AN EVALUATION OF THE BODMIN-NUPULSE MILKING MACHINE

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ABSTRACT

Two experiments were carried out to evaluate the milking characteristics of the Bodmin NuPulse milking machine. The first experiment describes the mode of operation of the NuPulse pulsation mechanism and establishes that the NuPulse has a distinctly different mode of action from the conventional type of milking machine.

The aim of the 2nd experiment was to determine if the liner movement characteristics of the NuPulse cluster had any advantage over the conventional type of pulsation and liner movement, in terms of milk production and mastitis over the period of a lactation.

Ten pairs of infection-free identical twins were allocated to the experiment; one member of each pair was milked by the NuPulse pulsation system and the other member was milked by the NuPulse cluster which had been modified for the conventional pulsation treatment by removal of the NuPulse pulsation mechanism. Because of this modification the experiment did not examine the difference between the NuPulse and a conventional machine but only the difference between the two pulsation mechanisms.

The Mark I NuPulse Cluster was used for both treatments in order to eliminate any possible effects of cluster weight, size and stability on the cow during milking.

The trial cows were grazed with a 100 cow, mixed aged herd. The herd was milked in an eight bail walk-through, high pipe-line dairy, equipped with four NuPulse clusters and four conventional (modified NuPulse) units.

The non-trial cows in the herd were milked by one machine or the other, at random, whereas the trial cows were milked by any one of the four machines appropriate to their treatment.

Before 'cups-on' the teats of all cows (including the trial cows) were squirted for five to ten seconds with water and only washed if they were dirty. At times during the summer months, cows with clean teats received no wash at all.

During the experiment (and including the first 3 months of the following lactation) no significant difference in mastitis or teat end condition developed between the two treatment groups. The one line NuPulse cluster, with the pulsator incorporated into the claw piece was associated with the same problem of frothing as other one line machines used with high lift pipeline machines.
However, the production data indicated that the pulsation mechanism of the NuPulse influenced the cows in some way during milking. The NuPulse group of twins recorded higher milk yields during the last 5 months of lactation and at the time of drying-off, were giving significantly ($P < 0.01$) higher yields than the group of twins milked by the conventional machine.

The group milked by the conventional machine (modified NuPulse) reached the drying off yield of the NuPulse group (5.9 ℓ/day) 12 days earlier.
When the lactation was ended for both groups at a yield of 5.9 ℓ/day and the total production for both groups compared, it was found that the NuPulse group achieved significantly higher yields ($P < 0.05$).
Compared to the conventional (or modified NuPulse) machine, the higher milk yields recorded with the NuPulse during the last 5 months of lactation suggests that the NuPulse was associated with a more positive stimulation effect during milking. However, in view of the small number of animals used in the experiment further studies should be made to verify the increased production effect of the NuPulse on a larger scale, as the efficiency of such increases in production has wider economic implications.
Possible stimulation mechanisms associated with the mode of action of the NuPulse are discussed.

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CHAPTER 1

There has always been some interest in the possibility that the milking machine can influence the cows milk yield over the period of a lactation.

With the present review the intention is to provide a background about the factors that influence milk yield, particularly those relevant to the research outlined in Chapter Two.

This review places emphasis on the cow's response to the milking process, mainly because it is an area often ignored by researchers and farmers when any discussion is made about maximising milk yield.

While the milking machine has always been implicated with mastitis, it has been difficult to assess the amount of mastitis that is directly attributable to the milking machine action or use.

The notable absence of comprehensive scientific study about mastitis and machine milking is probably linked to the difficulty and expense associated with undertaking research on this subject. Most of the evidence available is circumstantial and difficult to interpret because of its incomplete and contradictory nature.

1.1.0 The Development of Machine Milking

The earliest mechanical devices used to milk cows were metal tubes (cannulae) inserted into the teat canal. A patent for such a device was taken out by Blurton in 1836.

In 1860 the vacuumised suction teat cup was developed but it was not until 1889 that the first successful commercial milking machine was produced. The machine developed by William Murchland operated with a central vacuum system and a number of milking units.
Constant suction was applied to the teat by creating a vacuum in a teatcup so designed that it formed a seal around the top area of the teat.

An absolute pressure which is less than atmospheric pressure is called a vacuum and is measured on a scale in which atmospheric pressure at the time and place of measurement is zero vacuum. Half atmospheric pressure is expressed on the vacuum scale as approximately 50 kilopascals (kPa). For practical purposes vacuum indicating instruments are usually scaled 0 - 100 kPa of vacuum.

During the 1860 - 1889 period, inventors also attempted to imitate hand milking by using machines that applied pressure to the outside of the teat without the use of vacuum.

In 1895, Dr Shields of Glasgow patented a device which he called a pulsator and established the Thistle Mechanical Milking Company.
The Thistle pulsator was designed to relieve the teats of constant suction. The vacuum applied to the teat varied rhythmically or 'pulsated' between 50 and 15 kPa of vacuum.
The teatcups were made of thick rubber with thin rubber areas moulded on opposite sides and at the top, so that under the influence of the pulsating vacuum inside, and the constant atmospheric pressure outside, they squeezed the teats to some extent at pulsation frequency.

The Murchland continuous vacuum machine and another non stable vacuum type called the Brookside were first imported into New Zealand in 1893.

The next advance in the principle of mechanical milking came in 1902 from Hulbert and Park of New York. They introduced the idea of applying a pressure greater than atmospheric pressure to the teat surface in addition to vacuumising the teat orifice. A rubber liner was fitted into a cupshell that was divided into 3 annular chambers. It is not known if this device was ever commercially produced, as it was superseded by a two chambered teat cup invented by Alexander Gillies, a dairyman from Australia.
A regular pulsating vacuum was applied to the outer chamber and a constant milking vacuum was applied to the inner chamber of the teat cup. When vacuum in the outer chamber was replaced with air, the thin rubber liner separating the two chambers collapsed around the teat. By 1907 a Taranaki farmer, Ambrose Ridd had developed a commercially viable two chambered teat cup. About the same time both Gillies and Ridd patented air admission into the claw.

Another New Zealand machine, invented to avoid the labour of carrying the milk from each cow away in buckets, incorporated a milkline and releaser system. With these features the Gane machine was considered exceptional in 1913.

By about 1920, machines using pulsating vacuum with single chambered teat cups disappeared in most countries.
From this period onwards the two chambered teat cup system became the accepted way to milk cows (Hall, 1977a).

Progress from this point has been characterised mainly by the development of different types of milking installations, to the standard of the modern herringbone and rotary dairies.
This development followed the economic need to milk more cows with less labour. The requirement for improved hygiene has resulted in improved component design and better construction materials.

Despite this, the basic principle of the two chambered teat cup that incorporates a vacuum milking phase and an atmospheric pressure phase, is still the basis of modern machine design.

Differences between makes of modern machines arise mainly from variations in the milk to rest ratio, and in vacuum fluctuation at the teat end during each pulsation cycle.

Pulsating vacuum and single chambered teat cups have been re-investigated in recent years, (Jasper and Whittlestone, 1976; Tolle and Hamann, 1975; Whittlestone, 1978; Woolford and Phillips, 1978) and these more recent trials have indicated single chambered teat cups are still unable to match the performance of the conventional two chambered teat cup.

1.2.0 The Role of Physiological Factors in Milk Production

1.2.1 Basic mammary gland structure

The udder of the cow is made up of 4 independent glands that are not interconnected and are quite separate functionally. The basic functional unit of the mammary gland is the bulbous like secretory alveolus. The wall of the alveolus consists of a single layer of secretory epithelium or alveolar cells. Milk precursor substances are brought to the alveolar cells by a network of capillary vessels which surround each alveolus. As milk is formed by the alveolar cells, it is stored in the lumen or central cavity of the alveolus. Each alveolus is also surrounded by a basketlike structure of stellate myoepithelial cells.

Connective tissue in the gland forms a strong supporting meshwork for the tissue and alveoli clusters. Sometimes a cluster of alveoli may have a common opening into a duct or an alveolus may open directly into another alveolus. The ducts from adjacent alveoli join up and eventually large ducts are formed, which are clearly visible. The large ducts converge and open into the gland cistern(Cowie, 1977).

It is by way of the duct system that the milk formed by the alveoli cells, ultimately reaches the gland cistern and the teat cistern.

1.2.2 Teat structure

The gland and teat cisterns are lined by columnar epithelial membrane made up of two layers of cells. This membrane is similar to, and is in continuity with, the membrane of the ducts. The lining membrane of the teat cistern may be thrown into folds and there is sometimes a fold at the junction of the teat and gland cisterns.

The teat canal is lined with a different type of membrane, termed the stratified squamous epithelium (Milne, 1978). It is composed of many layers of flattened cells and is virtually a continuation of the skin of the teat.

The teat canal terminates proximally at Furstenburg's rosette, a group of 'petal like' folds of connective tissue. At the point of junction, the stratified squamous epithelium changes abruptly to a characteristic double layer columnar epithelium (Milne, 1978). Within the fold of Furstenburg's, Milne (1977), isolated areas of glandular tissue and suggested that such glands may play a role in anti-bacterial defence against infection. Antibacterial factors have been isolated from this portion of the teat as well as from the keratin and stratified squamous epithelium of the teat canal. Hibbitt (1970) has shown that cationic proteins, isolated from the teat canal are able to inhibit the growth of pathogenic mastitis organisms.

1.2.3 The teat end sphincter

Difference of opinion exists about the existence of a teat end sphincter. Cowie and Tindal (1971) consider that there is no well defined sphincter although a loose network of smooth muscle fibres is present. On the other hand Schalm *et al.* (1971) state that the teat canal is surrounded by a true sphincter. Linzell (1969) expressed the opinion that although the smooth muscle bundles extend to the teat tip, there was not a definitie sphincter of smooth muscle (as for example between the stomach and intestine)

whose contraction kept the milk from running out of the teat. Linzell believed that the layout of the teat canal tissue offered passive resistance to milk outflow.

Work by Milne (1978) indicated that the muscle layers were fairly evenly distributed down and around the teat with an increase in the circular muscle adjacent to the internal teat surface in the teat canal region. Williams and Mein (1978) discuss the longitudinal contractions of the teat that start and stop flow from the teat once it has been initiated by a pressure difference. Histological studies showed a pronounced layer of circular smooth muscle and collagen fibres in the form of an annulus around the keratinised epithelium and sub-epithelial layer of the teat canal. They also consider it a possibility, that the layers of smooth muscle could cause the more medially located tissue (as suggested by Linzell, 1969) to fold and actively reduce the size of the teat canal.

Williams and Mein (1978) conclude their paper by stating that if the teat sphincter does maintain canal closure, then an understanding of its physiology may lead to a better understanding of the pathogenesis of mastitis and perhaps to improvement of the design or action of the milking machine.

1.2.4 Nerve supply to the udder

While the nerves between the udder and the brain consist of afferent sensory fibres, they also contain some efferent fibres from the sympathetic nervous system, which are motor fibres to the muscular tissue in the walls of the arteries and to the scanty muscle fibres in the connective tissue of the udder (Cowie, 1977).

Pressure sensitive receptors have been identified in the dermis of the teats (Cowie and Tindal, 1971).

Velitok (1977a) believes that the first response to the stimulation of the teat receptors is a reduction in the resistance of the teat sphincter muscles and that this spinal reflex occurs in the cow in the course of 4 - 5 seconds, much sooner than the final effect of oxytocin, via the blood stream.

Velitok (1977a) investigated the effect of catheter weight, temperature and material on milk yield and the withdrawal of milk

from the alveoli, and found that the receptors of the teat canal sphincter were affected by the catheter differences. He concluded that the reflexogenic zone of the teat canal sphincter may, under various stimuli of inadequate intensity and temperature stress, become the source of impulses *inhibiting* the contractile activity of the alveolar myoepithelia.

For some years the nature of the mechanism causing the contraction of the alveoli was uncertain, but it is now known to be caused by myoepithelial cells positioned on the outer surface of the alveoli (Cowie, 1977). The myoepithelial cells are quite separate structures from plain muscle fibres and are not innervated (Linzell, 1952).

1.2.5 (a) *Milk ejection*

The phenomenon of milk ejection or letdown, was first explained by Ely and Petersen (1941) as the forceful expulsion or ejection of milk from the alveoli and fine ducts into the larger ducts and cisterns, where it can be readily removed from the udder.

In response to teat nerve-end stimulation, nervous impulses reach the brain via the spinal cord and bring about the release of the hormone, oxytocin from the posterior pituitary.
Oxytocin and possibly other oxytocin like substances, are carried in the blood to the mammary gland where they act on the myoepithelial cells that surround the alveoli, causing them to contract and expel the milk (Cowie and Tindal, 1971).

1.2.5 (b) *Measurement of the milk ejection response*

Tucker (1978) believes considerable advancement could be made in determining the application of stimuli which would optimize the milk ejection reflex, if assays could be made sufficiently specific and sensitive to measure the low quantities of oxytocin normally found in the blood during milking.

Past work with assay procedures based on the milk ejection response in the lactating guinea pig and rabbit, and the *in vitro* method using small pieces of lactating rat mammary gland, have given variable

results. Some doubt exists to the exact nature of the substances actually measured by the assays (Cowie and Tindal, 1971; Denamur, 1965).
Using the lactating rabbit assay, Cleverley and Folley (1970) found no indication of oxytocin release in 32 percent of experimental machine milkings, although in most cases milk yields were normal and increased intramammary pressure occurred in all animals. Vasopressin has been shown to cause milk ejection and to be released simultaneously under some circumstances with oxytocin (Fell *et al*.1970). There is also the possibility that other substances such as the plasma kinins play some part in the myoepithelial cell contraction (Cowie and Tindal, 1971). While it has been shown that the myoepithelial cells will contract in response to direct mechanical stimuli in the rat, rabbit and goat, no report has been made about the 'tap reflex' occurring in cows (Cowie and Tindal, 1971).
Milk let down in the goat quite often occurs without the detection of oxytocin, and some evidence (although not conclusive) exists to suggest that milk removal in the goat could occur in response to purely neural mechanisms (Cowie and Tindal, 1971).

Work by Sibaja and Schmidt (1958) using the rat tissue cube assay, indicated that oxytocin was released gradually until milk ejection occurred, and not released all at once following an initial stimulus. Using the lactating rabbit assay, Folley and Knaggs (1966) found that oxytocin was secreted in bursts most consistently at the application of the teat cups, but that sometimes an additional discharge of oxytocin could occur later in the milking process.

Later work by Cleverley and Folley (1970) indicated that the oxytocin response (when it was detected) in fully trained cows was probably due to all the stimuli normally associated with milking rather than any one stimulus in particular.

Tucker (1978) expressed the opinion that the observed differences in cow response are probably associated more with the lack of specific and/or sensitive assay techniques needed to measure small concentrations of oxytocin rather than with inherent cow differences.

1.2.5 (c) *The milk ejection reflex and conditioning*

Milk ejection is a reflex action and being so it is involuntary and not under the conscious control of the cow. Because the reflex involves a nervous pathway to the brain and a hormonal pathway back to the udder it is termed a neurohormonal reflex. This reflex is immediate and inherent and requires no training.

However animals can be trained to respond reflexly to stimuli other than those which evoke the inborn reflex.

If two stimuli, one of which evokes the inborn reflex and the other a neutral stimulus, are applied in close association a number of times then the neutral stimulus acquires the ability to arouse on its own, the same response as that produced by the unconditional original stimulus. The neutral stimulus then becomes a conditional stimulus and the reflex it induces is a conditional reflex.

Feeding concentrates before cups on, and the appearance of the milker may become conditioning stimuli (Cowie, 1977).

Peeters *et al*, (1960) observed that suckling by the calf was the most potent effector of milk ejection.

Until recently it was considered that the occurrence of milk ejection on presentation of the calf was a conditional reflex, but a recent study in Belgium by Peeters, quoted by Cowie (1977) has revealed milk ejection may occur in newly calved animals shown their calf for the first time and before the calf has touched the teats: the sight of the calf must therefore be an unconditioned reflex.

Cleverley (1968) found that the approach of the milker stimulated the release of oxytocin, indicating the cow can be conditioned to release oxytocin in response to visual and auditory stimuli associated with milking. 38 percent of the cows used in the trial by Cleverley and Folley (1970) responded to the conditioning stimuli of sight and sound.

Momongan and Schmidt (1970) using the Van Dongen and Hays (1966) assay, measured blood oxytocin levels during milking in cows milked with and without premilking stimulation.
The experiment indicated that the stimulus obtained from the application of the teat cups, in the absence of a premilking manual wash and massage resulted in an adequate release of oxytocin, as normal milk yields were obtained.
The premilking stimulation caused an earlier release of oxytocin and commencement of milk flow.
Peak levels of oxytocin occurred 1 minute after teat cup application when a premilking stimulation was used, and two minutes after teat cup application without premilking stimulation.

1.2.5. (d) *Inhibition of milk ejection*

It has long been recognized that the milk ejection reflex can be blocked or inhibited under conditions of excitement, fear, stress or pain, so that when the cow is milked the full yield is not obtained, but only that milk which is present in the cisterns and large ducts (Cowie, 1977).

Fright and stress (Ely and Petersen, 1941) appear to activate the neuroadrenal system and cause the release of adrenaline and noradrenaline, which results in either partial or complete cessation of milk ejection.

The inhibition effect on milk ejection results from either a central neural inhibiting mechanism, which blocks oxytocin release from the posterior pituitary (Sibaja and Schmidt, 1958), or from peripheral alterations which inhibit the milk ejection effect of ocytocin (Denamur, 1965).

The peripheral inhibitory effect acts either by vasoconstriction of the blood vessels (Cross and Silver, 1962) leading to the mammary gland, or by an intrinsic action directly upon the myoepithelium (Chan, 1965).

Cowie (1977) doubts whether the peripheral effect is the mechanism normally inhibiting milk ejection in the cow, as work by Cross (1955) strongly suggests that the main factor in emotional disturbances of the milk ejection reflex, is a partial or complete block of the release of oxytocin from the posterior pituitary. Cross *et al.* (1971) postulate that emotional upsets increase the release of noradrenaline which blocks the firing rate of neurons in the paraventricular nuclei. Tucker (1978) mentions that shortly after parturition heifers frequently exhibit central inhibition of milk ejection and that exogenous oxytocin will elicit milk ejection in such cases.

1.2.6 (a) *Milk removal and the maintenance of lactation*

The factors that inhibit primary milk secretion as milk accumulates in the udder have not been fully studied, but the information available indicates that a curvilinear depression in the rate of milk secretion occurs, the depression becoming greater after 12 hours.

The actual decline in secretion rate varies with each major constituent of milk (Wheelock *et al.* 1966). Fat secretion is known to continue after the milk volume and other constituents have stabilised and is responsible for an increase in fat concentration in milk as the milking interval is lengthened (Bailey *et al.* 1955; Elliot *et al.* 1960).

Variation in the secretion of the aqueous phase of milk (the vehicle for fat and protein) is the main cause of fluctuation in milk yield, the secretion of fat and protein to some extent varying independently of the milk yield.

There is little hindrance to the transfer of water from blood to milk and it has long been realised that osmotic forces are important in controlling the composition of the aqueous phase.
Lactose is the main contributor to the osmotic effect, with potassium, sodium and chlorine playing lesser roles (Linzell, 1972).

The increase in yield that can be obtained with more frequent milking has been reviewed by Elliot (1959).
More recently, Morag (1973a) was able to show with a half udder 4 x 4 Latin Square experiment, that half udders milked at 8 h intervals yielded 11 percent more milk than half udders milked at 12 h intervals.

Half udder trial designs suggest local factors can control the differential level of milk secretion, independent from a central mechanism.

The results obtained by Linnerud *et al.* (1966) indicate that the increase in milk yield is related to the more frequent milk removal and that the effect of oxytocin is merely associated with the degree of milk ejection and its effect on milk removal.
The theory, that improved milk clearance from the alveoli cells has a beneficial effect on subsequent secretion has received support from Morag (1967).
Further support for a local effect rather than an endocrine environment effect is given by the fact that quarters can be dried off rapidly and normally while other quarters of the same gland are milked.

Wheelock *et al.* (1967) believe that the inhibition of secretion is not due to an increase in pressure as the amount of secretion obtained when the pressure is decreased is small. Since the commencement of regular milk removal restores milk production the inhibition has the appearance of being controlled by certain constituents in the gland. As soon as these are removed secretion rapidly recovers.

Morag (1973b) has shown that the increased yield obtained from half udders milked at 8 h intervals is independent of the amount of residual milk (the milk obtained after a normal milking by injecting oxytocin into the cow.).
Elliot (1961b) recorded similar amounts of residual milk after 8 h and 12 h milking intervals, but found that the concentration of fat in the residual milk was higher after the 12 h intervals. Elliot (1961a) also reported that the yield of residual milk was independent of the length of the milking interval within the range of 4 - 16 hrs. The most notable observation was the steady increase in the concentration of fat in the relatively constant amount of residual milk, from a level of 20 percent at the 4 h interval to 16 percent at the 14 h interval.
Johansson (1952) also found that the concentration of fat in the residual milk increased as the milking interval was increased.

The depressing effect of a long milking interval on the rate of milk secretion in the following interval has been described by Elliot *et al.* (1960). Milk yield depression was evident during the secretion period following a 12 h interval, the depression lasting up to 16 hrs following intervals of 20 to 24 hrs.
The depression effect could also explain why 16 + 8 h milking intervals in most cases (Schmidt, 1971) give slightly lower 24 h production than 12 + 12 h intervals.
Identical twin milking interval comparisons (reviewed by Elliot, 1959) indicate that the higher secretion rate associated with a short interval is not completely depressed by a preceeding 16 h interval.

Levy (1964) found evidence of a feedback mechanism after studying lipid synthesis in rat mammary tissue. Certain fatty acids normally present in milk were able to inhibit the synthesis of fat in rat mammary tissue preparations.

Larson (1969) used *in vitro* cultures of bovine secretory cells to study protein synthesis and found that the synthesis of protein per cell decreased as the number of cells added to the culture increased,

the results indicating that an increased level of a particular protein decreased its own synthesis in the culture.

The overall data is suggestive of some type of end product inhibition, or feedback inhibition, specific to each constituent in milk. It is possible that the mammary gland may be the location of several feedback mechanisms that are able to shut off the synthesis of milk as it accumulates in the gland.

Increases in milk and fat yield and a reduction in the fat concentration in residual milk, obtained by increasing the completeness of the milk ejection response with the use of high vacuum machines, positive pressure squeeze pulsation and hand stripping have been discussed by Brandsma (1978).

These machine effects on the let down response, and in turn yield, indicate machine design is an important factor in determining the rate of secretion and the maintenance of lactation.

1.2.6 (b) *The effect of a poor milk-ejection reflex or let down*

Knodt and Peterson (1942) postulated that the amount of both milk and milk fat produced, may be dependent upon the completeness of the evacuation of the gland at each milking and that failure of the cow to completely let down the milk, may account for the decline in milk production with the advance in lactation.
Later work by Koshi and Petersen (1955) verified this theory. They found that as the percentage residual milk increased the persistency of lactation decreased; a correlation coefficient of ($r = -0.78$) between the two factors was highly significant.
Turner (1955) found that the mean relative amount of residual milk was very highly correlated ($r = 0.869$) with the percentage decline in daily yield during most of the lactation, independent of any relationship with yield. Turner also noted that cows in which residual milk was relatively high, were also erratic in milking behaviour, probably because of inherent temperamental differences

in the milk ejection reflex. The concentration of fat in milk was higher from cows in which the volume of residual milk was relatively high.

Brandsma (1978) demonstrated with a number of experiments that, techniques used to reduce residual milk increased lactation milk yields. The milking techniques used had less effect on cows with a low percentage of residual milk, and had more effect if residual milk was reduced over the latter part of the lactation.

Brandsma (1978) also noted that a reduction in residual milk was nearly always associated with a fall of the fat concentration in residual milk, and he presented the theory that the fat content in the residual milk depends mainly on the completeness of milk ejection at the preceding milking and less on the actual udder evacuation at any given milking.

Brandsma (1978) obtained a significant positive correlation ($r = 0.51$; $P < 0.05$) between the fall of the fat concentration in residual milk and the yield of milk fat. With heifers a negative correlation ($r = 0.31$) was found between the average fat concentration in the residual milk over a whole lactation and the average concentration of fat in the milk produced during the lactation.

Milk left in the lower duct system after machine milking (machine strippings) did not have the same effect on reducing secretion as did milk left in the alveoli regions of the udder (Brandsma, 1978).

1.2.7 Serum hormone response to milking stimuli

Prolactin was the first anterior-pituitory hormone shown to be concerned with milk secretion, but research soon demonstrated that in the cow, pituitary growth hormone was equally important in this process. Thyrotrophic and andrenocorticotrophic hormones of the anterior pituitary are also needed, as they control the secretory activities of the thyroid and adrenal glands. Thyroxine and corticoids secreted from these glands are needed for the maintenance of lactation (Cowie, 1977).

The injection of growth hormone and thyroid hormone to cows in declining lactation generally increases milk yield, which suggests that the decline in yield may be associated with a reduction in the production of these hormones, and in turn, an overall reduction in the general effect of an interrelated complex of hormones (Convey, 1974; Convey *et al.* 1973).

Although very little is known about the effect of these hormones on milk secretion in the cow, the relationship between exteroceptive stimuli and the release of anterior pituitary hormones has received some research attention.

It is generally believed that the production of the anterior pituitary hormones necessary for maintaining milk production, is regulated by the nervous impulses arising from stimulation of the teat during suckling or milking (Cowie, 1977).

Tucker (1971) has described how prolactin levels in the cow increase during the process of udder washing and machine milking.

Convey (1974) believes that the research so far indicates that, serum prolactin levels are not reflective of mammary gland function only, as a wide variety of stimuli are able to cause prolactin release. Prolactin levels are known to vary with changes in metabolic and feeding events and with the seasons.

Stressful stimuli such as pain, restraint and emotional disturbances also cause prolactin release (Convey, 1974).

Despite this, the milking stimulus is able to cause the most consistent response, and it is possible that the prolactin peaks that occur during milking stimulation could play an important role in the maintenance of lactation.

The use of ergot alkaloids to inhibit prolactin secretion specifically, without affecting the other pituitary hormones, has led to a better understanding of prolactin function.

Karg and Schams (1974) were able to show that mechanical stimulation of the teats acted as a highly potent stimulus for prolactin release, especially in heifers.

Johke (1970) found that milking without feeding caused a rapid increase in prolactin, that lasted from 4 - 20 minutes after milking, and also noted that a rise in plasma prolactin could

occur reflexively with the milking stimulus.
The prolactin peaks were highest in the early stages of lactation and decreased thereafter with the advance of lactation.

The effect of advancing lactation on the prolactin response to the stimuli of milking has been confirmed by Koprowski and Tucker (1973a). They demonstrated that the prolactin response during lactation reached a peak at 8 weeks of lactation and diminished with decreasing milk yields as lactation progressed.

Reinhardt and Schams (1974) obtained a prolactin response by teat stimulation, without milking out, in heifers and cows. The prolactin response increased with the number of teats manually stimulated. Manual stimulation carried out for periods ranging from 0.5 to 15 minutes on dairy heifers, indicated that the duration of the stimulus affected the prolactin response (Reinhardt and Schams, 1975).

Studies with an ergot alkaloid (2-Br-α-ergocryptine) have indicated that the injection of ergocryptine prior to parturition essentially prevents the initiation of lactogenesis, but only decreases milk yield by 10 - 20 percent if it is injected during an established lactation (Schams *et al.* 1972).

Fell *et al.* (1974) also found that milk yield declined 10 - 20 percent when ergocryptine was injected into cows at an early stage of lactation.

While the effect of ergocryptine is to reduce prolactin in serum to very low levels and inhibit the release of prolactin in response to milking stimulus, it does not entirely eliminate serum prolactin.

In a study by Smith *et al.* (1974) resting prolactin levels were reduced to 1 ng per ml in cows injected with ergocryptine. In contrast to the results of Schams *et al.* (1972) and Fell *et al.* (1974), milk yield was not significantly reduced by the treatment.

It is possible that prolactin released at a given milking may not be expressed in terms of production or metabolic function until until some time later, or that the low level of plasma prolactin that exists after the injection of ergocryptine is enough to sustain production in some circumstances (Convey, 1974).

The erocryptine studies indicate that prolactin is an essential component in the initiation of lactation but that it plays a less important role in the maintenance of milk secretion. It seems likely that prolactin is essential along with other hormones, for the achievement of maximum production in cows.

It is also conveivable that the lactational requirement for corticoids is satisfied by corticoids released at milking (Convey, 1974).

Wagner (1969) measured an increase in plasma corticoids in the cow 5 to 10 minutes after the stimulus of milking and found that the increased level persisted for a further 10 to 20 minutes.

Smith *et al.* (1972) were able to show that the milking stimulus *per se* and possibly exteroceptive stimuli associated with milking, can cause an increase in serum corticoids in cows.

As well as an increase in corticoids with milking stimulus Koprowski and Tucker (1973b) have presented evidence that shows insulin can also increase at milking.

Convey *et al.* (1973) obtained increases in milk yield by injecting thyrotropin releasing hormone (T R H) into cows, and suggested that the increased yield was probably caused by T R H increasing the availability of prolactin, growth hormone and thyroxine. Even though T R H can increase the level of growth hormone and thyroxine there is no evidence to suggest these two hormones increase at milking in response to the milking stimulus.

In conclusion, the available information tends to support the general belief that nervous impulses arising from the stimulation of the teat during milking are able to regulate some of the hormones involved with the maintenance of secretion during lactation.

1.3.0 Milk Removal and Machine Milking

The maintenance of milk secretion is dependent upon the removal of milk and a suckling or milking stimulus in most animals (Schmidt, 1971). The natural stimulus to milk ejection is the suckling of the calf.
Cineradiographic examination of a calf feeding from the cows teat shows that the production of a vacuum within the mouth cavity is not an essential feature of suckling, although it aids the process. Calf suckling is analogous to hand milking in that the milk in the teat cistern is trapped there by compression of the base of the teat, and then forced out through the teat canal by positive pressure, with the tongue and palate.

The evidence available suggests that machine milking may not be as complete a stimulus as suckling, because it involves a different physical action, as well as elements of discomfort which are not present in the natural stimulus.

Everitt and Phillips (1971) demonstrated that multiple suckled cows have higher secretion rates during suckling, than cows which are machine milked. The suckled cows had a higher peak performance that continued through lactation, despite the fact that suckling was replaced with machine milking after 7 - 10 weeks of lactation. Walsh (1974) found that suckling with 4 calves per cow twice a day at milking time in late lactation, increased milk yields by 16.7 percent, relative to machine milking.

The rise in plasma adrenal corticoids at milking has been used to measure the cows response to milking stimulus.
Whittlestone (1978) quotes work by Hudson, that showed the cortisol response to milking was similar to the response obtained for calf suckling.

The most reliable evidence about the cows response to machine milking comes from several full lactation trials. One of the first full lactation trials was carried out by Phillips (1960) with identical twin Jersey cows.
Twelve twin pairs were used to compare a 30 s hand wash massage and teat squirt premilking routine, with a milking method where the teat cups were put straight on, without any wash or udder preparation. The cows were milked at a pulsation rate of 40 per minute and a full air, pulsation squeeze phase of 30 percent.
The response of individual twin sets to the treatments was extremely variable.

A manual stimulation response was obtained between the twins in 7 pairs. Lactation length (to an end point fat yield of about half a kg/week) was longer, and butterfat production was 59 percent higher for the manually stimulated cows.
The premilking stimulation had the opposite effect on the treatment cows in the other 5 twin pairs. The 5 cows milked with machine stimulation only, produced 5 percent more than their manually stimulated twin mates.

A 2nd experiment by Phillips (1965) with 20 sets of identical twins, compared premilking stimulation to the individual cows requirements, with a short 5 - 8 s wash.

With 4 sets, the wash only methods gave the highest yields, but the twins in the other 16 sets that received the premilking stimulation, milked for an average of 58 days longer and yielded 26 percent more milk.

The stimulus level for the treatment cows was adjusted monthly to the requirement of each cow for a letdown response. The levels ranged from as little as 10 seconds to as much as 2½ minutes.

The effect of increasing the level of manual stimulation was to delay the decline in lactation. There was a smaller response to additional stimulation in early lactation.

To see if a standard pattern of stimulus could be used for all cows during a lactation,a 3rd experiment was conducted during the 1965/ 1966 seasons (Phillips, 1978a).

One twin in each of 21 sets of identical twins, was given a fixed level of stimulus which was adjusted stepwise through the lactation. The twin mate in each case again received the short 5 - 8 s wash. The stimulus levels for the treatment cows started with 20 s for 3 months, was increased to 30 s for the next 3 months and finally increased to 45 s for the last 4 months of lactation.

The stimulated cows on average milked for 31 days longer and produced 16.4 and 18 percent more milk and milk fat respectively.

A large trial was carried out at Moore Park (Ireland) to measure the effect of premilking hand stimulus (to individual cow requirement) on 44 mature Friesians, 22 mature Shorthorns and 22 first lactation Friesians (Phillips *et al*. 1967).

Cows in the control group received no preparation before the milking cluster was put on, whereas the cows in the treatment group received a wash for 5 - 8 s. followed by hand stimulus to letdown requirements. The cows had milked for an average of 10 weeks before the experiment started.
The treatment cows during the following trial period produced 8.4 percent more milk and 6 percent more fat than the control cows.

A trial repeating Phillips' (1965) second trial was carried out at Moore Park by Walsh (1969) with mainly Friesian identical twins. The cows stimulated to requirement milked 19 days longer and yielded 8 percent more milk. The smaller response indicates that, at the time, breed differences in the response to milking stimulus probably did exist.
Recent reports (Frommhold, 1977; Frommhold and Wehowsky, 1978) indicate that East German cows have a relatively high stimulus requirement.

Since 1965 it is possible that some selection for response to manual premilking stimulation has taken place with NZ cows.
Phillips (1969) investigated the stimulus requirements of 12 A.B. sires being used in NZ at that time and found that the requirement for stimulus was inherited.
He also found that the A.B. sires with the highest loss of merit rating (estimated by the Dairy Board progeny testing scheme) were the bulls whose daughters had high stimulus requirements.

A 4th trial conducted in 1974 by Phillips (1978a) with 36 sets of identical twins detected very little response to manual stimulation, and indicated that a successful milk ejection reflex or let down could occur in the absence of manual stimulation.
The 36 sets of twins included 13 sets of Jersey, 18 sets of Jersey x Friesian Cross, and 5 sets of Friesians.

The control group received a 10 s wash with warm running water, followed by machine milking and the treatment group were given the same wash, followed by an additional 45 s of hand stimulation of the teats before machine milking.

Both groups of cows were milked in a 17 bail rotary turnstyle described by Hicks (1971).

The number of Friesian twin sets used in the 1974 trial gives some indication of the shift towards the Friesian breed since the first trial by Phillips in 1958-59.

The response of the Jersey twins to the treatment, resulted in an increase in milk yield of 4.1 percent and fat yield by 6.3 percent. The same figures for the Jersey x Fresian cross cows were 3.3 and 4.0 percent respectively. The treatment cows in the 5 Fresian sets reacted negatively to the treatment by producing 5.3 and 5.17 percent less milk and milkfat respectively. Selection against high stimulus requirement cows over a 12 year period is one reason put forward for the lack of a significant treatment effect in the above trial.

To test this hypothesis and investigate the possibility that cows could become conditioned during the early stage of lactation to a fixed level of stimulation (as in experiment 4) and be less responsive during the later stage of lactation, a 5th experiment was carried out by Phillips (1978b). Thirty six sets of identical twins were used to repeat the 3rd experiment carried out 12 years earlier. The same (stepwise) increasing level of manual stimulation was applied to the treatment cows as lactation progressed. The control group of twins (given a 5 - 8 s premilking wash) had the same lactation yield as the manually stimulated group. This result suggested that the stimulation requirement of a sample of identical twins had changed over a 12 yr period. It is possible that identical twins do represent the change, or response to other forms of stimulation, that has occurred in the N.Z. cow population.

Velitok (1977b) has found that the type of milking installation can affect milk production and the milk ejection reflex. Compared to a walk through dairy, a herringbone caused twice as many and a portable (raised platform) herringbone 5 times as many let down failures. Three different milking machines tried in the portable herringbone failed to obtain alveoli milk (a let down failure). One machine was less successful than the other two in stimulating the cows.

1.3.1 Milk removal and the effect of machine factors

(a) *Liner design*

Phillips (1970) modified the design of the liner surface to test the idea that an irregular surface, like a calf's mouth might apply more stimulus during milking.

A liner was designed with a finely corrugated surface in the top half. The corrugations were concentric with the bore and about 1.0 mm deep and 1.5 mm from crest to crest. The ridges in contact with the teat were moulded with a small radius to give a sharp edge in contact with the teat.

To compare the performance of the corrugated liners with smooth bore liners, Phillips (1970) conducted a trial with 14 sets of first lactation identical twins.

All cows were given a short wash with cold running water before the cups were put on.
The cows milked by the corrugated liners produced 10.3 percent more milk and 11.7 percent more butterfat and milked for 12 days longer. This statistically significant response was not repeated in the following season with older cows and a modified liner with grooves extending into the bottom half of the liner.
Brandsma (1969) believes uncomfortable large bore liners can cause inhibition of the milk ejection reflex if the mouthpiece vacuum seal of the liner hurts the cow.

1.3.1 (b) *Thermal stimulation*

Frommhold (1977) conducted several stimulation experiments to determine the effect of temperature stimulation on cows, in the absence of any mechanical action. Heat was applied to the udder by immersing the lower part of the udder in a water bath, or by applying infra-red radiation, or warm air flows.

The let down response obtained with the 3 methods of thermal stimulation was compared to the let down response obtained using 60 s of manual stimulation or stimulation by high pressure water jets.
The peak flow rate and yield of residual milk, obtained by hand stripping were used to gauge the success of the let down response.
The let down response obtained with the thermal stimulation was less successful than the response obtained by manual stimulation or stimulation by high pressure water jets. Decreasing the water temperature in the water jet system from 40°C to 10°C had no detrimental effect on the let down response.

1.3.1 (c) *Pulsation*

Tolle and Hamann (1975) describe the (P.M.E) pulsationless, single chambered teat cup, milking system. The teat cup consists of a metal teat cup body that is slightly tapered, and fitted with a rubber mouthpiece in which are inserted two metal air admission holes. Milk is withdrawn under a continuously applied vacuum.
Even though the teat cups are immersed in a 50°C water bath before

being attached to the cow, the effect of the thermal stimulation has been shown to be minimal (Whittlestone, 1978).

Identical twin Jersey and Jersey Friesian cross cows were used in a trial by Whittlestone (1978) to test the P M E system over a full lactation.

The twins were split among 3 treatments, namely, 'thermal PME' where the teat cups were heated to 50°C prior to application;
'Manual PME' where the teat cups were unheated, but instead the cows were given 10 - 15 s of premilking manual stimulation;
'Orthodox milking' where the cows were given the same 10 - 15 s of premilking manual stimulation and milked by the conventional machine.

Lactation milk and fat yields obtained with the thermal and manual PME system were 10 - 12 percent lower than the comparative yields obtained with the orthodox milking system. Hygiene measures and cluster disinfection were undertaken at milking time to minimise new infections and the effect differences in infection levels between treatments might have on the production comparison (Jasper and Whittlestone, 1977).
Whittlestone (1978) believes the overall results suggest that the stimulating role of the machine is, if anything slightly more important than 10 - 15 s of manual stimulation applied prior to milking.

Extensive trial work by Phillips *et al.* (1975) with another single chambered teat cup also indicated the need for machine stimulation during the milk removal process. The machine developed by Woolford and Phillips (1978) operates with a swinging vacuum below the teat end instead of a relatively stable vacuum. The vacuum is regulated to swing between a high level of 40 - 50 kPa and a low level of 16 - 25 kPa. The machine is hereafter referred to as the swinging vacuum, single chambered, teat cup system (SVSC).

Two full lactation experiments using identical twins to compare the single chambered machine with a conventional machine both showed the SVSC machine to be associated with lower yields.
While the lactation yields in the first experiment were affected by a high incidence of mastitis, strict milking hygiene prodecures in the 2nd experiment minimised the confounding effects of different infection levels. An analysis of variance indicated that the SVSC machine effect was independent of breed, age and mastistis in the 2nd experiment. In the 2nd experiment yields of milk and milk fat were 12.1 and 11.7 percent lower (respectively) with the SVSC machine.

While the mechanisms responsible for the lower production are not fully understood, it appears the SVSC machine may provide less stimulus through diminished mechanical sensation.

Recordings were made to estimate the period of mechanical machine action required to induce a milk ejection response with the SVSC and conventional machines.
Measurements were made of time, from 'cups on' to a milk flow rate of 0.9 *l*/min after a minimal 5 s wash had been applied. The period of required mechanical action was 0.9 min for the conventional machine and 1.4 min for the SVSC machine.

The letdown response and milk yields could be increased in cows milked with the SVSC machine by premilking manual stimulation. Cows milked by the SVSC machine required, on average an extra 48 s of manual stimulation to match the let down response obtained with pulsation and the conventional machine (Woolford and Phillips, 1978).

1.3.1 (d) *Positive pressure pulsation*

Velitok (1977b) found that the teats needed to be compressed with a force equal to 67 - 80 kPa during hand milking to obtain a good milk ejection, and noted that the teat compression force observed during machine milking falls far short of this.

During short term trials Brandsma (1978) has found that better let down responses can be obtained with machines using a pressure greater than atmospheric pressure during the squeeze phase of pulsation.

Frommhold and Wehowsky (1978) describe the operation of the East German positive pressure pulsation machine, commercially produced, since 1969 under the brand name 'Impulsa'.

The Impulsa machine stimulates the cow with one minute of positive pressure pulsation just after the cups are placed on.
Because the pulsator has to remove a greater mass of air, each time the liner opens, during this phase, the pulsation ratio widens, and the pulsation rate decreases. The end result of these changes is a 40 - 50 percent reduction in milk flow rate, while positive pressure pulsation is applied.

Matthew (quoted by Frommhold and Wehowsky, 1978) compared the effects of compressed air stimulation, with two levels of manual stimulation on 3 groups of 20 cows over a period of 300 days.

The first group of cows were given the conventional preparation of 0.2 min manual stimulation of the teats, followed by a 0.8 min delay before attaching the teat cups.
The second group of 20 cows were manually stimulated for 1 minute before the teat cups were attached.
The third group was milked by the Impulsa machine.

The cows in the second and third groups had similar lactation yields. These results indicate that one minute of positive pressure pulsation after 'cups on', has the same effect as one minute of manual premilking stimulation, and has definite labour saving possibilities, with high stimulus requirement cows.

The cows in the first group outproduced the Impulsa milked group over the first 100 days by 7.6 percent but produced 39 percent less over the last 100 days and 4.4% less for the total 300 day lactation.

Brandsma (1969) believes hand and intensive machine stripping only influences lactation yields when other stimuli are insufficient for complete milk ejection.

The need for machine stripping with East German cows (yields decrease by 8 - 9 percent when it is omitted) and the response obtained from manual stimulation, imply that East German cows have an inherently high stimulation requirement (Frommhold, 1977; Frommhold and Wehowsley, 1978).

1.3.2 Factors that effect milk flow rate

(a) *Machine factors*

The pattern of milk flow rate is influenced by the different milking out characteristics of individual quarters, the effects of variable distribution of cluster weight between the quarters, and by the design and action of some machine components, notably those in the cluster.
Components other than those in the cluser cannot affect the pattern of milk flow from the teat unless they affect either liner vacuum or liner wall movement (Thiel and Mein, 1977).

Walsh *et al.* (1970) tested six commercially available milking machines for mechanical efficiency and their effects on udder health and milking characteristics. The machines differed mainly in the speed of milk removal and the amount of milk obtained.
The low yields obtained by two machines were significantly ($P < 0.05$) less than the yields obtained with two other machines. Significant differences also occurred between machines in milking rate and stripping yields.
With the exception of one machine the maximum milking rates were related to the machine settings. Machines using low vacuum, slow pulsation rates and narrow pulsation ratios had the slowest milking rates. This same conclusion was reached by Labussiêre and Richard (1965) after they reviewed the literature.
The exceptional machine, although having the fastest pulsation rate and the widest ratio had a maximum milking rate that was significantly

slower than that of the other machines.
Similarly, with the exception of one machine, the yield of strippings was inversely related to the weight of the cluster assembly. The exceptional machine had almost the lightest cluster but gave lower stripping yields than 3 machines with heavier clusters and also tended to fall off more than the others during milking.

This work indicates that the physical settings of machines are not always a good indicator of performance because of component interaction. Rabold (1969) believes that a lot of the contradiction present in the literature has been caused by investigators failing to recognize the interaction effect.
For example, it is thought that flow rate increases with pulsation rates above 60 per min (Thiel *et al*. 1966). Williams and Mein (1978) on the other hand, have shown that the increase in vacuum (above the nominal 50 kPa) that occurs below the teat as the liners open (Theil *et al*, 1964) increases in magnitude as pulsation rate increases from 60 to 180 pulses per min.
The increase in vacuum can be sufficient to account for the increase in flowrate that has occurred with pulsation rates above 60 per min. especially if the liner is opened and closed rapidly, in an effort to maintain a constant pulsation ratio.

1.3.2 (b) *Cow factors*

Mein *et al*. (1973b) were able to show that most of the milk obtained from a quarter is obtained at almost constant flow rate. However after the main period of constant flow rate, during which time about 90% of the available milk is obtained, there is usually a second period of greatly reduced flow rate. Only about 5 percent of the available milk is obtained during this 'low flow period' but it can take up 25 percent of the average milking time.
The amount of milk that can be removed by machine stripping will be low if teat cup crawl can be kept to a minimum. Teat cup crawl prevents milk present in the udder flowing into the teat cistern (Schalm *et al*. 1971; Mein *et al*. 1973a). Theil and Mein (1977) have shown that if the peak flow rate of the slowest quarters could

be maintained for 10 - 20 s longer, milking time could be reduced by 20 percent.

Low flow rate time and yield and the machine stripping yield of quarters, can be regarded as inter-related measures of inefficiency in the milking properties of a machine (Thiel and Mein, 1977).

The rate of milk flow from the teat is governed by the physical dimensions of the streak canal (Baxter *et al*. 1950) and the pressure difference acting across the teat opening (Williams and Mein 1978). Milking with a cannula standardises the streak canal diameter and reduces interquarter flow rate differences. Williams and Mein (1978) also noted that the flow rate usually increases as milking progresses, the higher the yield the higher the flow rate reached, and they suggest this phenomenon, in conjunction with the higher AM yields could account for the higher flow rate at AM milkings.
Phillips *et al*. (1975) have found that the teat can be subjected to a vacuum of 10 - 16 kPa continuously without showing evidence of tissue congestion.
Tolle and Hamann (1978) present recordings to show that the peak flow rate attained with single chambered teat cups depends on the diameter, weight and surface roughness of the cup as well as the vacuum level.
The peak flow rate reached a maximum at 50 - 60 kPa and then decreased below this with a further increase in vacuum.
Phillips *et al* . (1975) consider that the flow rate will be reduced if teat tissue congestion during the vacuum phase reduces the teat orifice diameter.
With the use of a low vacuum phase or a pulsation squeeze phase, the normal condition of the teat end is restored and flow is again returned to a high level at the start of the next vacuum phase.
Within the range of 50 - 60 pulsations per minute and a vacuum level of 50 kPa in the conventional machine it is unlikely that flow rate during the liner open phase is diminished significantly by teat congestion. (Refer to Thiel *et al*. 1966).

1.4.0 Machine Milking and Mastitis

1.4.0 (a) *Mastitis*

When obvious inflammation of the mammary gland occurs regardless of the cause, the condition is known as mastitis.

Most commonly, mastitis begins with the penetration of pathogenic bacteria through the teat canal into the interior of the gland. Mastitis caused by *Brucella abortus* is regarded to occur hematogenously. Despite many attempts experimentally, only one worker has claimed to have produced a bacterial infection of the bovine gland by way of the bloodstream (Newbould, 1974).

Large scale field research (Dodd and Neave, 1970) has shown, that more than 90 percent of infection is caused by the pathogenic bacteria *Staphylococcus aureus, Streptococcus agalactiae, Str. dysgalactiae,* and *Str. uberis*. The disease caused by these pathogens is infectious.

The introduction of a few colony-forming units (CFU) of the common mammary pathogens into the teat cistern causes mastitis (Newbould and Neave, 1965; Schalm *et al*. 1971), whereas bacteria placed artifically at the teat end seldom cause infection.
While it is known the teat canal can remain infected for some time before the development of mastitis, inflammation of the udder can occur without detectable preceeding infections of the teat canal (Forbes, 1968).

Hopkirk (1934) found that bacteria colonising the teat duct were able to produce a positive chemotaxis, which varied according to the type of organism established, and stated that a raised cell count and the presence of bacteria in a milk sample does not demonstrate whether the gland itself, is infected or not.

Little information is available about the actual mechanisms of bacterial invasion of the teat canal and the reasons for the occasional failure, (in the face of constant challenge) of the cows natural defence mechanisms.

1.4.0 (b) *The inflammation response*

In experimental studies (Schalm *et al.* 1971) the first detectable change in milk, in a developing case of acute mastitis, is an increase in the serum albumin content.
This response is followed by the appearance of leucocytes in milk. Leucocytes are of 5 distinct morphological types: (i) basophils (ii) eosinophils (iii) monocytes (iv) lymphocytes and (v) neutrophils, (or polymorphonuclear (PMN) leucocytes) (Schalm *et al.* 1971).

More is known about the function of the neutrophils than the other types.

Neutrophils from the bone marrow reserves and blood move into areas of acute inflammation in response to chemotactic factors generated locally. This directional movement of neutrophils towards an attractant is termed chemotaxis. Little is known about the mode of action of chemotactic substances, although some substances have been isolated (Jain, 1976).
As well as phagocytizing, killing and digesting bacteria with the help of opsonins, such as IgG antibodies, neutrophils apparently also act as incitors of the inflammatory reaction.
Jain *et al.* (1972) have conjectured that the neutrophils *per se* may be involved in maintaining a continuously high level of leucocyte numbers in the milk in an auto catalytic fashion, long after the irritant has been neutralised or removed.
The large fluctuations that occur with somatic cells and bacteria numbers during inflammation emphasise the point that, inflammation is not a static state; 10 to 20 percent of milk samples taken from quarters with clinical mastitis fail to yield common pathogens when cultured (Neave, 1975).
When mammary tissue injury has been extensive, weeks and months may elapse before complete healing follows. Leucocyte exudation into milk, therefore may continue for long periods after the cause of mastitis has been removed. This is especially the case in quarters from which bacterial pathogens have been removed by antibiotics (Schalm and Lasmanis, 1968; Duitschaever and Ashton, 1972).

Further research is needed to improve the understanding of the factors that inhibit or stimulate the phagocytic ability of leucocytes. It has been suggested that a somatic cell count of 500,000 cell/ml, gives some protection against infection when small numbers of organisms pass the teat canal barrier (Schalm *et al.* 1971; Bramley, 1975).

In the process of infection, fibrinogen escaping into milk is converted to fibrin strands which enmesh leucocytes, epithelial cells, bacteria and other debris to form flakes and clots (Schalm, 1977). However, Neave *et al.* (1954) found that the detection of a few flakes in the foremilk was not a reliable indication of infection with *Streptococci* and *Staphlococci* species.

Acute mastitis is characterised by all the cardinal signs of inflammation, namely redness, swelling, increased temperature and pain, accompanied by the systemic signs of fever, depression shivering and loss of appetite.
When the so called cardinal signs of mastitis are subdued and not accompanied by systemic effects, the mastitis is called subacute.

When the cardinal and systemic signs are absent, but inflammation can be detected by chemical means (Schalm *et al.* 1971) or by the prescence of leucocytes, fibrin clots and serum, then the condition is referred to as subclinical mastitis.

In addition to the leucocytes of blood origin, epithelial cells from the udder appear in milk in increasing numbers with mastitis, and it is common practice to count both leucocytes and epithelial cells in milk and express the results as the number of somatic cells per ml. (Schalm *et al.* 1971).

Epithelial cells are derived from the local tissue as a result of physiological wear during milk secretion or as a result of tissue injury. Epithelial cells generally increase in late lactation due to regression of the gland. Involution of the gland as a result of inflammation may enhance the sloughing of epithelial cells.

Great differences in opinion,exists concerning the proportion of different cell types in milk from mastitic quarters, although it is generally agreed that cell counts are elevated.
The differences seem to have arisen because workers investigating the cell types have failed to recognize all the factors that influence the natural variation (Schalm *et al.* 1971).
Of the cells found in normal milk, it is reported that 65-70 percent are epithelial cells. With severe mastitis the proportion can decrease to 10 - 15 percent when diluted with blood leucocytes. Giesecke and Van Den Heever (1974) believe that an increase in cell count, limited to epithelial cells during premature regression is more of a physiological process rather than mastitis.

The proportion of neutrophils can be as high as 90 - 95 percent of the cells in mastitic milk. The other types of leucocytes may be shed in large numbers with chronic mastitis but neutrophils remain predominant (Schalm *et al.* 1971).

It is generally considered that the presence of neutrophils beyond a certain number consitutes an abnormality.
Due to a lack of information, no definite limits to define abnormality have been set (Schalm *et al.* 1971).

Until differential cell counting techniques (Sheldrake *et al.* 1977) are developed further, the interpretation of somatic cell counts in bulk, cow and quarter milk samples, must be used with some reservation, particularly with cow samples below 300,000/ml (Smith and Schultze, 1978).

1.4.0 (c) *Subclinical mastitis*

Many workers have attempted to define normal and abnormal levels of somatic cells in milk.
With persistent infections opposite patterns of rise and fall of bacteria and somatic cell numbers in milk can occur (Neave, 1975).

Very little information is available about somatic cell counts in normal milk or uninfected glands mainly because it is difficult to guarantee a gland has not been infected and recovered spontaneously between sampling periods.
Dodd and Neave (1970) estimate spontaneous or natural recoveries to be as high as 20 percent.

Schultz (1977) compared the somatic cell counts of several cows falling into the following infection categories at the time of sampling; (a) non-infected (b) infected with non pathogens (c) infected with pathogens. Bucket milk samples were taken at each milking over a one month period. Mean cell counts for the 3 groups were 169,500, 225,800 and 997,800 cells per ml, with coefficients of variation (COV) of 94, 66 and 82 percent.
The high COV occurs because the distribution of cell count is skewed towards the higher values (Renner, 1975).

In the first two groups, only 2.5 percent of the samples taken at each milking during the 1 month period exceeded a somatic cell count level of 500,000 cells per ml.

The major limitation of using somatic cell count to predict bacterial infection is demonstrated by the observation that the level of 500,000 cells per ml was not exceeded by 25 percent of the samples taken from the infected cows in group (C).

Neave (1975) found that quarters infected with bacteria,only yielded milk with somatic cell counts above 500,000 per ml in 50 percent of samples, the count fluctuating to levels as low as 150,000 per ml.

Increasing the number of test samples as in production testing schemes, decreases the chance of between sample variation causing a false diagnosis.

The presence of bacteria in milk samples is also used to diagnose subclinical mastitis, particularly in research work where a simple 'infected' or 'non-infected' demarcation is usually required.

Neave (1975) has shown that the infection technique is accurate in determining the presence of the major pathogens (Griffin *et al*. 1977) causing mastitis, by testing the method with cows diagnosed as infected by other indirect tests.

The method requires trained technicians using a defined sampling method, so that extraneous bacterial contamination and errors are minimised. The teat end is scrubbed vigorously for 15 - 20 s with 70 -80 percent ethanol before the milk sample is taken.
Because the bacterial concentration is higher in the foremilk, Neave (1975) believes that discarding the foremilk probably increases the chance of obtaining a false negative diagnosis from infected quarters.

The chance of teat canal infections causing false positive results has been reduced by plating only 0.01 - 0.05 mls of the milk sample onto the growth medium.
The evidence provided by Neave (1975) indicates that the presence of bacteria in two successive quarter samples taken about a week apart (with a third sample when two disagree) is likely to give an assessment of infection with less than 1 percent of false positive and negative quarters, when compared with an assessment based on combined bacteriological and indirect tests of 6 or more milk samples.

Pearson (1975) has pointed out that the method developed by Neave (1975) has been designed for use in mastitis control schemes, where the aim is to detect and control the major mastitis pathogens only.

Pearson and Greer (1974) believe that if the aim of mastitis control is to reduce the cellular response caused by inflammation irrespective of the cause, then the minor pathogens (Griffin *et al.* 1977) and the increase in somatic cell count caused by them have to be included in any diagnostic method.

Several workers (Pearson and Greer, 1974; Thompson *et al.* 1978; Wesen and Schultz, 1970) have used a definition of infection which requires both the isolation of a pathogen and a raised somatic cell count.

The International Dairy Federation (IDF; Tolle, 1975) has put forward a method outlined below to define subclinical mastitis in individual quarter samples.

Assessment of cytological-bacteriological findings in mastitis diagnosis

Cell count per ml	Pathogenic micro-organisms not isolated	isolated
< 500,000	normal secretion	latent infection
> 500,000	non-specific mastitis	mastitis

The IDF definition is restricted to pathogenic micro-organisms but lacks a definition of the procedures to be followed to determine the presence of micro-organisms.
Neave (1975) has found the IDF definition of subclinical mastitis too cumbersome, because many infections can pass through all the definitions in the course of a few weeks.

Griffin (1975) tested the repeatability of the IDF assessment of infection over a 12 week period without intervening interference. The repeatability for the various infection classifications were - normal quarters 74 percent; non specific mastitis, 41 percent; latent infection, 20 percent; mastitis, 80 percent.
When using bacterial methods alone the classifications were - infected quarters, 89 percent; non-infected quarters, 96 percent.
When using somatic cell count alone and a threshold level of 500,000 cells/ml - assessed infected, 77 percent; assessed not infected 83 percent.
These data show that for diagnosing new infection, bacteriological methods are least likely to result in false conclusions with infection caused by the major pathogens, and that a cell count threshold method alone is better than a method which combines the use of both somatic cell count and bacteriological methods.

In conclusion,it appears that to obtain a reliable diagnosis,more than one examination or a repetition of the result is required, and that whatever technique is used the method must be described in detail. Bacterial work, even though costly and time consuming is needed to define the term infection, at least in scientific work.
The somatic cell count is the best indirect test available for the analysis of subclinical mastitis in herd bulk milk and individual cow samples, and can be usefully employed in mastitis control schemes, provided that several counts are made during the lactation to assess the inflammation status and overcome the non-static nature of the biological parameter.

1.4.1 Mastitis and its effect on milk yield

One of the reasons put forward for the control of subclinical mastitis is that high cell counts are associated with lower yields.
The bulk of the literature clearly indicates that samples from most non infected quarters contain less than 300,000 somatic cells/ml, and that almost all contain fewer than 500,000 somatic cells/ml. More precise quantification is very difficult due to physiological variation and the natural processes of spontaneous recovery (Smith and Schultze,1978).

Blackburn (1966) found that the somatic cell count and the number of neutrophil leucocytes increased with the age of the cow. The rise in the neutrophil leucocyte count was attributed to an increase in the extent of subacute inflammation of the ducts as well as an increase in the severity of existing infections. Natzke *et al.* (1972) were able to show that the somatic cell count did not increase with age or towards the end of lactation if the cow remained uninfected. Schultz (1977) and Natzke *et al.* (1972) found that cows uninfected for long periods, but with prior cases of clinical mastitis, have higher somatic cell counts, in the range of 480-600,000 per ml Morris (1976) has found that when infections were successfully treated at drying off, yield in the affected quarter returned to normal in the next lactation. When infections were successfully treated during lactation, the yield also returned to normal in the next lactation.

This data suggests that for economic reasons higher cell count thresholds should be tolerated in older cows with a previous history of mastitis (Schultz, 1977).

The many attempts that have been made to estimate the production losses that occur with mastitis have been reviewed by Janzen (1970) and Morris (1976). The reports on the reduction in yield and the change in milk composition that occurs with both subclinical and clinical mastitis are highly variable.
There is also an absence of published information on whether the depression in yield results from a lowered efficiency of conversion of feed into milk or lowered feed intake by affected animals, and if feed intake needs to be increased in order to obtain higher yields when subclinical mastitis is reduced.

It is difficult to assess the real effect of mastitis on yield, by comparing herds with high and low infection levels, as differences in environmental factors have been shown to account for most of the apparent effect in such comparisons (Mein *et al.* 1977; Natzke, 1974).

High somatic cell counts have been associated with low milk yields (Reichmuth, 1975; Meijering *et al.* 1977) but this does not prove a cause and effect relationship particularly with quarter somatic cell counts below 500,000 per ml. In the study by Meijering *et al.* (1977) the variation in cell count accounted for only 2 - 3 percent of the total variation of quarter yield.

The variance can be reduced by comparing the milk yield of quarters having low cell counts with those of opposite quarters with raised cell counts.

Schultz (1977) compared the milk loss between quarters and found yield started to decline at about 500,000 somatic cells per ml. The loss was 7.5 percent at 1 million, and 15 percent at 2 million cells per ml. Reichmuth, (quoted by Meijering *et al.* 1977) found that the drop in quarter yield became significant when the count exceeded 500,000 per ml.

Hoare (1976) has found that the number of cells shed per milking tends to be constant and that the higher milk production generally obtained at the morning milking results in a lower cell concentration.

The actual reduction in milk yield due to mastitis, depends on the stage of lactation and the duration of infection (Schultz 1977).

While an absence of such detail in most of the literature further confuses the issue, most workers agree that when the costs of discarded milk, treatment and extra labour are added to the cost of some estimate of the depression in yield, mastitis becomes a costly disease.

1.4.2 Mastitis and machine milking

Tolle (1975) believes three biosystems are involved in the multi-factor disease of mastitis. The first involves the susceptibility and resistance of the cow to mastitis (Bramley *et al.* 1978). Cows with small diameter teat canals appear to be more resistant to infection than cows with large diameter teat canals (McDonald, 1975a) and Dodd *et al.* (1977) have found that 65 percent of all new infections diagnosed during lactation in 14 herds occurred in cows already infected in one or more quarters.

The second biosystem involves the infectious agents. Natzke (1974) believes that differences in the bulk milk somatic cell counts between herds appears to be due more to cow and/or bacterial species differences, rather than management differences.

Research has demonstrated that marked reductions in new infections can be made by reducing the bacteria population on the teat (Philpot, 1975). Teat disinfectants also markedly reduce the incidence of clinical mastitis (Neave, 1971) by some mode of action that is, to date, unexplained.

Several workers have reported that clinical mastitis has occurred more frequently during the first 3 months of lactation. About 50 percent of the lactation incidence occurred in the first 3 months. The incidence in one of the studies seeming to decrease about one month after conception (Guidry *et al.* 1976).

Even under conditions of strict hygiene large between herd variation in the incidence of mastitis exists (Dodd and Neave, 1970).
The third biosystem is the environment, and among a host of factors involved, is the method of milking.
Despite the obvious possiblities of interaction between the three biosystems it appears that the most generally accepted views, associating milking machines and udder disease are based on uncontrolled field observations and surveys of doubtful value. Direct research is limited by the fact that new infections only occur once or twice per cow per lactation even in a highly infected herd (Dodd *et al*. 1977). The long duration of an infection and the low rate of new infection make it difficult and costly to carry out trials to detect treatment differences.

1.4.2 (a) *Milking machine factors*

There is fairly good evidence to support the claim that the milking machine acts as a vector in transmitting pathogens from infected quarters to non-infected quarters (Dodd and Neave, 1970).
The number of organisms transmitted by the milking machine may be little different from that occurring in hand milking, but its control may be more difficult. Oliver (1975) mentions that in Rhodesia, it has been found that bulk milk somatic cell counts can be higher from hand milked herds, than from machine milked herds.

Contamination of the teat and teat orifice appears to be the main risk associated with machine milking, because once contaminated, bacterial invasion can occur during the intervals between milkings or during the dry period (Philpot, 1975).

While the biological importance and necessity of pulsation have not been adequately demonstrated by science (Tolle and Hamann, 1975) recent research indicates pulsation (liner movement) is associated with lower infection levels and less clinical mastitis than some forms of 'pulsationless' milking.

The (SVSC) machine (Woolford and Phillips, 1978) has been shown to predispose cows to infection, and possibly induce infection directly. While the specific infection mechanisms and predisposing factors are not known (Woolford *et al.* 1978) the infection rate can be reduced by hygiene procedures that prevent bacterial build up on the teatcup and teat surface.
Woolford *et al.* (1978) were able to show that in the two chambered teatcup, organisms on the teat and liner surface are effectively dislodged and flushed away during the main flow period by the mechanical action and movement of the liner. The flushing effect occurs to a lesser extent with the SVSC teatcup. Jasper and Whittlestone (1976) have also found that bacteria adhere to the PME cup surface in high numbers for several subsequent milkings.

The most surprising feature with both the SVSC (Woolford and Phillips, 1978) and the PME machines (Jasper and Whittlestone, 1977) was that the teats seldom showed teat end eversions, whereas eversions were common on the teats of cows milked by the conventional machine in both trials.
It appears that in the absence of specific hygiene measures the single chambered teatcups can cause higher infection rates than two chambered teatcups, despite the better teat end condition that is found with cows milked by the former.

Bramley and others as the National Institute for Research in Dairying, Reading (NIRD) have investigated the effects of using the two chambered teatcup without liner movement (Bramley *et al.* 1978).

Using a change over experimental design, the half udders of 20 cows were milked for nine days with pulsation and after a 3 day interval, for another 9 days without pulsation.
All teats were immersed in a bacterial suspension (bacterial challenge) before and after milking to increase the risk of infection.
In the absence of pulsation the rate of new infection increased, and there was evidence to suggest bacteria colonized the teat apex more readily.

Some cows were apparently more susceptible to the infection mechanisms than others, since 11 of the 20 cows remained uninfected during the trial.

A second half udder experiment showed that infection and colonization of the teat apex could be kept low, when milking without pulsation, if the teats were disinfected at the end of milking.

Further work with half udders and bacterial challenge was undertaken to determine if the streak canal was more susceptible to infection (when a teat disinfectant was not used) if it was held open for long periods during milking. Pulsation rate and ratio were adjusted to produce, different liner open and closed times. One experiment compared a fourfold difference in liner open time combined with similar closed times, and a second experiment compared a twofold difference in liner closed time combined with a common liner open time in each cycle.

Since no difference in infection occurred, the work suggests that, provided some sort of liner movement occurs during milking wide differences in the rate and ratio of pulsation can be tolerated (Bramley *et al.* 1978).

Milking without liner movement is known to occur with the two chambered teatcup if the teat is able to extend and move into the lower region of liner (Mein *et al.* 1970).

While it has been shown that teat lesions are associated with higher rates of new infection (Neave, 1971) information about the role of specific milking machine factors (particularly pulsation and vacuum levels) in producing teat lesions, it not conclusive and is often contradictory (Farnsworth *et al.* 1978).

Much of the information is found in the older literature, and is of questionable value due to changes in machine design and operation.

However, it is possible that once a break in the skin surface has occurred, viral, bacterial and mechanical action, all interact in the development of teat lesions (Jackson, 1970).

While there is no real evidence to prove that overmilking directly causes mastitis (Natzke *et al.* 1978), internal teat damage, can sometimes occur (Peterson, 1964).

Vacuum fluctuations in the claw and milk transport system have been associated with increased levels of mastitis (Nyhan 1969), and based on this association several workers (McDonald 1975b) have recommended that cyclic fluctuation (vacuum variation in the claw caused by liner movement and milk clearance) and irregular fluctuation (a drop in overall plant vacuum) should be minimised.

McEwen and Samuel (1946) demonstrated that it was possible for bacteria to pass through the teat canal carrier during machine milking. They claim to have isolated *Bacterium coli*, in the teat cistern, after a broth culture of the bacteria had been jetted (at a pressure of 34 kPa) against the teat end prior to slaughter.

Work at the NIRD (Thiel, 1974) demonstrated that during milking (with bacterial challenge) infection rates could be increased by applying artifically produced cyclic and irregularly vacuum fluctuations at the same time. The presence of large cycle fluctuations alone or irregular vacuum fluctuations alone, failed to increase the infection rate.

Further work on a test rig indicated that the fluctuations developed transient pressure differences that were capable of accelerating droplets of milk towards the teat end as the liners opened. Thiel (1974) postulated that when the frequency and force of the droplet 'impacts' are great enough (as occurs when both types of fluctuation occur together) bacteria present in the droplets are carried far enough into the teat canal to cause infection. With the appropriate combination of cyclic and irregular vacuum fluctuation phases, a transient pressure difference as great as 45 kPa can exist between the teat end and the point of air admission.

O'Callaghan *et al.* (1976) have shown that under practical milking conditions, artificially created cyclic and irregular fluctuations *per se* do not cause higher infection rates. The Irish workers recorded impact pressure differences and higher infection rates only when liner slip and air leakage into the teatcup occurred. Liner

slip and air leakage usually occur during the liner opening phase of the pulsation cycle.
Thompson and Schultze (1975) have also demonstrated that the abrupt admission of air into one teatcup at the end of milking can elevate the cell count in milk from the other teats back-jetted with milk picked up by the in-rush of air. It seems this effect can occur, in the absence of cyclic fluctuations (Thompson, 1974).

The NIRD impact theory was supported by the evidence that, elevated somatic cell counts could be induced in cows when bacterial endotoxin was used to form the droplets (Thiel, 1974).
Because O'Callaghan *et al.* (1976) have been unable to verify that artifically created cyclic and irregular vacuum fluctuations create 'impacts' or result in higher infection rates, it is possible that the factors responsible for the impact effect in the NIRD laboratory test rig were different from the factors causing the impact effect during the NIRD cow milkings.

In each of the above experiments the common factor associated with the higher infection levels has been the momentary reverse flow of air back towards the teat at risk.

In practical milking situations it is likely that the 'impact' mechanism would combine or reinforce other mechanisms operating in the multifactor process of infection, rather than operate in an independent fashion (Thiel, 1974; Thompson *et al.* 1978; Tolle *et al.* 1970). The work so far published about the impact mechanism does suggest some effort should be made to minimise the sudden in-rush of air that occurs during liner slip and cup changing. More attention should be given to liner design, as Gibb and Mein (1976) and O'Shea and O'Callaghan (1978) have found that some liners are more prone to slip than others. It is possible that the many reported contradictions associating the milking machine with mastitis, have been partly caused by differences between trials in liner characteristics or other factors which might influence liner slip.

1.5.0 Introduction

In Section 1.1.0 it was shown that at least two workers in New Zealand were involved in the development of the conventional milking machine. More recently another New Zealander, Mr Syd Bodmin of Tauranga has after 14 years of development work, produced a machine that represents a major departure from the principles associated with the conventional type of milking machine, and will, without doubt add a further chapter to the history of machine milking.

The distinctive design feature about the machine is that each cluster has its own self activating pulsator directly attached to the claw. This does away with the need to have separate air pipelines and long pulse tubes to each cluster. The machine developed by Mr Bodmin is made mainly from polysulphone plastic and is traded under the name of the Bodmin-NuPulse cluster.

Similar one line machines with the pulsator connected to the claw-piece have been developed in West Germany and Russia (Korolev, 1962) but have failed to attract widespread approval or commercial backing.
The Flacco machine developed in West Germany is now nearly out of existence because official tests showed that, the Flacco machine was associated with a rise in the fat acidity of milk (de Vries and Jellema, 1975; Tolle and Heeschen, 1975).

The unique features of the one line machines arise as a result of the common vacuum source to both sides of the liner and the way in which milk is cleared from the claw by air evacuated from behind the liners as they open.

Even though air from the pulsation chamber (PC) entered the milk, the first NuPulse models were sold to farmers without any mechanism to clean the pulsation chamber or pulsator.

At the time, it was considered that if the NuPulse cluster was sold without a cleaning system it would be a source of bacterial contamination to milk (Gooding, 1975).

N.Z. Dairy Division approval was given for commercial sale of the cluster after a jetter cleaning system was developed (Miller *et al.* 1976), Because the cleaning system only washed the PC area and not the pulsator the approval included the condition that farmers must manually clean the pulsator after each milking.

Farmers and proponents of the NuPulse cluster claimed that the need for manual cleaning of the pulsator was a small price to pay for the other apparent advantages of the NuPulse.

Mr Bodmin believes that the teat is not'ballooned' as much because of the common vacuum source to both sides of the liner, and as a result the teat and teat sphincter suffer less distortion and damage. The NuPulse cluster has been designed to reduce teat end 'nipping' during the squeeze phase, as Mr Bodmin considers that a foreceful squeeze phase 'flattens' out the teat end and could also have a detrimental effect on milk let down (Gooding, 1975; Miller *et al.* 1976). However, no documented experimental evidence is available to support the claims.

CHAPTER TWO

EXPERIMENTAL SECTION - Aims and Objectives

The experimental work is divided into 3 sections; the first describes the joint research project carried out with Dr Graeme Mein at the Werribee milking research centre, Victoria, Australia. Electronic pressure recording equipment was used to -
Record and describe in detail the characteristics of the mechanical operation of the NuPulse and conventional pulsation systems used in the 2nd experiment.

The 1st section also describes the pilot investigation made to determine the force applied to the teat, by the closing liner during milking with the NuPulse and the conventional machine at the Massey dairy.

The 2nd section describes an experiment using the Massey University identical twin herd. Ten sets of identical twin pairs and the rest of the herd were used in an experiment designed to achieve the following objective -

To determine if the liner movement characteristics of the Mark I NuPulse cluster had any effect on milk production and mastitis when compared with the conventional or usual method of controlling liner movement and milk removal. The experiment was designed to avoid the confounding effects of such variables as the claw bowl size, and cluster weight and stability.

EXPERIMENT ONE

2.00 A comparison of the milking characteristics of the NuPulse and conventional pulsation systems.

2.1.0 Materials and Methods

The objective of this experiment was to record in detail the mechanical action of the NuPulse and conventional pulsation systems used in the 2nd experiment.

Experiment two was carried out in an 8 unit walkthrough dairy with 8 NuPulse clusters connected to a pipeline milking machine. For the purposes of the experimental comparison, the NuPulse pulsator mechanism was removed from 4 of the clusters (Appendix 1) and the pulsator chamber area sealed off from the claw bowl and connected to a conventional pneumatic pulsator, master relay system, as shown in Appendix II and Illustration 1.

The modified NuPulse claw-piece (fitted with a 1 mm diameter air admission hole) was used as the claw for the conventional pulsation system so that all cows were milked with units of the same claw bowl size, cluster weight and shape. Because of this modification the 2nd experiment did not examine the difference between the NuPulse and a conventional machine, but only the difference between the two pulsation mechanisms. The modified NuPulse or conventional pulsation system is hereafter referred to as the Conventional Pulse. Further machine specifications for the NuPulse and Conventional Pulse are given in Appendix II.

The International Dairy Federation (IDF), (1974) milking machine definitions and terminology have been used throughout this thesis.

One NuPulse pulsator and 1 Conventional Pulse claw piece, as well as the liners, were randomly selected from the experiment two treatment machines and taken to the Werribee milking research centre and used to conduct Experiment 1.

2.1.1 The Werribee test equipment.

A simulated milking system or test rig was used in an attempt

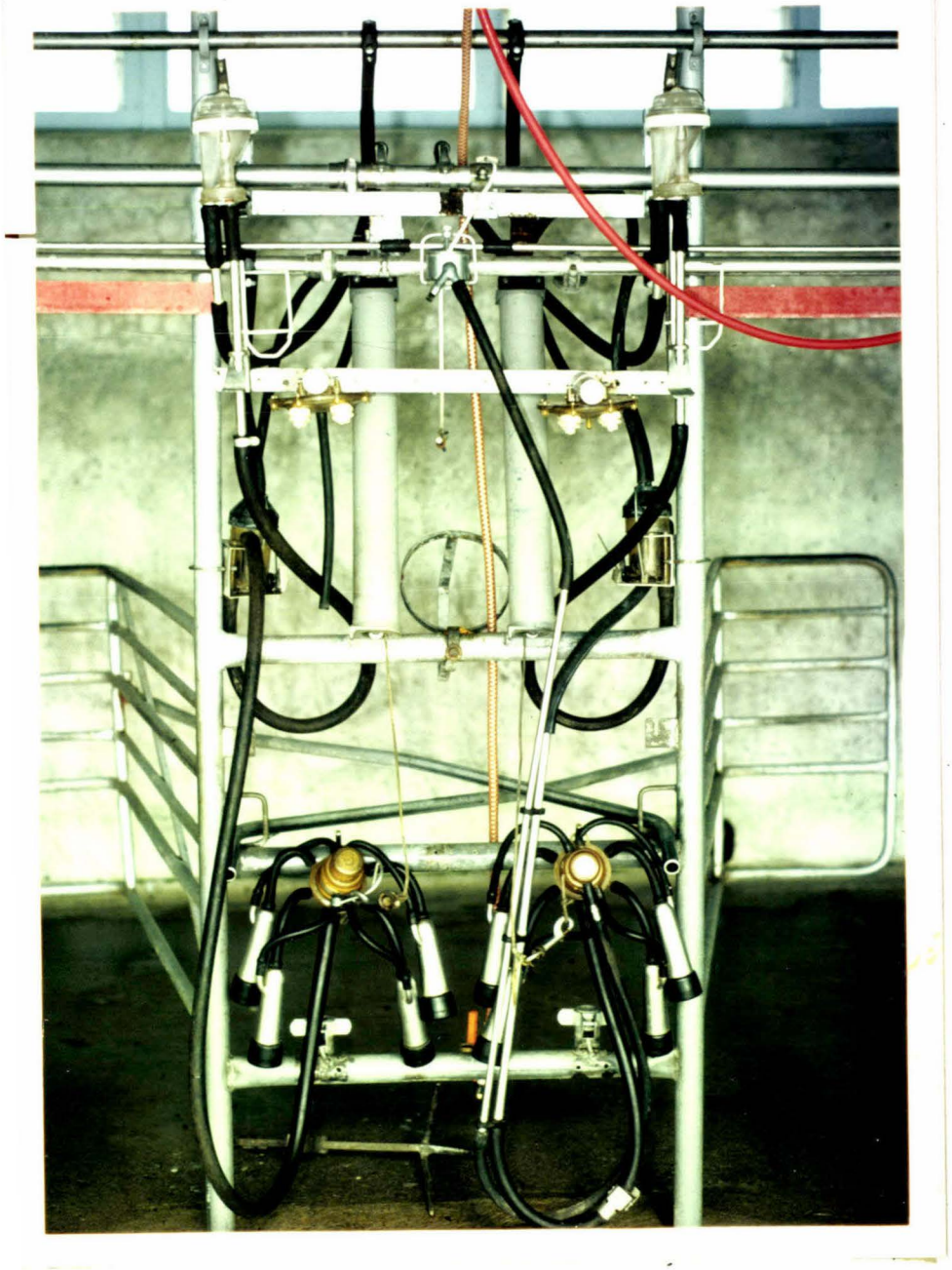


Illustration 1. The design of the two machines used in the experiment. The NuPulse (left) and the Conventional Pulse (right).

to imitate the fluid flow conditions of machine milking. Water was used as the test liquid and no corrections were made for specific gravity or viscosity.

The machine factors shown in Table 1 were chosen and measurements were made under all possible combinations of them, both with the NuPulse and Conventional Pulse.

A total of 32 treatments were tested using the simulated milking system, the NuPulse and the Conventional Pulse were each combined with the 16 treatments shown in Table 2.

Table 1: The machine factors and the two levels of each factor tested in all combinations with the NuPulse and Conventional Pulse.

Factor			Level 1 (Low)	Level 2 (High)
L	Lift to Receiver and Length of Long Milk Tube (LMT)	(m)	0.16 1. 0	1.6 2.1
D	Diameter of (LMT)	(mm)	12	16
F	Water Flow Rate through the rubber teats	(kg/min)	2 ± 0.2	4 ± 0.2
T	Tension of the liner used in the experimental teatcup	(kg)	3.16	5.30

The cluster for each treatment was attached to an artifical udder fitted with rubber teats (7 cm calfeteria teat, Patent No. 126 D.McL. Wallace, Ltd. Hamilton, NZ).

NDA (Appendix II) tapered cup shells were fitted to 3 liners and the transparent experimental teatcup fixed to the 4th liner as shown in Fig. 1.

The claw piece under test was attached to a vacummised bucket receiver by a long milk tube (LMT) (Table 1).

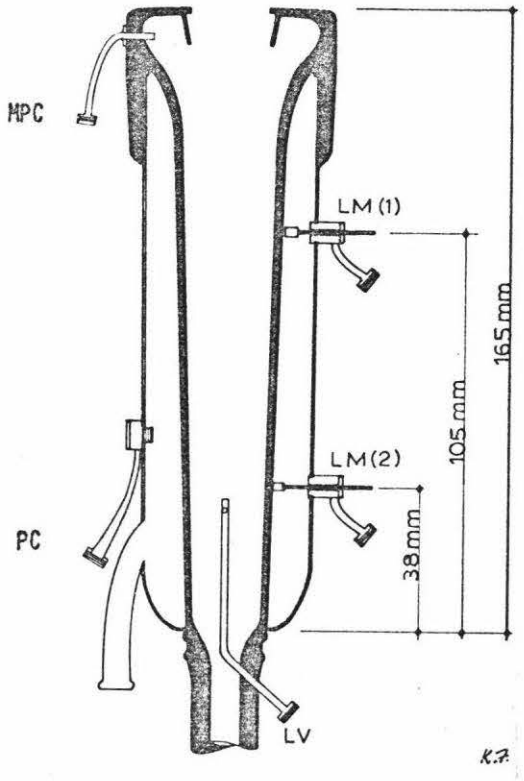


Figure 1

The experimental teat cup used in the test rig and for the cow milkings, at the Werribee Milking Research Centre, Victoria. Pressure transducers, Endevco 8503-40 (Endevco UK. Branch, Upper King St, Royston, Herts.) were connnected to the Pulsation Chamber (PC) and the Mouthpiece Chamber (MPC) via 2mm bore air filled catheters, and to the liner beneath the teat via a 2mm liquid filled probe positioned in the fold of the closing liner.
Two linear transducers (PD 11, Ether Ltd, Caxton Way, Stevenage, Herts. England.) were mounted in the teat cup shell, (LM(1) and LM(2) to measure the liner wall movement. The linear transducers moved 8 to 10 mm each time the liner closed at right angles to the probe. The output from the 5 transducers was recorded on a u.v. recorder, (Savage and Parsons 12-12 Servo drive recorder, Watford, WD28HT Herts, England).

Table 2: The treatment combinations used with both the NuPulse and the Conventional Pulse, a total of 32 treatments

Treatment No	Factors and Level	Treatment No	Factors and Level
1	L_1 D_1 F_1 T_1	9	L_2 D_1 F_1 T_1
2	L_1 D_1 F_1 T_2	10	L_2 D_1 F_1 T_2
3	L_1 D_1 F_2 T_1	11	L_2 D_1 F_2 T_1
4	L_1 D_1 F_2 T_2	12	L_2 D_1 F_2 T_2
5	L_1 D_2 F_1 T_1	13	L_2 D_2 F_1 T_1
6	L_1 D_2 F_1 T_2	14	L_2 D_2 F_1 T_2
7	L_1 D_2 F_2 T_1	15	L_2 D_2 F_2 T_1
8	L_1 D_2 F_2 T_2	16	L_2 D_2 F_2 T_2

L D F T = Factors; 1 and 2 = Level of factor (Refer to Table 1)

The flow of water into the artifical udder was controlled by a valve. The water flow rate was measured by attaching the bucket receiver to a spring balance and recording the increase in weight over half minute periods.

The Conventional Pulse pulsator was operated by an electronic master controller. The pulsation chamber (PC) waveform used in Experiment 2 was reproduced for this experiment by setting the adjustable rate and ratio electronic master controller. The NuPulse pulsators used in experiment two and the NuPulse pulsator used in this experiment, were not fitted with the 'pulsator rate adjuster' shown in Fig.4. The MARK I NuPulse pulsators were operated instead, with a fixed stainless steel tube fitted to the diaphragm housing (Refer to Section 2.2.1).

The pressure transducers attached to the experimental teatcup recorded fluctuations in vacuum below the teat (variables A - E, Figs 2 and 3) and the PC waveform and liner movement variables, F - H, Figs 2 and 3.

The A - D variables recorded for the NuPulse and Conventional Pulse represent the vacuum level at similar stages of the pulsation waveform, except for vacuum level C.

Vacuum level C, although occurring at a different stage of the PC waveform in the NuPulse and Conventional Pulse is associated with milk clearance from the claw in both machines.
During the simulated milking treatments liner movement at the LM(1) position and the mouth piece cavity vacuum (MPC) were not recorded. The output from each transducer was traced simultaneously on a Savage and Parsons u.v. printout recorder (Fig 1). The half scale waveforms in Figs 2 and 3 represent typical recordings and show how the A - H variables were obtained. At least 6 consecutive pulsation cycles were measured during each treatment.

The position of the liner during the open stage (as in Fig. 1) was calibrated on the u.v. recorder while the top of the liner was sealed and 50.8 kPa of vacuum was applied to both sides of the liner. A scale of 10 divisions on the u.v. recorder was used to trace the movement of the linear transducer when the liner opened and closed.
Any expansion of the liner from the calibrated open position was called distension and because of the 1:10 scale was recorded as a percentage. Therefore liner distension represents the percentage increase in the liner radius. In the LM(2) liner position (Fig 1.) a 6 percent increase in liner distension represents a 0.5 mm increase in the radius or a 1 mm increase in the internal diameter of the liner.

2.1.2 Statistical analysis

The NuPulse and Conventional Pulse factors in this experiment have been taken as fixed effects in a factorial model, analysis of variance (ANOV); that is, a repeat of this experiment with another NuPulse unit or conventional unit would be expected to give another new set of values for the A - H vairables shown in Figs 2 and 3. In addition to the factors, lift, diameter, flow rate and tension shown in Table 1 the type of pulsation was taken as a 5th factor (the level being either the NuPulse or Conventional Pulse) so that the data could be analysed as a 5 factor, 2 level (2^5) factorial model.

The ANOV was carried out using a computer programme designed and run by the Victorian Department of Agriculture in Melbourne.
In describing the effect of a factor, the adjective main is used as a reminder that, the value is an average taken over the levels of the other factors. Interaction is defined as a significant difference in the effect of two levels of a factor, when tested at low and then high levels of the other factors. The interaction effects significant by F test were tested further using the L.S.D. test statistic (Snedecor and Cochran, 1967). The significance levels used throughout this experimental section are presented in Table 3.

Table 3: Significance levels and symbols

NS	Not significant	
*		($P < 0.05$)
**		($P < 0.01$)
***		($P < 0.001$)

2.1.3 Milkings performed with the experimental teatcup

Four cows were milked 4 times with the experimental teatcup so that the A - H variables obtained during the cow milkings could be compared with the results from the simulated milkings.
At 4 consecutive AM milkings the same 4 cows were milked by the treatment machines shown in Table 4. Each day the experimental teatcup was attached to the cluster of the treatment machine and used to milk the right rear quarter of the 4 cows.

The NuPulse was tested with the 16mm diameter LMT and the Conventional Pulse with the 12 mm diameter LMT because the above diameters were the ones used in Experiment two and are the sizes used in practice. Other differences that occurred between the test rig treatments and the cow milking treatments are shown in Table 5.

Table 4: The 4 machine treatments used to milk the same 4 cows at 4 consecutive morning (AM) milkings.

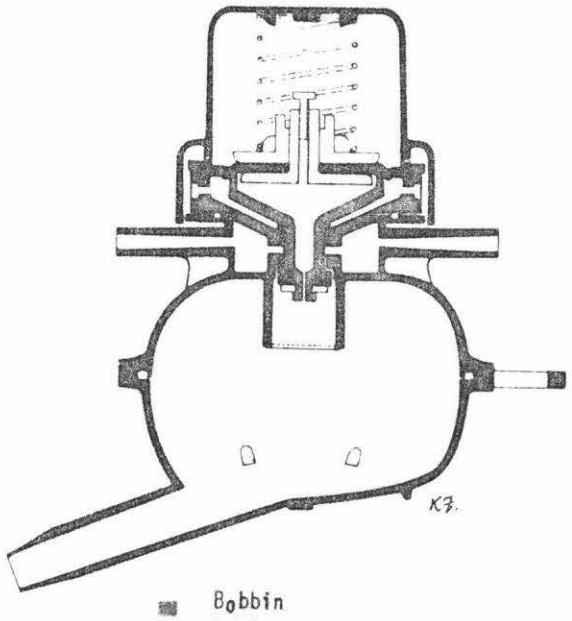
	Treatment Machine Factors			
Day	Pulsator type	Diameter LMT	Lift	Tension
1	Conventional Pulse	12	Low	High
2	NuPulse	16	Low	High
3	NuPulse	16	High	Low
4	Conventional Pulse	12	High	Low

TABLE 5: A comparison of the treatment factors used in the simulated milkings and the cow milkings

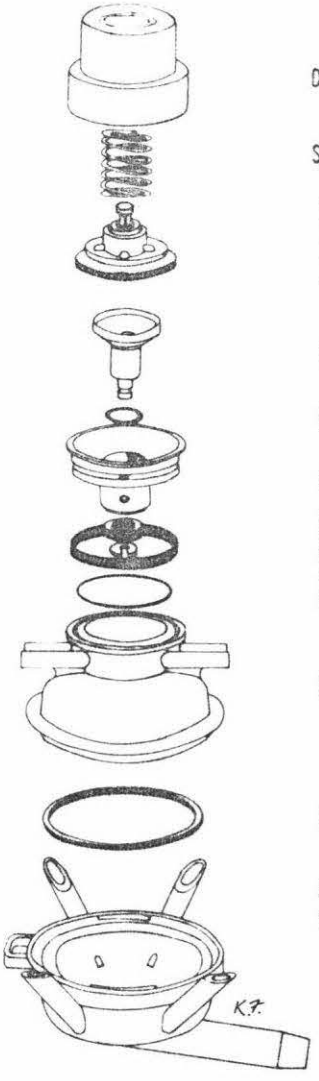
Treatments	Test Rig Lift (m)	Cow milking Lift (m)
High lift	1.600	1.320
Low lift	0.160	-0.040
Difference	1.440	1.360
	Length (m)	Length (m)
High lift (LMT)	2.1	2.1
Low lift (LMT)	1.0	2.1

The LMT used with the test rig, low lift treatment was found to be too short for the cow milkings and had to be lengthened from 1 m to 2 m to reach the receiver jar (Table 5).
The mouth piece cavity vacuum (MPC) was recorded at each cow milking. The LM_2 liner movement transducer was installed after the 2nd day for the two high lift treatments and the output from 5 transducers traced simultaneously on the u.v. print out recorder.

While it was not possible to record the milk flow rate from the teat milked by the experimental teatcup, the 4 quarter milk flow rate was recorded and used to indicate the likely quarter flow rate.



Bobbin
Bobbin Housing
Diaphragm attachment



Dome
Spring
Pulsator rate adjuster
Diaphragm
Bobbin
Bobbin-O-Ring
Bobbin Housing
Bobbin Valve
Bobbin clip
S.S. Air filter
Middle - O-Ring
Middle Piece
Base Ring
Automatic cut-off inlets.
Base

Figure 4 NuPulse Claw : Cross Section and Components.

One minute after the start of milk flow and again during the low flow period, towards the end of milking, at least 6 consecutive pulsation cycles were traced by the u.v. recorder.
The recordings measured during the low flow period of milking were usually taken after the teat had penetrated deeper into the liner. During the high lift Conventional Pulse treatment (day 4 Table 4) the depth of teat penetration into the liner during milking was measured by placing a ruler alongside the transparent shell of the experimental teatcup.

2.1.4 Vacuum records made to describe the operation of the NuPulse

The component parts of the NuPulse, presented diagramatically in Fig 4. are used in conjunction with the vacuum and liner movement recordings to describe the mechanical operation of the pulsator. The vacuum change in the pulsator dome was recorded simultaneously with the liner vacuum and PC vacuum.

2.2.0 Results

2.2.1 The mode of action of the NuPulse Cluster

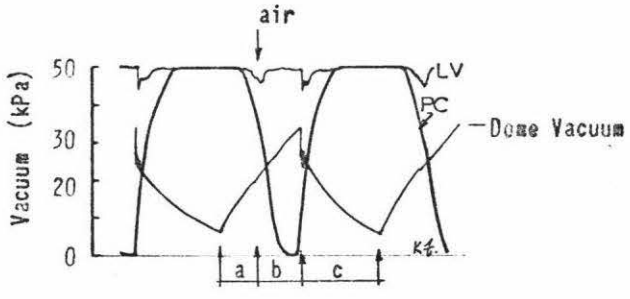


Figure 6. A simultaneous recording of the vacuum changes in the liner and the pulsator dome and chamber of the NuPulse.

Stage (a) of Figs 5 and 6

The pulsation chamber (PC) has been vacuumised and the liner is in the open position. Vacuum starts to form in the dome or upper diaphragm area. The rate of air removal (development of vacuum) is controlled by the diameter and length of the pulsator rate adjuster (Fig 4). The pulsation rate is not adjustable when a stainless steel tube is fitted into the diaphragm housing instead

of the pulsator rate adjuster. When the vacuum level in the dome reaches 20 kPa, air pressure acting on the underside of the diaphragm and bobbin becomes greater than the downward force of the spring. The pressure difference forces the bobbin and diaphragm upwards and opens the port around the bobbin-o-ring (Fig 5b).

Stage b of Figs 5 and 6.

During stage b, air flows under the bobbin-o-ring, into the pulsation chamber, and causes the liner to collapse. As the bobbin-o-ring opens the rubber bobbin valve closes against the bobbin housing and prevents incoming air from flowing into the claw bowl. The slight drop in the liner vacuum shown in Fig 6 indicates that some air has leaked past the bobbin valve before it closed.
The closed bobbin valve prevents the bobbin from lifting further as the vacuum level increases in the dome. When the vacuum level in the dome reaches 35 kPa the air pressure force acting on the underside of the diaphragm causes the diaphragm to separate from the bobbin.

Stage c

Air flows into the dome and at the same time forces the bobbin downwards until the bobbin-o-ring has sealed and the bobbin valve has opened. Air is removed from the pulsation chamber until working vacuum is reached, in the pulsation chamber of the teatcups.
As air enters the claw bowl it creates a major pressure difference between the vacuum source and the claw bowl. The pressure force generated accelerates the flow of air and milk through the LMT. The rate of air removal from the pulsation chamber during this stage can be determined from phase (a) of the pulsation waveform (Fig 3).

The downward force of the spring and eventually nearly full air pressure in the dome, force the diaphragm to reseal on the bobbin, and start the cycle again.
The spring tension and port clearances have been designed to give the characteristic 'NuPulse' liner movement.

2.2.2(a) *The main effects of the factors on the A - H variables*

Results and discussion

The main effect obtained for each factor is presented together with any significant interactions in Table 6.

2.2.2(b) *Vacuum level A: The minimum vacuum recorded with the liner closed*

The results in Table 6 show that, flow rate had twice the effect of any other factor. Vacuum A dropped (on average) to 18 kPa at the 4 kg/min flow rate.

Vacuum A was higher with the low lift and the 16 mm bore LMT treatment and probably indicates that a better clearance of fluid from the LMT also results in an improved rate of clearance from the short milk tube. Compared to the NuPulse,the lower Vacuum A level recorded with the Conventional Pulse (Table 6) appears to have been caused by a lower initial vacuum (variable C, Fig 2) before the liner started to close.

2.2.2 (c) *Vacuum level B: The maximum vacuum reached when the liner was closed*

Vacuum level B was lower in the Conventional Pulse than in the NuPulse (Table 6). The interaction between the NuPulse and Conventional Pulse with lift is shown in Table 7.

Vacuum level B in the Conventional Pulse appears to gradually increase as milk clears from the short milk tube and LMT before the liner opens. However Fig. 3 shows that a different principle of milk clearance operates in NuPulse. The milk appears to clear quickly from the liner into the claw bowl and as a result the end of the teat becomes exposed to full vacuum while the liner is collapsed beneath the teat. The milk accumulated in the claw bowl, is cleared, as air enters when the liners re-open. With both the low and high lift treatments an instantaneous rise in vacuum was usually recorded with the NuPulse (Fig 3) at the same time as the bobbin-o-ring reseated.

The instantaneous peak in vacuum could have been an artefact of the transducer, as it is possible that the vibration caused when the bobbin closed, accelerated the fluid in the transducer probe.

Table 7: The effect of lift on vacuum level B (kPa) in the NuPulse and Conventional Pulse

	Low Lift	High Lift	Difference
NuPulse	53.1	49.5	-3.6
Conventional Pulse	50.8	44.0	-6.8
			3.2

For the NuPulse, the instantaneous peak in vacuum was recorded as vacuum level B.
The vacuum peaks reached levels greater than the regulated plant vacuum of 50.8 kPa during the low lift and 16 mm bore LMT treatments. Except for the instantaneous peak, the vacuum level in the NuPulse with the liner closed, was similar to the regulated vacuum.

The two levels of flow rate (factor 4) had the same main effect on vacuum B (Table 6). However the main effects were influenced by interaction between flow, lift (factor 3), and LMT bore (factor 2). Generally, vacuum B remained the same or decreased with increasing flow rate in both the NuPulse and Conventional Pulse. The main interaction occurred with the Conventional Pulse fitted to the 16 mm bore LMT; vacuum increased with low lift and high flow, and decreased with high lift and high flow.

2.2.2 (d) *Vacuum level C: The minimum vacuum in the NuPulse when the liner opened: and in the Conventional Pulse when the liner was open*

The vacuum conditions in the NuPulse liner differ markedly from those recorded in the Conventional Pulse as the liner opens (compare Figs 2 and 3).
When air evacuated from the pulsation chamber enters the NuPulse claw bowl, the vacuum decreases and a pressure difference develops between the claw bowl and the milk line and causes milk to flow from the claw.

In the Conventional Pulse, vacuum C reached its lowest level just before the liner started to close.

Table 6 shows that vacuum level C decreased with the high lift, the 12 mm bore LMT and the high flow rate treatments.

A significant interaction ($P < 0.01$) occurred between the NuPulse and Conventional Pulse with factors 3 (LMT) and 5 (liner tension), (refer to Table 8).

Table 8: The effect of LMT size and liner tension on vacuum level C (kPa) with the NuPulse and Conventional Pulse

	LMT			Liner Tension		
	12 mm	16 mm	$\overline{D}$	Low	High	$\overline{D}$
NuPulse	25.3	32.1	+6.8	30.0	27.4	-2.6
Conventional Pulse	40.0	43.0	+3.0	41.5	41.5	0
			3.8**			-2.6**

In the NuPulse vacuum C reached its lowest level about the stage the liner was half open (Fig 3). The high Tension liner was associated with a lower vacuum C level than the high tension liner ($P < 0.01$; Table 8). It is possible that the high tension liner partially expelled air from the pulsation chamber when the liner opened. The 16 mm bore LMT increased vacuum C in the NuPulse by 27 percent (Table 8).

When the NuPulse was fitted with the 16mm bore LMT, vacuum C was not significantly decreased by the high flow rate treatment, but in the Conventional Pulse vacuum C was reduced by high flow rate (Table 9).

2.2.2 (e) *Vacuum level D: The maximum vacuum recorded when the liner was open*

In the NuPulse both sides of the liner are connected to a common vacuum source and as a result the changes in vacuum D follow a similar pattern to the vacuum in the pulsation chamber (Fig 3). Air removed from behind the liners and evacuated into the claw bowl as the liners

open, compensates for the increase in the internal volume of the liners.

Table 9: The effect of flow rate and LMT bore on vacuum C (kPa) in the NuPulse and Conventional Pulse

Factor	Level	Flow		$\overline{D}$
		Low	High	
NuPulse	12 mm	26.5	24. 0	-2.5*
	16 mm	32.3	32.0	-0.3 NS
Conventional Pulse	12 mm	42.4	37.8	-4.6 **
	16 mm	44.5	41.5	-3.0 *

The sharp rise in vacuum D recorded in the Conventional Pulse as the liners open, indicates that a vacuum has developed as the internal volume of the liner has increased.
The vacuum D average for all the Conventional Pulse treatements was 56.6 kPa (Table 6).

Table 10: The effect of flow rate on vacuum level D (kPa) in the NuPulse and Conventional Pulse

	Flow Rate			Liner Tension		
	Low	High	$\overline{D}$	Low	High	$\overline{D}$
NuPulse	50.1	47.6	-2.5	49.1	48.6	-0.5
Conventional Pulse	55.4	57.9	+2.5	56.4	56.9	+0.5
			5.0 **			1.0 *

The significant interaction that occurred between the NuPulse (-2.5kPa) and the Conventional Pulse (+2.5 kPa, Table 10) masked out the main effect of the high and low flow rates (Factor 4, Table 6). Liner tension (Table 10) had a slight by not significant effect ($P > 0.05$) on vacuum D; (-0.5 kPa in the NuPulse and +0.5 kPa in the Conventional

Pulse), the interaction again masking out the main effect of liner tension (Table 6).

Table 11: The effect of lift, and LMT bore on vacuum level D (kPa) in the NuPulse and Conventional Pulse

	Lift			LMT		
	Low	High	$\overline{D}$	12 mm	16 mm	$\overline{D}$
NuPulse	50.3	47.5	-2.8	47.9	49.9	+2.0
Conventional Pulse	57.3	56.0	-1.3	56.3	57.0	+0.75
			1.5**			1.25*

Table 11 shows that the high lift treatement reduced vacuum level D more in the NuPulse than in the Conventional Pulse. The 16 mm bore LMT increased the vacuum D level in the NuPulse by 2 kPa. The vacuum D peaks in the Conventional Pulse were higher (57.3 kPa) with the low lift treatment.

2.2.2 (f) *Vacuum level E: The vacuum level (kPa) recorded when the liner was half open*

Table 6 shows that an average vacuum of 32.2 kPa and 51.2 kPa occurred in the NuPulse and Conventional Pulse respectively. Vacuum E in the NuPulse was markedly affected by high lift and flow rate and the 12 mm bore LMT, whereas the Conventional Pulse was not affected significantly ($P > 0.05$, Table 12) by these factors.

Table 12: The effect of lift and flow rate on vacuum level E (kPa) in the NuPulse and Conventional Pulse

	Lift			Flow rate		
	Low	High	$\bar{D}$	Low	High	$\bar{D}$
NuPulse	37.4	27	-10.4	34.9	29.5	-5.4
Conventional Pulse	51.6	50.7	-0.9	51.4	51.9	-0.4
			9.5 **			5.0 *

A vacuum E level of 22.5 kPa was recorded when the NuPulse was combined with the high flow rate, high lift and the 12 mm bore LMT treatment.

The vacuum level increased from 22.5 to 29.5 kPa when the 16 mm bore LMT was used instead of the 12 mm bore LMT. The main effect of the LMT bore on vacuum E in the NuPulse and Conventional Pulse is shown in Table 13.

Table 13: The effect of LMT bore on vacuum level E (kPa) in the NuPulse and Conventional Pulse

	LMT		
	12 mm	16 mm	$\bar{D}$
NuPulse	28.4	36.0	+8.4
Conventional Pulse	51.5	50.9	+0.6
			+7.8**

Table 14: The effect of lift on vacuum level E (kPa) in the NuPulse attached to the 16 mm LMT and the Conventional Pulse attached to the 12 mm LMT

	LMT	Lowlift	Highlift	$\bar{D}$
NuPulse	16 mm	43.5	28.5	-15
Conventional Pulse	12 mm	52.0	51.0	- 1
	$\bar{D}$	8.5	22.5	

The difference in vacuum level E between the NuPulse (fitted with the 16 mm bore LMT) and the Conventional Pulse (fitted with the 12 mm bore LMT) increased from 8.5 kPa with low lift to 22.5 kPa with high lift (Table 14).

2.2.2 (g) *The pulsation chamber wave form, (Phase a, b, c, d , expressed as a percentage of 1 pulsation cycle*

The Conventional Pulse, operated by a master pulsator controller, maintained a constant pulsation chamber waveform during all the treatment combinations (Table 15). However the pulsation waveform for the NuPulse varied with the factors (2, 3 and 4) that influenced the supply of vacuum to the claw piece.

The significant difference ($P < 0.05$) between the main effects for high and low tension (Factor 5, Table 6) was caused by a longer phase c in the NuPulse when the high tension liner was used. This result suggests that the higher tension liner offered more resistance to closing than the low tension liner. The effect is probably associated with the flow of air from the pulsation chamber to the claw bowl as the liners open.

The NuPulse pulsation waveform, obtained during calibration without fluid flow, was 18: 50: 20: 12:(Table 15).

With fluid flow the pulsation waveform was characterised by a short full vacuum (or phase b) period during each pulsation cycle.

2.2.2 (h) *The liner open to close ratio, measured when the liner was half open.*

The liner open to close ratio is defined by (G) in Figs 2 and 3. The data in Table 16 shows that the liner open ratio during the peak flow period remained relatively constant, despite the large variation in the pulsation waveform in the NuPulse with factors 2, 3 and 4. A significant interaction ($P < 0.05$) occurred between the NuPulse and Conventional Pulse in the response to the two LMT sizes. The decrease in the liner open ratio in the NuPulse from 68.5 to 65.8 percent (Table 16) when the LMT was changed from 12 mm bore to 16 mm bore was also accompanied by a change in

pulsation rate from 54 per minute to 56 pulsations per minute. The relationship between pulsation rate and the time that the liner remained open is given in Section 2.2.2 (j).

Table 15: The effect of lift, flow rate, and LMT bore on the pulsation chamber waveform in the NuPulse and Conventional Pulse

The waveform a,b,c,d is expressed as a percentage of a pulsation cycle

		NuPulse				Conventional Pulse			
Phase		a	b	c	d	a	b	c	d
Main effect (from Table 6)		33	29	18	20	11	42	11	36
During calibration (no flow)		18	50	20	12	12	41	11	36
FACTOR 2 Lift:	Low	29	35	19	17	10	42	11	37
	High	37	24	17	22	11	42	11	36
FACTOR 3 LMT	12 mm	37	23	17	23	11	42	10	37
	16 mm	29	35	19	17	10	42	11	37
FACTOR 4 Flow	Low	30	33	19	18	11	42	11	36
	High	36	25	17	22	11	42	10	37
FACTOR 5 Tension	Low	33.1	29.1	17.5	20.3				
	High	32.6	29.4	18.4	19.6				
12 mm LMT, High Lift and Flow		39	18	14	29				
16 mm LMT, High Lift and Flow		37	25	18	20				

Averaged over all factors the liner remained, more than half open for 67 percent of each pulsation cycle in the NuPulse and for 49 percent of the pulsation cycle in the Conventional Pulse - a 37 percent longer, liner open time in the NuPulse.

The liner movement wave form in Fig 3 shows that the NuPulse liner only remains closed for a very short period. The liner in the Conventional Pulse remained closed for 0.2 to 0.3 s (Fig 2).

Table 16: The effect of lift, LMT bore , flow rate and liner tension on the liner open ratio (expressed as a percentage) in the NuPulse and Conventional Pulse

	NuPulse	Conventional Pulse
Main effect (from Table 6)	67.1	48.9%
FACTOR 2 Lift Low	66.9	48.1
High	67.4	49.6
	+1.5 (NS)	+1.5 (NS)
FACTOR 3 LMT 12 mm	68.5	48.6
16 mm	65.8	49.1
	-2.7*	+0.5 (NS)
FACTOR 4 Flow Low	66.4	48.8
High	67.8	49.0
	+1.4 (NS)	+0.2 (NS)
FACTOR 5 Tension Low	66.6	49.1
High	67.6	48.6
	+1.0 (NS)	-0.5 (NS)

2.2.2 (i) *Liner distension*

The linear transducer in the LM(2) position recorded no liner distension with the NuPulse during the simulated milkings. Except for two low lift treatments, liner distension was recorded with all the Conventional Pulse treatments.

Table 17: The percent liner distension recorded in the Conventional Pulse at the two levels of lift, LMT size, flow rate and liner tension

FACTOR 2	Lift	Low	2.3 **	(44.0)
		High	8.6	(39.0)
FACTOR 3	LMT	12 mm	5.6 NS	(40.0)
		16 mm	5.4	(43.0)
FACTOR 4	Flow	Low	4.2 **	(43.4)
		High	6.7	(39.6)
FACTOR 5	Liner Tension	Low	5.6 NS	(41.5)
		High	5.3	(41.5)
Conventional Pulse (average)			5.5%	(41.5) kPa

Vacuum level C (Section 2.2.2(d)) is given in brackets.

The difference between the pulsation chamber vacuum (50.8 kPa) and vacuum level C (Fig 2) represents the force acting across the liner in the Conventional Pulse.

The largest vacuum difference, 11.8 kPa caused an 8.6 percent increase in liner diameter and the smaller 6.8 kPa difference (Factor 2, Table 17) caused a 2.3 percent increase.

The low tension liners distended 0.3 percent more than the high tension liners with the same pressure difference acting across the liner (Factor 5, Table 17). The difference in distension between the high and low tension liners was not significant ($P > 0.05$).

Interaction occurred between liner distension, the LMT size and vacuum level C. The 16 mm bore LMT was associated with nearly the same amount of liner distension as the 12 mm bore LMT, but at a 3 kPa lower pressure difference acting across the liner (Factor 4 Table 17).

2.2.2 (j) *Pulsation rate and liner open time.*

Lift, LMT size, and flow rate effected pulsation rate in the NuPulse (Table 18).

Table 18: Variation in Pulsation rate in the NuPulse

Factor		Pulsation rate/min	
Lift	High	54.9	
	Low	55.9	NS (1.0)
LMT	12 mm	54.5	
	16 mm	56.4	** (2.0)
Flow	High	55.1	
	Low	55.6	NS (0.5)
Tension	High	55.5	
	Low	55.3	NS (0.2)

The pressure difference acting between the NuPulse claw bowl and pulsator dome, affects the rate at which vacuum increases in the dome and hence the pulsation rate. The 12 mm LMT was associated with the slowest pulsation rate. The high lift and high flow treatments also decreased the rate slightly (Table 18).
The preset, master pulsator controller maintained a constant pulsation rate in the Conventional Pulse machine.

Figure 7 Relationship between Pulsation Rate and liner open time. (NuPulse)

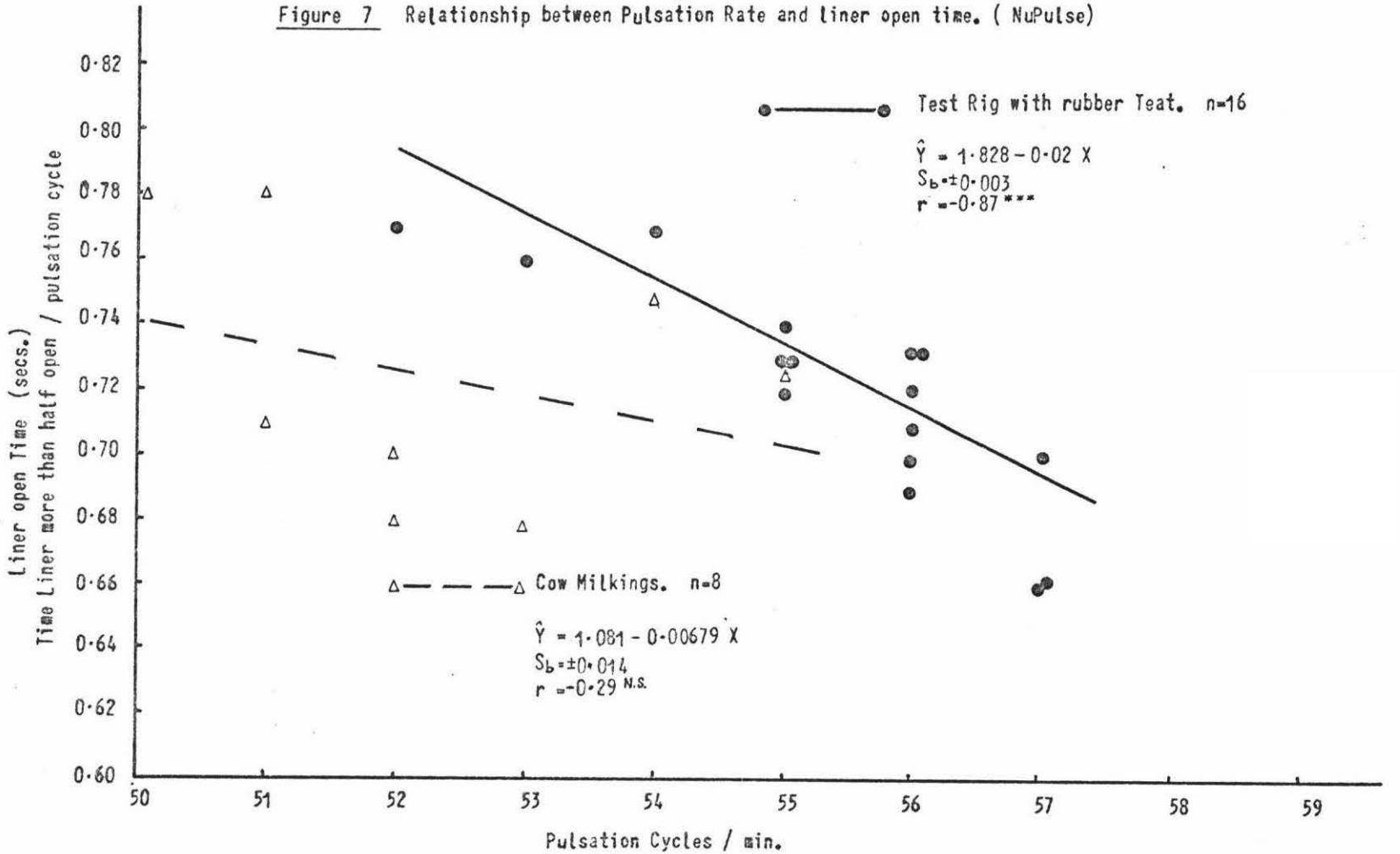


Table 19: The relationship between pulsation rate and the time that the liner remained open in the NuPulse

NuPulse pulsation rate/min		Time the liner was more than ½ open during each cycle	Liner open time per minute
		s	s
53	(3)	0.76	40.63
55	(4)	0.73	40.15
56	(6)	0.71	37.76
57	(3)	0.67	38.37

The figure in brackets represents the number of NuPulse treatments used to compile the mean values

In the NuPulse a decrease in pulsation rate was associated with a slight increase in the liner open time per minute (Table 19).

The correlation coefficient ($r = -0.87$, Fig 7) obtained between pulsation rate and the time that the liner was open, indicates that 76 percent of the variation in liner open time is associated with changes in pulsation rate, during simulated milking conditions (Appendix III).

2.2.3 The results obtained when the experimental teat cup was used to milk cows.

Figs 8 and 9 show the recordings obtained from one cow milked by the 4 machine treatments described in Table 4 and are typical of the recordings obtained for the other 3 cows.

The comparison made between the simulated test rig milkings and the cow milkings (Table 20) excludes the test rig treatments that included the 12 mm bore LMT with the NuPulse and the 16 mm bore LMT with the Conventional Pulse. The variables obtained during the cow milkings have been grouped together in Table 20 according to the milk flow rate that was the closest match to the two flow rates of water (2 and 4 kg/min) used in the rest rig simulated milkings.

Table 20: A comparison between the cow milkings and the simulated milking recordings obtained with the experimental teatcup.

Variable	Flow Rate kg/min	A	B	C	D	E	F	G	Pulsator Rate	H, L.M(2)
		kPa					%	%	/min	%
NuPulse Low lift										
2 Rig Recordings	4.0	22.8	56	35.0	50.0	38.5	27/36/20/17	66/34	55.5	Nil
2 Cow Recordings	3.7	18.0	49	28.0	48.5	30.0	38/22/19/21	70/30	52.5	Nil
NuPulse Low lift										
2 Rig Recordings	2.0	28.5	52.5	34.5	51	48.5	21/46/20/13	62/38	57.0	Nil
2 Cow Recordings	2.7	24.0	50.0	26.5	47	30.0	33/30/18/19	69/31	54.5	2
NuPulse High lift										
2 Rig Recordings	2.0	26	51.0	30	50	23.5	30/34/18/18	66/34	56	Nil
4 Cow Recordings	2.2	24.5	50.3	27	48	28.0	35/24/18/23	65/35	51	7.5
Con.Pulse Low lift										
2 Rig Recordings	2.0	23.5	50.0	44.5	56.0	53	10/42/11/37	48/52	48	1.3
4 Cow Recordings	2.1	22.8	46.5	43.8	55.8	53	12/40/10/38	50/50	48	8.0
Con.Pulse High lift										
2 Rig Recordings	2.0	20.5	43.5	40	54.5	50.5	12/41/10/37	50/50	48	6.5
4 Cow Recordings	2.1	18.3	42.0	39	52.0	50.3	15/38/ 9/38	52/48	48	17.0

NuPulse used with a 16 mm LMT

Conventional Pulse " " " 12 mm LMT

Table 20 shows that the variables (A - G) obtained during the simulated milkings were in close agreement with the same variables recorded during the cow milkings, with the exception of the NuPulse, low lift treatments.

The differences between the variables obtained for the NuPulse low lift simulated milkings and cow milkings (Table 20) could have been caused by a difference in the length of the LMT (2m for the cow milkings and 1 m for the simulated milkings).

More liner distension occurred during the cow milkings than with the simulated milkings using the rubber teat.
The correlation co-efficient (r= - 0.29, Fig 7) obtained between the pulsation rate and the liner open time, for the 8 cow milkings made with the NuPulse, was not significant ($P > 0.10$).
The 'liner open time per minute' decreased with increasing pulsation rate up to 57 pulsations per minute during the simulated milkings (Fig 7). During the cow milkings the liner open time decreased with increasing pulsation rate up to 53 pulsations per minute and then increased at pulsation rates of 54 and 55 per minute. A possible explanation for the increase might be that the teat moved deeper into the liner during the peak flow period and influenced the liner open to closed ratio. The same two recordings were also associated with the 2 percent liner expansion shown for the NuPulse low lift treatments in Table 20.

2.2.3 (a) *Pulsation rate and liner movement during the peak flow and low flow period of milking.*

During the peak flow period the NuPulse pulsation waveform developed a saw tooth shape particularly during the high lift milking treatments. Compared with the low flow period of milking, pulsation rate decreased and the liner open time increased during the high flow period (Table 21 and Figs 8 (b) 1 and 2).
The liner open time also increased in the Conventional Pulse due to pressure changes acting across the liner during the peak flow period (Table 21 and Fig 9 (c) 1 and 2).

Table 21: Variation in pulsation rate, and liner movement during milking in the NuPulse and Conventional Pulse

	Flow rate kg/min	Pulsator rate (/min)		Liner ratio (open/closed)		Liner more than ½ open time (s)		
		Flow		Flow		Flow		
		Peak	low	Peak	low	Peak	low	
NuPulse								
High lift	2.2	51	52.5	65/35	60/40	0.74	0.67	n = 4
Low lift	3.7	52.5	55.5	70/30	61/39	0.69	0.65	n = 2
Low lift	2.7	54.5	55.5	69/31	66/34	0.74	0.68	n = 2
Con. Pulse								
High lift	2.1	48	48	52/48	48/52	0.64	0.59	n = 4
Low lift	2.1	48	48	50/50	48/52	0.61	0.57	n = 4

n = number of milkings

Table 22: Teat penetration into the experimental teatcup during the Conventional Pulse (high lift) treatment.

	Teat length before milking	Teat penetration into the liner during peak flow	Teat penetration into the liner at the end of milk flow
	cm	cm	cm
Cow 1	4.8	6.6	8.3
2	4.3	6.2	7.6
3	5.0	6.6	9.0
4	3.9	4.2	8.0

2.2.3 (b) *Teat penetration into the experimental teatcup liner during milking*

The depth of teat penetration into the vacuumised liner during milking is shown in Table 22. Fig 9 (d_1) shows the liner movement waveform for cow 4, and the effect that the length of the teat had on the recordings. The LM(1) linear transducer recorded the liner closing just below the teat end, about 0.3s before the liner closed in the LM(2) position (Fig 9(d_1). However, following the loss of teat cistern pressure and further penetration of the teat into the liner, the LM(1) linear transducer trace shows that the liner failed to collapse in that position. Similar recordings were obtained for cow 4 during the NuPulse milking (Fig 8 b_1 and b2).

2.2.3 (c) *Percent liner distension recorded during the cow milkings*

The average values obtained for liner distension with the 4 machine treatments are shown in Table 23. The difference between the NuPulse and Conventional Pulse at the LM (2) linear position was significant ($P < 0.01$) when analysed by pooled variance t test (Snedecor and Cochran, 1967; Appendix IV). The 8 percent difference in liner distension between the NuPulse and Conventional Pulse in the LM (1) position (Table 23) was not significant. Each mean was calculated from only 4 observations. Liner distension increased in both the NuPulse and Conventional Pulse at the LM (2) position when the liner was adjusted to operate at low tension. Distension of the liner in the LM (2) position appears to be affected by the distension that occurs in the LM (1) position and is possibly the reason why 7.5 percent liner distension occurred in the NuPulse (Table 23) in the absence of any pressure difference (acting outwards) across the liner.

A positive teat cistern pressure apparently has some effect on liner distension, as similar vacuum C levels in the Conventional Pulse simulated milkings and cow milkings (Table 20) were associated with widely divergent levels of liner distension. An hypothesis to explain the difference in liner distension between the NuPulse and Conventional Pulse (Table 23) is that, in the NuPulse, the teat is only exposed to full (50.8 kPa) pulsation chamber vacuum for 0.1-0.2 s when the

pulsation waveform develops a saw-tooth shape during the peak flow period of milking.

Table 23 The percent liner distension recorded during milking with the NuPulse and Conventional Pulse

		% liner distension (mean and standard error)	
		LM (2)	LM (1)
Low lift and High tension liners	Nu Pulse	1.0 (± 0.41) ***	(not recorded)
	Con. Pulse	8.0 (± 0.76)	
High lift and Low tension liners	Nu Pulse	7.5 (± 0.04) **	22 (± 3.4) NS
	Con. Pulse	17.0 (± 2.38)	30 (± 3.7)

Each mean is the average of 4 observations.

Note: 6% liner distension represents a 1 mm increase in the internal liner diameter

In the Conventional Pulse on the other hand, the teat is exposed to (50.8 kPa) pulsation chamber vacuum for a period of 0.4 - 0.5 s and therefore has a pressure difference applied across the teat wall for a longer period of time.
During the low flow period and after the loss of positive teat cistern pressure, no liner distension was recorded for either the NuPulse or Conventional Pulse (Fig 8 (a2 and b2); Fig 9 (c2)).

2.2.3 (d) *Mouth piece cavity vacuum during milking*

The mouth piece cavity vacuum (MPC) remained at the level shown in Table 24 during the peak flow period. Except for Cow 1 during the low lift milking, the NuPulse was associated with lower mouth piece vacuum levels than the Conventional Pulse, during the peak flow period. The difference between the means was not significant ($P > 0.1$).

After the loss of teat cistern pressure and following the deeper penetration of the teat into the liner, the MPC vacuum usually followed a pulsating waveform, increasing when the liner opened

and decreasing when the liner closed with both the NuPulse and Conventional Pulse (Figs 8 b(2) and 9 d(2). The maximum MPC vacuums recorded during the 'low flow' stage of milking are shown in Table 24.

Table 24: Mouth piece cavity vacuum (kPa) recorded during the cow milkings

	Treatment	During peak flow		During low flow	
		NuPulse	Con.Pulse	NuPulse	Con.Pulse
Cow 1	Low lift	10	2	16	3
	High lift	3	4	28	34
2	Low lift	6	12	33	18
	High lift	5	12	18	18
3	Low lift	12	14	25	34
	High lift	7	8	22	28
4	Low lift	14	22	24	26
	High lift	13	22	25	26
	$\bar{x}$	8.8	12.0	23.9	23.4
		NS		NS	

2.3.0 A pilot investigation made to determine the closing force of the liner in the NuPulse and Conventional Pulse

2.3.1 Materials and method

A sealed rubber calfeteria teat (9cm, D.McL.Wallace Ltd. Pat. No 119177, Hamilton NZ) was attached to a 2 m length of 9 mm internal bore plastic tube. After filling the teat and tube with water, the rubber teat was inserted into one teatcup while the other three cups remained on the cow.

An estimation of the squeeze action was made by observing the rate of water movement up and down to marked levels in the tube with each pulsation cycle, during the milking of 4 cows by the NuPulse and 4 cows by the Conventional Pulse.

2.3.2 Results

During the squeeze phase of pulsation the column of water was forced up to the same level in the tube with both pulsation systems, and indicated that a similar total force was being applied to the water in the rubber teat, or that the difference in force was too small to be detected by the method.

The column of water moved up and down during each pulsation cycle with a slow damped rise and fall when the rubber teat was inserted into the NuPulse liner.

When the rubber teat was inserted into the liner of the Conventional Pulse cluster the column of water in the plastic tube was observed to move up and down with greater velocity and fluctuation than the rate noted for the NuPulse.
Compared with the NuPulse, the Conventional Pulse caused the water level in the tube to fall 30 percent lower during the liner opening stage of pulsation. The Conventional Pulse effect was reproduced by squeezing the rubber teat by hand. A sudden release of hand pressure caused a quick fall in the water level, and appeared to accelerate and impart momentum to the column of water. The column of water continued to fall and expand the rubber teat until the momentum was lost.
Based on these observations it appears that the NuPulse applied the pressure changes to the fluid in the rubber teat more evenly and gradually than the Conventional Pulse.

2.4.0 Discussion

The main difference between the NuPulse and Conventional Pulse in liner movement appears to be the open to closed ratio (G) and the length of the liner closed phase of pulsation. The recordings in Fig 8 show that in the NuPulse, the liner only closed below the teat for an instant.
The shortness of the squeeze was observed with transparent liners

and cups. Visual observation through transparent liners (Transflow, Norton Stoneware, U.S.A) did not reveal whether the short liner closing phase of the NuPulse was associated with less bending of the liner around the end of the teat than when the liner was operated in the Conventional Pulse

When the liner movement waveforms obtained for the NuPulse and Conventional Pulse during the low flow period of milking were superimposed (Figs 8 a2 and 9 c2) it was found that the liner movement trace was similar from the closed to open position and the open to closed position.

When the liner movement waveforms obtained during peak flow (Figs 8 a1 and 9 c1) were superimposed it was found that the Conventional Pulse liner closed 0.1 s slower when liner distension occurred

The NuPulse liner remained open for 0.2 s longer than the Conventional Pulse liner.

Conversely the Conventional Pulse remained closed for 0.2 - 0.3 s longer than the NuPulse.

2.4.0 (a) *Conventional Pulse recordings*

The vacuum conditions recorded in the liner of the Conventional Pulse during milking are nearly identical to the pressure changes recorded by Thiel *et al.* (1964) in the liner of a similar conventional cluster. The vacuum recordings made during the low flow stage of milking are also similar to those reported by Mein *et al.*(1973a)

Theil and Mein (1977) describe the conditions that cause the rise and fall of vacuum during each pulsation cycle. The sharp fall in liner vacuum A, (Fig 2) occurs as the liner closes because the milk in the liner is unable to move away quickly enough during the squeeze phase of pulsation to accomodate the decreasing volume inside the liner. When air trapped in the liner is compressed, the pressure increases, that is the vacuum decreases. By the time the liners are half closed a substantial pressure difference exists between the high pressure formed in the liner (a low vacuum A) and the low pressure (a 50.8 kPa milk line vacuum) at the end of the long milk tube.

The force developed by the increasing pressure difference rapidly accelerates milk away from the liner and enables the liner to close without a further decline in vacuum A.

The milk flowing away from the liners in the long milk tube does so with considerable speed and kinetic energy, generating (by a piston effect) an increase in vacuum in the liners. In addition to this vacuumizing effect, that tends to decelerate or draw the milk back towards the claw, the vacuum level in the liner is augumented by an increase in the liner volume as it opens.
The net effect is a high final vacuum as the liner opens (Vacuum D, Fig 2), considerably higher than either the pulsation chamber vacuum or the regulated plant vacuum of 50.8 kPa.
The rise and fall of vacuum during each pulsation cycle is termed, cyclic vacuum fluctuation by Thiel and Mein (1977).
Only when the cluster is extremely free draining, that is with all tubes of large cross section and the long milk tube either completely absent or sloping downwards all the way to a milk collector, is it likely that cyclic vacuum fluctuations will be reduced to levels of 10 kPa with fast milking cows.

Thiel *et al.* (1968) found that cyclic vacuum fluctuations in the liner and claw piece were similar, only when the bore of the short milk tubes and the short milk tube nipples on the claw bowl were increased to 11 - 12 mm.
The 8 mm bore short milk tubes used in this experiment probably caused a marked restriction to air and fluid flow as the liner opened and closed and reduced the sensitivity of liner vacuum to some of the experimental variables. Vacuum differences of 2 - 4 kPa sometimes occurred between the liner vacuum and P.C vacuum during the opening of the liner in the NuPulse. However the liner vacuum was always higher than the PC vacuum and this probably indicates that the restriction to air flow was greater through the pulsator ports.

Thiel *et al.*(1968) showed that even though the peak flow rate was 7 percent lower when high levels of cyclic fluctuation were produced in a conventional machine, the total milking time was not significantly

($P > 0.05$) affected.

The results obtained from the simulated milkings with the Conventional Pulse are in agreement with the data obtained by Thiel *et al.* (1968) with simulated milking conditions.

They found that the average milking vacuum, recorded when the liner was open, decreased with increasing lift, flow rate and LMT length, and increased slightly as the claw bowl was enlarged. With increasing lift both the minimum vacuum (liner closing) and the maximum vacuum (liner opening) decreased and as a result the magnitude of the cyclic fluctuation in the low lift and high lift machines remained similar. The same effect occurred with increasing lift in this experiment.

Many contrasting views exist about what constitutes effective pulsation (Thiel and Mein, 1977).

During the liner closing stage of pulsation there can be no direct collapsing force developed over the region of the teat in contact with the liner, while pressure in the teat cistern is greater than or equal to atmospheric pressure.

When air enters the pulsation chamber the liner bends around the teat end as the lower part of the liner collapses.

Phillips (1963) has shown that a reasonably thin and flexible liner is able to fit 'snugly' around the teat without 'pinching' the teat end into a point. It is the tension in the liner walls, developed by the liner closing beneath and bending around the teat end, that applies force to the teat.

Mein *et al.* (1973a) have shown using radiographs that, the force exerted on the teat by the closed liner is greatest near the end of the teat and that in the final stages of liner movement it appears that movement is confined to a tighter bending of the walls of the liner around the end of the teat.

Thompson (1978) has measured localised compression forces of 10 kPa at the teat end during the liner closing phase of pulsation and mentioned that the magnitude of the force must depend on a multitude of variables such as teat size and shape, liner tension and elasticity and the point of teat and liner contact. Phillips (1963) has recommended that a period of less than 15 percent of the pulsation cycle on full air pressure is inadvisable and with

first lactation cows frequently insufficient to allow the teat to recover from the effects of vacuum before the next liner open stage of pulsation. Phillips (1963) also reported that a 'slowly applied squeeze', where the the change from vacuum to air in the pulsation chamber occupied 20 percent of the pulsation cycle,had been effective in reducing cow discomfort during milking.

2.4.0 (b) *The NuPulse recordings*

The liner movement waveforms obtained for the NuPulse showed that the liner only remained closed for an instant. Visual observations of the rubber liner in the transparent experimental teatcup indicated that the squeeze was short and because of this the liner appeared to be unable to collapse, close to or at the teat end.

Terms such as a 'soft squeeze' or a squeeze without 'nipping' are used by the manufacturer to describe the liner action.

The compressive force exerted on the teat by the closing liner could be further investigated using the techniques developed by Thompson (1978).

It is difficult to explain why the NuPulse is able to operate with such a short liner closed time when it has been shown that a very short squeeze phase applied in the conventional machine can cause discomfort and considerable loss of production (Jackson, 1970; Phillips, 1963).

In the NuPulse, it is possible that the teat is subjected to lower levels of tissue congestion and stress during the period of milking when the liner is open and as a result the teat does not require a long squeeze or rest period, before the next vacuum stroke.
The lower levels of liner distension recorded in this experiment and the lower MPC vacuums obtained for 3 of the 4 cows, adds indirect support to the above hypothesis.

The sawtooth shape of the pulsation waveform and the slow rise to full vacuum, that occurs when the liner is opening during the peak

milk flow rate period are probably responsible for the lower levels of liner distension and the variation in MPC vacuum.

The lower levels of vacuum applied to the end of the teat during the opening of the liner could also off-set the need for a long or forceful squeeze period.

The pulsation waveforms obtained during the simulated milkings showed that the vacuum levels (vacuum level E) were 32.3 kPa for the NuPulse and 51.2 kPa for the Conventional Pulse when the liner had reached the half open stage. The vacuum E levels obtained during the cow milkings were, 29 kPa and 52 kPa for the NuPulse and Conventional Pulse respectively.

It is possible that the lower level of vacuum operating in the NuPulse as the liner opens results in less cup crawl and consequently less congestion in the teat tissue during the latter stage of milking. Mein and Martin (1977) have shown that the stripping yields obtained with the NuPulse were similar to the yields obtained with a conventional machine 1 kg heavier.
Phillips (1963) found that liner crawl occurred at an earlier stage of milking when the vacuum phase of pulsation, (phase b of the pulsation waveform) was increased by 10 percent. The sawtooth shape of the NuPulse liner vacuum waveform could therefore be the unique feature responsible for the ability of the NuPulse to milk successfully with a light-weight cluster.
Mein *et al.*(1973a) believe that increased teat congestion seems unavoidable once the connection between the udder and the teat cistern has become restricted and liner crawl has occurred. They also noted from radiograph studies that teat wall congestion appeared to increase only after the flow of milk into the teat cistern became restricted and the volume of milk in the teat cistern decreased. Very little teat wall congestion was noticed during the peak flow period of milking.

The radiograph studies of Mein *et al.*(1973a) clearly show the different degrees of liner distension during peak flow and verify the existence of liner distension measured indirectly in this

experiment.
The position of the teat in the liner, liner tension, milk yield and teat cistern pressure would all be expected to cause variation in liner distension measurements.

As the liners open in the NuPulse the increase in internal liner volume is compensated for by the admission of air (taken from behind the liners) into the claw bowl.
The decrease in vacuum that occurs as the air enters the claw bowl, creates a pressure difference that forces most of the milk, accumulated from the previous liner open period to flow away from the claw bowl to the milk line.

The results from the simulated milkings showed that the 16 mm LMT increased the mean vacuum level in the NuPulse during the milking phase of pulsation (that is vacuum level C, D and E) and generally reduced that vacuum drop effect of lift and high flow recorded with the 12 mm LMT.

The recordings obtained with the single NuPulse unit used in this experiment (Table 20 and 21) show that the pulsation characteristics of the NuPulse are far from static during milking.
The pulsation rate decreased and the liner open time increased during the peak flow period of milking. The net effect was usually little change in the time that the liner was more than half open, because a longer open time during each cycle, off-set the reduction in the pulsation rate or cycles per minute.
The common vacuum source to both sides of the liner in the NuPulse enables the liner to open before full vacuum is reached in the pulsation chamber. Despite a decrease in phase b of the pulsation waveform during the peak flow period of milking, the liner movement waveform, while the liner was open, was similar to that recorded during the low flow period when phase b occupied up to 50 percent of the PC waveform.

The NuPulse was more sensitive to liner tension than the Conventional Pulse.

The high tension liner possibly increased the rate of air removal from the pulsation chamber when the liner opened and appeared to delay the rate of air flow into the pulsation chamber when the liner closed. The effectiveness of the short squeeze in the NuPulse could also be reduced by high tension liners, and deserves further study.

In conclusion, the waveform recordings obtained for a single NuPulse unit during the simulated and cow milkings show that the NuPulse has a distinctly different mode of action from the conventional type of milking machine.

The results also show that the NuPulse is very likely to be associated with less liner distension (called ballooning by the manufacturer) and that the brief 'liner closed time', is probably associated with lower squeeze forces or with lower levels of 'nipping' as claimed by the manufacturer.

EXPERIMENT TWO

3.0.0 The Effect of the NuPulse and Conventional Pulse on Milk Yield and Mastitis

3.1.0 Materials and Methods

3.1.1 Milking equipment

Milking was carried out in an 8 unit walkthrough dairy fitted with 4 NuPulse and 4 Conventional Pulse units (Appendix I and II).

3.1.2 Animals

Ten pairs of identical twin cows (hereafter termed the trial cows) were selected from 34 available pairs and allocated to a full lactation experiment; these ten pairs of twins were free of udder infection at the beginning of the experiment.
The methods used to define and select cows free of infection are given in Appendix V.
The trial cows were grazed with 100 non trial cows of mixed age and breed before calving and throughout the lactation.
After calving each cow was left for 2 - 3 days to be suckled by its calf, before being milked by the machine.
Thirteen twin pairs had been selected before calving as potential experimental animals. One member of each twin pair was allocated at random to the NuPulse treatment, and the other member to the Conventional Pulse treatment; the treatment for each member to commence at the first milking.

Aseptic foremilk samples were taken at the first milking to detect the presence of infective mastitic bacteria. Ten of the 13 pairs of twins were found to be free of infection and were selected for the trial. Two of these ten pairs had to be replaced after the death of one of the twins in each pair. The cows in the replacement twin pairs were the only cows finally selected for the trial that were not milked by their treatment machines at the first milking. The trial cows which were finally selected were all free of

infection and included 8 pairs of cows starting their first lactation and 2 pairs of cows starting their second lactation.
Further detail about the breed composition of the twin pairs and the difference in calving date between the cows in each pair is given in Appendix VI.

The trial cows received the same grazing treatment as the non trial cows before and after calving. All the cows in the herd started the lactation in thin condition after enduring a cold wet winter and a period of underfeeding before calving. The feed shortage continued for several months after calving. Supplementary hay and silage was fed during the winter and the latter stages of the lactation when pasture was in short supply.

3.1.3 Herd milking method

At milking, the trial cows entered the yard with the rest of the herd and were selected for milking without any special treatment once the cows in their first lactation had been trained.
The non trial cows were milked randomly by one treatment machine or the other, whereas the trial cows were milked by any one of their 4 treatment machines. (The machine layout is shown in Appendix 1).

The teats of each cow were squirted with warm water from a hose for 3 to 10 s and the teatcups attached after a 0 - 15 s delay. Dirty teats were manually cleaned at the same time, but during the summer months cows with clean teats were not squirted with water or washed. Only rarely was foremilk taken and examined for clots.

Machine stripping (downward pressure applied to the cluster by hand) was not part of the usual milking routine, as the clusters were removed by automatic detachers (Refer to Appendix II and Section 3.1.8 (d)).
However cows were occasionally remilked and machine stripped by the milkers if automatic cup removal had occurred prematurely

Periods of overmilking occurred when the milkers forgot to switch the removal device onto the automatic position.
With some of the older non trial cows and with the two cows in twin set No 10, weights were occasionally added to the claw towards the end of milk flow.

All cows were drenched with Bloatenz (Pluronic L 62) during the evening (pm) milking at those times of the year when there was a risk that bloat would occur.

For the first 3 months of lactation an iodine based grease was used to treat sores and cuts on the teats of both the trial and non trial cows. From the 4th month of lactation onwards the teats of the non trial cows were sprayed with a mixture incorporating 0.75 percent chlorhexidine (10 percent hibitane) and 10 percent glycerine mixed with water. This treatment continued during various periods of lactation for the trial cows.

The cows were milked by two milkers until mid lactation because two milkers were needed to get the first lactation trial cows into their treatment bails. After mid lactation most milkings were carried out by one milker. Milking started at about 6 am and 4 pm.

3.1.4 Mechanical aspects

(a) *Milking plant efficiency checks*

A Ruakura air flow meter and vacuum recorder (Hall, 1977b) were used to measure reserve air flow and pulsation chamber vacuum respectively while the machine was not milking (static) as outlined by Phillips (1952). Airflow was measured in ℓ/s of expanded air or NZ units of airflow.

Before the experiment started a static machine efficiency check was carried out. The reserve air flow capacity was measured with the vacuum to the claw turned off at the teatcup remover activator (refer to Appendix II) and with the 4 conventional bail

pulsators operating and the 4 NuPulse pulsators not operating. To allow for the air flow into the plant associated with the use of the milk meters and automatic cup removers during milking, the vacuum pump speed was increased so that the plant operated with a reserve air intake of 16 ℓ/s during the static test.

To ensure consistent operation during lactation the vacuum gauge, the vacuum regulator and the rate and ratio of the pulsators were checked before milking once a month and again before the milking efficiency study described in section 3.1.8. At each test a check was made to ensure that the reserve air level remained at 16 ± 1 ℓ/s, and that the vacuum level at the end of the milking pipeline was able to recover from 35 kPa to 50.8 kPa within 2 s. At one of the monthly static tests the teatcup liners were plugged with rubber teats and measurements made to estimate the air flow rate through the air bleed holes in the Conventional Pulse clusters and the air flow requirement of the NuPulse clusters.

3.1.4 (b) *Plant breakdowns and claw breakages*

A record was kept of all breakdowns and maintenance required during the experiment. During the 4th month of lactation the tension of all the liners described in Appendix II was increased by tightening them into the 2nd notch position in the teatcup shell. All the liners were used for the complete lactation except for 3 liners which had to be replaced. Each liner was estimated to have performed 6700 milkings during the experiment.

3.1.4 (c) *Machine cleaning*

Two in-place cleaning methods were used to clean the machine. After the morning milking the NuPulse and Conventional Pulse clusters were attached to jetting devices (shown in Illustration 1) and cleaned by cold and then hot cleaning fluids circulated by a 3rd line system. The method is described in more detail by Currier (1973).

To clean the pulsator chamber of the 4 NuPulse clusters with cleaning fluids, the wash tube shown attached to the jetter in Illustration 1 was connected to the middle piece of the NuPulse

claw. The wash tube connection was made by disconnecting one of the short pulse tubes.

After the evening milking a cold water reverse flow cleaning system (described by Currier, 1973) was used instead of the circulation system. Cold water was pumped into the receiver and forced to flow (in the reverse direction to milk flow) down the milk line and through each cluster to waste.

The NuPulse dome and pulsator parts were cleaned manually twice a week.

3.1.5 Measurement of milk production

(a) *Measurement of milk yield*

Once a week milk samples were taken at an evening milking (pm) and at the following morning (am) milking using a Tru-Test milk meter (Tru-Test Distributions Ltd. Panmure, Auckland). The meters were attached to the milking pipeline as shown in Appendix II.
The procedure followed at each milking was to disconnect the flask from the meter as each cow finished milking and store the flasks in two wire baskets kept in the bail area. Before recording the milk volume the flask was rotated by hand to whirl the milk around inside the flask. The whirling remixed the fat layer and formed a definite liquid layer before the volume was estimated with a limit of reading of 25 ± 12.5 ml.

The am milk sample was added to the chilled (5°C) pm sample and the fat and protein concentration of the composite sample measured. (Fat Milko Tester, Mk. III; and Protein Milk Analyser, A/s N. Foss Electric, Hillerod Denmark).
The fat and protein yield was estimated by multiplying the concentration by the volume (ℓ) estimated by the milk meter.

3.1.5 (b) *Calibration of the milk meter*

The two meters nearest to the receiver (refer to Appendix I) were calibrated with both the NuPulse and Conventional Pulse systems.

The single test was undertaken at the end of the 6th month of lactation with the meters connected up in the same way as they were used to measure the weekly milk yields during the experiment (Appendix II).

After wetting the plant by milking one cow, 11 cows with varying milk yields were milked one at a time by either the NuPulse or Conventional Pulse cluster. While each cow was being milked, the milk was collected in the receiving vessel that had been disconnected from the releaser milk pump. After each cow had been milked the milk was drained from the receiver and after the addition of the milk from the flask, weighed and compared with the volume estimated from the milk meter flask. The milk was at room temperature (15 ± 1°C) when the weight was measured.

The milk yield for each cow was recorded 35 ± 1 times during the lactation and randomly by any one of 4 meters at each milking. As a result, errors associated with the other meters not tested would be expected to be independently and normally distributed and unlikely to bias the production estimates and the experimental comparison. The limit of reading and the error of an observation from the milk meter was 25 ± 12.5 ml and the error of the between twin difference in milk yield ± 25 ml or 2.5 percent.

3.1.5 (c) *Froth in milk*

The level of froth present on top of the milk in the milk meter flask was recorded during several milkings about the 8th month of lactation.

3.1.5 (d) *Hand stripping yield*

During the 7th and 8th months of lactation the trial cows were hand stripped after automatic cup removal at 6 milkings when the milk meters were connected for the weekly measurement of milk yield. Strip yields were recorded at consecutive pm and am milkings on two occasions and at another 2 pm milkings.

3.1.6 Cow health factors

(a) *Teat condition*

At the start and end of lactation and 5 times during lactation, teat sores and cuts were recorded and the end of the teats inspected (by the same person, R.K.F) and scored using a 0 - 4 scale of orifice diameter after automatic teatcup removal. A score of zero was given when the teat orifice was small and a score of 4 given when the orifice diamter was about 2 mm. The symbol (W) was used to record the presence of white tissue around the teat orifice. Six times during the lactation the teats of the non trial cows were also inspected for teat sores and cuts.

3.1.6 (b) *Somatic cell count*

Ten mls of the composite milk sample used for the fat and protein tests were preserved with formalin and the somatic cells in 0.5 ml counted using a model B Coulter Counter and IDF (1971) testing procedure (Coulter Electronics Ltd, Harpenden, Herts, England). The cell count was also obtained for quarter milk samples (10 mls) taken from the trial cows at 2 week intervals and for monthly milk meter samples taken from the non trial cows.

3.1.6 (c) *Clinical mastitis*

Cases of clinical mastitis which occurred in the herd were treated by the milker with intramammary antibiotics when the symptoms of clinical inflammation were noticed. With some cases bacterial diagnosis was made by the herd veterinarian before treatment. Usually the cows had been treated by the milkers before samples could be taken for bacteriological examination.

3.1.6 (d) *The use of foremilk samples to diagnose infection*

Just before the end of lactation and again at the start of the next lactation quarter milk samples were taken from the trial cows and subjected to bacteriological examination in order to diagnose infection. The testing and sampling procedure was identical to that used to select cows free of infection at the beginning of

the trial (Refer to Appendix V). Teats had been sprayed with the chlorhexidine-glycerine disinfectant after each milking for a week before the foremilk samples were taken at the end of the lactation in order to decolonize the teat ducts and reduce the chance of false negative results (Neave, 1975).

3.1.7 Measurements made during the following lactation

At drying-off no antibiotic treatment was given to the trial cows. Eight twin pairs were milked for various periods at the beginning of the following lactation by the NuPulse and Conventional Pulse treatment clusters before the trial was finally discontinued. During this period,milk, fat and protein yields were recorded and somatic cell counts were measured.
Three weeks before the trial ended the teat orifice of two teats (on either the right or left side of the udder) were photographed. The incidence of clinical mastitis was recorded for the period each cow was milked during the 2nd lacation.

The chronological sequence of events for the complete experiment is shown in Fig. 10.

3.1.8 The milking rate and efficiency of the herd

(a) *Introduction*

Six times during lactation the trial and non trial cows (referred to as the herd) were used to estimate the milking rate and let down response for the NuPulse and Conventional Pulse systems. At the same time the efficiency of the automatic teatcup removers was assessed.
The mean calving date for the herd was the 3rd of August and the mean lactation length 258 days.
The milking recordings were made at 28, 122 and 229 days after the mean calving date and are subsequently referred to as recordings A, B and C respectively.
A preliminary recording was made to familiarize the observers with the recording techniques and to correct equipment faults before recording A was made.

3.1.8 (b) *Milking routine*

During the 6 milkings all cows were milked by 2 milkers using the method described in section 3.1.3, with the exception that the teats of all cows were squirted with water and manually washed for 5 to 8 s, followed by a 10 s delay before the first teatcup was fitted to the cow.

3.1.8 (c) *Milk yield and milking rate*

In addition to the 2 milkers, the writer (R.K.F.) and 3 others (observers) were present at the 6 milkings to obtain information about the rate of milk flow from each cow by recording the milking time and milk volume in the milk meter flask at 30 s intervals.
The following information was recorded -

1. Total milking time - the time between the last cup on and automatic cup removal.
2. Total milk yield - after automatic cup removal. The milk level was read to the bottom level of the froth if any froth was present.
3. The operation of the automatic cup remover.

The average milking rate for the group of cows milked by the NuPulse and Conventional Pulse at each milking was calculated by adding the milk yields and milking times for the individual cows and dividing the cumulative yield by the total milking time.
The non trial cows were milked at random by any one of the NuPulse or 4 Conventional Pulse machines, and the trial cows were milked by their respective treatment machines.
The data obtained during the recordings for the trial cows has been presented separately as well as combined with the non trial cow data.

3.1.8 (d) *The end point of milking and automatic teatcup removal*

The Waikato Automatic teatcup remover (AHI, Plastic Products Moulding Company, Hamilton, NZ) was used to detect the end point of milking and remove the teat cups.

The automatic detacher operates with an in-line flow sensor that disconnects the cluster from the milk line vacuum and activates a vacuum operated ram that removes the teatcups from the cow by means of a connecting cord. All the component parts are shown in Illustration 1.

The milk flow sensor contains a float with a disc attached to the top. When the cups are placed on the cow it is necessary to hold the float in a raised position with the support of a lever until the flow of milk from the cow is fast enough to support the float. Once this has occurred the supporting lever can be removed (called tripping the lever) and from this point onwards, the end point of milking is determined automatically by the float level.

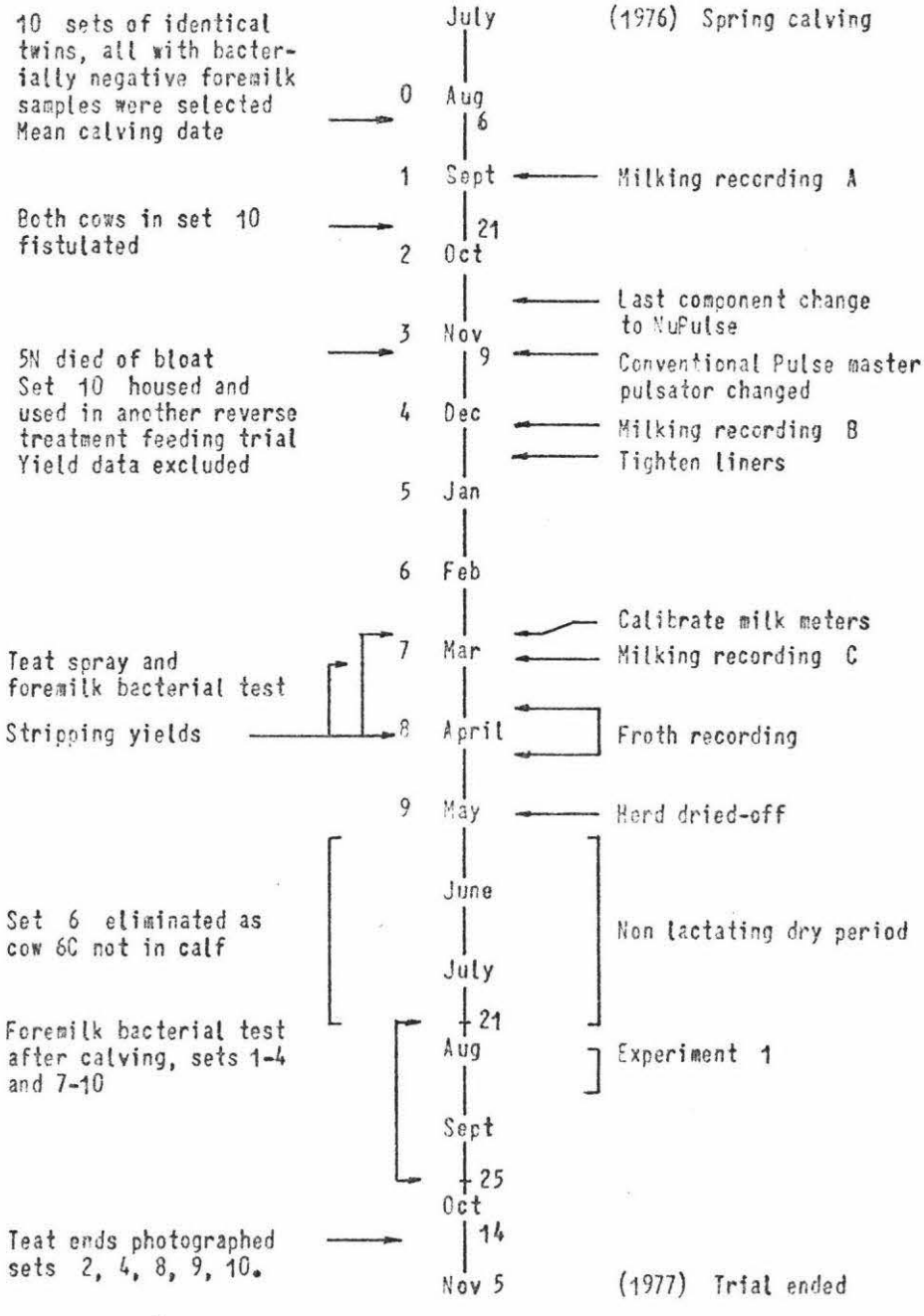
The float (with the disc attached to the top) falls as the volume of milk in the chamber of the sensor decreases.
The milk level in the sensor falls when the milk flow out of a drain hole in the sensor (equivalent to a flow rate of about 0.150 litres/min.) is greater than the inflow from the claw bowl. After the flow of milk from the cow has stopped a delay of 15 - 18 s elapses before the sensor empties and the float disc seals-off the vacuum from the claw piece.

3.1.9 (a) *Statistical analysis*

A paired twin experiment compares the average effects of the two treatments over a number of twin sets. In the statistical analysis the deviations of the twin pair difference from the group average are assumed to be normally and independently distributed with 'population mean zero'.
The standard error of the deviations ($S_{\bar{D}}$) is used in the students t distribution to test the significance of the mean difference ($\overline{D}$) (Snedecor and Cochran, 1967).
The t test is not markedly affected by wide departures of the deviations from a normal distribution. The treatment or any one of the 4 treatment machines was applied to each pair randomly to ensure that any errors would be independently distributed.

Figure 10

Chronological sequence of events during the experiment.



0 - 9 = month of lactation

The difference in the average somatic cell count between the twin pairs was analysed statistically by randomized complete block design. Each twin set was used as a block in a two way classification, analysis of variance. Although the variance was 5 times higher for the NuPulse group the F ratio was not significant and was even less significant when a logarithmic transformation of the data was made to account for the difference in variance. When the trial cow data was combined with the non trial cow data the means were compared by pooled variance, with the assumption that the means were obtained from two independent samples. When unequal group sizes occurred the pooled estimate of variance was adjusted as recommended by Snedecor and Cochran (1967). The method of regression and covariance analysis was taken from Snedecor and Cochran (1967). An example of each type of analysis is included in the Appendix. Copies of the analyses not included in this thesis can be obtained from the Professor of the Dairy Husbandry Department, Massey University.

3.2.0 Results

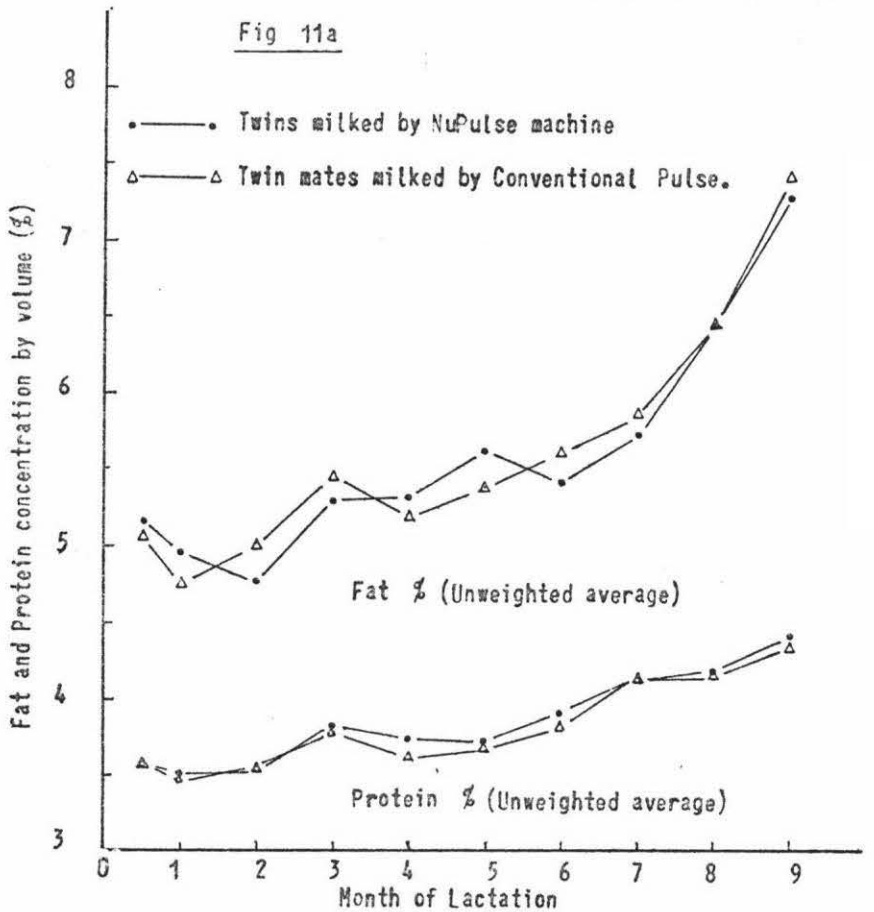
3.2.1 (a) *Milk production*

The production records for the two experimental groups are shown in Fig 11. After the 3rd month of lactation only 8 twin sets were available to compile the monthly production average. Twin set 5 was eliminated from the trial when one twin died of bloat. Although the twins in set 10 were milked by their respective treatment machines for the full lactation, their production records had to be excluded from the production comparison because both twins were fistulated after 2.5 months of lactation and later used in another indoor feeding experiment. However the cows in set 10 were used in the experimental comparison of the cow health factors detailed in section 3.1.6.

The lactation yields for 8 twin sets are shown in Table 25. The number of twin sets used to compile the production graphs in Fig 11a and 11b is shown as n.

Figure 11a & 11b Results for milk production

Fig 11a



n = 3, 7, 10, 10, 8, 8, 8, 8, 8, 8.

n = The number of identical twin pairs production records, used to compile the monthly averages.

These values have been calculated from weekly measurements on each cow.

Fig 11b

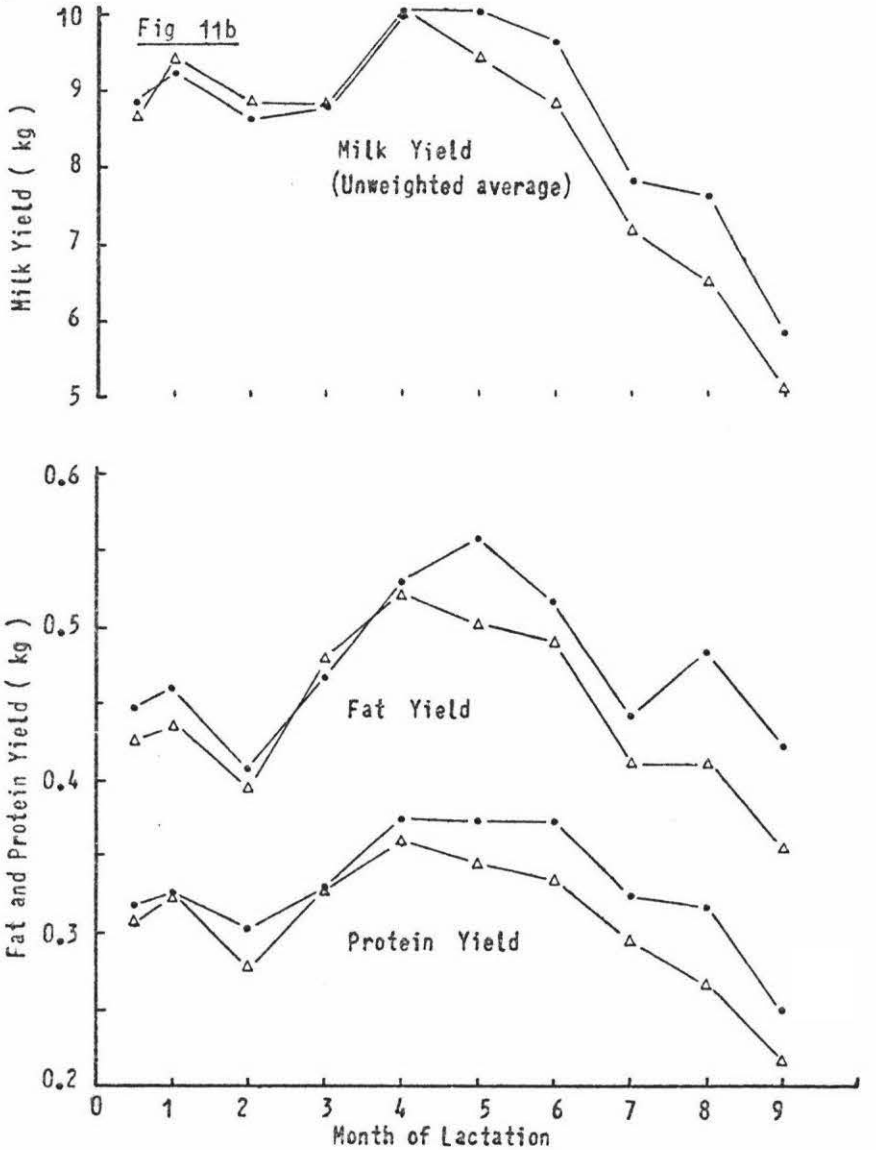


Table 25: The average values for milk, fat and protein yields and length of lactation for 8 twin pairs

Yield	Milk ℓ	Fat kg	Protein kg	Lactation length days
NuPulse	2294	128.1	89.0	267
Conventional pulse	2120	117.9	80.3	264.4
Probability, that the difference is significant	NS	NS	NS	

The total production of fat and protein for each cow during the lactation was calculated by multiplying the mean fat and protein concentrations by the number of days in milk. The differences in yield, shown in Table 25 were not significant when analysed by paired t tests (Snedecor and Cochran, 1967).

However the analyses takes no account of the difference in production between the two groups at the time of drying off (refer to Fig. 11b). After the 4th month of lactation the milk yield of the Conventional Pulse group appears to decrease at a faster rate than the yield of the NuPulse group.

As the average fat and protein concentrations during lactation were similar for both groups (Fig 11a) the monthly fat and protein yields (Fig 11b) followed a similar pattern of decrease as the milk yield.

The yields of the NuPulse cows have been presented in Table 26 as a percentage of the yield achieved by their twins in the Conventional Pulse group to indicate the change in production between the twins in a pair over the last 5 months of lactation. The difference in milk yield between the two groups for the last 5 months was analysed by paired t test. In the 9th month, when all the cows in the NuPulse group were giving more milk than their twin pairs (Table 26) the difference was highly significant ($P < 0.01$). The most surprising feature concerns the recovery of the NuPulse treatement twins in sets 3 and 8 because both of the twins had been infected with *Staphylococcus aureus* in one quarter for most of the lactation (Figs 16 and 17).

Table 26: The percentage difference in milk yield between the twin pairs during the last 5 months of lactation [1]

Month of lactation	5	6	7	8	9
Twin Set No					
1	+ 28.9	+ 19.6	+ 24.6	+ 38.1	+ 33.1
2	+ 39.4	+ 5.4	+ 5.9	+ 37.5	+ 26.2
3	- 13.9	- 13.0	- 10.9	+ 7.1	+ 13.7
4	+ 15.2	- 4.3	- 10.9	+ 8.0	+ 16.7
6	+ 11.7	+ 6.2	+ 10.7	+ 10.4	+ 14.0
7	+ 1.9	+ 18.8	+ 49.6	+ 30.2	+ 10.9
8	- 2.1	+ 21.9	- 11.7	- 7.9	+ 5.1
9	+ 0.5	+ 20.4	+ 12.0	+ 28.9	+ 4.7
Mean	+ 9.0%	9.3	11.6	19.0	15.5
Significance level	P > 0.1	P < 0.1	P > 0.1	*	** - ***

[1] For each twin set the yield of the NuPulse twin is expressed as a percentage of the yield of the Conventional Pulse twin mate

When the cows were dried off the twins milked by the NuPulse had an average yield of 5.9 ℓ per day whereas the yield of the twins milked by the Conventional Pulse was 5.1 ℓ per day (Fig 11b). The twins milked by the Conventional Pulse had decreased to 5.9 ℓ 12 days before they were dried off. To adjust for this difference between treatment groups the milk produced during the last 12 days of the lactation was deducted from the yield of each cow in the Conventional Pulse group.

The adjusted differences (Table 27) were found to be significant when analysed by paired t test (Appendix VII).

Table 27: The average values for milk, fat and protein yields with the lactation terminated for both treatment groups at the same milk yield (5.9 ℓ/day).

Yield	Milk ℓ	Fat kg	Protein kg	Lactation length days
NuPulse	2294	128.1	89.0	267
Conventional Pulse	2063	113.8	77.8	252.4
Probability that the difference is significant	P = 0.05	*	P = 0.02	

3.2.1 (b) *Froth in the milk in the milk meter flask*

A layer of froth (2 - 5 mm) was usually present on top of the milk in the milk meter flask with both the NuPulse and Conventional Pulse. During the 8th month of lactation larger volumes of froth were noted in the flasks of the meters connected to the NuPulse. To quantify the observation, the amount of froth was recorded in the same manner as milk yield, at consecutive am + pm milkings and at another am milking. The volume of froth was expressed in litres and as a percentage of milk yield (Table 28).

The difference between the NuPulse and Conventional Pulse in the amount of froth recorded in the meter flask was highly significant ($P < 0.001$).

A paired t test was used as the test statistic.

Table 28: The volume of froth measured in the milk meter flasks (Yield of froth: ℓ.)

Twin Set No	Conventional Pulse	NuPulse
1	0.5	1.5
2	0.5	1.75
3	1.0	1.88
4	0.88	3.75
6	1.0	2.0
7	0.63	2.63
8	0.74	2.25
9	0.38	2.75
10	0.50	3.13
Mean froth level	0.68 (ℓ)	2.40 (ℓ)
Difference	1.7ℓ ***	
Mean milk yield	3.40 ℓ	4.08 ℓ
Froth yield, expressed as a percentage of milk yield,	20%	58.8%

The amount of froth associated with the NuPulse appeared to decrease during the 9th month of lactation.

3.2.1 (c) *Hand stripping yield*

The hand stripping yields obtained from each twin after automatic cup removal are given in Table 29.

The Conventional Pulse cluster although operating with the light NuPulse claw, weighed 0.1 kg more than the NuPulse cluster in the milking position (Appendix II).

Table 29: The mean values of hand stripping yields obtained after automatic cup removal (ml)

Twin set no.	Conventional Pulse	NuPulse
1	11.5	9.0
2	27.6	9.0
3	5.0	5.0
4	32.5	15.0
6	35.7	27.0
7	6.5	30.0
8	22.7	38.6
9	6.0	9.5
10	52.3	19.0
Mean	0.022 ℓ	0.018 ℓ
Mean milk yield	3.10 ℓ	3.73 ℓ

3.2.1 (d) *Calibration of the milk meter*

The yield (in litres) estimated by the milk meter, agreed closely with the weight of milk collected in the receiver, for both the NuPulse and Conventional Pulse clusters (Table 30).

Since 1 kg of milk at 6 percent fat and 20°C equals 0.9709 litres, it appears that the two meters have over-estimated the true milk volume by about 2 percent.

Because the milk weight to milk volume ratio was so close to 1 with both the NuPulse and Conventional Pulse, the milk volume indicated by the meter was assumed to be equal to the milk weight with no correction for specific gravity (SG).

(Without the correction for SG and the 2 percent over estimate of volume, the assumed weight is about 1 percent less than the true weight.)

The fat and protein concentrations were multiplied by the assumed weight to give the fat and protein yields in kgs.

Therefore the milk yield shown in Fig 11b is likely to be about 2 percent higher than the true milk yield because the milk meter estimate was too high.

Because the yield was not adjusted and no corrections were made for SG the fat and protein yields, given in kgs in Fig 11b are probably about 1 percent too low.
As the errors do not effect the comparison between the twins in a pair no adjustments were made.

Table 30: Values recorded during the calibration of the two milk meters.

NuPulse			Conventional Pulse		
Test cow number	Receiver milk weight	Meter reading	Test cow number	Receiver milk weight	Meter reading
	g	ml		g	ml
8	3 397	3 350	6	3 230	3 250
127	4 365	4 300	21	3 395	3 500
104	7 385	7 500	30	3 213	3 200
109	8 143	8 000	57	2 775	2 620
2	1 324	1 250	15	8 443	8 250
54	2 650	2 670			
	27 264	27 070		21 056	20 820
$\bar{X}$	4 544	4 512		4 211	4 164

Mean* Ratio = $\frac{\text{Milk Wgt}}{\text{Meter Vol}}$ 1.007 Mean Ratio = 1.011

Note that, if the meters had estimated the true yield, the mean ratio * would have been closer to 1.03 (the SG at 6 percent fat and 20°C).

3.2.2 Cow health factors

(a) *Teat condition and teat spraying*

The teat orifice diameter was scored after automatic cup removal using a 0 - 4 scale. The average score per cow for the last month of lactation is presented in Table 31 and the group averages during the lactation in Table 32.

Table 31: The average teat orifice score and the number of teat canal eversions for the individual twin sets during the last month of lactation

	Conventional Pulse		NuPulse	
Twin set no.	Score	Teats with eversions	Score	Teats with eversions
1	0.5		8.0	
2	6.0	1	4.0	
3	6.0		6.5	
4	6.0	4	6.0	2
6	5.0		6.0	
7	6.5		6.0	
8	6.0	4	6.0	4
9	6.0	4	6.0	4
10	12.0		11.0	
$\bar{X}$	54.0		57.5	

Table 32: The average teat orifice score and the number of teats with white tissue around the orifice in the NuPulse and Conventional Pulse groups (n = 9 twins in each group)

	Conventional Pulse		NuPulse	
Month of lactation	Score	White tissue rings	Score	White tissue rings
1	43	36	37	33
4	69	36	70	36
5	54	36	56	36
7	39	36	36	36
8	47	32	50	38
9	54	36	57.5	36
Total	306	212	306.5	215

The results in Tables 31 and 32 indicate that the teat end condition for the NuPulse group was similar to that recorded for the Conventional Pulse group.

On seven occasions during lacation the teats of the trial cows were examined for the presence of skin sores and cracks. The results (Fig 13) show that, at the start of the experiment the cows in the Conventional Pulse group had twice as many teats with cuts and sores as the cows in the NuPulse group. Most of the cuts and sores were noted at the first milking and seem to have been caused by calf bites sustained during suckling, before machine milking. Until teat spraying was first used (Fig 13) the injured teats were treated with an iodine grease. However after 3.5 months of lactation the 8 teats with cracks and sores in the Conventional Pulse group (Fig 13) involved 5 cows, whereas the 4 teats recorded for the NuPulse group involved only 2 cows.

To reduce the possibility that the difference in the number of teat sores between the two groups might bias the mastitis comparison, all the teats were treated for 56 days with the teat spray mixture. The teat spray was associated with a reduction in the number of cuts and sores to a reasonably static level (Fig 13).
The teats of the trial cows were not sprayed again until a week before the milk samples were taken for the diagnosis of infection carried out one month before the end of lactation (Refer to Section 3.1.6d). The teat injury status was also recorded for the non-trial cows 6 times during the lactation (Fig 12) and the data has been included to give an overall indication of the milking environment and the possible level of cross infection between the trial cows and the non trial cows.

3.2.2 (b) *The incidence of clinical mastitis*

Table 33: The cases of clinical mastitis observed by the milkers and treated with intramammary antibiotics

NuPulse (N)		Conventional Pulse (C)	
Twin No		Twin No	
8 (N)	2nd month (LR)		
10 (N)	2nd month (RF)	10 (C)	7th month (RR)
	5th month (RF)		

(RR) and RF) = right rear and front quarters; (LR) = left rear quarter

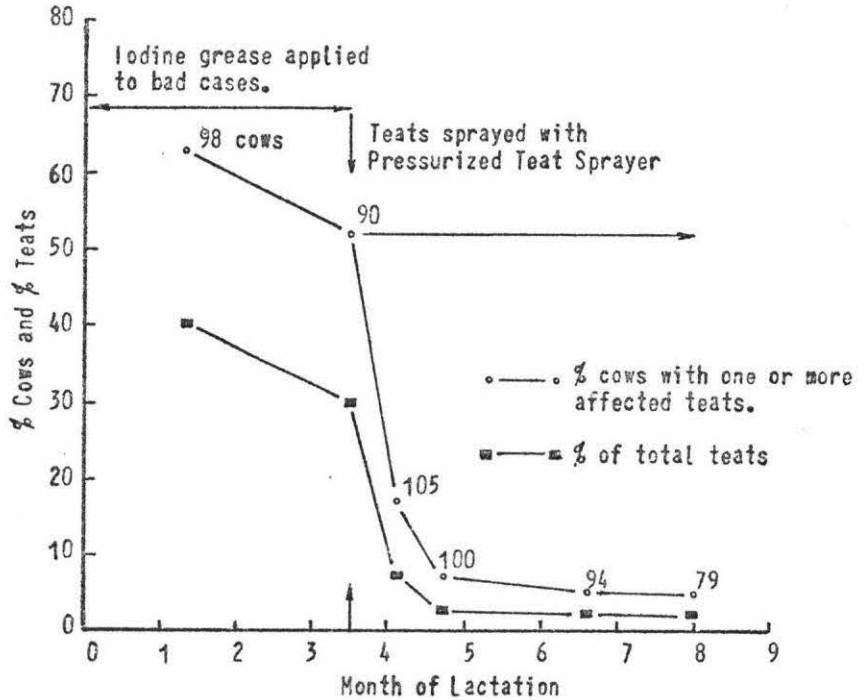


Figure 12 The % of cows in the herd with teat sores and/or teat skin cracks. (Trial and non trial cows).

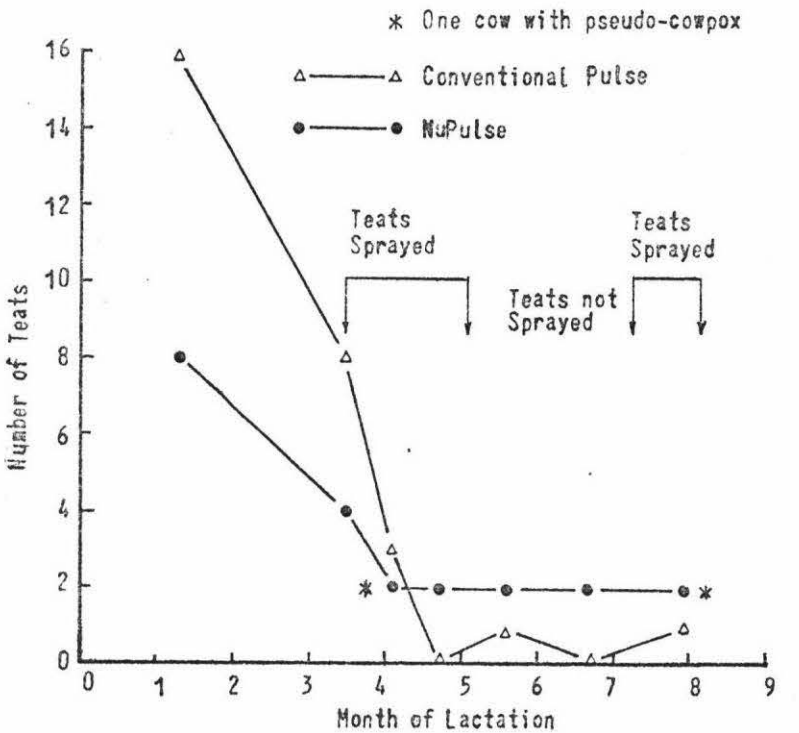


Figure 13 The number of teats with sores and/or teat skin cracks. (Trial cows)

3.2.2. (c) *The infection status near the end of lactation*

Only two cows were found to be infected at the time the samples were taken.

Staphylococcus auerus was isolated from the left rear (LR) quarter of cow 3N and the LR quarter of cow 8N.

An infection free diagnosis was obtained for cows 10N and 10C and this probably indicates that the intramammary antibiotics administered by the milkers was effective in controlling the cause of the clinical mastitis. The somatic cell count for cows 10N and 10C at the time the samples were taken was less than 120,000 per ml.

3.2.2 (d) *Somatic cell count*

The average cell counts obtained for the infected quarters are given in Table 34.

Table 34: The mean somatic cell count for the quarters of the cows found to be infected during the lactation (Mean and standard error).

Twin No	Infected quarter	Average for 3 uninfected quarters	4 quarter average
3N*	2735 ± 1036 (LR)	196 ± 36	830 ± 244
8N*	2530 ± 813 (LR)	133 ± 14	732 ± 205
10N	2369 ± 1422 (RF)	83 ± 8	654 ± 355
10C	148 ± 46 (RR)	120 ± 17	127 ± 26

* Refer to Figs 16 and 17

The fluctuation in somatic cell count for cow 3N and 8N during the lactation is shown in Figs 16 and 17.

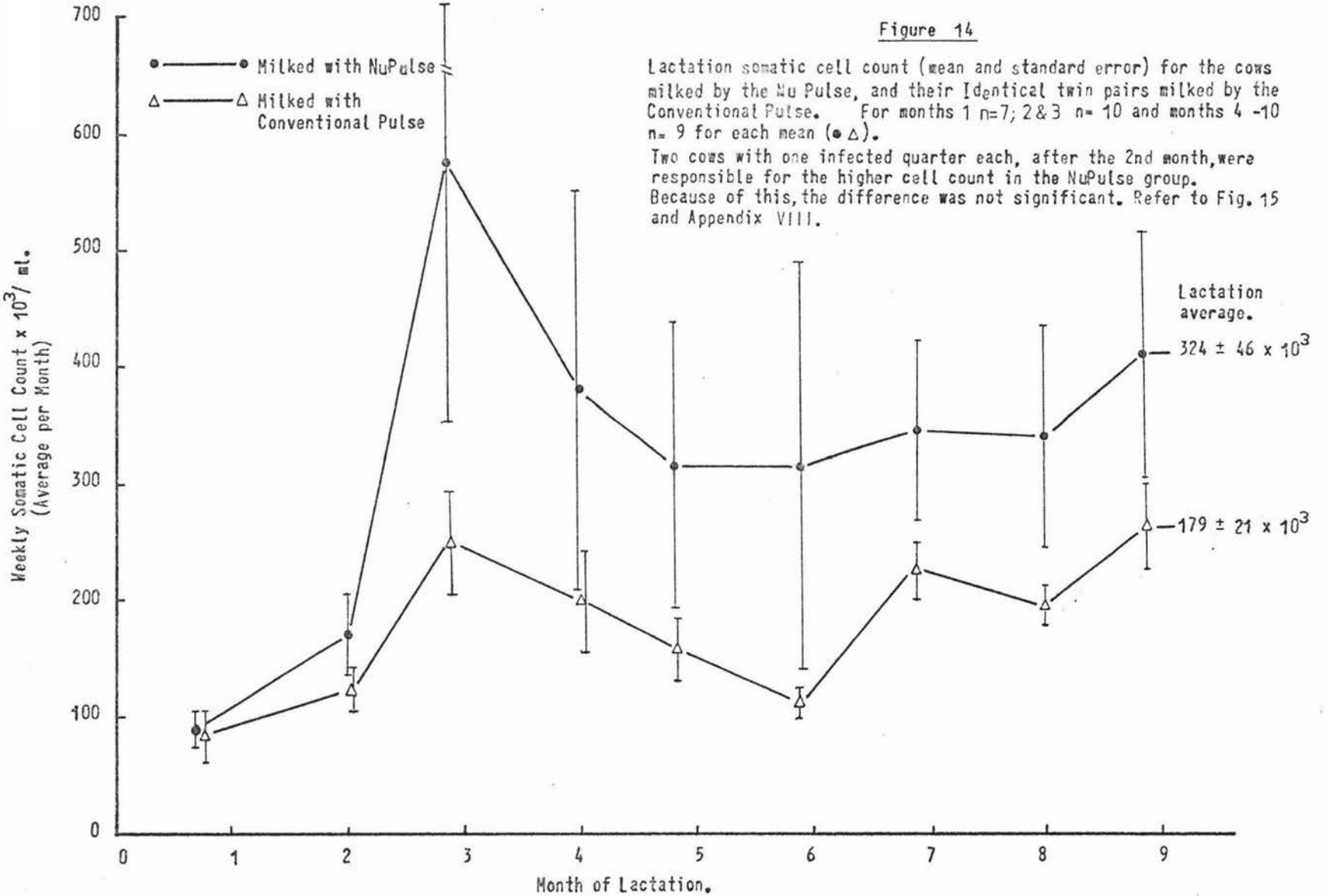


Figure 14

Lactation somatic cell count (mean and standard error) for the cows milked by the Nu Pulse, and their Identical twin pairs milked by the Conventional Pulse. For months 1 n=7; 2&3 n= 10 and months 4 -10 n= 9 for each mean (● △).

Two cows with one infected quarter each, after the 2nd month, were responsible for the higher cell count in the NuPulse group. Because of this, the difference was not significant. Refer to Fig. 15 and Appendix VIII.

Figure 15

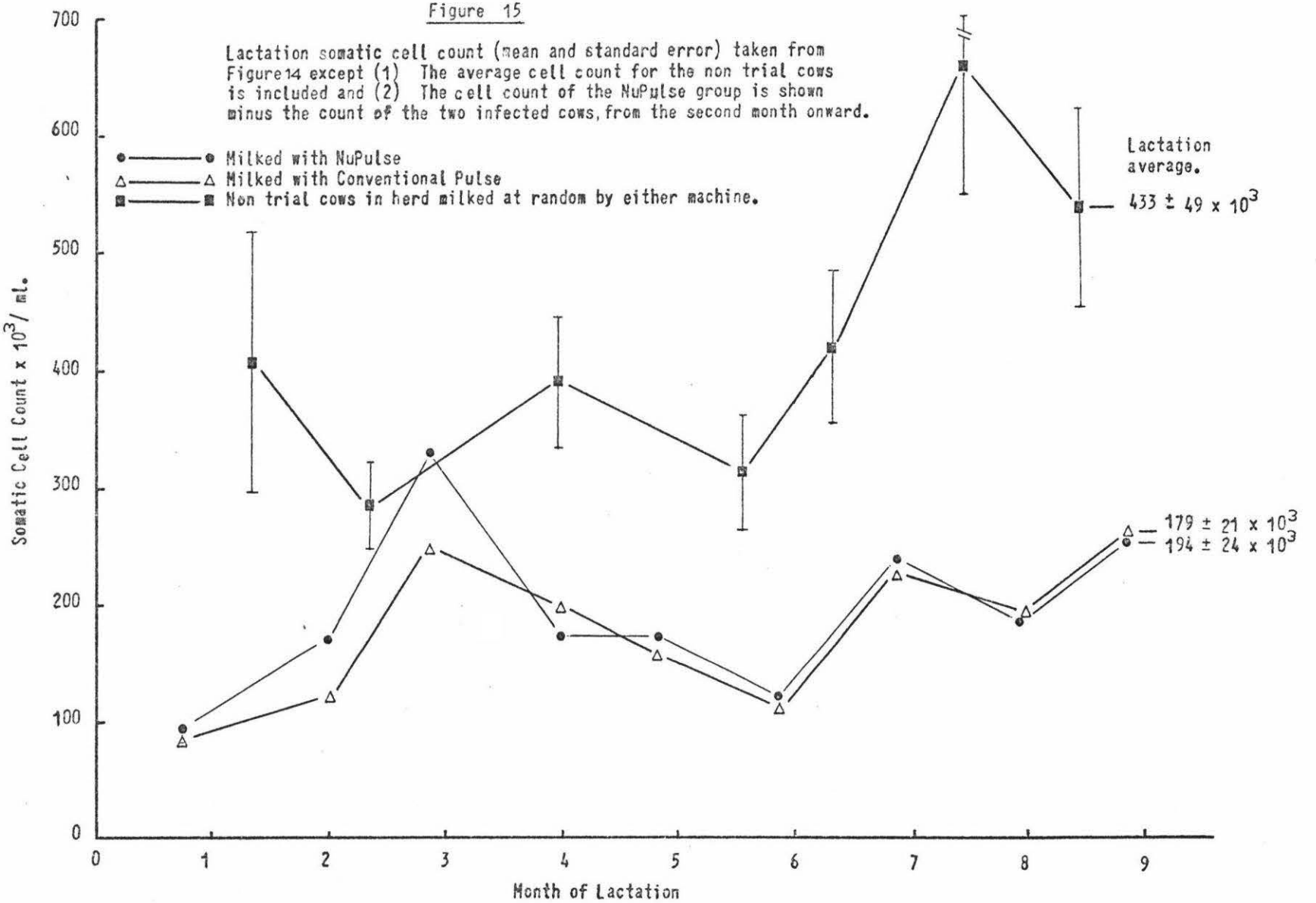

Lactation somatic cell count (mean and standard error) taken from Figure14 except (1) The average cell count for the non trial cows is included and (2) The cell count of the NuPulse group is shown minus the count of the two infected cows, from the second month onward.
Milked with NuPulse
Milked with Conventional Pulse
Non trial cows in herd milked at random by either machine.
Lactation average.
433 ± 49 x 10^3
179 ± 21 x 10^3
194 ± 24 x 10^3
Somatic Cell Count x 10^3/ ml.
Month of Lactation
0
100
200
300
400
500
600
700
1
2
3
4
5
6
7
8
9

Figure 16

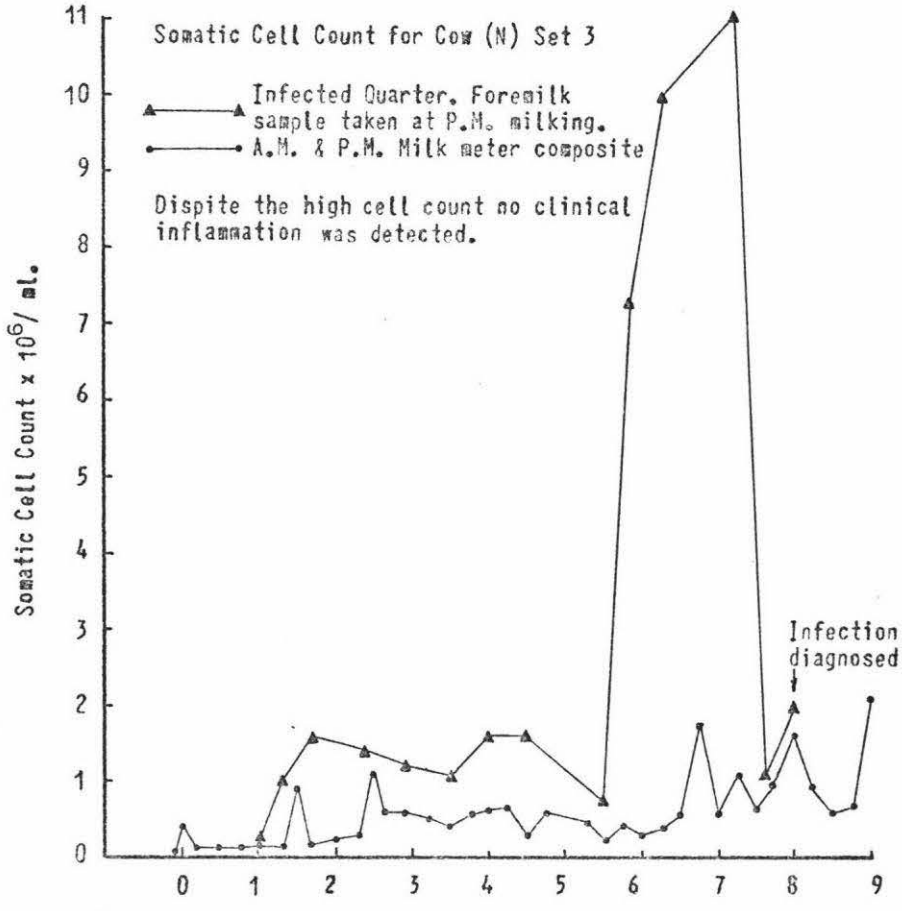
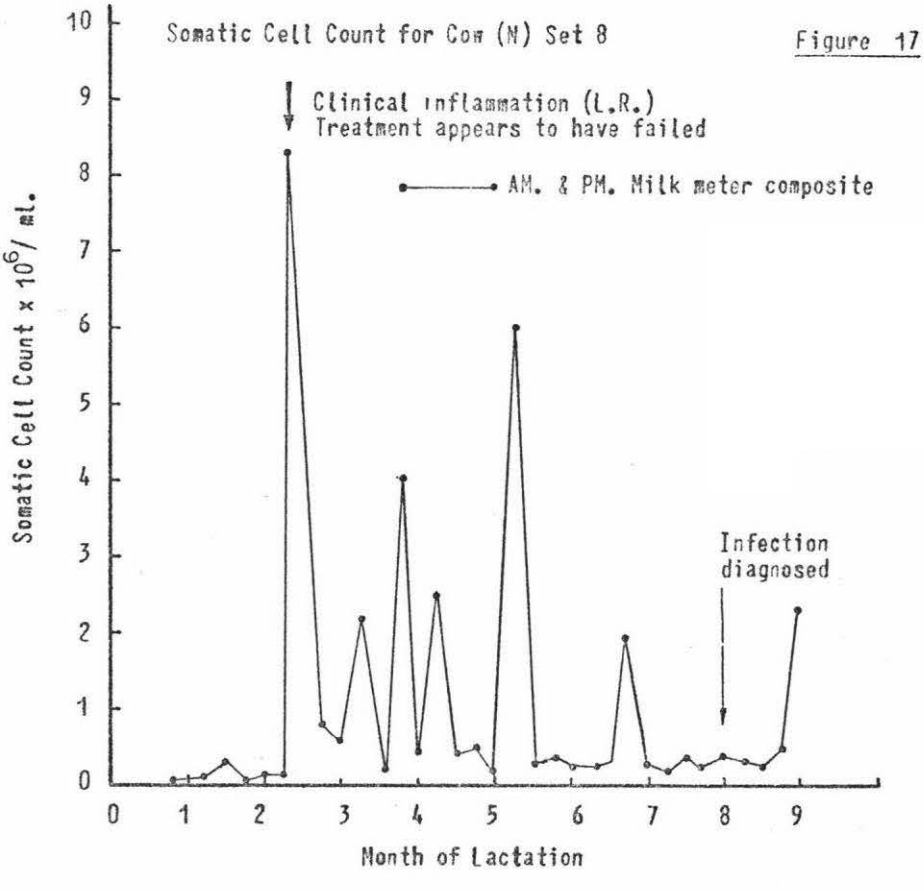


Figure 17



The weekly somatic cell counts obtained for the two treatment groups have been presented as monthly averages in Fig 14.
The average count for the whole lactation for 9 twin pairs (Appendix VIII) was subjected to an analysis of variance (Snedecor and Cochran, 1967) without log transformation. The difference was not significant ($P > 0.1$).

Two cows, 3N and 8N with a high cell count in one quarter were responsible for the higher cell count and standard error exhibited by the NuPulse group. To illustrate the effect that the two infected quarters had on the average cell count for the NuPulse group, the average was recalculated after the exclusion of the count obtained for cows, 3N and 8N and is shown in Fig 15.
The individual quarter cell counts for cows 3N and 8N (Table 34) show that the average count for the 3 low count quarters was similar to the group average shown in Fig 14.
For cow 3N (Fig 16) 30 percent of the composite counts after the 2nd month were below 500,000 per ml despite the fact that one quarter had extremely high counts over the same period. For cow 8N (Fig 17) 50 percent of the counts were below 500,000 per ml.

The average cell counts for the individual quarter, foremilk samples obtained during the lactation are given in Appendix IX. The individual cow comparison of the foremilk average and the composite average indicated that for the uninfected cows (excludes cows 3N, 8N and 10N) the average foremilk cell count was 20 percent lower ($P < 0.001$; by paired t test) than the composite milk cell count.

The accuracy of the Massey Coulter counter was compared with the National Dairy Laboratory (NDL) Coulter counter by measuring the number of cells in preserved milk samples, with both machines on two occasions.
The duplicate counts were expressed as a Massey to NDL count ratio.
The first comparison made with 8 samples at the start of the experiment gave a mean ratio of 0.9.
A mean ratio of 0.85 was obtained from 18 samples compared during the 8th month of lactation. The similarity between the count from the

two machines was tested by ratio analysis (Duirs and Cox, 1977). The values obtained during the 2nd test and the ratio analysis used to compare the deviation from a ratio of 1 is given in Appendix X. The ratio difference, (1 - 0.9) calculated for the first comparison was not significant at P = 0.5.
However the 2nd test indicated that the counts obtained with the Massey Coulter would need to be increased by 13 percent (at P = 0.5) to be similar with the NDL Coulter estimate.

3.2.2 (e) *The incidence of clinical mastitis and the somatic cell count for the non trial cows*

The somatic cell count and the incidence of the first case of clinical mastitis for each cow was recorded.
During the first 3 months of lactation 9 cows were treated for their first case of clinical mastitis for the lactation. A repeat of the inflammation in the same quarter was not considered as a new case of clinical mastitis.
During the 8th and 9th month of lactation the milkers detected and treated two more cows for their first case of clinical mastitis.
During the lactation 4 - 14 percent of the non trial cows had a somatic cell count greater than 1 million per ml (Table 35). The average count for each month is shown in Fig. 15.

Table 35: The somatic cell count distribution for the non trial cows

Month of lactation	> 300,000/ml	> 1 million/ml	Number of cows (n)
2	28% of n	11% of n	63
3	32	4	76
4	30	14	72
6	28	6	70
7	36	7	66
8	48	14	63
9	58	10	62
$\bar{x}$	37%	9%	67

3.2.3 Measurements made during the 2nd lactation

Starting at the first milking of the second lactation the trial cows were again milked by their respective treatment machines, until the trial ended (Table 36).

Foremilk samples were taken (using the method described in Appendix V) to determine if the infection status had changed during the dry period.

Table 36: Second lactation length, somatic cell count and milk yield

Set No	Wks of 2nd lactation	Mean somatic cell count x 10^3/ml	Weekly milk yield (ℓ)	Fat concentration	Protein
1 N	1	-			
C	7	379			
2 N	7	208	9.7	4.69	3.75
C	9	179	8.6	5.37	3.90
3 N	10	530			
C	2	813			
4 N	9	350	13.4	4.61	3.47
C	8	479	13.4	4.84	3.56
6 N					
C	Not in calf				
7 N	4	555			
C	7	154			
8 N	5	278	10.2	5.78	3.75
C	6	248	11.0	4.76	3.71
9 N	11	171	10.9	6.00	3.64
C	11	203	10.5	5.68	3.70
10 N	11	265	15.7	4.90	3.69
C	11	254	13.7	5.17	3.67
NuPulse	43 Mean =	336.7	= 11.98	= 5.20	= 3.66
Con. Pulse	45 Mean =	332.9	= 11.44	= 5.16	= 3.71

3.2.3 (a) *The infection status after the dry period and at the start of the 2nd lactation*

Staphylococcus aureus was isolated from the infected quarter of cow 3N before the end of the first lactation (Section 3.2.2 (c)) and again after the dry period.
Micrococci and *C. bovis* were isolated from the LR and RF quarters respectively of cow 3C. The 4 quarter composite cell count for cow 3C was 1.17 million/ml at the last test of the experiment.
Cow 8N was diagnosed to be free of infection after calving but had a composite cell count of 1.9 million at the last test. During the first month of lactation cow 10C was treated for clinical mastitis in the right front quarter. The 4 quarter composite cell count during the first month averaged 610,000/ml.

3.2.3 (b) *Somatic cell count and milk production*

For the 5 twin pairs with similar calving dates (Table 36) the average values for milk yield and fat and protein concentration and cell count were similar.
Both the cows in Set 9 contracted an infection of the reproductive tract after calving and because of a steady loss in condition and health, both cows were dried off after the 12th week of lactation.

Only 7 twin pairs were left after the loss of the cows in Set 9 and because the cows in sets 1 and 3 had different calving dates, it was decided to end the trial.

3.2.3 (c) *Teat end photographs*

Three weeks before the trial ended the twins in sets, 2, 4, 8, 9 and 10 were used to make a photographic comparison of the teat end condition. The photographs, taken of the teats on the same side of the udder for both cows in a pair, showed little difference in teat orifice condition and have not been presented. The teat orific of the LR quarter of cow 8N (Fig 17) appeared to be inflamed and was the only exception.

3.2.4 The herd milking rate and milking efficiency

The non trial cows were milked at random by any one of the 4 NuPulse or 4 Conventional Pulse clusters.
A check was made to determine if the non trial cows were milked as many times by the NuPulse as they were by the Conventional Pulse during the 6 milkings.
Only 40 cows were present at all 6 milkings. Table 37 shows the number of times each cow was milked by either the NuPulse or Conventional Pulse

Table 37: The number of times the non trial cows were milked by the NuPulse or Conventional Pulse at the A, B & C recordings

No. times milked by the Nu Pulse	0	1	2	3	4	5	6
No. times milked by the Con. Pulse	6	5	4	3	2	1	0
No. of cows	-	2	8	16	12	2	-

A mean ratio, of the number of times a cow was milked by the NuPulse to the number of milkings was calculated for all the cows that were present at more than two of the A, B and C milking recordings. The ratio indicated that on average each cow was milked at 49 percent of the milkings by the NuPulse or at 51 percent of the milkings by the Conventional Pulse. The normal shape of the frequency distribution shown in Table 37 suggests that the cows showed no real preference for either one of the treatment machines.

3.2.4 (a) *The preliminary milking recording*

The information obtained during the preliminary recording indicated that the milk flow sensing device in the automatic cup removers was not operating properly. The teatcups were being removed automatically before the true end of milk flow and causing high stripping yields, especially from the rear quarters. The teatcups were removed too early from 13 out of 36 cows milked by the NuPulse and 2 out of 39 milked by the Conventional Pulse.

To improve the performance, the manufacturer's (Appendix II) latest milk flow rate sensor was installed in the existing cup removal device. The drain hole in the new sensor was reduced in diameter so that the end point of milking occurred at about 0.15 litres per min. instead of 0.3 ℓ/min.

The change to the smaller drain hole effectively reduced the hind-quarter stripping yields. Nine out of 36 cows had to be remilked (or machine stripped) after the teatcups were removed automatically when the Conventional Pulse was used with the large diameter hole in the sensor. Only 2 out of 40 were machine stripped when the new sensor and the small drain hole was installed. With the new sensor, only 3 out of 40 cows, milked by the NuPulse required machine stripping.

3.2.4 (b) *Milk yield*

At the A and B recordings, the difference in daily milk yields between the NuPulse and Conventional Pulse trial cows was not significantly different.

However, the difference in daily milk yield that developed between the two groups of trial cows (Fig 11b) after the 4th month of lactation was reflected in the milk yields obtained at the C recordings.

The difference in daily milk yield between the NuPulse and Conventional Pulse groups was significant ($P < 0.05$) by paired t test.

When the trial and non trial cow data was combined (Table 39) a similar trend was noted.

At the C recordings higher yields were obtained from the cows milked by the NuPulse.

The difference at the PM milking was not significant ($P > 0.1$) but was significant ($P < 0.05$) at the AM milking (Appendix XI).

Table 38: The mean values obtained for the trial cows at the A, B and C milking rate recordings.

		Yield	% Yield at 2 mins	Time before first 0.5ℓ	Average milking rate	Twin pairs
		ℓ	%	s	ℓ /min	n =
NuPulse	A	3.47	50	56	0.71	9
PM	B	3.64	38	75	0.84	8
	C	3.17	70	53	0.99	6
	$\bar{x}$	3.43	53	61	0.84	
Conventional Pulse	A	4.24	46	49	0.71	9
PM	B	4.39	43	73	0.92	8
	C	2.73	77	53	0.80	6
	$\bar{x}$	3.79	55	58	0.81	
NuPulse	A	4.54	40	61	0.87	9
AM	B	6.26	36	42	1.00	9
	C	4.50	55	42	1.08	9
	$\bar{x}$	5.10	44	48	0.98	
Conventional Pulse	A	4.63	43	53	0.80	9
AM	B	5.90	45	37	1.03	9
	C	3.61	58	55	0.82	9
	$\bar{x}$	4.71	49	48	0.88	

Table 39: The mean values obtained at the A, B and C milking rate recordings. Trial and non trial cow data combined. (The non trial cows milked at random by either the NuPulse or Conventional Pulse machine).

		Yield	% Yield at 2 mins	Time before first 0.5 ℓ	Average milking rate	No. cow
		ℓ	%	s	ℓ/min	n
NuPulse	A	4.89	40	47	0.96	42
PM	B	4.64	40	64	0.88	40
	C	3.45	54	56	0.83	39
Mean	$\bar{x}$	4.33	45	56	0.89	
Conventional Pulse	A	4.83	45	50	0.80	41
PM	B	4.73	40	67	0.81	41
	C	2.90	56	68	0.66	41
	$\bar{x}$	4.19	47	62	0.76	
NuPulse	A	6.31	34	47	0.95	40
AM	B	7.19	32	45	1.06	45
	C	5.26	47	42	1.11	40
	$\bar{x}$	6.24	38	45	1.04	
Conventional Pulse	A	6.26	40	42	1.05	43
AM	B	6.68	36	43	0.92	44
	C	4.26	47	59	0.82	43
	$\bar{x}$	5.73	41	48	0.93	

3.2.4 (c) *The commencement of milk flow*

The time between the last cup being put on and the first half litre of milk being recorded in the milk meter flask was used to represent the time for each cow to commence milking.
The milk yield was recorded every 30 s and on those occasions when the first volume of milk recorded was greater than 0.5 litres, the time was calculated back to the nearest 15 s by interpolation.

No real difference in the commencement of milk flow occurred between the two groups of trial cows (Table 38 and Appendix XII).
However with the addition of the times obtained for the randomly milked non trial cows (Table 39; Appendix XIII) a significant difference was noted ($P < 0.05$) between the two groups at the C recordings. A pooled variance (unequal group size) t test was used as the test statistic (Snedecor and Cochran, 1967).
The mean difference between the two groups at the (C) am milking was 17 s, or a 40 percent longer time for the Conventional Pulse.
A difference of 18 s would have been required to achieve a significant level of ($P < 0.01$).

3.2.4 (d) *The total milking time and average milking rate*

The total milking time was the time taken from the last cup on until automatic teatcup removal occurred.
The milkings that occurred without premature automatic cup removal or cluster fall-off, were used to calculate the total milking time and the average milking rates.

The milk flow rate during the first two min. period of milking was calculated by dividing the yield recorded at the two minute stage by the time calculated as follows (2 mins. minus the time before the first 0.5 litre of milk was recorded).
The milk flow rate calculated by this method overestimates the true maximum flow rate because the first half litre of milk was not deducted from the milk yield recorded at the two minute stage.
The milking rates for the trial and non trial cows have been combined and presented in Table 40.

Table 40: The rate of milking for the trial and non trial cows combined before two minutes and after two minutes of milking. The average values measured at the A, B, and C recordings (litres/min).

		NuPulse	Conventional Pulse
Milking rate	PM	1.76	1.95
before 2 mins	AM	1.83	1.92
	$\bar{x}$	1.80	1.94
Milking rate	PM	0.85	0.65
after 2 mins	AM	0.98	0.83
	$\bar{x}$	0.92	0.74

The Conventional Pulse average milking rate before two minutes was 8 percent faster than the NuPulse. However after 2 minutes the NuPulse milked on average, 24 percent faster than the Conventional Pulse. The values obtained at each milking recording are given in Appendix XIV.

The average milking rates for the trial cows before and after two minutes of milking (Table 41) are similar to those obtained for the combined trial-non trial cow analysis with the exception that the difference in milking rates between the two treatment groups at the A, B and C milkings was not so consistent (Appendix XV).

The total milking time is affected by the delay in the commencement of milk flow, the milk yield, and the flow rate at the beginning and end of milking.
At milk yields of 6.2 - 7.2 litres (Table 39) it appears that the total milking time of the two machines is similar because the higher flow rate of the Conventional Pulse during the early stage of milking is off-set by the higher flow rate of the NuPulse towards the end of milking. The difference between the two machines in total milking time appears to change with milk yield and the length of the peak flow rate period.

Table 41: The rate of milking for the trial cows before and after two minutes of milking. The average values measured at the A, B and C recordings (litres/min).

		NuPulse	Conventional Pulse
Milking rate	PM	1.79	1.96
before 2 mins	AM	1.83	1.86
	$\bar{x}$	1.81	$\bar{x}$ 1.91
Milking rate	PM	0.79	0.65
after 2 mins	AM	0.95	0.77
	$\bar{x}$	0.87	$\bar{x}$ 0.71

After the two minute period the NuPulse milked, on average 18 percent faster than the Conventional Pulse at the AM milkings, the difference increasing to 31 percent at the lower yield PM milkings (Appendix XIV). A regression of time on yield was used to calculate the average milking rate for the NuPulse and Conventional Pulse from the 6 milking recordings. The two regression lines were compared by covariance analysis (Snedecor and Cochran, 1967; Appendix XVI). The difference in slope between the two regression lines (Appendix XVII) was not significant ($P > 0.1$) and the difference between the mean milking time for the NuPulse and Conventional Pulse was not significant ($P > 0.05$). The higher average milking rate shown for the NuPulse group at the C recordings (Table 39) appears to have been caused in part by the quicker commencement of milk flow.

Correlation coefficients (r), between time and yield of 0.90 and 0.92 were obtained for the Conventional Pulse and NuPulse respectively. The difference between the milking rate regression lines calculated for the trial cows was not significant ($P > 0.1$; Appendix XVIII). Correlations (r) of 0.88 and 0.83 between time and yield ($P < 0.05$) were calculated for the Conventional Pulse and NuPulse trial cows respectively.

3.2.4 (e) *The operation of the automatic teatcup remover at the A B and C recordings*

Despite the modifications made to the milk flow sensing device after the preliminary milking recording (section 3.2.4 a) the teatcup remover appeared to operate less successfully with the NuPulse than with the Conventional Pulse. During the peak flow period of milking, 18 premature removals occurred at the 254 milkings made with the NuPulse. Only 5 premature removals occurred at the 258 milkings made with the Conventional Pulse.

Premature removals before the end of the low flow period were also higher with the NuPulse (Table 42).

The NuPulse was more sensitive to faults associated with the float in the sensing device (factors 3 and 4 in Table 42).

The remainder of the unsuccessful removals with the NuPulse and Conventional Pulse were caused by the more randomly occurring factors, 5 - 8 shown in Table 42.

Table 42: The success rate of automatic cup removal (ACR) during the A, B and C recordings.

Factor		NuPulse No	Conventional Pulse No
	Total Milkings	254	258
1.	Premature automatic removal during the peak flow	18	5
2	Premature automatic removal during the low flow period	6	3
3	Faulty floats (with water leaked into the interior)	6	0
4	Milk flow too low to lift the float and allow tripping of the lever onto automatic	6	3
5	Stripping weights added so ACR not used	3	3
6	Milkers forgot to trip the lever onto automatic	5	2
7	Blocked drain hole in the sensor	5	9
8	Cups kicked off or fell off	7	4
		56	29
	Percent, successful automatic removals	78%	89%

3.2.5 Mechanical aspects

(a) *Milking plant maintenance*

A MacEwans testron controller (MacEwans Machinery, Hamilton, NZ) was used as the master pulsator controller to the 4 conventional bail pulsators for the first 100 days of lactation.
The pulsation chamber (PC) pressure changes were recorded by the Ruakura vacuum recorder, with the liners left unplugged. The PC waveform is presented using the 4 phase (a,b,c,d) pulsation cycle described by Hall (1977b).
The average pulsation waveform (a,b,c,d) for the 4 Conventional Pulse units was 17 (± 4); 30 (± 3); 13 (± 2); 40 (± 1) at 50 cycles per minute.
The PM milking, at the (A) milking recording (Table 39) showed that with the above PC waveform the Conventional Pulse units milked at an average rate of 0.80 litres/min.
The average milking rate for the NuPulse at the same milking was 0.95 litres/min, a 20 percent faster rate.

One of the experimental objectives was to subject the trial cows in the NuPulse and Conventional Pulse groups to a similar total milking time. To increase the milking rate of the Conventional Pulse, the pulsation rate was increased to 54 - 55 per min. and the PC waveform changed to 15; 37 (± 1); 12 (± 1); 36 (± 2). The average milking rate at the A (AM) milking recording was 1.05 litres per min. for the Conventional Pulse and 0.95 litres per min. for the NuPulse (Table 39).

The pulsation waveform for the 4 NuPulse units was obtained with the units operating but with the vacuum to the liner shut-off by bending the short milk tube across the bevelled automatic cut-off inlets (Fig 4).
After the (A) milking recordings the pulsator mechanisms of the 4 NuPulse units used for the 1st month of lactation were replaced by the manufacturer with newer components incorporating minor modifications.
Halfway through the 3rd month of lactation the bobbin housing and the middle piece (Fig 4) were replaced for a 2nd and final time with Mark I model components. No further changes were made during the remaining trial period.

The pulsation rate of the NuPulse units used in the experiment was predetermined by the size of the stainless steel tube fitted into the diaphragm housing, as the pulsator rate adjuster (shown in Fig 4) was not used.
The mean pulsation rate and ratio of the NuPulse units is shown in Table 43.

Table 43: The pulsation characteristics of the NuPulse units used during the experiment.

Period	No of units	Pulsation rate /min	PC waveform (average ± range) a	b	c	d
1st month	2	48	21(± 1)	41(± 1)	15(± 1)	23(± 2)
	2	56	23(± 3)	48(± 2)	16(± 1)	13(± 2)
2nd month	2	52	18(± 0)	51(± 2)	18(± 0)	13(± 2)
	2	56				
3rd month	2	52	19(± 3)	51(± 5)	16(± 2)	14(± 4)
	2	56				

The MacEwans testron controller automatically switched-off (and required manual resetting) each time abnormal voltage fluctuations occurred in the power supply system during milking.
Because the unit was obsolete and could not be serviced the controller was replaced at the beginning of the 4th month by a vacuum operated master controller (NDA. Hamilton, NZ) described by Phillips (1958). Without changing the bail pulsators, the pulsation rate was set at 49 - 50 per minute and the mean PC waveform (with the liners left unplugged) set at 13 (± 2); 42(± 2); 11(± 1); 34(± 2). No further changes were made to the Conventional Pulse for the remaining period of the experiment.
Before the beginning of the 2nd Lactation a new (Waikato 170 Regulator (Appendix I) was installed as a vacuum drop greater than 2 kPa occurred when 15 litres/s of air was allowed to enter the plant. A new set of NDA No 1 petal inflations was fitted to each cluster before the start of the 2nd lactation.

3.2.5 (b) *Pulsator air consumption*

To measure the pulsator air consumption while the units were operating the liners of the 4 Conventional Pulse and 4 NuPulse units were plugged with rubber teats. The air flow per unit given in Table 44 is the 4 unit average.

Table 44: The NuPulse and Conventional Pulse air consumption per unit (in ℓ/minute of expanded air).

	Conventional Pulse*	NuPulse*
Pulsator Consumption	68 ℓ/min	38 ℓ/min
Claw air hole inlet	20 ℓ/min	

* Both machines were fitted with the NDA tapered cup shell

The NuPulse air consumption was first measured, with the 4 units operating with plugged liners, and then measured with the 4 units not operating. The pulsator spring was removed from the dome to stop the unit working. The difference in air flow, measured with the units operating and not operating is shown as pulsator consumption in Table 44.
The difference in air flow, measured with the Conventional Pulse master pulsator operating and not operating was 68 litres per min. The 4 Conventional Pulse bail pulsators the master and one signal reverser pulsator operated with an air flow rate of 68 ℓ/min.

3.2.5 (c) *Claw-piece breakages with the 4 NuPulse and 4 Conventional Pulse units*

The breakages shown in Table 45 occurred with 7 separate units during the 1st lactation and during the 3 months of the 2nd lactation.

Five times during the early stages of the experiment the bobbin housing, spring and diaphragm in the NuPulse were scattered about the dairy when the dome unscrewed from the middle piece after the cluster was kicked-off during milking.
The replacement middle piece added to the cluster during the 3rd

month of lactation (Section 3.2.5 (a)) incorporated an improved dome latching device that effectively reduced the problem.

Table 45: The number of breakages that occurred with polysulphone claw-piece.

	NuPulse	Conventional Pulse
Short milk tube inlets broken from the base (Fig 4).	2*	2
Broken cup hooks	1	1
Base piece broken from the middle piece	1	

* one with a broken cup hook as well as a broken short milk tube inlet.

3.2.5 (d) *Cluster cleaning*

The exterior of both the NuPulse and Conventional Pulse claw piece gradually accumulated dirt and had to be completely dismantled for exterior cleaning 3 times during the lactation. Discolouration used to occur on the outside area of the base ring seal.
The recycle and reverse flow cleaning system effectively cleaned the Conventional Pulse units. The modified jetter recycle cleaning system cleaned behind the liner and in the pulsation chamber of the NuPulse teatcups well enough to prevent any visual deposit.
The reverse flow cold water cleaning, used at the PM milkings was a failure with the NuPulse. The liners had to be pulled back off the teatcup shells to prevent water collecting in the pulsation chamber.
The reverse flow wash or flush technique is unsuitable with the NuPulse because milk residues are forced back up the small bobbin vacuumizing hole and onto the rubber diaphragm. The cloth air filters in the NuPulse were replaced every month with new ones.

4.0.0 DISCUSSION

(a) *Mechanical aspects and milking rate*

The breaks recorded in the polysulphone claw piece have isolated structural weak points that deserve further design attention.

The changes made to the NuPulse pulsators during the first 3 months of lactation are unlikely to have altered the treatment effect, as no departure from the principle of the Mark I pulsation system was made. The difference in pulsation rate and ratio between the 3 models was not any greater than the variation between the 4 units used at any one time.

The milking rates obtained in this experiment can be compared with the results of a milking rate study made at the Werribee milking research centre by Mein and Martin (1977).
Two of the treatments in a 6 x 6 latin-square experiment (6 treatments x 6 morning milkings x 6 groups of 4 cows) were made with a Mark I model NuPulse and a modified NuPulse, nearly identical to the Conventional Pulse used in this experiment.
The Conventional Pulse units used in the Werribee Trial operated with a 15 to 18 percent longer liner open time (a PC waveform of 20: 40: 25: 15: at 50 per min.) than the Conventional Pulse units used in this experiment and milked at an average peak flow rate of 1.93 kg/min.

The estimate of peak milk flow rate recorded in the present experiment (1.94 ℓ/min. for the Conventional Pulse and 1.80 ℓ/min, for the NuPulse) is probably higher than the true rate and cannot be compared directly with the Werribee results, as the method of calculation did not include the time taken to obtain the first 0.5 litres of milk.

The average peak flow rate recorded for the NuPulse units used in the Werribee experiment (1.67 kg/min) was 13.5 percent slower than the flow rate for Conventional Pulse units (1.93 kg/min.). The difference was significant ($P < 0.05$). The stripping yields, obtained after a flow rate of 0.3 kg/min were found to be similar for both the Conventional Pulse and NuPulse.
The NuPulse units used in the Werribee experiment were 8 percent slower than the Conventional Pulse in reaching the 0.3 kg/min end point of milking but the difference was not statistically significant ($P > 0.05$).

As in this experiment the NuPulse units used in the Werribee trial appeared to overcome the disadvantage of a slower peak flow rate, by milking quicker during the low flow period.
The Werribee results suggest that, the Conventional Pulse used in this experiment would have milked with a higher pre and post two minute milking rate if the liner open time had been increased and the squeeze time decreased.

Baxter *et al.* (1950) have shown that the difference in the peak flow rate between cows is caused mainly by variation in the bore of the teat canal. An increase in the streak canal diameter and the pressure difference acting across the teat canal have been shown to be associated with an increase in the milk flow rate from the teat (Mein *et al.*1973a; Reitsma and Scott, 1977). Reitsma and Scott (1978) have presented data to show that the teat canal diameter is likely to increase by 18 - 20 percent when the vacuum level is increased from 30 kPa to 50. They also predicted theoretically that milk flow would be reduced if teat expansion was reduced and that the radial stresses in the teat tissue decrease in a linear manner with decreasing vacuum.
Mein *et al.* (1973a) found that the teat canal reached a maximum diameter, when liner distension during the peak flow period was also at a maximum. The factors responsible for the lower flow rate of the NuPulse at the beginning of milking are probably related to the slowly applied vacuum and the short period of full vacuum, recorded in experiment 1 and the effect they both have on teat distension and teat canal diameter.

4.0.0 (b) *Cow health factors*

The method of teat scoring used in this experiment was the same as the method used by Woolford and Phillips (1978), as the writer (R.K.F.) had the opportunity to personally inspect the teat condition of the cows used in the Ruakura twin experiment.
Compared with the conventional machine, Woolford and Phillips (1978) found that the orifice condition of the cows milked by the single chambered teatcup (SVSC) was markedly superior. The group mean score for the SVSC was 7 times lower than the group mean score for

the conventional machine.
Woolford and Phillips (1978) were unable to detect any difference in teat size by either radiographs or physical measurement.
Jasper and Whittlestone (1977) found that the teat ends of cows milked with the single chambered (PME) teatcups were seldom affected by eversions and erosions, whereas eversions and slight erosions were common on the teat ends of cows milked with conventional teatcups.

In this experiment no significant difference in the teat end score developed between the NuPulse and Conventional Pulse groups of twins. The score for each individual teat hardly varied throughout the lactation except for the slight teat end eversions that developed with 3 twin sets; the effect was similar for both cows of the pair. The teat end photographs, taken just before the end of the experiment failed to illustrate any real difference in the teat orifice condition.
Woolford and Phillips (1978) thought that the eversions and erosions developed by the conventional machine were associated with the degree of periodic mechanical extension and retraction of the teat in a vertical plane during each pulsation cycle.

Balthazar and Scott (1977) thought that longitudinal stress was caused by vertical tension in the tissue when the teat elongated, and that longitudinal stress was probably not involved in the opening of the teat canal.
The absence of any real difference in teat end condition between the NuPulse and Conventional Pulse could imply that the longitudinal stress (rather than the radial stress or the force of the closing liner) needs to be reduced before any marked change occurs in the tissue surrounding the teat orifice.

Neave (1971) has shown that teat lesions are associated with higher infection rates because the lesions act as reservoirs to the spread of bacteria from cow to cow by the liners and milkers hands. The high level of teat lesions associated with the non trial cows during the first 4 months of lactation should have presented a real level of bacterial challenge to the trial cows.

During the 2nd and 4th months of lactation, 11 and 14 percent of the non trial cows had somatic cell counts greater than 1 million cells per ml.

Natzke *et al.* (1972) have estimated that a cow, with an average cell count during the lactation of about 700,000 cells per ml, is likely to have two infected quarters. Nine non trial cows received at least one course of antibiotic treatment for clinical mastitis during the 1st 3 months.

The challenge level over the early lactation period is emphasised because several studies have shown that more than half the lactation incidence of clinical mastitis occurs in the first 3 months (Guidry *et al.* 1976; Oliver *et al.* 1956).

After 3.5 months of lactation, teat spraying was introduced and was associated with a dramatic reduction in the number of teat lesions. Based on the work of Neave (1971) the reduction in teat lesions probably resulted in a reduction in the level of cross contamination between the trial cows and the non trial cows.

Teat spraying of the trial cows was discontinued once the difference in the number of teat lesions between the two groups of trial cows had been reduced. Since the lesions were related more to the pre-trial period than to the experimental treatment, the lesions were treated to prevent a possible experimental bias.

The accuracy of the diagnostic method used to select infection free cows is verified to some extent by the low cell counts obtained for the trial cows during the first month of lactation.

During the 2nd month of their lactation two NuPulse cows (8N and 10N) were treated for clinical mastitis in one quarter. Cow 10(N) had a relapse during the 5th month of lactation.

The cell count for cow 8(N) remained high during the 1st lactation. The high cell count quarter was found to be infected with *Staphylococcus aureus*.

During the 7th month of lactation cow 10(C) was also treated for clinical mastitis. The infection free diagnosis obtained for both the cows in set 10 at the end of lactation and after the dry period, probably indicates that the antibiotic therapy was successful.

Cow 10(C) developed clinical mastitis in a 2nd quarter during the 1st month of the 2nd lactation.

High cell counts were recorded for the NuPulse cow 3(N) about the 2nd month of lactation, the quarter cell count reaching levels of 10 -11 million per ml. during the 7th month of lactation. The high cell counts suggest that clinical symptoms probably occurred without detection by the milkers. The *Staphylococcus aureus* infection persisted through the dry period and into the 2nd lactation. However cow 3(C) was found to be infected in two quarters after the dry period. One quarter was infected with *micrococci* and a second with *C. bovis*.

During the 1st lactation the number of infected quarters in the NuPulse group was 8 percent of the total and 3 times higher than the one infected quarter in the Conventional Pulse group. Woolford and Phillips (1978) found that with cows milked by a conventional machine for a full lactation, 8 - 16 percent of quarters became clinically infected and 16 percent subclinically infected. Oliver *et al.* (1956) found that with 1st and 2nd lactation cows, 7 - 10 percent of quarters became infected clinically and 15 percent became infected subclinically for the first time. The marked difference in the infection rates between the NuPulse and Conventional Pulse groups during the first lactation appears to have been caused more by the low level of infection that occurred with the latter group rather than an abnormally high level in the NuPulse group.

However after the dry period and the early stage of the 2nd lactation the Conventional Pulse group included 4 infected, or previously infected quarters compared to the 3 in the NuPulse group.

Although an equal number of infections occurred in both treatment groups by the end of the trial(apparently in the more susceptible twin sets) the mastitis occurred earlier in the NuPulse group. Although the difference only involves a small number of infections, some discussion needs to be made about possible predisposing infection mechanisms.

However the lack of any spread of infection from the infected quarters to the other 3 uninfected quarters with the NuPulse cows equally suggests that no predisposing factor to cross infection exists.

Based on the present evidence it is not possible to say that the NuPulse is associated with any predisposing infection factor, but one characteristic that should be investigated further is the regular reverse flow of milk that occurs up the liner stem during each pulsation cycle.

The regular exchange of milk that occurs between the liners and across the claw bowl of the NuPulse can be demonstrated with transparent liners. The reverse flow towards the teat seems to occur as the liners open and as air enters the claw bowl. One way to overcome the reverse jet would be to partition the claw bowl into a quarter milker, if it can be shown that the reverse flow is a problem.

Tolle *et al*. (1970) have studied the occurrence of reverse flow between the teats in the conventional machine and its effect on mastitis.

They found that a medium amount of reverse flow as associated with less mastitis than correspondingly low and high levels of reverse flow between diagonal teat cups.

The hypothesis, that as the volume of milk involved in the reverse flow decreases there is an increase in the formation of smaller high velocity reverse jet particles called aerosols,was developed to explain the higher somatic cell counts that were associated with the low levels of reverse flow.

The aerosol infection mechanism is considered to operate in a similar way to the impact infection mechanism proposed by Thiel (1974). Another theory put forward to explain why a medium amount of reverse flow is associated with lower levels of mastitis, is that the operating vacuum is more stable and more damaging to the teat apex when no flooding occurs in the claw (Tolle *et al*. 1970).

While neither of these theories have been proven it is possible other mechanisms also operate. The washing or flushing away of

pathogenic bacteria from the liner surface might reach optimum levels with a medium amount of reverse flow, and result in low levels of bacterial challenge (Woolford *et al*. 1978).
If the NuPulse is modified to work as a quarter milker, the advantages of the washing or flushing effect could be lost and merely replaced with possible aerosol formation. To clarify the situation with the NuPulse further study is needed, especially before any large scale move is made to form the claw bowl into a quarter milker.

Liner slip has been shown to cause aerosols or impacts at the teat end and cause higher infection rates (O'Shea and O'Callaghan 1978). In this experiment an attempt was made to measure the rate of cup fall with the NuPulse and Conventional Pulse. However no difference in cup fall off was noted between the 2.3 kg NuPulse cluster and the 2.4 kg Conventional Pulse cluster during two 7 days period when cup fall-off was recorded.
During the experiment it was noted that the wide base of the NuPulse claw enabled the teatcups to be readily attached to mis-shaped udders.

With the use of a latin square layout and 24 cows, Mein and Martin (1977) compared the liner stability properties of the NuPulse cluster with a conventional cluster. Over 7 day treatment periods, the type and weight of cluster had no significant effect on milk yield, but there were significant differences ($P < 0.05$) in cup slip and fall. The 2 kg NuPulse cluster was found to slip and fall at a rate of 4/100 milkings and the 3 kg conventional cluster at a rate of 13/100 milkings.
The NuPulse fall and slip rate increased to 23/100 milkings when the cluster weight was increased to 3 kg.
The results indicated that the NuPulse is able to milk successfully at lower cluster wieghts than the conventional machine, and consequently operates with a lower incidence of cup slip and fall.

4.0.0 (c) *Frothing of milk*

The fat in the fat globules in milk is protected from the lipase enzyme, present in milk, by a membrane that surrounds each globule. The incorporation of air into milk can break the fat globule membrane and expose 'free fat' to the action of the milk and bacterial lipases.

Lipolysis occurs when the lipase acts on the free fat and releases fatty acids into the milk (Whittlestone, 1967). When milk is agitated by air, Tarassuk and Frankel (1955) have shown that milk foaming is a prerequisite to lipolysis.

Differences in the susceptibility of the milk of individual cows to lipolysis has been widely reported (Whittlestone, 1967), but to date the cause is unknown. Johnson and von Gunten (1962) (quoted by Whittlestone 1967) have shown that the amount of free fatty acid in milk, increases as yield decreases and tends to be higher in late lactation.

Jellema (1975) has put forward the hypothesis that changes in feed and low milk yields towards the end of lactation may induce changes in the physiological processes of milk synthesis and the production of an activator, which in turn may increase the susceptibility of milk fat to lipolysis. He also hypothesised that the secretion and presence of the activator in milk is controlled by hormone action. From indirect evidence Jellema (1975) has assumed that a secretion or leakage of an activator from the blood serum into the milk is responsible for the susceptibility differences between cows, and the change in the susceptibility of milk fat to lipolysis.

The NuPulse was associated with larger volumes of froth in the milk meter than the Conventional Pulse during the 8th month of lactation. The within twin pair comparison showed that the NuPulse was associated with 2.9 times more froth in the meters for a given milk volume. The development of the frothing difference during the 8th month of lactation could have been associated with the shortage of pasture, and the fact that silage was being fed at the time. Jellema (1975) found that lipolysis increased markedly, some weeks after a herd was fed grass silage of poor quality and low energy value.

Salvatierra *et al.* (1978) have reported that when froth is generated by the NuPulse, difficulties can be experienced in clearing the milk and froth from the receiver with centrifugal milk releaser pumps. While the comparison by Salvatierra *et al.* (1978) was not a strict one, and for this reason should be regarded as preliminary, it did indicate that the foam forming capability of the NuPulse was associated with increased fatty acid levels and more damage to the fat globule membranes.

The Flacco one line machine (with a pulsator connected to the clawpiece) was associated with higher levels of free fatty acids when it was operated in a highline machine. Tolle and Heeschen (1975) claimed that the additional volume of air entering the milk, via the pulsator, generated greater turbulence, and they thought that the increased lipolysis associated with the Flacco machine was caused by the physical treatment the milk incurred during turbulent flow.

De Vries and Jellema (1975) found that the lipolysis problem could be overcome with the Flacco machine, without separating the pulsator from the claw piece, if the air from the pulsator was taken via a separate line to the milk pipe.
An air bleed hole, admitting 2.1 ℓ/min of air was mounted in the claw piece to assure smooth, rather than turbulent flow to the milk pipe. To enable the NuPulse to operate successfully with, high lift machines, further development work should concentrate on reducing the air usage by the pulsator and slowing the admission of air into the claw bowl.

The estimate of pulsator air usage made during the static machine test, indicated that the NuPulse would probably admit 1.8 times more air into the milk during milking than the Conventional Pulse. The actual amount of air admitted into the milk with either machine would depend on the frequency of liner slip and cup fall off. Without considering the effects of such factors, Salvatierra *et al.* (1978) have shown that the amount of dissolved air in milk is about 2 times higher with the NuPulse than with a conventional machine.

They found that the average volume of dissolved air in 6 milk samples, taken after the receiver in a highline herringbone plant over a two week period, was 3.7 percent for NuPulse. The average volume of dissolved air, obtained when the conventional machine was used, during the next two week period, was 1.7 percent.

In this experiment, the milk in the meter flasks was not tested for dissolved air before the milk volume was recorded, but if it is assumed that the milk volume in the NuPulse flask contained two percent more air, then it is possible that the NuPulse yields could have been overestimated by 2 percent. However, excluding the froth also excludes the small amount of milk incorporated in the foam layer from being correctly recorded as milk yield.
If the NuPulse yields are reduced by 2 percent, the difference in fat and protein yields between the NuPulse and Conventional Pulse remains significant at ($P < 0.05$) and the difference in milk yield reduces in significance to just under ($P = 0.05$).

4.0.0 (d) *The accuracy of the milk meters*

The milk meters were capable of estimating the volume of milk to the nearest 25 ml and detecting a difference in milk yield greater than 2.5 percent.
The calibration of two milk meters indicated that the milk weight to milk volume ratio, for the NuPulse was not significantly different from the ratio obtained for the Conventional Pulse.
While the average difference in total milk yield between the two treatment groups was 8.2 percent, the average obscures the fact that the milk yields for both groups were similar during the first 4 months of lactation.
Over the last 3 months of lactation the NuPulse was associated with 11.6; 19; and 15.5 percent higher yields. With one twin set, the average difference in milk yield during one month was as high as 49.6 percent (Table 26).

It is unlikely that the milk meters were affected greatly by variation in milk yield, as the milk yields recorded from the 1st to the 4th month of lactation were similar to the daily yields

recorded during the months when the NuPulse group started to maintain higher production levels.

The method of reading the volume of milk in the milk meter flasks during the weekly samplings was more accurate than the method of reading during the A, B and C milking recordings.

At the A and B recordings, a small layer of froth occurred in the meters attached to both the Conventional Pulse and NuPulse and no real difference in the amount of froth was noted at that stage of lactation. Any error associated with reading the milk level below the froth layer in the flask, would have been associated with the results obtained with both the Conventional Pulse and NuPulse. However at the (C) recordings, the NuPulse was associated with larger volumes of froth, and because no cross checks were made to establish the error between the 4 observers, in reading the milk yield, the higher milk yields recorded for the NuPulse at the C recordings should be regarded as preliminary until the observation is repeated. The same criticism can be applied to the observation that indicated, that milk flow commenced sooner with the cows milked by the NuPulse at the C recordings.

The method used to read the milk yield at the weekly recordings was more precise and it was from these recordings that the lactation yields were estimated. By the time the reading was made the froth layer had dispersed and the milk fat layer had usually settled out. The milk meters were tested using a method that did not alter the actual milking machine treatments, but it does not guarantee the accuracy of any one meter when all, or only some of the clusters are milking.

Before further study or a repeat of this experiment is made, consideration should be given to the use of a more direct method of estimating milk yield.

A separate milk line and milk storage vat for each treatment group could be used to increase the experimental accuracy.

4.0.0 (e) *Milk production*

The number of full lactation trials conducted since 1956, to determine the effect of various stimulation methods on the production of identical twins have been reviewed in Section 1.3.0. The production differences obtained in the present experiment have a lot in common with the production increases attributed to manual stimulation during the early Ruakura trials (Phillips, 1978b) and to machine stimulation during milking in the more recent trials by Whittlestone (1978); Woolford and Phillips (1978).

Phillips (1960; 1965) found that the average stimulation time required to cause a let down, increased as lactation progressed and because the cow's requirement was usually low at the beginning of lactation, 1 - 2 months of lactation needed to pass before low stimulus levels became insufficient.
The twins that received no manual stimulation, showed a faster rate of decline in milk yield as lactation progressed, than their twin pairs stimulated adequately. The fat percent of the milk, for both the NuPulse and Conventional Pulse groups during the lactation did not differ greatly. Similar results were obtained by Phillips in the Ruakura trials.

The trial cows were underfed during the lactation and subjected to these conditions the NuPulse group maintained production at a higher level than the Conventional Pulse group, particularly when two periods of feed shortage occurred.
After the 4th month of lactation the yield of the Conventional Pulse group appeared to decline at a greater rate than the yield of the NuPulse group.
After two months of lactation the mean live weight for the trial cows was 240 kg. By the end of 6.5 months of lactation the mean live weight was 316 kg; the average for the NuPulse and Conventional Pulse groups was very similar. The live weight was obtained in retrospect from other trial work and was not available for the last 2.5 months of lactation.

The low stripping yields obtained from the trial cows, show that the automatic teatcup removers did not remove the cups too early and also suggest that the 2.4 kg Conventional Pulse cluster was able to obtain all the milk present in the gland cisterns.

The NuPulse group of twins recorded higher milk yields during the last 5 months of lactation and at the time of drying off, were giving significantly ($P < 0.01$) higher yields than the Conventional Pulse group. The Conventional Pulse group reached the drying off yield of the NuPulse group (5.9 ℓ/day) 12 days earlier. When the lactation was ended for both groups at a yield of 5.9 ℓ/day and the total production for both groups compared, it was found that the NuPulse group achieved significantly higher yields ($P < 0.05$).

Higher yields were recorded for the NuPulse group despite the fact that, two NuPulse cows (3N and 8N) had one infected rear quarter with an average somatic cell count for the lactation, of 2.735 (3.325) and 2.530 (3.274) million/ml, respectively. The figures in brackets are the average cell counts over the period of the infection.
Meijering *et al.* (1977) found that the milk yield from a quarter with a cell count, greater than 3 million/ml was reduced by 31 percent relative to the opposite healthy quarter. They also found that a non infected rear quarter produced 29 percent of the total yield.
This work suggests that the milk yields from cows 3N and 8N could have been reduced by 8 - 9 percent as a result of the infections.

Meijering *et al.* (1977) were unable to verify the claim that, compensatory yields could occur in the 3 uninfected quarters. Cow 8N was the only NuPulse twin that failed to outproduce its twin mate during the lactation; total milk yield was 5.3 percent lower, to a drying off yield of 5.9 ℓ/day.

Despite the infections and the lower production in the 5th to 8th months, cows 3N and 8N outproduced their twin mates during the 9th month of lactation (Table 26).

Whittlestone (1978) has suggested that the stimulating role of the machine <u>during milking</u> is possibly more important than a period of manual stimulation prior to milking.
The lower yields obtained with pulsationaless milking has resulted

in the hypothesis that, the periodic mechanical action of the liner during milking stimulates the cow in a way that differs in its physiological effect from premilking stimulus (Woolford and Phillips 1978).

Phillips (1978a) has estimated that the physiological response time of the cow to stimulus (either by hand or machine) to be approximately 40 s.
In the absence of premilking stimulation the trial cows required 50 - 60 s of liner movement before the first 0.5 litres of milk was recorded.
Better let down responses and 5 - 12 percent higher yields have been obtained with machines that use a pressure greater than atmospheric pressure in the pulsation chamber during the squeeze phase of pulsation, for a period of one minute after the start of milking. In one trial, the extra production was gained over the last 100 days of lactation (Frommhold and Wehowsky 1978).
Phillips (1970) has shown that a particular type of corrugated liner was able to increase production. Velitok (1977a) found that the weight, material and temperature of catheters used to milk cows could effect the let down response. Velitok believes that the reflexogenic zone of the teat canal sphincter may, under various stimuli of inadequate intensity, become the source of impulses inhibiting the contractile activity of the alveoli myoepithelia.

Velitok states that it is precisely on this zone of the teat that the liner vacuum acts most strongly and that parameters, such as the weight and temperature of the teatcups, the vacuum level, and the extent and action of the teatcup liner, could possibly effect the let down response.

The experiments quoted in this discussion add support to the theory that, the let down response and its long term manifestation in lactation yields, can be influenced by the mechanical action of the machine during milking.

The most likely explanation for the higher production achieved by the twins in the NuPulse group during the last 5 months of lactation is that, the NuPulse was associated with a more positive let down response during milking than the Conventional Pulse. It is possible that the long squeeze action and the 50 : 50 liner movement ratio of the Conventional Pulse inhibited let down rather than the NuPulse being associated with an improved letdown.
However there is little published evidence about any optimum form of liner movement. Phillips (1963) reported that, with the conventional machine, a short rather than a long squeeze phase has been known to cause discomfort and considerable loss of production.

The machine factors responsible for the NuPulse effect on milk yield could enhance or alternatively be less inhibiting to milk ejection.

The machine factors of the NuPulse most likely to be involved are the gradual rise in vacuum and the short period of full vacuum, during the peak flow stage of milking and possibly as a result of this type of vacuum application, the ability of the NuPulse to operate with a brief liner closed time.
These characteristics would be expected to reduce stress in the teat tissue and possibly the inhibiting effect, discomfort might have on milk ejection.
The evidence and theories presented in Experiment 1 and 2 should assist farmers and proponents of the NuPulse cluster to evaluate and substantiate some of the previously undocumented characteristics of the NuPulse cluster.

4.1.0 Conclusion:

The NuPulse has been shown to operate with a pulsation mechanism, that is different from the conventional type of milking machine. The mechanism enables the NuPulse to milk successfully with a light weight cluster. The one-line cluster, with the pulsator incorporated into the claw-piece, is associated with the same problem of frothing as other one-line clusters used with high lift, pipeline machines.
When milk was susceptible to frothing, during the 8th month of lactation, the NuPulse generated more froth than the Conventional Pulse.

During the experimental period the NuPulse was associated with the same level of mastitis as the Conventional Pulse and although limited by a small number of experimental animals, the results suggest that the NuPulse pulsation mechanism does not differ from the conventional method of pulsation in its effect on teat end condition and the final level of mastitis.

The higher milk yields recorded with the NuPulse during the last 5 months of lactation, suggests that the NuPulse is associated with a more positive stimulation effect during milking. However in view of the small number of animals used for the production comparison, the milk yield results must be regarded as preliminary.

The stimulation effects of different milking machines during milking needs to be more clearly defined.
This preliminary study with the NuPulse, has highlighted the possibilities of gaining increased production without increasing the labour inputs during milking.
Further studies should be made to verify the increased production effect of the NuPulse on a larger scale, as the efficiency of such increases in production has wider economic implications.

The development of the NuPulse cluster is a remarkable achievement, and further improvement, will assure the NuPulse a position in the history and development of machine milking.

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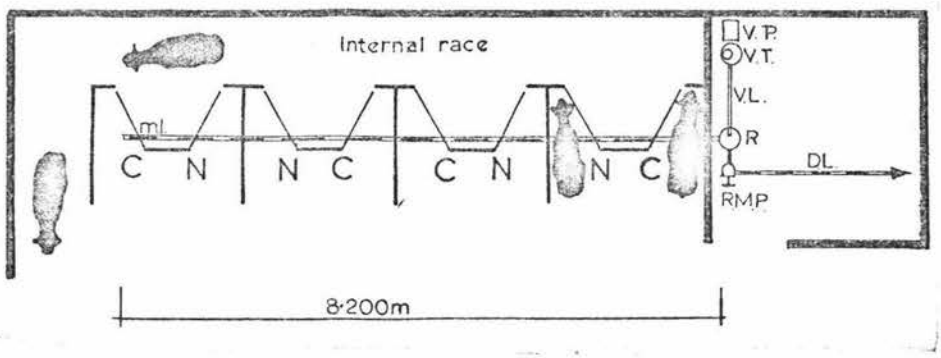
Appendix 1

Layout of the Experimental Dairy at Massey University.



8 Bail Walk-through Dairy (Abreast Parlour) with 8 milking units.

N 4 NuPulse units.

C 4 Conventional Pulse (Modified NuPulse units).

V.P. Vacuum pump.

V.T. Vacuum tank and Regulator (Waikato 170, AHI. Hamilton, NZ.)

V.L. Vacuum line (38mm ϕ) with vacuum gauge fitted.

R. Receiver (20 l).

R.M.P. Releaser milk pump.

m.l. Milking line. Height at far end-1.9 m. Slope- 1 in 40.

D.L. Delivery line to milk cooler and storage vat.

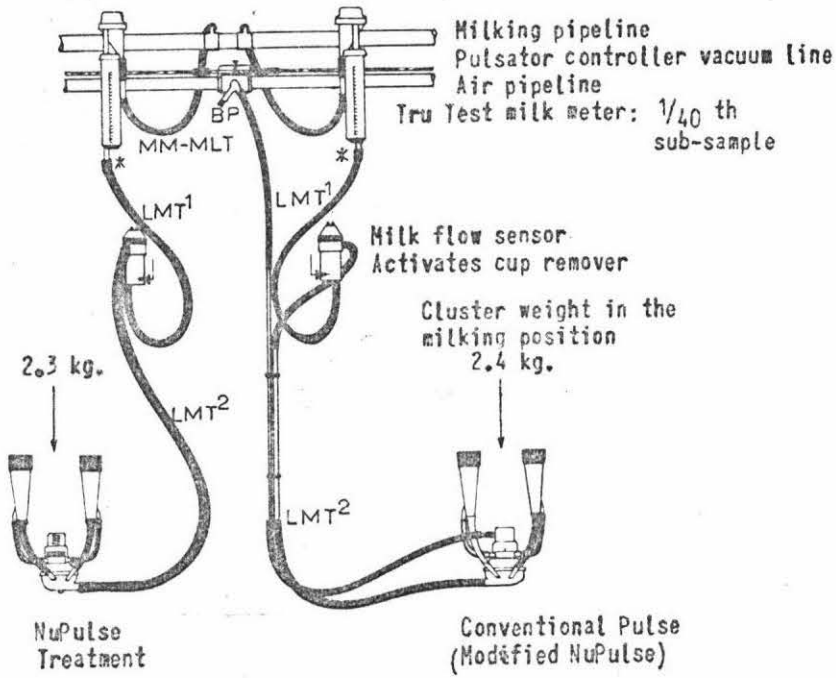
Vacuum level: 50.8 kPa.

Vacuum reserve: 16 l/ sec $\pm$ 1 - 4 NuPulse units not operating.

Vacuum recovery at the end of the milk line. 35 kPa to 51 kPa in 1.5 - 2 sec.

Anti-bloat drenching : The cows were drenched at the PM. milking, by the milker working from the internal race area.

Teat Cups: N.D.A. tapered teat cups fitted with N.D.A. No. 1 petal liner.



The design of the two machines used in experiment 2

Milk line height above floor 1.9 m
Milk line slope 0.2 m (1:40)
Milk line size 38 mm ϕ

Milk meter, Tru Test Distributions Ltd, Panmure, Auckland.
Milk meter-Milk line connection tube (MM-MLT)
On average the milk meter was connected in line for 3 milkings per week. LMT* was attached direct to the milk line for the remaining 11 milkings per week.

Milk flow sensor. Cups detached at a flow rate of 0.125ℓ/min.
Manufactured by A.H.I. Plastic Products Moulding Company, Private Bag Hamilton, N.Z.

Bail Pulsator (BP) one port blocked off. Manufactured by N.D.A. Ltd. Hamilton, N.Z.
N.D.A. Tapered teat cup fitted with N.D.A. petal inflation.
Liner tension : mean and standard error, measured for a sample of 8 liners at the end of the first lactation.
(One set of NuPulse and 1 set of Conventional Pulse).
Tension at the first notch 2·57 ± 0·19 kg.
" " " 2nd " 4·93 ± 0·14 kg.

	NuPulse		Conventional Pulse	
	Length	Diameter ϕ	Length	Diameter
LMT²	1.7 m	16 mm	2.0 m	12 mm
LMT¹	1.0 m	16 mm	1.0 m	12 mm
MM- MLT	0.5 m	12 mm	0.5 m	12 mm

Bail pulsator long pulse tube 10 mm

The regression of pulsation rate on liner open time for the simulated milkings (refer to Fig 7).

Pulsation rate	52	53	54	55	55	55	55	56	56	56	56	56	56	57	57	57	X
Liner open time s	•77	•76	•77	•72	•73	•73	•74	•69	•70	•71	•73	•73	•73	•66	•66	•70	Y

ΣX	886	ΣY	11.52	ΣXY	637.32
ΣX^2	49092	ΣY^2	8.310		
CT	49062.25	CT	8.294	CT	637.92
Σx^2	29.75	Σy^2	0.016	Σxy	-0.60

$$b\ \frac{\Sigma xy}{\Sigma x^2} = \frac{-0.6}{29.75} = -0.02^{**}$$

$$\hat{Y} = 0.72 + (-)0.02\ (X - 55.375)$$

$$= 0.72 + 1.108 - 0.02\ X$$

$$= 1.828 - 0.02\ X$$

$$d_{y \cdot x^2} = \Sigma y^2 - \frac{(\Sigma xy)^2}{\Sigma x^2} = 0.016 - \frac{(-0.6)^2}{29.75} = 0.0039$$

$$s_{y \cdot x^2} = \frac{\Sigma d_{y \cdot x^2}}{n-2} = \frac{0.0039}{14} = 2.785 \times 10^{-4}$$

$$s_{y \cdot x} = 0.017$$

$$s_b^2 = \frac{s_{y \cdot x^2}}{\Sigma x^2} = \frac{2.785 \times 10^{-4}}{29.75}$$

$$s_b = \sqrt{\frac{2.785 \times 10^{-4}}{29.75}} = 0.003\ s$$

$$t = \frac{b}{s_b} = \frac{0.02}{0.003} = 6.412^{**}$$

$$r = \frac{\Sigma xy}{\sqrt{\Sigma x^2 \cdot \Sigma y^2}} = \frac{-0.6}{\sqrt{29.75 \times 0.016}} = -0.87$$

Appendix IV

Pooled variance t test. Liner distension (%) measured at the LM_2 liner position (refer to Table 23).

	Conventional Pulse	NuPulse
	High lift treatment	High lift treatment
	20	5
	18	8
	20	10
	10	7
ΣX_1	68	ΣX_2 30
$\bar{X} \pm s$	17 ± 2.38	7.5 ± 1.04
ΣX^2	1224	238
C T	1156	225
Σx^2	68	13
s^2	22.6	4.3
s	4.75	2.08
COV	27 %	27.7 %

$$\text{Pooled } s^2 = \frac{68 + 13}{6} = 13.5$$

$$s_{\bar{x}_1 - \bar{x}_2} = \sqrt{\frac{2 \times 13.5}{4}} = 2.59$$

$$t = \frac{17 - 7.5}{2.59} = 3.668$$

$$t\,(0.01) = 3.707$$

APPENDIX V

The Criteria Used to Select Infection-Free Cows

An identical twin pair (twin pairs identified by being identical in colour and whirl markings), were selected for the experiment if -

1. no teat defect was observed;
2. if no mastitic pathogens were isolated in two consecutive foremilk samples taken about a week apart.

The bacteriological method is based on the NIRD method described by Heave (1975) for the diagnosis of infection.

Method:

All teats were washed with warm water and soap and dried with a paper towel.

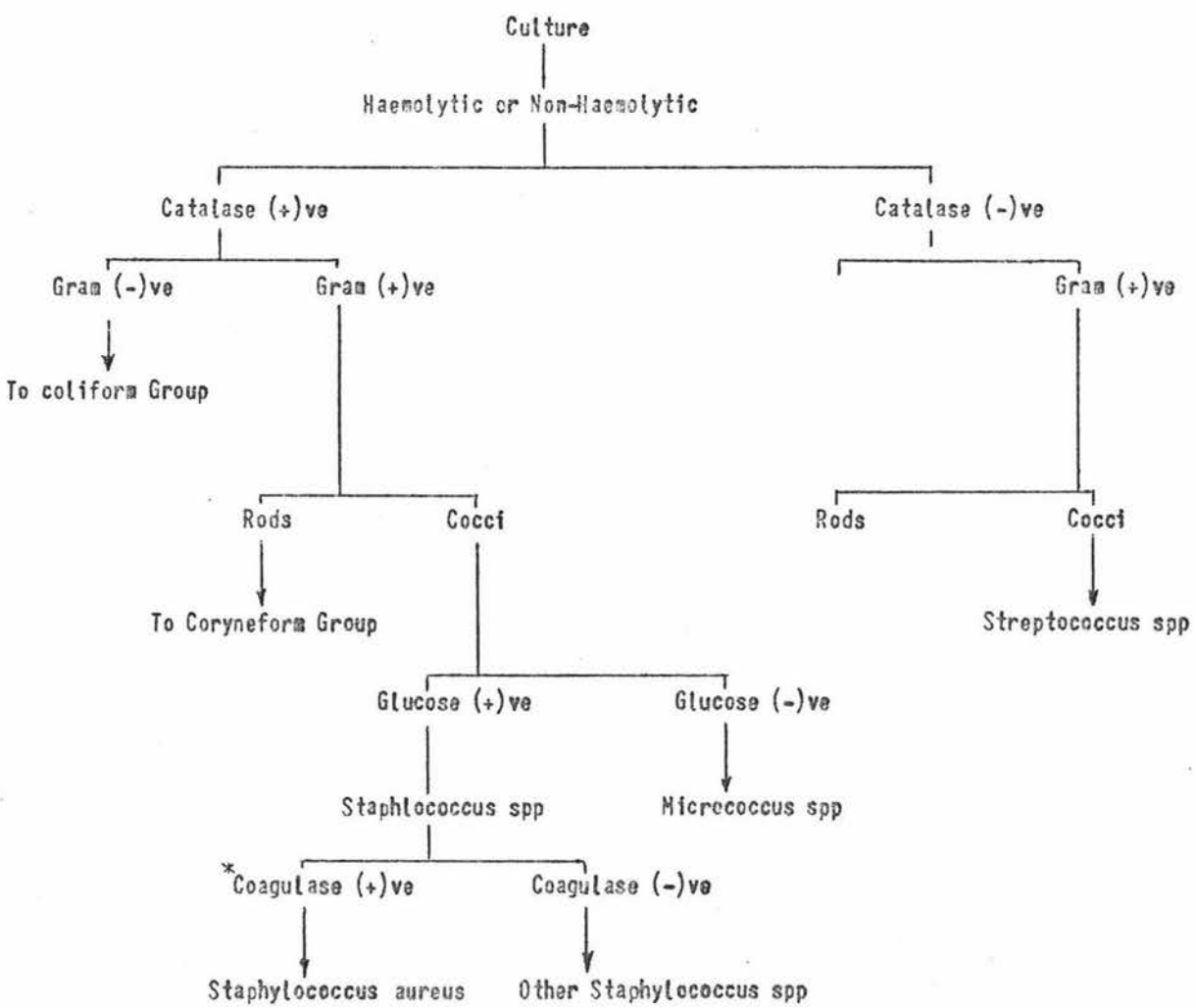
Each teat was scrubbed vigorously for 15 - 20 s with a separate piece of cottonwool soaked in 70% alcohol and the sides of the teat, excluding the orifice dried with the same piece of cottonwool squeezed dry. The nearest teats to the sampler (R.K.F.) were sampled first.

To increase the severity of the test, the first foremilk strippings were not discarded.

Seven to 10 mls of foremilk was squirted into universal bottles, held nearly horizontal to reduce air borne contamination.

Within one hour, 0.01 mls of milk was plated onto sheep blood aesculin agar (7.5 percent sheep blood agar plates containing 0.1 percent aesculin) and incubated at 37 degrees Celsius for 48 hours. Bacterial growth was classified as follows:

Bacteria Identification method



A growth of less than 10 colonies per plate was considered not significant when it occurred on only one plate out of two. * Wellcome Reagents Ltd, Wellcome Research Lab. Bechenham Eng. BR3 3BS.

Appendix VI

Lactation data for the experimental animals

TWIN SET NO.	BREED	TWIN NO.	CALVING DATE DIFFERENCE C - N		DAYS MILKED BY C OR N	START OF TREATMENT	COMMENTS
1	J	3		C	264	At the first milking for all the cows in Sets 1 to 6 and Sets 8 and 9.	
		4	+5	N	259		
2	J	5		N	278		
		6	-2	C	276		
3	J	7		C	253		
		8	-27	N	280		
4	J x F	21		C	279		
		22	+4	N	275		
5	J x MG	29		N	74		Died of Bloat.
		30	+9	C	83		
6	F	33		N	260		
		34	-31	C	232		
7	J	47		N	236	27th Milking	
		48	+20	C	236	47th Milking	
8	J x F	53		N	257		
		54	+7	C	264		
9*	J	141		N	264		
		142	0	C	264		
10*	A	147		N	250	11th Milking	
		148	0	C	250	11th Milking	

$\bar{x} = -15$

N = NuPulse treatment

C = Conventional Pulse Treatment

J = Jersey

F = Friesian

A = Aryshire

MG = Murray Grey

X = Crossbreed

* = 2nd calvers, the other pairs were 1st calvers.

The difference in calving date shows that the NuPulse group calved 15 days or any average 1.5 days earlier. Two of the preselected sets were replaced after the death of one of the twins in each pair, with the infection free sets 7 and 10. Set 5 was eliminated from the experiment when cow 29 died of bloat. The lactation was terminated on the 5th of May.

Appendix VII

A paired t test for the NuPulse and Conventional Pulse milk fat yield shown in Table 27.

The average values for fat yield, with the yields obtained during the last 12 days of lactation deducted from the yield of each cow in the Conventional Pulse group.

Twin set no.		NuPulse kg.	Con. Pulse kg.	x'	Con. Pulse (adjusted)	$\bar{D}$	$\bar{D}^2$
	1	150.22	122.50	- 4.59 =	117.91	32.31	1043.936
	2	123.15	96.32	- 3.37 =	92.95	30.20	"
	3	115.08	113.85	- 3.29 =	110.56	4.52	
	4	127.05	129.74	- 4.73 =	125.01	2.04	
	6	130.52	103.47	- 4.50 =	98,97	31.55	
	7	103.36	96.79	- 3.40 =	93.39	9.97	
	8	112.57	123.29	- 4.45 =	118.84	-6.27	
	9	162.62	156.82	- 3.95 =	152.87	9.75	
$\bar{X}$	8	128.07	117.85		113.81	14.26	3209.747

x' Production during the last 12 days.

$$CT = \frac{(114.07)^2}{8} = 1626.496$$

$$s_{\bar{D}}^2 = \frac{3209.747 - 1626.496}{7} = \frac{1583.251}{7} = 226.179$$

$$s_{\bar{D}} = \sqrt{\frac{226.179}{8}} = 5.317$$

$$t = \frac{14.26}{5.317} = 2.682^{*} \qquad t_{(0.05),\,(7)} = 2.365$$

The analysis of variance in somatic cell count for the NuPulse Conventional Pulse groups (refer to section 3.2.2 d)
Somatic cell count x 10^3/ ml.

Twin set no.	1	2	3	4	6	7	8	9	10	sum	$\bar{x}$	s
Con. Pulse	341	169	194	158	139	163	156	158	183	1661	184.6	60.8
NuPulse	346	223	582	176	152	172	1132	159	177	3119	346.6	325.8
	687	392	776	334	291	335	1288	317	360	4780		

ANOV.

$$CT. = \frac{(4780)^2}{18} = 1{,}269{,}355.6$$

$$\text{Total SS} = (341^2 + 169^2 - - + 177^2) - CT$$

$$= 2{,}265{,}988 - CT = 996632.4$$

$$\text{Treatment SS} = \frac{(1661)^2 + (3119)^2}{9} - CT = 1{,}387{,}453.6 - CT = 118098$$

$$\text{Block SS} = \frac{(687)^2 + (392)^2 + ---(360)^2}{2} - CT$$

$$= 1{,}712{,}652 - CT = 443296.4$$

ANOV Table	Source of variation	SS	d.f.	Mean square	F
	Treatment	118098	1	118098	2.17
	Between twin pairs	443296.4	8		
	Residual	435238	8	54404.8	
	Total	996632.4	n - 1		

F ratio , NS (P>0.1)

APPENDIX IX (Section 3.2.2d)

THE AVERAGE CELL COUNT ($\times 10^3$/ml) FOR THE A.M. AND P.M. WEEKLY COMPOSITE MILK SAMPLE

TWIN SET	NUPULSE			CONVENTIONAL PULSE		
	Mean	$S\bar{x}$	n	Mean	$S\bar{x}$	n
1	346	81	35	341	56	35
2	223	32	37	169	22	37
3	582	108	37	194	34	35
4	176	24	37	158	20	37
5	116	14	11	96	9	11
6	152	19	35	139	18	32
7	172	21	33	163	20	33
8	1 132	282	35	156	18	35
9	159	38	35	158	32	35
10	177	34	37	183	25	37
	324			178		

THE AVERAGE CELL COUNT FOR FOREMILK SAMPLES

TWIN SET	NUPULSE			CONVENTIONAL PULSE		
	Mean	$S\bar{x}$	n	Mean	$S\bar{x}$	n
1	228	43	14	186	42	14
2	142	20	15	144	21	14
3	830	244	15	141	14	12
4	108	13	15	109	18	15
5						
6	101	16	12	90	11	12
7	157	31	13	121	15	13
8	732	205	13	107	11	14
9	97	14	14	104	12	14
10	654	355	14	124	21	14

n= the no. of samples.

APPENDIX X (Section 3.2.2d)

SIMILARITY (BY RATIO ANALYSIS) BETWEEN THE MASSEY COULTER CELL COUNTS AND THE NATIONAL DAIRY LABORATORY (NDL) COULTER CELL COUNTS

	MASSEY SCC x 10^3 /ml	NDL CC x 10^3 /ml	RATIO MASSEY/NDL
1	205	254	0.81
2	293	262	1.12
3	260	184	1.41
4	169	168	1.01
5	154	290	0.53
6	1 214	1 181	1.03
7	168	217	0.77
8	127	127	1.00
9	57	99	0.58
10	93	122	0.76
11	135	152	0.89
12	155	247	0.63
13	210	186	1.13
14	89	113	0.79
15	108	251	0.43
16	156	227	0.69
17	117	96	1.22
18	71	147	0.48
Mean	210	240	Mean Ratio (x) = 0.85

$S = 0.273$

$S\bar{x} = \frac{s}{\sqrt{n}}$

$S\bar{x} = 0.064$

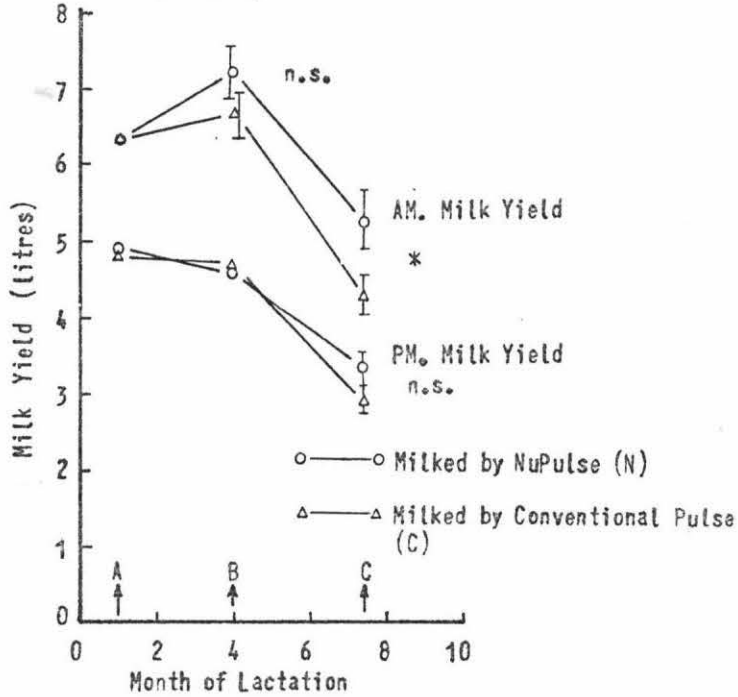
$t = \frac{1 - 0.85}{S\bar{x}} = \frac{0.15}{0.064} = 2.332$

Therefore, the difference between the Massey SCC and NDL SCC is significant ($P<0.05$)
The mean ratio (x) should equal 0.96 for the difference to be not significant at ($P = 0.5$).

$t = \frac{(1 - x)}{0.064} = 0.690 \quad \left(t(0.5) = 0.690\right)$

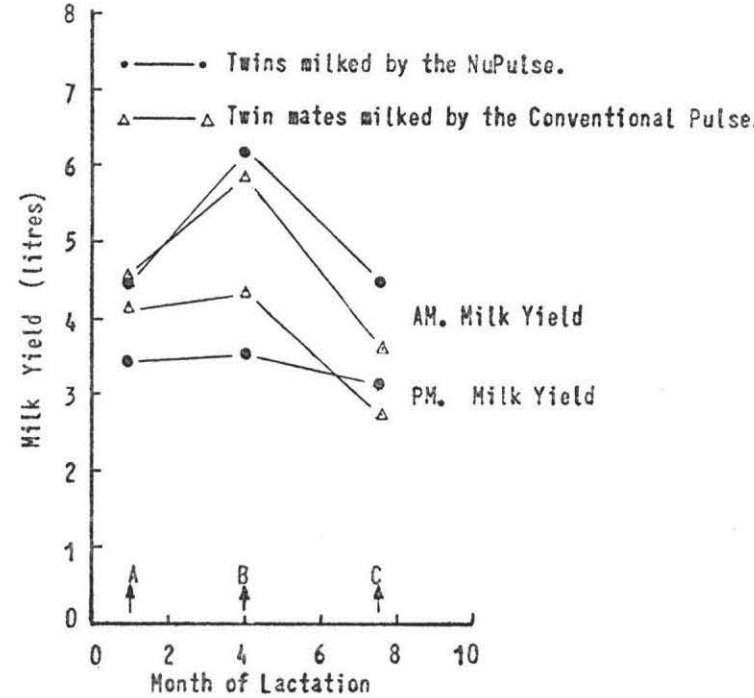
$(1 - x) = 0.04$ Therefore, to increase the ratio from 0.85 to 0.96 the Massey SCC average needs to be increased by 13 percent.

Milk yield (mean and S.E.) recorded at the A, B, & C milking recordings. Trial and non trial cow data combined.



		A	B	C
PM.	N	42	40	42
	C	41	41	41
AM.	N	40	45	38
	C	43	44	43

Milk yield (mean) recorded at the A, B & C milking recordings. Trial cows only.

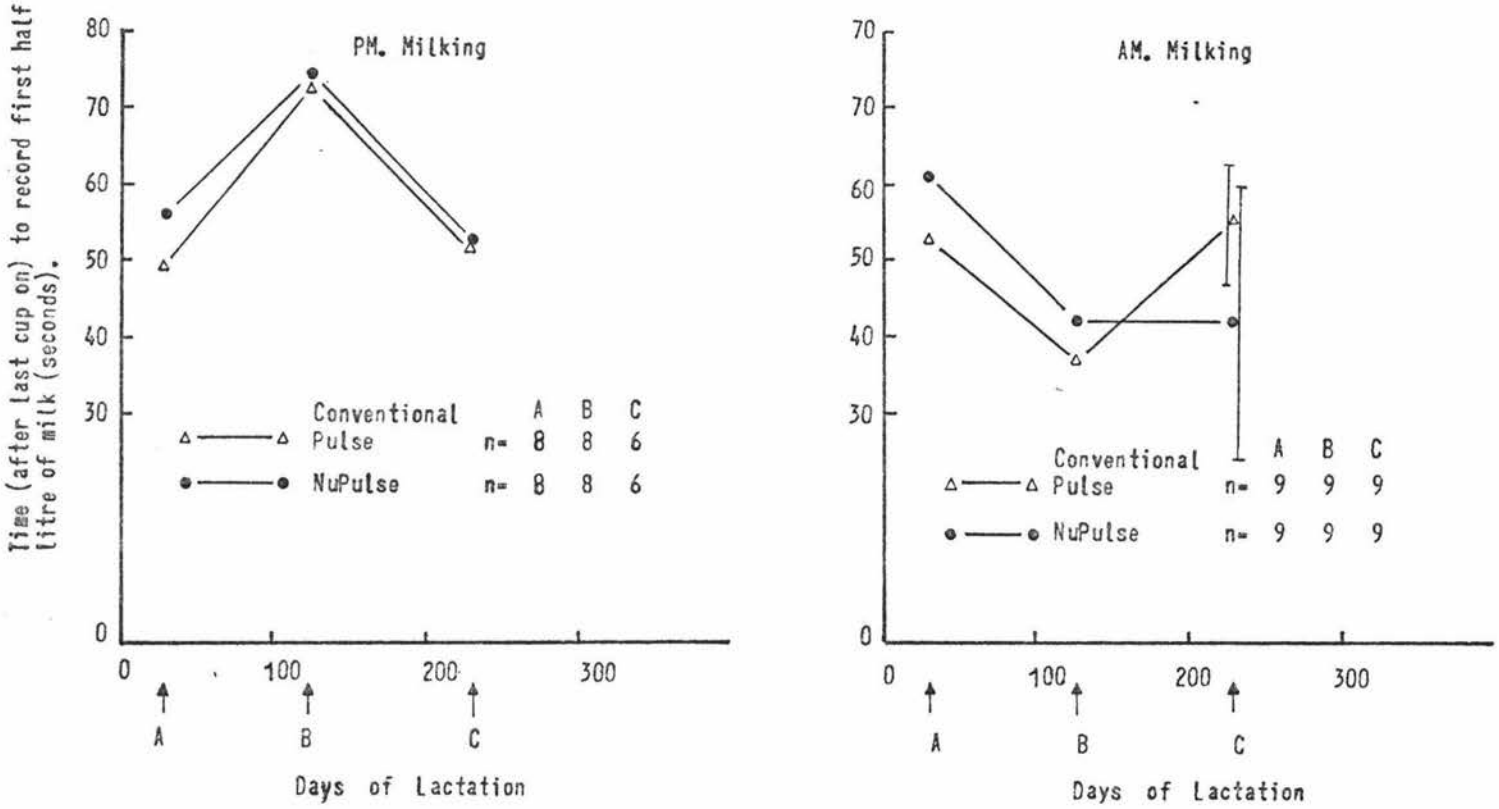


		A	B	C
n=	AM.	9	9	9
	PM.	8	8	6

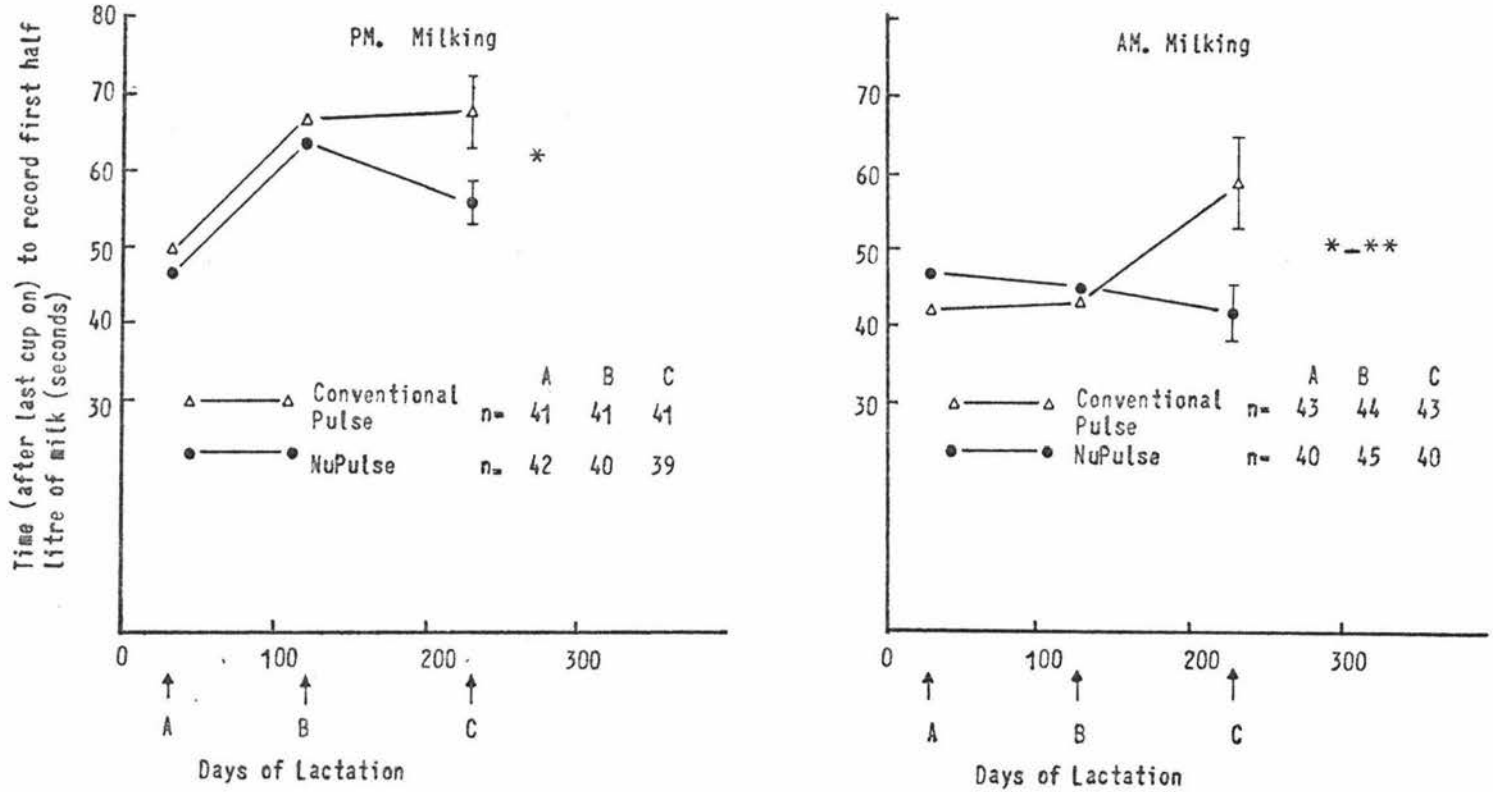
n= No. Twin sets.

Appendix XI.

The time taken to commence milking- the mean values obtained for the trial cows.
(n= the no. of twin pairs used to compile the means).



The time taken to commence milking- the mean values obtained for the trial and non trial cows combined. (n= the no. of cows used to compile the means).



Appendix XIII.

APPENDIX XIV (Section 3.2.4d)

The average milking rate before the two minute period for the NuPulse and Conventional Pulse (Combined trial and non-trial cow data).

Milking Recordings		NuPulse (N) Yield at 2 min.	Time	Milking Rate*	Conventional Pulse (C) Yield at 2 min.	Time	Milking Rate*	(C)-(N)
		l	mins.	l/min.	l	min.	l/min.	l/min.
PM	A	1.97	1.22	1.61	2.16	1.17	1.86	
	B	1.86	0.93	2.00	1.87	0.88	2.12	
	C	1.79	1.07	1.68	1.63	0.87	1.88	
	$\bar{x}$	1.87	1.07	1.76	1.89	0.97	1.95	0.19
AM	A	2.15	1.22	1.76	2.50	1.30	1.93	
	B	2.30	1.25	1.84	2.41	1.28	1.87	
	C	2.45	1.30	1.88	2.00	1.02	1.97	
	$\bar{x}$	2.30	1.26	1.83	2.30	1.20	1.92	0.09

* Milking Rate = $\frac{\text{Yield at 2 mins}}{\text{2 min - Time before 0.5 l of milk.}}$

The average milking rate after the two minute period of milking with the NuPulse and Conventional Pulse (Combined trial and non-trial cow data.

Milking Recording		NuPulse (N) Yield	Time	Milking Rate*	Conventional Pulse (C) Yield	Time	Milking Rate*	N-C
		l	mins.	l/min.	l	mins.	l/min.	l/min
PM	A	2.92	3.1	0.94	2.67	4.0	0.67	
	B	2.78	3.3	0.84	2.86	3.8	0.75	
	C	1.66	2.2	0.76	1.27	2.4	0.53	
	x	2.45	2.87	0.85	2.27	3.4	0.65	0.20
AM	A	4.16	4.65	0.90	3.76	3.9	0.96	
	B	4.89	4.80	1.02	4.27	5.2	0.82	
	C	2.76	2.70	1.02	2.26	3.2	0.71	
	x	3.94	4.05	0.98	3.43	4.1	0.83	0.15

* Milking Rate = $\frac{\text{Yield after 2 mins}}{\text{Total Milking Time - 2 mins.}}$

APPENDIX XV (Section 3.2.4d)

The average milking rate before the two minute period. The NuPulse and Conventional Pulse trial cows only.

		NUPULSE (N)			Conventional Pulse (C)			
		Yield at 2 mins.	Time	Milking Rate*	Yield at 2 mins.	Time	Milking Rate*	(C)-(N)
Recording		l	mins.	l/min.	l	mins.	l/min.	l/min.
PM	A	1.74	1.07	1.63	1.95	1.18	1.65	
	B	1.38	0.75	1.84	1.89	0.78	2.42	
	C	2.22	1.17	1.90	2.10	1.17	1.80	
	$\bar{x}$	1.78	1.00	1.79	1.98	1.04	1.96	0.17
AM	A	1.82	0.98	1.86	1.99	1.17	1.70	
	B	2.25	1.30	1.73	2.66	1.38	1.93	
	C	2.48	1.30	1.91	2.09	1.08	1.94	
	$\bar{x}$	2.18	1.19	1.83	2.45	1.21	1.86	0.02

* Milking Rate = $\frac{\text{Yield at 2 mins.}}{\text{2 min - Time before 0.5 l of milk measured in the flask}}$

The average milking rate after the two minute period of milking with the NuPulse and Conventional Pulse (Trial Cows Only.)

		NuPulse (N)			Conventional Pulse (C)			
		Yield at 2 mins.	Time	Milking Rate*	Yield at 2 mins.	Time	Milking Rate*	(N)-(C)
Recording		l	mins.	l/min.	l	mins.	l/min.	l/min.
PM	A	1.73	2.89	0.60	2.29	3.92	0.58	
	B	2.26	2.29	0.99	2.50	2.78	0.90	
	C	0.95	1.20	0.79	0.63	1.38	0.46	
	$\bar{x}$	1.65	2.13	0.79	1.81	2.69	0.65	0.15
AM	A	2.72	2.17	1.25	2.64	2.47	1.07	
	B	4.01	4.20	0.96	3.24	5.38	0.60	
	C	2.02	3.19	0.63	1.52	2.39	0.64	
	$\bar{x}$	2.92	3.19	0.95	2.47	3.41	0.77	0.18

* Milking Rate = $\frac{\text{Yield after 2 mins.}}{\text{Total milking time - 2 mins.}}$

An analysis of the relationship between the average milking time and milk yields obtained at the A, B & C milking recordings. (Combined trial and non trial cow data, refer to Appendix XVII.

Conventional Pulse

Time	Y	Yield	X
PM(C)	4.4		2.9
AM(C)	5.2		4.3
PM(B)	5.8		4.7
PM(A)	6.0		4.8
AM(A)	5.9		6.3
AM(B)	7.2		6.7
ΣY	34.5	ΣX	29.7
$\bar{Y}$	5.75	$\bar{X}$	4.95

ΣY^2 202.69 ΣX^2 156.61 ΣXY 176.59

CT 198.38 CT 147.00 CT 170.78

Σy^2 4.31 Σx^2 9.61 Σxy 5.81

$$r = \frac{\Sigma xy}{\sqrt{\Sigma x^2 \cdot \Sigma y^2}} = \frac{5.81}{\sqrt{4.31 \quad 9.61}}$$

$= 0.903$ *

$r^2 = 81.5\ \%$

NuPulse

Time	Y	Yield	X
PM(C)	4.2		3.5
PM(B)	5.3		4.6
PM(A)	5.1		4.9
AM(C)	4.7		5.2
AM(A)	6.65		6.3
AM(B)	6.8		7.2
ΣY	32.75	ΣX	31.7
$\bar{Y}$	5.458	$\bar{X}$	5.28

ΣY^2 184.29 ΣX^2 175.99 ΣXY 179.37

CT 178.76 CT 167.48 CT 173.03

Σy^2 5.53 Σx^2 8.51 Σxy 6.34

$$r = \frac{\Sigma xy}{\sqrt{\Sigma x^2 \cdot \Sigma y^2}} = \frac{6.34}{\sqrt{5.53 \quad 8.51}}$$

$= 0.924$ **

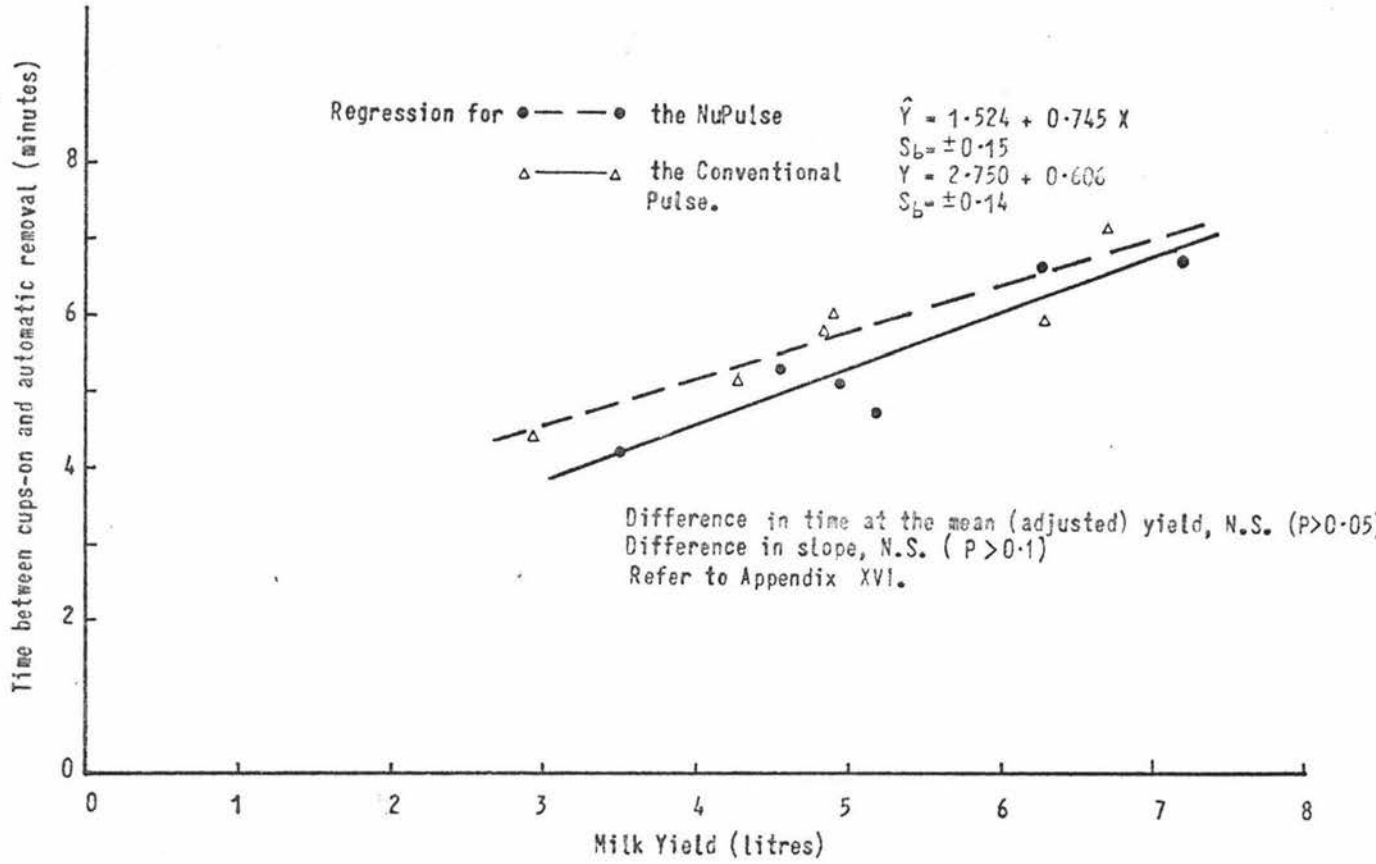
$r^2 = 85.4\ \%$

	d.f.	Σx^2	Σxy	Σy^2	b	d.f.	SS	MS	$s_{x \cdot y}$	s_b
Con.Pulse	5	9.61	5.82	4.31	0.606	4	0.785	0.196	0.443	0.143
NuPulse	5	8.51	6.34	5.53	0.745	4	0.807	0.202	0.449	0.154
						8	1.592	0.199		
Pooled	10	18.12	12.16	9.84	0.671	9	1.680	0.187		
		Difference between slopes				1	0.088	0.088		
Between		0.28	-0.30	0.16						
Total	11	18.40	11.86	10.00		10	2.356			
		Between adjusted means				1	0.676	0.676		

Comparison of slopes: $F = \frac{0.088}{0.199} = 0.422$ d.f. 1, 8. (NS)

Comparison of elevation $F = \frac{0.676}{0.187} = 3.6$ d.f. 1, 9. (P 0.05, NS)

The relationship between the average milking time and milk yield for the combined trial and non trial cows at the A, B, C, milking recordings.



The relationship between the average milking time and average milk yield for the identical twin pairs at the A, B, C, milking rate recordings.