44 ± 4
Sinclair *et al.,* 1995a	43	42 ± 8	40 ± 8	44	57 ± 7	58 ± 7
Takada *et al.,* 1991	15	47 ± 13	32 ± 12	44	41 ± 7	45 ± 8
Van Soom *et al.,* 1994	62	31 ± 6	30 ± 6	28	39 ± 9	41 ± 9

TABLE 2: Comparison of observed and expected pregnancy rates to various stages of pregnancy in recipient cattle (data from McMillan *et al.,* 1997).

Stage of Pregnancy	Single ET			Twin ET		
	No. Recipients	Observed Pregnancy Rate (%)	Expected Pregnancy Rate (%)	No. Recipients	Observed Pregnancy Rate (%)	Expected Pregnancy Rate (%)
ET to Day 14	26	46 ± 10	54 ± 10	8	88 ± 12	73 ± 16
ET to Day 18	28	61 ± 9	59 ± 9	35	77 ± 7	78 ± 7
ET to Day 26	34	32 ± 8	38 ± 8	26	58 ± 10	51 ± 10
ET to Day 42	24	42 ± 10	41 ± 10	46	61 ± 7	61 ± 7
ET to Day 60	24	42 ± 10	38 ± 10	46	54 ± 7	56 ± 7

(Table 3, 51 ± 7 vs. 80 ± 2, χ^2 = 18.77, 1 d.f., P<0.001). Expected pregnancy rate in single ET recipient goats was almost two standard deviations higher than observed pregnancy rates, although the difference between observed and expected pregnancy rate was only two percentage units in twin ET recipients (Table 3).

Since expected pregnancy rate in single ET recipients is the product of *e* and *r*, it follows that expected pregnancy rate changes are equally sensitive to increases in *e* and *r*. This is illustrated in Table 4 where *e* and *r* are both scaled up by a factor of 1.5. However, in the case of expected twin ET recipient pregnancy rate, which is the product *e* x *r* x (2 - *e*), changes in expected pregnancy rate are more sensitive to changes in *r* than changes in *e* (Table 4). The relationship between *r* and observed and expected pregnancy rate in twin ET recipients was further examined by regression analysis using the 18 sets of data in Table 1 to 3. Over 90% of the variation in either observed pregnancy rate or expected pregnancy rate amongst these sets of data was accounted for by variation in *r*. In contrast, only about 33% of the variation was accounted for by variation in *e*.

DISCUSSION

The first key finding from this study was that a binomial model of independent embryo and maternal effects on embryo survival is able to predict actual pregnancy rate within either 5 percentage units, or one standard deviation in nearly all of the sets of data examined. The second key finding was that improvements in pregnancy rate in twin ET recipients or twin ovulating sheep and cattle is more sensitive to increases in the maternal rather than the embryo component. The third key finding was that pregnancy rate is generally higher in twin compared with single ET recipients and in twin compared with single ovulating females.

It has been shown elsewhere that a binomial model of independent embryo and maternal effects on embryo survival adequately explains embryo survival to term in recipient cattle (McMillan, 1997b). The current study extends these findings in several ways. Firstly, it demonstrates that the model can also adequately explain pregnancy rate to term in single and twin ET recipient cattle. In the five pairs of data examined, the difference in observed and expected pregnancy rate were generally no more than five percentage units different. Secondly, not only is the model applicable to calving data in recipient cattle, it also appears to apply equally well to calving data in spontaneously single and twin ovulating cattle. Although only a single pair of data was examined in this regard, the expected and observed pregnancy rates did not differ by more than three percentage units. Thirdly, the model applies to pregnancy rates during the early stages of pregnancy, at least between ET and day 60 of pregnancy in cattle. Finally, the model can be successfully applied to single and twin ovulating ewes as well as single and twin ET recipient goats. Col-

TABLE 3: Comparison of observed and expected pregnancy rates to term in sheep, cattle and goats (data from McMillan, 1996b).

Stud 1986 (sheep)y	Single			Twin		
	No. Females	Observed Pregnancy Rate (%)	Expected Pregnancy Rate (%)	No. Females	Observed Pregnancy Rate (%)	Expected Pregnancy Rate (%)
Kelly and Johnstone, 1983 (sheep)	1104	81 ± 1	79 ± 1	857	88 ± 1	90 ± 1
Kelly and Johnstone, 1983 (sheep)	1326	81 ± 1	79 ± 1	1215	89 ± 1	90 ± 1
Kelly and Johnstone, 1983 (sheep)	2430	81 ± 1	79 ± 1	2015	88 ± 1	90 ± 1
Kelly and Johnstone, 1983 (sheep)	2430	81 ± 1	78 ± 1	4087	89 ± 1	89 ± 1
Smith and McGowan, 1986 (sheep)	11	55 ± 15	66 ± 14	66	82 ± 5	81 ± 5
Kelly and Allison, 1976 (sheep)	188	87 ± 2	77 ± 3	314	89 ± 2	91 ± 2
Echternkamp *et al.*, 1990 (sheep)	319	68 ± 3	66 ± 3	155	77 ± 3	80 ± 3
Armstrong *et al.*, 1983 (goats)	51	51 ± 7	64 ± 7	329	80 ± 2	79 ± 2

TABLE 4: Illustration of effect of changes in embryo and maternal contributions to changes in expected pregnancy rate in single and twin ET recipients.

Description	'e'	'r'	Expected Pregnancy Rate -Singles	Expected Pregnancy Rate - Twins
Base	0.5	0.5	0.25	0.38
Increase 'e' by 1.5	0.75	0.5	0.38	0.47
Increase 'r' by 1.5	0.5	0.75	0.38	0.56

lectively, the present findings suggest that the model is sufficiently robust to explain embryo survival and pregnancy rates in at least three farmed ruminant species. Other studies are underway to determine if the model applies to humans, by using data from assisted reproduction programmes.

The second key finding was that improvements in pregnancy rate in twin ET recipients or twin ovulating sheep and cattle is more sensitive to increases in the maternal rather than the embryo component. This finding has implications for the nature of research programmes aimed at improving pregnancy rates in females with a propensity to produce twins at term. It is clear that unless additional research effort is focused on the maternal as opposed to the embryo determinants of successful pregnancy, progress in improving pregnancy rate is likely to be slower. Furthermore, since variation amongst studies in the maternal, rather than the embryo, component of survival accounts for most of the variation in expected embryo survival rate (McMillan, 1997a), a stronger case for additional research into the maternal determinants of successful pregnancy can be advanced. However, if the objective is to reduce the partial failure of multiple pregnancies, then research effort should be directed to improving the embryo determinants of embryo survival (McMillan, 1996b). Taken together, these findings suggest that a balanced programme of embryo and maternal research is required to advance reproductive efficiency in farmed species.

The third key finding from this study was that pregnancy rate is generally higher in twin compared with single ET recipients and in twin compared with single ovulating females. A higher pregnancy rate would be expected if indeed embryo survival was independent for each of a pair of embryos. However, in the current study, most of the sets of data (13/18) were not congruent with a model of independence (McMillan, unpublished). This finding is consistent with a more comprehensive analysis of cattle data which showed that about 85% of cases were not consistent with a model of independence (McMillan, 1997a). Instead, it is proposed that some females have a higher intrinsic ability to sustain a pregnancy compared with their contemporaries. This hypothesis is the subject of current research (Cox, unpublished).

In conclusion, a model of embryo survival which assumes independent binomial effects of embryos and a maternal component on embryo survival has been found to adequately explain pregnancy rate in cattle, sheep and goats that have a propensity for either single or twin pregnancies. Additional research to identify procedures for improving the maternal component seems warranted to improve pregnancy rates.

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