# Catecholamines, oxytocin and milk removal in dairy cows

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Summary. Experiments were designed to study the effects of catecholamines on oxytocin responses and milk removal in dairy cows. Adrenalin, noradrenalin, dopamine, isoproterenol (a $\beta$-adrenoceptor agonist), phentolamine (an $\alpha$-adrenergic blocker) and propranolol (a $\beta$-adrenergic blocker) were infused intravenously. In addition, adrenalin was infused together with phentolamine and/or propranolol. Infusions started 8 min before milking and lasted until the end of milking. In some cases electroshocks (for 5 s) were applied immediately before milking in the absence and presence of phentolamine and propranolol. Adrenalin, noradrenalin and dopamine reduced milk removal, but only if administered in supraphysiological amounts. The effect of adrenalin and electroshocks on milk removal could be inhibited by $\alpha$-, but not by $\beta$-adrenergic blockade. The effect of dopamine could be inhibited only partly by phentolamine. Inhibition of milk removal was not mediated by reduced oxytocin responses. Enhanced local release of catecholamines from sympathetic nerves was presumably responsible for lowered milk removal in response to electroshocks. Milk removal was facilitated during $\alpha$-adrenergic blockade and during $\beta$-adrenoceptor stimulation.

Oxytocin (OT) is primarily responsible for stimulation of milk ejection (Lincoln & Paisley, 1982; Gorewit *et al.* 1983; Lefcourt & Akers, 1983). However, other factors can modify milk removal. This is particularly true for the sympathetic nervous system (Mena *et al.* 1978, 1979; Goodman & Grosvenor, 1983; Gorewit *et al.* 1983; Schams *et al.* 1984). This can be explained by close association between OT containing neurons and the sympathetic nervous system of the brain (Aulsebrook & Holland, 1969; Moos *et al.* 1983; Seybold *et al.* 1978). Furthermore, there are close connections between OT effects and the sympathetic nervous system in the mammary gland (Peeters *et al.* 1949; Lefcourt & Akers, 1983). Thus, arteries, arterioles and smooth muscles of the teat are sympathetically innervated (Peeters *et al.* 1949; Bernabé & Peeters, 1980). Moreover, arterial muscles in the mammary gland are under active sympathetic tone (Goodman & Grosvenor, 1983; Lefcourt, 1982*b*). In addition, rhythmical contraction of teat muscles is due to changes in the activity of sympathetic nerves in the mammary gland (Sambraus, 1971; Lefcourt, 1982*a*). The turgid state of the engorged mammary gland enhances, whereas its relief

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by milking decreases the sympathetic tone in the gland (Mena *et al.* 1978; Lefcourt, 1982*b*).

Administration of adrenalin and noradrenalin inhibits milk removal (Lefcourt & Akers, 1983), but it is unclear whether this is a pharmacological effect or whether it is also observed when only physiological amounts are administered. In addition, it is not known whether this effect is due to inhibition of OT secretion (central effect), or primarily situated in the mammary gland (peripheral effect). Also, it is not clear whether adrenalin and noradrenalin, transported through the vascular system to the mammary gland, are important for reduction of milk let-down under conditions of emotional stress. However, marked inhibitory effects on milk let-down of locally released noradrenalin or of other amines can be expected under conditions of emotional stress. Alpha- and $\beta$-adrenergic receptors are located on arterial and teat (sphincter) smooth muscle cells (Peeters & De Bruycker, 1975; Peeters *et al.* 1977; Bernabé & Peeters, 1980; Vandeputte-Van Messom *et al.* 1984*a*).

Alpha-adrenoceptor agonists stimulate contraction, whereas $\beta$-adrenoceptor agonists and $\alpha$-adrenergic blocking agents cause relaxation of these muscles (Peeters & De Bruycker, 1975; Peeters *et al.* 1977; Bernabé & Peeters, 1980). The effects of adrenalin and noradrenalin are inhibited by $\alpha$-adrenergic blocking agents, at least in cattle (Bernabé & Peeters, 1980; Vandeputte-Van Messom *et al.* 1982, 1984*a*). There is no evidence for direct sympathetic innervation of myoepithelial cells, but adrenalin and noradrenalin inhibit the contractile response to OT (Lefcourt & Akers, 1982). Furthermore, amines other than noradrenalin and adrenalin, such as serotonin, can modify milk let-down (Vandeputte-Van Messom *et al.* 1984*b*). Surprisingly, effects on milk let-down of dopamine, which is highly concentrated in mast cells of ruminants (Falck *et al.* 1964; Blum *et al.* 1980) and may be released under certain conditions, have not yet been studied to our knowledge. Thus, catecholamines can influence milk removal. Effects may be mediated by alteration of OT release and by changes in blood flow and therefore the amount of OT presented to myoepithelial cells (Dhondt *et al.* 1973; Gorewit & Aromando, 1985; Gorewit & Scott, 1986). Catecholamines could change the sensitivity and/or responsiveness of myoepithelial cells to OT. In addition they could directly alter the tension of smooth muscles surrounding mammary ducts and in the teat and, as a consequence, the transport of milk within the mammary gland.

We have studied the conditions under which catecholamines, transported to the mammary gland via the vascular system, could modify milk removal in dairy cows.

## MATERIALS AND METHODS

Three series of experiments were performed during different periods of the year. Fifteen dairy cows, five animals/experimental series, were available. They were German Braunvieh $\times$ $\frac{1}{4}$ to $\frac{1}{2}$ Brown Swiss. Cows belonged to the Institute of Physiology, Technical University of Munich, Weihenstephan. The herd average annual yield was 7000 kg. The animals weighed 550–700 kg. They were in months 3–6 of their first to ninth lactation. The animals had free access to hay and were fed silage and concentrate twice daily.

To equalize a.m. and p.m. milk yields milking started at 06.00 and 18.00, i.e. at 12 h intervals, beginning about 1 week before (period of adaptation) and during the experimental period. The milking system and methods of measuring parameters of milk removal have been described in detail (Mayer *et al.* 1984). Milking was started after 1 min of manual prestimulation. The main milking period was finished when

milk flow rate fell below 0·2 kg/min. In the ensuing period milk was stripped until milk flow fell again below 0·2 kg/min.

Sixteen experimental protocols were followed: control experiments (no treatments); infusions of NaCl, adrenalin (in two doses), noradrenalin (in two doses), isoproterenol (a $\beta$-adrenergic agonist) or phentolamine (an $\alpha$-adrenergic blocker) alone; infusions of phentolamine combined with propranolol (a $\beta$-adrenergic blocker), of phentolamine with adrenalin, of propranolol with adrenalin, of phentolamine with propranolol or with adrenalin and of phentolamine with dopamine. Furthermore, electric shocks (electroshocks) were applied for 5 s alone or combined with infusions of phentolamine and propranolol. Amounts infused are given in Table 1.

Intravenous steady state infusions by pumps were started 8 min before milking and were stopped at the end of the main milking period. Indwelling catheters were inserted 1–2 d before the experiments into the jugular vein. Electroshocks were applied by use of an electric prod (42 V/impulse) immediately before prestimulation.

Adrenalin bitartrate and noradrenalin bitartrate were purchased from Fluka AG, Buchs, Switzerland; dopamine-HCl from Hausmann Laboratories, St. Gallen, Switzerland; and isoproterenol-HCl from Winthrop Products, Macclesfield, Cheshire, UK. Phentolamine methanesulphonate was donated by Ciba-Geigy AG, Basle, Switzerland and D,1-propranolol by ICI, Surbiton, Surrey, UK. All substances were dissolved in 0·92% NaCl shortly before use and kept on ice in light-protected bottles during the experiments. Citric acid (300 mg/l) was added to propranolol solutions.

Blood samples (10 ml) were obtained through a catheter, inserted 1–2 d before the experiments, from the jugular vein contralateral to the one used for the infusions. Samples were obtained at 10, 9, 8, 2, 1 and 0 min before milking; at 0·5, 1, 1·5, 2, 2·5, 3, 4 min and then every min during the main period of milking; and at 2 and 5 min after the end of milking. Blood was immediately transferred to tubes containing heparin which were left on ice and then centrifuged at 4 °C within 15–30 min for the separation of plasma. Plasma was stored at −20 °C in multiple aliquots in plastic cups until determination of adrenalin, noradrenalin or OT.

Adrenalin and noradrenalin were measured radioenzymically (Blum *et al.* 1980) and OT radioimmunologically (Schams, 1983) after extraction with SEP-PAK C 18 cartridges.

Statistical analysis was performed by Wilcoxon-Test and by linear regression analysis. Data are presented as means ± s.e.m.

## RESULTS

Milking parameters were similar in cows infused with NaCl and in control animals without infusions. OT responses were in the normal range (Table 1) except for one animal which reacted excessively (545 pg/ml; data not used). Levels of adrenalin and noradrenalin did not change before and during milking in control experiments (Fig. 1).

During adrenalin infusions, concentrations of adrenalin increased markedly within minutes in a dose-dependent manner (Table 1). OT responses were not altered by adrenalin administration (Fig. 2). Total and main yield decreased (significantly for 0·21 $\mu$g adrenalin/kg) (Table 1). Total and main milking times were markedly and significantly shortened and, in addition, mean and peak flow rates were decreased (significantly for 0·21 $\mu$g adrenalin/kg; $P < 0·05$).

During noradrenalin infusions, concentrations of noradrenalin increased within minutes in a dose-dependent manner, the rise being absolutely and relatively smaller

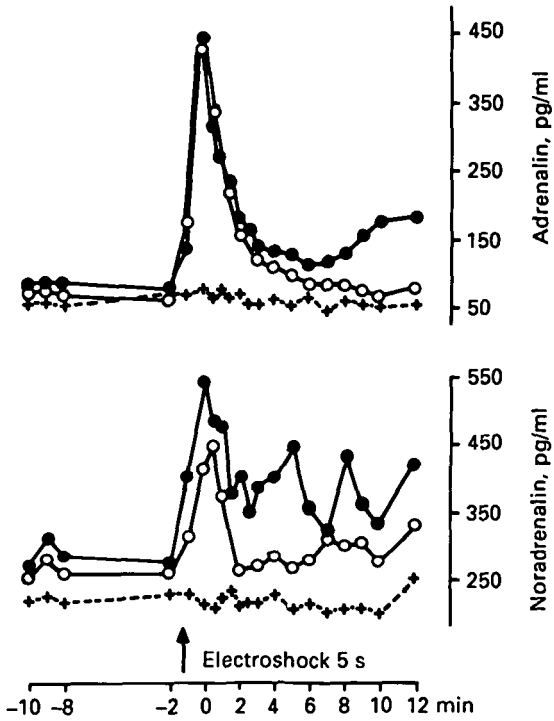


Fig. 1. Mean changes in adrenalin and noradrenalin before and after electroshocks (↑; immediately before prestimulation, i.e. 1 min before milking) in the absence (○) and presence (●) of phentolamine (10 μg/kg.min) and propranolol (10 μg/kg.min), i.v.-infused from 8 min before until the end of milking, compared to controls (+).

than that of adrenalin during adrenalin infusions ($P < 0{\cdot}05$; Table 1, Fig. 3). OT responses were not significantly affected by noradrenalin administration. Total and main yield were decreased with 0·21 μg noradrenalin/kg ($P < 0{\cdot}05$). Peak flow rate decreased ($P < 0{\cdot}05$).

Infusions of dopamine caused a significant decrease of total and main yield ($P < 0{\cdot}05$) as well as yield by stripping ($P < 0{\cdot}05$). OT responses were not changed (Table 1) but OT increased excessively in one cow (242 pg/ml; data not used).

During infusions of the β-adrenoceptor agonist isoproterenol total and main yield increased and milk flow rate increased, but total and main milking time decreased, although effects were not significant (Table 1). Time to peak flow was significantly reduced ($P < 0{\cdot}05$). OT responses were in the normal range except for one cow which reacted excessively (234 pg/ml; data not used).

Total and main yield increased 15 and 19% respectively, during α-adrenergic blockade with phentolamine (Table 1), whereas yield by stripping was half that in controls, but none of these effects were significant. However, time to peak flow was reduced significantly ($P < 0{\cdot}05$). OT responses were in the normal range except for one cow which responded excessively (240 pg/ml; data not used).

The combined administration of the α- and β-adrenergic blocking agents phentolamine and propranolol did not change milking parameters as well as adrenalin and noradrenalin levels (Table 1). OT responses were not modified, but in experiments with dopamine combined with phentolamine, OT response was excessive in one cow (208 pg/ml; data not used). During adrenalin infusion combined with

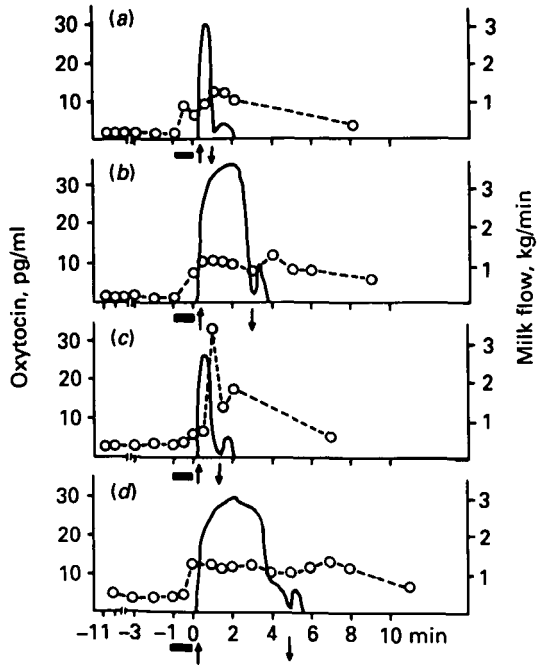


Fig. 2. Changes in milk flow (——) and blood levels of oxytocin (----) in a cow in the presence of exogenous (*a*), adrenalin (0·21 μg/kg.min) combined with propranolol (10 μg/kg.min); (*b*), adrenalin (0·21 μg/kg.min) together with phentolamine (10 μg/kg.min); (*c*), adrenalin alone (0·21 μg/kg.min) or (*d*), in the absence of exogenous adrenalin and blocking agents (control). Adrenalin, propranolol and phentolamine were i.v. infused from 8 min before until the end of milking. Prestimulation was from −1 min until 0 min (▬). Arrows (↑ ↓) indicate the start and end respectively, of the main milking period.

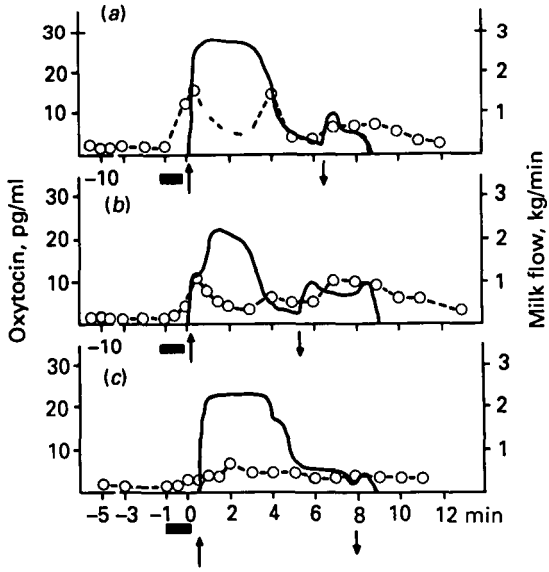


Fig. 3. Changes in milk flow (▬) and blood levels of oxytocin (----) in the presence of exogenous noradrenalin ((*a*) 0·21 and (*b*) 0·06 μg/kg.min, i.v. infused from 8 min before until the end of milking) and (*c*) in the absence of exogenous noradrenalin (control). For further details see Fig. 2.

Table 1. *Effects of adrenalin, noradrenalin, dopamine, isoproterenol, phentolamine, propranolol, electroshock or NaCl (alone or combined) on oxytocin response, blood plasma levels of adrenalin and noradrenalin and on parameters of milk removal (means ± s.e.m.)*

| | | μg/kg.min | n | Oxytocin[a], pg/ml | Adrenalin[b], pg/ml | Noradrenalin[b], pg/ml | Total yield, kg | Stripping, kg | Total milking time, min | Main milking time, min | Main flow rate, kg/min | Time to peak flow, min |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Control | – | 10 | 11 ± 3 | 60 ± 8 | 211 ± 13 | 10·2 ± 0·7 | 0·4 ± 0·1 | 6·4 ± 0·6 | 5·3 ± 0·6 | 2·0 ± 0·2 | 1·9 ± 0·2 |
| 2 | NaCl | – | 5 | 29 ± 9 | ND | ND | 10·1 ± 0·6 | 0·3 ± 0·1 | 6·3 ± 0·6 | 5·1 ± 0·5 | 1·9 ± 0·1 | 1·1 ± 0·2* |
| 3 | Adrenalin | 0·06 | 10 | 14 ± 3 | 1922 ± 541* | 332 ± 29 | 8·9 ± 1·0 | 0·5 ± 0·1 | 5·5 ± 0·5 | 4·4 ± 0·5 | 1·9 ± 0·2 | 1·3 ± 0·1* |
| 4 | Adrenalin | 0·21 | 10 | 21 ± 5 | 6892 ± 1819* | 485 ± 87 | 4·3 ± 0·9* | 0·5 ± 0·1 | 3·7 ± 0·4* | 2·6 ± 0·3* | 1·2 ± 0·2* | 0·8 ± 0·2* |
| 5 | Noradrenalin | 0·06 | 5 | 11 ± 2 | 62 ± 6 | 955 ± 181* | 9·8 ± 0·1 | 0·4 ± 0·1 | 5·6 ± 0·6 | 4·6 ± 0·6 | 2·1 ± 0·4 | 1·2 ± 0·1* |
| 6 | Noradrenalin | 0·21 | 10 | 23 ± 10 | 108 ± 12 | 3857 ± 818* | 7·2 ± 1·0* | 0·6 ± 0·1 | 5·3 ± 0·7 | 4·0 ± 0·6 | 1·6 ± 0·2 | 1·8 ± 0·6 |
| 7 | Dopamine | 5·00 | 5 | 10 ± 4 | ND | ND | 6·8 ± 1·2* | 0·2 ± 0·0* | 6·0 ± 0·9 | 5·1 ± 0·9 | 1·2 ± 0·1 | 1·2 ± 0·6 |
| 8 | Isoproterenol | 0·04 | 5 | 56 ± 26 | ND | ND | 10·8 ± 0·6 | 0·4 ± 0·0 | 5·5 ± 0·2 | 4·3 ± 0·3 | 2·4 ± 0·1 | 1·1 ± 0·3* |
| 9 | Phentolamine | 10·00 | 5 | 44 ± 4 | ND | ND | 11·7 ± 0·7 | 0·2 ± 0·2 | 5·9 ± 0·6 | 5·9 ± 0·6 | 2·0 ± 0·1 | 1·1 ± 0·2* |
| 10 | Phentolamine | 10·00 | | | | | | | | | | |
| | + propranolol | 10·00 | 5 | 15 ± 2 | 77 ± 17 | 199 ± 27 | 10·2 ± 0·6 | 0·5 ± 0·1 | 5·4 ± 0·6 | 4·2 ± 0·6 | 2·4 ± 0·3 | 1·4 ± 0·3 |
| 11 | Phentolamine | 10·00 | | | | | | | | | | |
| | + adrenalin | 0·21 | 5 | 27 ± 20 | 4999 ± 1584* | 339 ± 28 | 11·2 ± 1·4 | 0·4 ± 0·2 | 6·0 ± 1·0 | 4·9 ± 0·8 | 2·2 ± 0·2 | 1·8 ± 0·2 |
| 12 | Propranolol | 10·00 | | | | | | | | | | |
| | + adrenalin | 0·21 | 5 | 15 ± 7 | 4586 ± 1822* | 362 ± 45 | 3·9 ± 1·4* | 0·4 ± 0·2 | 3·2 ± 0·8* | 2·5 ± 0·6* | 1·2 ± 0·2* | 0·5 ± 0·2* |
| 13 | Phentolamine | 10·00 | | | | | | | | | | |
| | + propranolol | 10·00 | 8 | 14 ± 4 | 6650 ± 2070* | 365 ± 77 | 10·3 ± 0·7 | 0·5 ± 0·1 | 5·9 ± 0·8 | 4·6 ± 0·7 | 2·4 ± 0·4 | 1·6 ± 0·2 |
| | + adrenalin | 0·21 | | | | | | | | | | |
| 14 | Phentolamine | 10·00 | | | | | | | | | | |
| | + dopamine | 5·00 | 5 | 23 ± 11 | ND | ND | 8·0 ± 1·5 | 0·2 ± 0·0* | 5·3 ± 0·7 | 4·5 ± 0·7 | 1·7 ± 0·3 | 1·0 ± 0·3* |
| 15 | Electroshock | | 9 | 10 ± 7 | † | † | 7·6 ± 1·2 | 0·9 ± 0·3* | 6·4 ± 0·7 | 4·7 ± 0·6 | 1·3 ± 0·2* | 2·8 ± 0·7 |
| 16 | Phentolamine | 10·00 | | | | | | | | | | |
| | + propranolol | 10·00 | 6 | 8 ± 2 | † | † | 8·3 ± 0·8 | 0·9 ± 0·2* | 5·1 ± 0·7 | 3·7 ± 0·6* | 2·1 ± 0·4 | 1·3 ± 0·2* |
| | + electroshock | | | | | | | | | | | |

[a], Means from 0 to 2 min of milking; [b], means from 8 min before to the end of milking. Significance of difference from control experiments: *, $P < 0·05$; no symbol, $P > 0·05$. ND, Not done; †, see Fig. 1. Statistical analysis of each experimental series was based on its own control.

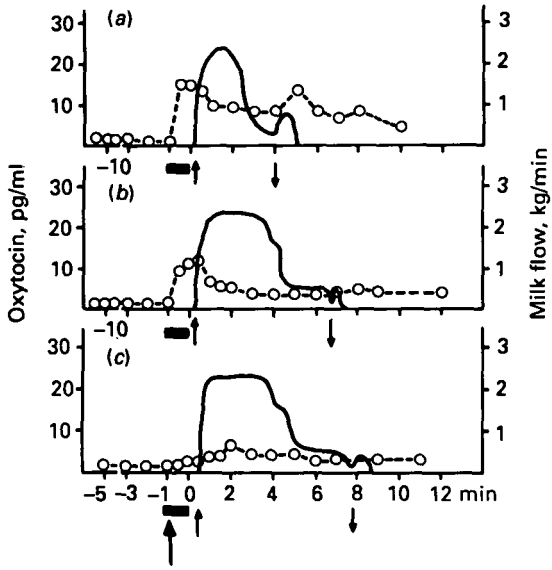


Fig. 4. Changes in milk flow (——) and blood levels of oxytocin (----) in a cow with application of electroshock (↑, lasting for 5 s and applied immediately before prestimulation, i.e. 1 min before milking); (*a*), in the presence of phentolamine (10 μg/kg.min) and propranolol (10 μg/kg.min), both i.v. infused together from 8 min before milking until the end of milking; (*b*), with application of an electroshock alone; (c), without electroshock (control). For further details see Fig. 2.

phentolamine and/or propranolol, levels of adrenalin increased to the same extent as in the absence of blocking agents (Table 1; Fig. 2). OT responses, too, were not significantly affected by combined infusions of adrenalin with blocking agents. Whereas total and main yield slightly but not significantly increased during adrenalin and phentolamine infusions, total and main yield were decreased during the administration of adrenalin and propranolol ($P < 0{\cdot}05$). In addition, total and main milking time, mean flow rate and time of peak flow were significantly decreased when adrenalin and propranolol were infused ($P < 0{\cdot}05$), but were not changed significantly during combined adrenalin and phentolamine administration. When adrenalin was infused together with propranolol and phentolamine, milking parameters were not significantly changed. When dopamine was infused together with phentolamine, yield by stripping was half that in controls ($P < 0{\cdot}05$) and time to peak flow was also markedly reduced ($P < 0{\cdot}05$).

Electroshocks were followed by a rapid, but transient, increase particularly of adrenalin and less of noradrenalin ($P < 0{\cdot}05$; Fig. 1). OT responses were not changed by electroshocks alone or electroshocks in the presence of phentolamine and propranolol (Fig. 4). Electroshocks only slightly decreased total yield, but significantly decreased main yield ($P < 0{\cdot}05$), whereas yield by stripping was more than doubled compared to controls ($P < 0{\cdot}05$) (Table 1; Fig. 4). Main flow rate was reduced ($P < 0{\cdot}05$), whereas time to peak flow became markedly greater, but not significantly so. Infusions of the $\alpha$- and $\beta$-adrenergic blocking agents (phentolamine and propranolol) partly inhibited effects of electroshocks on total and main yield. However, yield obtained by stripping remained elevated ($P < 0{\cdot}05$). Main yield and time to peak flow were significantly shortened in the presence of blockers ($P < 0{\cdot}05$).

## DISCUSSION

Milking parameters in controls were in a range comparable to previous studies (Mayer *et al.* 1984; Schams *et al.* 1984). Main yield was closely related to main flow rates which thus determined total yield. Electroshocks markedly increased yields by stripping and thus differed from effects of other treatments. Although there were consistent effects within experimental protocols, individual variability was considerable, especially in response to electrical shocks (not shown).

Oxytocin concentrations increased during prestimulation and milking, in accordance with previous reports (Mayer *et al.* 1984; Schams *et al.* 1984). In experimental series 2, 7, 8, 9 and 14 OT responses were excessive in one cow and therefore excluded while in the remaining animals OT was in the normal range. The magnitude of OT responses during the first 2 min of milking was not related to parameters of milk removal, as in previous studies (Sagi *et al.* 1980; Gorewit *et al.* 1983; Schams *et al.* 1984). Our results therefore demonstrate that OT responses to prestimulation and milking were not modified by the administration of various catecholamines, by blocking agents, or by electroshocks. Thus, the administered catecholamines and electroshocks mediated their effects on milk removal independent of circulating OT. Similarly, OT responses in cows were not changed during noradrenalin administration (Lefcourt & Akers, 1982). Excessive amounts of adrenalin used were possibly responsible for decreased OT responses reported by Gorewit & Aromando (1985). In our study we found no evidence for a delayed OT release after treatment of cows with electrical current as found by Henke Drenkard *et al.* (1985).

Levels of adrenalin and noradrenalin did not change during normal milking in this study. The sympathetic reflex during milking (Lefcourt, 1982*b*; Goodman & Grosvenor, 1983) is therefore not accompanied by changes in blood catecholamine levels. However, levels of adrenalin and noradrenalin increased immediately after electroshocks in our study, in contrast to Lefcourt & Akers (1984) and Lefcourt *et al.* (1985). Electroshocks decreased milk removal even though blood levels of adrenalin and noradrenalin reached after this treatment were much smaller than those reached during infusions of adrenalin and noradrenalin. Therefore, factors other than circulating catecholamines must have been responsible for inhibition of milk let-down. Catecholamines and possibly other substances, released locally in the udder following electrical shocks, possibly caused decreased milk let-down.

Blood levels reached during infusions of adrenalin and noradrenalin were greatly above those reached after electroshocks or during strenuous treadmill exercise (Blum *et al.* 1979). Only with 0·21 $\mu$g adrenalin or noradrenalin/kg was milk removal decreased significantly. Thus, only supraphysiological blood levels of adrenalin and noradrenalin decreased milk let-down, in contrast to Lefcourt & Akers (1983). Gorewit & Aromando (1985) suggested that adrenalin exerts its inhibitory effects on milk removal peripherally by preventing OT from reaching myoepithelial cells. Based on our own studies this cannot be the only effect explaining the inhibition of milk let-down (R. Bruckmaier, unpublished observations). Adrenalin was a more potent inhibitor of milk removal than noradrenalin. This was possibly the consequence of higher blood levels of adrenalin compared to noradrenalin, even though the same amounts were administered. It is explained by faster clearance from the circulation of noradrenalin than of adrenalin (Fröhli & Blum, 1988).

To our knowledge it has not been demonstrated before that dopamine causes a decrease in milk removal. Dopamine differed from adrenalin and noradrenalin by

decreasing especially yield obtained by stripping. It seems therefore to be particularly efficient in causing milk retention. Dopamine in the amounts used has marked effects on circulation and endocrine systems, even though it is extremely rapidly destroyed in bovine blood plasma (Blum *et al.* 1980; Blum, 1984; Fröhli & Blum, 1988). Dopamine released locally from mast cells, where it is highly concentrated (Falck *et al.* 1964; Blum *et al.* 1980), may be responsible for decreased milk removal under certain pathological conditions.

The $\beta$-adrenoceptor agonist isoproterenol tended to improve milk removal and particularly enhanced time to peak flow, as reported by Bernabé & Peeters (1980), Hamann (1981) and Bernabé & Ricordel (1985*a*, *b*) who also used isoproterenol or clenbuterol. Peeters *et al.* (1977) and Bernabé & Peeters (1980) demonstrated relaxation of the smooth muscles of the teats as well as decreased spontaneous motility in response to isoproterenol. Thus, $\beta$-adrenoceptor agonists seem to enhance milk flow rates by permitting greater opening of the teat canal.

The $\alpha$- and $\beta$-adrenergic receptor blockers, phentolamine and propranolol, were administered to define receptors mediating effects of catecholamines on milk removal. Phentolamine alone particularly enhanced time of peak flow, in accordance with Dhondt *et al.* (1973), Bernabé & Peeters (1980) and Bernabé & Ricordel (1985*a*). In previous studies with cows, administration of the same amounts of phentolamine as in the present investigation was associated with a decrease of systemic blood pressure and an increase of the heart rate, of nonesterified fatty acid and of noradrenalin levels (Blum *et al.* 1978; Fröhli & Blum, 1988). These cardiovascular and metabolic effects are typically seen also during the administration of $\beta$-adrenoceptor agonists. Improvement in milk removal can be explained by blockade of $\alpha$-adrenergic receptors, an enhanced release of noradrenalin, interaction of noradrenalin with $\beta$-adrenergic receptors on smooth muscle cells. This would be followed by relaxation of muscle cells of ducts and teats. Phentolamine even reversed inhibitory effects of exogenous adrenalin on milk removal, by removing $\alpha$-adrenergic and possibly also by unmasking $\beta$-adrenergic components of adrenalin. These results are in accordance with those of Bernabé & Peeters (1980), Mielke (1981) and Vandeputte-Van Messom *et al.* (1982, 1984*a*). On the other hand, the combined $\alpha$- and $\beta$-adrenergic blockade, with or without exogenous adrenalin, did not modify parameters of milk removal. In this situation propranolol presumably reduced milk removal by blocking effects via $\beta$-adrenergic receptors of adrenalin or noradrenalin. Milk removal by adrenalin was inhibited by propranolol to the same extent as in its absence, demonstrating that blockade of $\beta$-receptors does not inhibit the effect of adrenalin. This is in accordance with Bernabé & Peeters (1980).

As $\alpha$-adrenergic blockade only partly suppressed effects of dopamine, this suggests that dopamine mediates its inhibitory effects on milk removal also via specific (dopaminergic) receptors. Similarly, combined $\alpha$- and $\beta$-adrenergic blockade did not suppress completely inhibitory effects of electroshocks on milking parameters. In particular, yield by stripping remained increased. Besides adrenalin and noradrenalin, whose release was transiently enhanced, additional factors must have been responsible for inhibition of milk removal following electroshocks.

Our study supports findings of others that adrenalin and noradrenalin mediate their inhibitory effects on milk removal through interaction with $\alpha$-adrenergic receptors located in the udder, most likely on smooth muscle cells of ducts and teats. Effects of dopamine may be mediated by specific receptors, at least in part. It appears that effects of adrenalin, noradrenalin and dopamine are direct and independent of OT, whose release was not modified by treatments. Our data indicate

that adrenalin and noradrenalin, circulating in increased amounts in blood under conditions of emotional stress, are of small importance compared to noradrenalin and possibly dopamine or other substances, released locally in the udder under stress and other conditions. Alpha-adrenergic blocking agents may be used to remove inhibition of milk let-down under stress conditions and in udders with injured teats.

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