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Study of the structure and function of the sheath of tropically adapted bulls and risk factors for preputial eversion and preputial prolapse

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Abstract

Preputial prolapse is an obvious condition affecting bulls from many breeds. Unfortunately, the losses in production and welfare concerns associated with preputial prolapse can remain undetected for long periods of time in the extensive beef areas of northern Australia where the bulls are not inspected regularly. Thus, there is a critical need to identify the structural factors predisposing to preputial prolapse in young bulls so that they can be culled early.

Despite there being no firm scientific evidence of an association between preputial eversion and preputial prolapse, it seems logical that the increased exposure of the sensitive prepuce as a consequence of preputial eversion may increase the risk of bulls developing preputial pathology, in particular preputial prolapse. This may be particularly relevant in *Bos indicus* bulls as they have a more pendulous sheath and thus eversion of the prepuce may be associated with a greater risk of injury to the prepuce compared to that in *Bos taurus* bulls. Further, studies of preputial eversion in *Bos taurus* bulls have concluded that there is an association between polledness and increased prevalence and severity (length of everted prepuce and duration of eversion) of preputial eversion due primarily to the absence or poor development of the caudal preputial muscles. No similar definitive work in *Bos indicus* bulls has been conducted and thus anatomical studies reported in this thesis were conducted to determine if a similar association occurred in *Bos indicus* bulls.

A survey of a sample of large beef breeding herds in northern Australia found that preputial prolapse is a significant problem in *Bos indicus* and *Bos indicus* derived bulls and affected both young and older bulls. The importance of preputial prolapse confirmed the value of further research into the causes of this problem. A series of anatomical studies confirmed that preputial eversion in *Bos indicus* derived bulls was not more prevalent in polled bulls than horned bulls and was not associated with deficiency of the caudal preputial muscles as was established in *Bos taurus* bulls. An anatomical study of *Bos indicus* derived bulls with preputial prolapse found that preputial prolapse occurred in horned bulls of varying ages and these bulls did not have any evidence of deficiency in the caudal preputial muscles. However, preputial prolapse was

observed in young polled bulls that had poorly developed or absent caudal preputial muscles. It was concluded that deficiency of the caudal preputial muscles in polled *Bos indicus* derived bulls may predispose to preputial prolapse at an early age, but no predisposing anatomical factors were found for horned *Bos indicus* derived bulls. In these studies, preputial eversion and preputial prolapse were found in horned *Bos indicus* derived bulls that did not have any preputial muscle deficiency and it was noted that preputial eversion was not related to the length of the prepuce.

Further studies confirmed that preputial eversion was linearly and consistently associated with position of the glans penis within the sheath in *Bos indicus* derived bulls, and movement of the glans penis towards the preputial orifice consistently resulted in preputial eversion in these bulls. A method to objectively measure the relationship between movement of the glans penis within the sheath and preputial eversion was developed. Studies in humans have linked function of some abdominal muscles to function of the pelvic organs. This relationship was investigated in *Bos indicus* derived bulls to determine whether the function of specific abdominal muscles affected position of the penis in the sheath. Using the method developed to objectively measure the relationship between penis movement and preputial eversion, the abdominal muscles that potentially were associated with movement of the glans penis or preputial eversion were examined but no significant relationships were observed.

In the anatomical study of *Bos indicus* derived bulls not affected with preputial prolapse a more pendulous sheath was associated with increased prevalence of preputial eversion. This relationship was confirmed for horned and polled bulls in the penis movement studies. *Bos indicus* derived bulls with more pendulous sheaths evert their prepuces more than bulls with less pendulous sheaths thus increasing the risk of damage to the prepuce either from the environment, other bulls, or from them inadvertently stepping on the everted prepuce when they get to their feet. Culling *Bos indicus* derived bulls with more pendulous sheaths should reduce the incidence of preputial eversion and possibly preputial prolapse. The anatomical study of *Bos indicus* derived bulls that did not have preputial prolapse demonstrates that there are herds of bulls where the polled bulls do not have any evidence of deficiency of the caudal preputial muscles. There is a need to develop a practical and cost effective test to identify polled *Bos indicus* bulls that have a deficiency in their caudal preputial muscles.

Declaration by author

This thesis is composed of my original work, and contains no material previously published or written by another person except where due reference has been made in the text. I have clearly stated the contribution by others to jointly-authored works that I have included in my thesis.

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Contributions by Others to the Thesis

Professor McGowan contributed to the early direction and design for chapters 3, 4 and 5 and the overall focus of the thesis. Sue Markwell contributed to the concept of abdominal muscle involvement in pelvic organ functions in chapter 7.

Departmental biometricians (particularly Vivienne Doogan, Gary Blight and David Mayer) contributed to the statistical analysis and interpretation for chapters 3, 4, 5, 6 and 7. Biometricians were involved in the planning stages of all the studies to ensure data collected could be successfully analysed. Some of the more complicated regression analyses were performed by these professional biometricians. All data analyses and interpretation were completed in consultation with these biometricians. Dr Dianne Vankan provided professional editorial input into two of the chapters.

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Keywords

bull, *bos indicus* derived, preputial eversion, preputial prolapse, survey, anatomy, abdominal muscles, penis movement, *bos indicus*

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Abbreviations

AI – artificial insemination

g – gram

H - horns

Kg - kilogram

M – missing data

mm – millimetre

mth – month

n – number

NS – not significant

P – probability (statistical figure)

P – polled (bull)

R – correlation coefficient

R2 – coefficient of determination

S – scurred

SD – standard deviation

SE – standard error

YO – years old

Chapter 1.

Introduction

Preputial prolapse in bulls is a very obvious clinical abnormality. The welfare implications of sensitive preputial tissue continuously exposed and injured are evident to the general community as well as the cattle producer. The associated losses in production are also well understood by the cattle producers as bulls with untreated preputial prolapse cannot usually mate successfully with cows.

Affected bulls are usually culled when preputial prolapse is detected but losses in production have usually already occurred by this stage and the losses can be quite large under some management conditions (Wolfe *et al.* 1983). In the more extensive production areas the welfare of an affected bull can be compromised for some time before the condition is detected. If bulls that were more susceptible to preputial prolapse were able to be identified and removed from the breeding herds, welfare issues and production losses could be reduced.

To establish the causes, and the significance of each of the causes, of preputial prolapse in *Bos indicus* and *Bos indicus* derived bulls, a longitudinal study is needed. To be effective, the longitudinal study would have to objectively measure the possible contributing factors to preputial prolapse on a large number of *Bos indicus* and *Bos indicus* derived bulls and observe them over a long period of time (years) for development of preputial prolapse.

From the literature it was obvious that there was some confusion regarding the predisposing causes of preputial prolapse in *Bos indicus* and *Bos indicus* derived bulls so studies determining the possible main predisposing causes were needed before a longitudinal study could be efficiently conducted. Much of the confusion in the literature was due to differences between *Bos indicus* and *Bos taurus* bulls in their susceptibility and mechanisms for development of preputial prolapse. Work in this thesis was done to clarify some possible predisposing causes of preputial prolapse specifically in *Bos indicus* and *Bos indicus* derived bulls. If anatomical indicators are present for preputial prolapse in *Bos indicus* and *Bos indicus* derived bulls and if these can be objectively measured, bulls could be removed from the breeding population before pathology develops.

The importance of preputial prolapse in these bulls in the extensive areas of northern Australia needs to be accurately determined. A survey involving large numbers of extensively managed *Bos indicus* and *Bos indicus* derived bulls is to be conducted to determine the prevalence of preputial prolapse in the beef industry in northern Australia. The survey results would allow cattle producers to balance their selection processes with genuine estimates of what proportion of *Bos indicus* and *Bos indicus* derived bulls are likely to develop preputial prolapse each year and what emphasis should be placed on selection against anatomical structures that may predispose bulls to preputial prolapse.

The anatomy of bulls affected with preputial prolapse and bulls not affected with preputial prolapse could be compared to determine the importance of the anatomy of reproductive structures in the development of preputial prolapse. Two studies are needed. An anatomical study is to be conducted on *Bos indicus* derived bulls that are not affected with preputial prolapse to describe the anatomy of the external reproductive organs and associated structures of unaffected bulls. This study is to provide normal bull baseline measurements to compare with anatomical measurements of *Bos indicus* derived bulls affected with preputial prolapse. A companion study of the anatomy of reproductive organs and associated structures of *Bos indicus* derived bulls affected with preputial prolapse is to be conducted to identify anatomical factors that may predispose bulls to preputial prolapse.

Although not confirmed as a major cause of preputial prolapse in *Bos indicus* and *Bos indicus* derived bulls, preputial eversion is suggested by many authors as a major predisposing factor (Donaldson and Aubrey 1960; Ott 1986; Larson 1986). The anatomical studies in this thesis were to investigate if preputial eversion is related to the movement of the penis. To confirm this relationship a study is to be conducted to determine the relationship between the position of the penis and preputial eversion in *Bos indicus* derived bulls. This study will utilise a new technique for objectively quantifying preputial eversion and the associated penis movement.

The causes of preputial eversion in *Bos indicus* and *Bos indicus* derived bulls are not well described in the literature and are often assumed to be similar to the causes of preputial eversion identified in *Bos taurus* bulls. Other, less obvious causes, may be affecting preputial eversion. Research in humans identified some abdominal muscles as important in the pelvic area functions such as micturition, defaecation and parturition (Getty 1975). Despite the difference in stance between humans and cattle, the literature stated that abdominal muscle function is similar between these species (Lansman and Robertson 1992). An ultrasound study is to be conducted to determine the association of the identified abdominal muscles with preputial eversion in bulls utilising the newly developed technique for quantifying preputial eversion and penis position in bulls. If measurements of abdominal muscles could determine which bulls evert their prepuces more than others, these objective measurements could be utilised in initial bull selection to avoid bulls that are likely to excessively evert their prepuces, and may reduce the likelihood of the development of preputial problems in the selected bulls.

In summary, the objectives of this thesis are to:

- determine the importance of preputial prolapse to the Northern Australian beef industry;
- find anatomical differences in the external reproductive organs between normal *Bos indicus* derived bulls and *Bos indicus* derived bulls with preputial prolapse;
- confirm the relationship of the position of the penis in the sheath to preputial eversion;
- determine the relationship between some abdominal support muscles and preputial eversion.

Chapter 2.

Literature review: Factors affecting preputial function in bulls

Introduction

This thesis is specifically concerned with preputial function in *Bos indicus* and *Bos indicus* derived bulls but the conditions of the prepuce are general and affect other genotypes. This review includes preputial function in these other groups for comparison. More work has been recorded in *Bos taurus* bulls in some aspects of preputial function and preputial problems. This work has been covered to give some direction to the studies in the *Bos indicus* and *Bos indicus* derived bulls. Specific information on preputial function in *Bos indicus* bulls is limited and much of the information that is available is not recent.

Influence of bull fertility on overall herd fertility.

Reduced bull fertility affects overall cattle herd fertility (Benesch and Wright 1950). Factors affecting bull fertility may be congenital or acquired and may be temporary or permanent. Permanent loss of fertility is obviously a source of revenue loss but even temporary infertility may result in great loss due to wasted breeding time in any cattle industry and also a loss in milk yield in the dairy industry (Benesch and Wright 1950). Reported importance of the bull to herd fertility varied in the literature from bulls being responsible for 72% of herd fertility problems (Smit 1994) to some stating that the cause of infertility more often lies with the female than the male (Benesch and Wright 1950). Others were more general saying that infertility or sterility is probably as common in the male as in the female (Roberts 1971). One group did not compare the sexes but examined 263 bulls on a property near Darwin in the Northern Territory of Australia and identified low and variable bull fertility as a constraint on reproductive rates in this extensive, multiple sire mated herd (McCosker *et al.* 1989).

Economic estimates of the importance of bull fertility are often presented in general terms and copulation failure has been described as economically devastating to cattle producers (Wolfe *et al.* 1983). Others described the loss of use of bulls as representing a major source of concern to breeders (Bellenger 1971). With the introduction of artificial insemination (AI), some authors noted that bull fertility has become even more important (Santamarina and Reece 1957). AI allows greater use of selected sires and reduced fertility of these sires would result in greater potential loss to the industry.

Causes of bull infertility can be subdivided into a number of categories, and analysis of records from Southern Africa suggests 76% are due to functional unsoundness (Smit 1994). Part of this functional unsoundness includes preputial problems in bulls. These are a common cause of impotence (Wolfe *et al.* 1983; Wolfe 1986) and occur frequently in the bovine (Frank 1959). This was reiterated by authors who stated that pathological changes in the genital system of the male in cattle are very common (Hungerford 1990) and that laceration complicated by prolapse of the prepuce is commonly encountered (Walker and Vaughan 1980).

Preputial prolapse may lead to mating difficulties (Lagos and Fitzhugh 1970) and it has been stated that the subsequent inability to copulate due to prolapse has forced the slaughter of many bulls (Walker 1966).

An accurate and repeatable method of predicting bull fertility could have an important economic impact on beef production. The ability to consistently select herd sires of high fertility could result in more cows calving early in the calving season, and thus producing more kilograms of calf weaned in beef herds (Smith *et al.* 1981).

Problems affecting the fitness of the bull for service are not new and Kingman (1948) stated that industry groups should unite to learn more about the problems relating to reproduction. Also in 1932, authors stated that little attention had been given to the question of the fertility of the male as a factor in reducing the breeding efficiency of the female (Webster 1932).

Importance of *Bos indicus* and *Bos indicus* derived cattle in tropical/subtropical regions of the world

Bos indicus breeds play a dominant role in beef production in tropical and sub-tropical parts of the world (Swanepoel and Hoogenboezem 1993) because they are adapted to hot climates. To promote heat loss it has been suggested that the surface of skin is increased by greatly developed dewlaps and, in many of these breeds, an excessively pendulous sheath (Hofmeyr 1987). To test the theory that excess skin may help the *Bos indicus* breeds cope with hot weather, some researchers removed the dewlap from a *Bos indicus* bull and found that it did not change his ability to resist high temperatures (USDA 1956). Despite being contrary to current thinking, in that study this led to the conclusion that the outsize *Bos indicus* dewlap has no influence on heat tolerance. Despite this finding in one bull, selection against excess skin (including the sheath) could be detrimental to the survivability of the cattle in some harsh environments if the excess skin is, in fact, important for survival in hot conditions.

The importance of utilising livestock breeds adapted to specific environments needs to be emphasised. This is particularly true for tropical environments where, in the absence of resources for substantial improvements of the production environment, the most viable and widely available option is the utilisation of adapted animal genetic resources. *Bos indicus* are essentially beef animals that survive under poor grazing conditions and are able to respond to better nutrition or feedlot management. These breeds have a long productive life and do not appear to be unduly troubled by ticks and other ectoparasites and exhibit considerable tolerance to infectious keratoconjunctivitis (pink-eye), and squamous cell carcinoma of the eye. In addition these breeds are considerably tolerant of heat and gastrointestinal nematodes and have a relatively low incidence of calving problems. The international popularity of *Bos indicus* especially in tropical climates is testimony to these attributes (Rege 1993).

Extent of bull fertility problems due to preputial problems

Preputial problems are one of the most common abnormal conditions affecting the ability of the male bovine to copulate (Walker 1970; Walker and Hull 1984; Memon *et al.* 1988), and are frequently observed in some breeds of cattle (Walker 1970). Preputial problems include traumatic injury to the prepuce that is most common under range breeding conditions (Walker and Vaughan 1980). Pearson (1972) has reported that even minor lesions of the prepuce may render a bull incapable of natural service and are frequently the cause of insurance disputes. Preputial prolapse adversely affects penis function because protrusion of the penis depends on free movement of the preputial mucosa and any fibrotic lesion in this tissue may seriously impede the ability of the penis to extend (Arthur *et al.* 1982).

Data obtained from some Australian abattoir studies has not confirmed how prevalent the preputial problems may be in *Bos indicus* derived breeds, and the breeds involved in these abattoir studies may partially explain the lack of agreement between studies. Pathological conditions of the prepuce were detected in 0.8% of 504 bulls surveyed at three Western Australian abattoirs over an 18 month period (Turnbull 1977). The mean age of the bulls (with histories provided) was 4.4 years. The survey included mostly *Bos taurus* breeds including Hereford (30%), Shorthorn (16%), Friesian (14.3%) and Angus (13.9%) bulls and the conditions detected were three abscesses and one diverticulum, which presented as a pocket in the prepuce. Of 80 bulls culled through a NSW abattoir, none were culled for preputial problems. All were over 30 months old and the breeds were again mostly *Bos taurus* and included Hereford (32.5%), Poll Hereford (20%), Shorthorn (13.8%), Angus (15%), Santa Gertrudis (3.7%) and Devon (1.3%) (Bellenger 1971).

Analysis of data from 10940 bull examinations in Colorado showed that abnormalities of the prepuce (0.5%) were less common than penis defects (3.5%). Preputial abnormalities included posthitis, and fibromas with scar tissue and these were seen more commonly in polled breeds. The age of the bulls examined ranged from one to greater than ten years of age but a mean age was not given. There was an apparent increase in physical defects in bulls eight years of age and older but no supporting data were provided. As less than 2% of the bulls in the data set had *Bos indicus* content this only reflected the situation in the local *Bos taurus* breeds (Carroll *et al*. 1963).

Similar results were seen by Chenoweth and Osborne (1978) and Chenoweth (1978) who examined 702, 16-31 month old bulls from three different Queensland properties. Prolapse of the prepuce was seen in 0.8% of the bulls. The breeds examined included *Bos indicus* and *Bos indicus* derived (26%), Africander and Africander derived (26%) and Hereford or Hereford derived (48%). The percentage found in the study may be a reflection of the age of the bulls examined and it was noted that total preputial abnormalities (including ulceration and abscess) was 9.5%.

In contrast there is a view that the economic importance of preputial problems is appreciable, considering the high cost of breeding bulls, the age at which the condition occurs, and the losses caused by the temporary cessation of service. For example, out of 368 bulls presented at a Colombian University clinic for abnormalities of the genital tract, 15.2% presented with preputial inflammation (Amaya Posada 1979). Without presenting supporting data, Amstutz (1981) stated that injuries to the prepuce were the most common lesions seen at the Purdue University Veterinary teaching clinic. This was contrasted by the fact that bull soundness examination records of two Southern Queensland veterinary practices showed that only 11 bulls (0.37%) with preputial problems were found from the total of 2996 bulls examined (Bertram *et al.* 1993). This may not be surprising as preputial problems are generally readily detected by producers and the bulls would not usually be submitted for a breeding examination. Thus the reported prevalence of preputial abnormalities is likely to be underestimated.

Painful preputial lesions (Arthur 1956) and chronic inflammation of the prepuce may cause a bull to become reluctant to mate due to pain felt on erection and protrusion (Zemjanis 1970). Reluctance to mate is also seen with excoriation of the preputial orifice (Smythe 1959). Chronic inflammation of the prepuce can develop into prolapse or a condition where the penis can not extend through the preputial orifice (phimosis). This often renders the bull incapable of natural service (Johnson and Williams 1968). After dissection of the penis and prepuce, Walker and

Vaughan (1980) found that deep to the epithelium of the visceral prepuce is a series of elastic lamellae that are continuous with those surrounding the penis. Lacerations or contusions that penetrate the epithelium and involve the elastic layers interfere with the normal unfolding action of the prepuce and thus prevent normal extension of the penis. Many authors suggest that normal preputial eversion does not interfere with copulation unless the everting portion becomes traumatised (Wheat 1951; Zemjanis 1970; Wolfe 1986).

Semen straw production from bulls affected with preputial problems may also be interrupted. Preputial eversion in bulls at AI centres may lead to an unhygienic situation, which may impact normal semen quality due to contamination with environmental pathogens (Klug *et al.* 1979). Semen production problems were seen by Shires and Evans (1978) in a six year old Poll Hereford bull but these were due to prolapse rather than eversion. In this bull, chronic preputial prolapse with phimosis resulted in intrapreputial ejaculation and grossly contaminated sperm. This sperm was unfit for freezing and storage. In a study in which prepuces of 60 Murrah buffalo were examined, (Rao *et al.* 1988) sheaths were classified as tight, medium, pendulous and pendulous with eversion. Classification criteria were not given but photos of an example of each classification were provided. Results showed that the classification of the sheath did not influence the semen quality. In this study, preputial eversion was not considered a problem for semen production in buffalos.

Historical perspective of the importance of sheath conformation.

Historically, in the beef industry, greater selection pressure has been placed on growth rate than on sheath conformation. To improve selection balance, Hoogenboezem and Swanepoel (1995) suggested that information on the relationship of growth rate and sheath area would be helpful. It has also been stated that there is a paucity of objective measurements describing the variation in sheath characteristics in tropically adapted breeds, particularly in relation to bull mating performance (Bertram *et al.* 1997).

When evaluating cattle for functional efficiency, sheath conformation is important (Swanepoel and Hoogenboezem 1993, Bertram *et al.* 1997). Little is known about the inheritance of sheath area or its relationship to preweaning growth or body size, but most Zebu and derived breed associations discriminate against large and pendulous sheaths (Franke and Burnes 1985). Selective breeding against pendulous sheaths is meeting with some success in reducing the problem of sheath damage (Walker 1970). This is important because of the effects on mating ability, which are as significant as semen quality for fertility in the bull (Zemjanis 1970).

Bull external reproductive anatomy and function

Definitions

Although definitions by most authors are similar, there are some variations in descriptions, which cause confusion. A major problem in this field is that the prepuce is often called the sheath (Trotter and Lumb 1958). The two terms of sheath and prepuce are sometimes used interchangeably. One author who used the terms interchangeably defined the prepuce or sheath as a double invagination of skin which contains and covers the free portion of the penis when not erect and which covers the body of the penis behind the glans when the penis is erect (Roberts 1971). The terms, eversion and prolapse are also interchangeably used in the literature.

Sheath

One definition is that the sheath (or external layer of the prepuce) extends from the scrotum to within five cm of the umbilicus where it is reflected ventrally and laterally forming the thick margin of the preputial orifice (Donaldson and Aubrey 1960). A more general definition has the sheath extending to the scrotum and the inguinal area (Walker and Hull 1984).

For this review the sheath is defined as the hair-covered skin appendage that supports and protects the penis along the ventral abdomen. It extends from the scrotum to the preputial orifice (Wolfe 1986).

Prepuce

Some definitions were complicated and one author interpreted the prepuce to include all the lining epithelium from the tip of the penis extending to the preputial orifice, but this author acknowledged that differences in nomenclature do occur (Bellenger 1971). Other authors referred to the whole structure as the prepuce and the sheath as the external layer of the prepuce. The internal layer or prepuce proper then extends backwards from the preputial orifice and turns forwards on the penis to the glans penis (Donaldson and Aubrey 1960; Getty 1975). Other researchers divided the prepuce into sections. After dissection of 10 penises from adult bulls one group divided the prepuce into penile and prepenile portions (Ashdown *et al.* 1968). They found the collagen fibres much denser in the penile than in the prepenile prepuce and the penile prepuce to be less extensible than the prepenile prepuce. Another author divided the prepuce up into the internal lamina (or lining membrane, parietal layer, or mucous membrane), and the visceral layer (Hofmeyr 1987). The internal lamina is covered by squamous epithelium and extends from the orifice to the fornix. Usually, with the penis at rest, this is two-thirds of the distance between the orifice and scrotum. At the fornix it is reflected onto the penis, forming the visceral layer.

Williams (1918) description of the prepuce is when the penis is in the resting position. The prepuce extends back from the mucosal attachment at the base of the glans and then forward to the position of the apex of the penis (when in resting position) on the parietal layer. The sheath extends from this position forward to the orifice. Although not easily identified in live bulls, this definition is based on the embryonic history of the two membranes. The preputial epithelium is delicate and easily abraded and the epithelium of the sheath is coarser and offers higher resistance. The preputial mucosa is even and smooth, and the sheath mucosa is thrown into wavy longitudinal rugae.

For this thesis, the prepuce has been defined as the hairless epithelium within the sheath that extends caudally from the preputial orifice, is reflected at the fornix, then extends cranially to attach at the base of the glans penis (Walker and Hull 1984).

Preputial eversion

The condition in which a variable length of the prepuce protrudes temporarily from the preputial orifice is referred to as "preputial eversion" (Long 1969; Monke 1976). This definition has been used in this thesis.

Preputial prolapse

Preputial prolapse is a readily diagnosed condition but penile haematoma can be mistaken for prolapse of the prepuce, so careful examination is needed (Farquharson 1952). This confusion may occur because there is extensive swelling of the tissue along the sheath associated with rupture of the corpus cavernosum of the penis and the swelling may extend to the preputial orifice.

For this thesis preputial prolapse is defined as the protrusion of the prepuce with no tendency or ability to spontaneously retract it (Arthur 1964).

Anatomical Development

Large differences in rates of development of the penis and sheath are seen in bulls as demonstrated in a longitudinal study of five young bulls (three Jersey and two Galloway/Ayrshire cross bulls; Ashdown 1960). At the age of four months, the penis in these bulls could not be exteriorised. Despite all five animals repeatedly mounting each other while quite young, the penis was not protruded until they were approaching sexual maturity at eight to nine months. A similar study of another five calves and ten foetuses found that the wall of the penis portion of the prepuce was adherent to the free end of the penis during foetal and early postnatal life (Ashdown 1960). In a more extensive macroscopic and microscopic examination of 103 penises from bull calves and young bulls it was found that in the first week of life no preputial cavity exists between the glans penis and the prepuce because it is filled with irregularly arranged epidermal cells (the ectodermal lamella; Abdel-Raouf 1960).

From the study by Ashdown (1960) of five bull calves (aged between one and three weeks) and 10 foetuses, two distinct tissues were found to be involved in this adherence. Over the surface of the penis a thin lamella of ectodermal cells is adherent to the penis and to the prepuce. Near the urethral opening the ectodermal lamella is incomplete. The edges overlap without joining and a frenulum of connective tissue joins the penis to the prepuce. This description was simplified by stating that at birth, a single lamella of ectodermal cells fuses the epithelial surfaces of penis and internal lamina. The frenulum, a fine band of connective tissue, connects the penis and prepuce ventrally where the lamella is incomplete (Hofmeyr 1987).

By cleavage of the lamella two stratified squamous epithelial layers develop, one lines the prepuce and the other covers the glans penis. It was found that the process of cleavage starts at the age of four weeks and is finished sometime after the age of 32 weeks (Abdel-Raouf 1960). A mechanism for this was presented as being due to male hormonal action in late foetal life. With this action the lamella is split into keratinised epithelial layers of penis and prepuce (Hofmeyr 1987). Variation on the age of commencement of separation was found with others stating that at about four months the separation commences and is usually complete at nine months (Hofmeyr 1987). In breeds that show early sexually maturity, this process is concluded much sooner. The explanation of the timing of this separation was simplified by stating that keratinisation separated the penis from the prepuce in later life and proceeded in the ectodermal lamella (Ashdown 1960).

Parts of this development are comparable to other species and one group found in their work on 110 rams that the age at which the prepuce became completely separated from the glans penis was variable and associated with the general rate of growth (Watson *et al.* 1956). Although a study of 277 ram lambs found that with increasing age the glans penis is progressively freed (Johnstone 1948).

<u>Musculature</u>

An understanding of what is known and not known about the anatomy of the sheath, prepuce and penis is needed before any anatomical study in this area should commence. The literature can provide baseline information and can be compared with any study observations.

Preputial muscles

Two pairs of muscles, the cranial preputial (protractor) muscles and the caudal preputial (retractor) muscles are associated with the prepuce. (Trotter and Lumb 1958; Roberts 1971; Getty 1975; Walker and Vaughan 1980). These muscles are derivatives of the cutaneous muscles (Getty 1975; Walker and Vaughan 1980; Dyce *et al*. 1987) and are stated to be present in both sexes (Trotter and Lumb 1958) or at least a homologue of the cranial preputial muscle is present in the cow (Getty 1975). These muscles are subject to a good deal of variation (Getty 1975) and may partly account for a comment in an earlier report that published descriptions of the structure and function of the cranial and caudal preputial muscles of the bull are inaccurate (Aubrey and Butterfield 1970). Many anatomical studies of these muscles did not identify bull breed and this may explain some of the variation in description between studies.

Cranial (protractor) preputial muscle

Origin

The cranial preputial muscles originate from three distinct areas of the ventral abdominal wall: (a) the deep fascia, near the midline at the level of the xiphisternum, (b) the hypodermis or the superficial fascia overlying the ventral edge of the cutaneous trunci muscle and; (c) as slips from the most caudal part of the cutaneous trunci muscle (Ashdown and Pearson 1973). Other authors have provided a more simplified description as this muscle group arising from the xiphoid region (Dyce *et al*. 1987). Others describe the muscle group as originating from the fascia in the region of the xiphoid process of the sternum with each muscle having a cranial part about three times as wide as a caudal part (Aubrey and Butterfield 1970).

The muscles have been described as two flat bands, five to six cm in width, which arise close together in the xiphoid region, about 20 cm cranial to the preputial orifice (Getty 1975). Other descriptions include the muscles originating from the abdominal tunic anterior to the umbilicus (Trotter and Lumb 1958). Further descriptions have the muscles originating near the umbilicus and travelling posteriorly as flat bands (Walker and Vaughan 1980).

Insertion

The insertion of the paired cranial muscle is around the preputial orifice (Trotter and Lumb 1958) or forms a sling around the preputial orifice (Aubrey and Butterfield 1970). This sling is formed when the wide cranial part anastomoses with its collateral muscle ventral to the penis and many fibres insert into the skin. The narrow caudal part anastomoses with its collateral muscle dorsal to the penis (Aubrey and Butterfield 1970). Similarly (Walker and Vaughan 1980) described the muscles as terminating around the preputial orifice by attaching to the subcutaneous tissue of the sheath in a circumscribing manner with the muscles inserting beside and behind the preputial opening (Dyce *et al.* 1987). This was described as a loop around the prepuce at the start of the pendulous part (Ashdown and Pearson 1973) as these muscles insert into the outer layer of the wall of the prepuce dorsal to the orifice of the sheath. This loop was formed by the muscles as they diverged caudally leaving free the umbilicus and an area about 3.5 cm wide; they then unite caudal to the preputial orifice (Getty 1975).

Function

Stimulation of the motor nerves to the preputial muscles showed that when the cranial preputial muscles contract, the pendulous part of the sheath is pulled dorsally and cranially. The pendulous part of the sheath is elevated and the orifice is more or less constricted. The effectiveness of the cranial preputial muscles of the sheath in closing the orifice varies considerably in different bulls (Ashdown and Pearson 1973). Other authors provided various combinations of this action and reported that the muscle: draws the pendant part of the prepuce forward and upward and helps to constrict the orifice (Dyce *et al*. 1987); draws the prepuce forward (Getty 1975); controls the orifice of the sheath (Ashdown and Hancock 1968); raises the preputial orifice cranio-dorsally (Aubrey and Butterfield 1970); and raises and constricts the preputial orifice (Wolfe 1986). It also pulls the sheath forward and constricts the orifice of the prepuce. This constrictive action is most important since it serves as a barrier to foreign material entering the preputial cavity. Abnormal constriction of this muscle can prevent normal extension of the penis (Walker and Vaughan 1980). During mating, these muscles pull the external layer of the prepuce and the orifice backward prior to copulation, thus exposing a greater length of the penis (Trotter and Lumb 1958).

Caudal (retractor) preputial muscle

The caudal preputial muscles are long and narrow. They run parallel to the penis and are surrounded by abundant loose connective tissue (Trotter and Lumb 1958). Despite their considerable size, attempts to palpate these muscles in live bulls have been unsuccessful (Long and Hignett 1970). These muscles are frequently absent or vestigial in polled bulls and their absence may be associated with the development of habitual preputial eversion. When the caudal preputial muscles are absent, preputial retraction is a passive act and occurs secondarily to penis retraction by the retractor penis muscles. Because of this, polled bulls commonly evert the prepuce when relaxed (Wolfe 1986). Other authors also found that the size and presence of these muscles varies considerably, from being completely absent to partially developed in many polled bulls. Bulls that habitually expose the prepuce have been found to have no or incomplete development of these muscles (Walker 1980).

Origin

The caudal preputial muscles each originate from two separate sites. The lateral origin is from the dense layer of fascia that leaves the lateral edge of the external inguinal ring and runs into the scrotum to form the scrotal fascia. The medial origin is from the medial aspect of the scrotal septum, near its point of origin from the yellow elastic lamina of the abdominal wall (Ashdown and Pearson 1973). Many researchers have simplified this and stated that the muscles: pass from the region of the prepubic tendon (Aubrey and Butterfield 1970); originate from the abdominal tunic near the external inguinal ring (Trotter and Lumb 1958); arise from the abdominal tunic (Wolfe 1986); originate in the inguinal region lateral to the spermatic cord (Walker and Vaughan 1980); and arise in the inguinal region (Getty 1975).

Insertion

A variety of descriptions were provided which may reflect the variable development within and between breeds. Authors have stated that the caudal preputial muscles:

- insert into the outer layer of the wall of the prepuce (Ashdown and Pearson 1973)
- lie separately in the loose fascia dorsal to the penis. They unite near the cranial end of the prepuce dorsal to the penis. These muscles do not insert to the skin, but to the lining membrane of the prepuce at the junction of the smooth region and the region which is arranged in longitudinal folds (Aubrey and Butterfield 1970)

- insert to several inches of the lateral surface of the external layer of the prepuce (Trotter and Lumb 1958)
- insert into the insertion of the cranial preputial muscles (Wolfe 1986)
- pass anteriorly along the abdominal wall dorsal to the penis to their point of insertion into the deeper layers of the elastic lamellae of the prepuce (Walker and Vaughan 1980)
- converge on the cranial part of the prepuce (Getty 1975).

A method to identify these anatomical differences in live animals may help our understanding of preputial abnormalities and may assist detection of animals that may develop these abnormalities.

Function

Actions of the caudal preputial muscle remain unclear and their function is described as being of uncertain importance (Dyce *et al*. 1987). Dissection of tissues from seven bulls from breeds that do not normally evert showed that, on maximum protrusion of the non-erect penis, the insertion of the caudal muscles into the outer concentric layer of the prepuce moves very little (Ashdown and Pearson 1973). The inner parts of the prepuce slide out while the loosely connected outer layer moves little. When the caudal preputial muscles are stimulated, the outer layer of the prepuce and the surrounding fascia are pulled caudally but there is little effect on the penis or on the inner layers of the prepuce. Under these conditions, the outer concentric layer of the prepuce appears not to participate in eversion to any significant degree, however protrusion of the erect penis was not studied at this time. In most bulls the muscle is large and powerful and might assist in penis retraction. Where present it was of considerable size having a belly of about 2.5 by 1.0 cm and an extensive insertion over some 10 cm (Long and Hignett 1970) and it seems inconceivable that it should play no role in the function of the prepuce or penis (Ashdown and Pearson 1973).

In contrast, other authors have stated that when the penis is protruded, the caudal preputial muscles pass through the sling of the cranial preputial muscles and insert to the deep surface of the now everted preputial lining, which is a considerable distance along the extended shaft of the penis (Aubrey and Butterfield 1970). This should indicate that the muscle is involved in movement of the prepuce. Other authors supported the muscle involvement and stated that these muscles draw the prepuce caudally (Getty 1975) and returned the prepuce to its original position after service (Trotter and Lumb 1958).

Retractor penis muscles

The retractor penis muscles are strong muscles that retract the penis (Trotter and Lumb 1958). If the retractor penis muscles are short (due to hypoplasia in the congenital condition) or contracted (due to fibrosis), the muscles feel like distinct cords behind the scrotum (Hofmeyr 1967). However, the tone of this muscle was found to be not uniform throughout its length (Ashdown and Pearson 1973).

Origin

Each retractor penis muscle consists of two bands and is flat at its origin from the transverse processes of the first coccygeal vertebra (Trotter and Lumb 1958; Ashdown and Pearson 1973) or arises from the caudal vertebrae as others simply stated (Dyce *et al*. 1987). Both groups of authors may be correct as many muscles that are flat at their origins have wide attachments through the local fascia.

Insertion

This muscle group inserts on the penis at, and anterior to, the ventral bend of the sigmoid flexure (Trotter and Lumb 1958; Ashdown and Pearson 1973). Some fibres attach here but most proceed to a more distal and diffuse insertion (Dyce *et al*. 1987). The insertion point for this muscle group has also been described as ending in the outer layers of the peripenile fascia, 12-15cm caudal to the free end of the penis (Hofmeyr 1987).

Function

The retractor penis muscles are exceptionally strong and their action is to retract the penis after protrusion and to maintain the sigmoid flexure in the relaxed state (Trotter and Lumb 1958). Others describe the action as pulling the penis caudally, which increases the sigmoid flexure and stretches the sheath. These muscles also maintain the resting position of the penis after service (Ashdown and Pearson 1973).

<u>Vasculature to the sheath and prepuce</u>

Most authors have described the blood supply to the sheath and prepuce as arising from the external pudendal artery (Ashdown and Hancock 1968; Roberts 1971; Hofmeyr 1987). Other descriptions also mention the dorsal artery of the penis (Trotter and Lumb 1958; Hofmeyr 1987) and the subcutaneous abdominal artery (Trotter and Lumb 1958). Ashdown (1958) summarised the vasculature as the main artery of the sheath being the unpaired recurrent artery which runs along the dorsal surface. The recurrent artery is a branch of the caudal superficial epigastric artery, with small branches from the paired dorsal arteries of the penis also supplying the sheath.

A summary of the venous drainage of the sheath area has been given by Ashdown (1958). The large branched ventral vein of the sheath anastomoses with the dorsal veins of the penis and drains into a venous plexus situated near the orifice. This plexus is itself drained by one or both subcutaneous abdominal veins. The general pattern of circulation in the bovine sheath is that blood reaches the sheath flowing back along the dorsal surface in the main artery of the sheath (the recurrent artery) and is collected by the main vein (the ventral vein of the sheath). The ventral vein runs forwards to the plexus of veins at the orifice (Ashdown 1958).

Blood supply to the penis.

There is a variation in nomenclature of descriptions in that the perineal artery and the artery of the bulb supply the penis (Trotter and Lumb 1958). However Hofmeyr (1987) indicated that the blood supply of the penis comes from the internal pudendal artery, which gives off the dorsal artery of the penis and the deep branch (the deep artery of the penis). When considering possible variation in blood supply it is interesting to examine the anatomy of other animals. A variety of animals (dog, red deer, wapiti and monkeys) were examined by Deysach (1939) and it was found that the blood supply to the erectile bodies of the penis is derived from branches of the internal pudic artery: the dorsal artery of the penis, the artery of the corpus cavernosum, and the artery to the bulb. This was also recorded in cattle (Getty 1975).

Injected specimens revealed the important venous channels in the penis as: the superficial dorsal vein, the deep dorsal vein, the venae profundae, the venae bulbi urethrae and the circumflex veins (Deysach 1939). This information was unearthed from a range of species and was not limited to cattle.

<u>Innervation to the external reproduction organs</u>

As with many anatomical studies, descriptive differences have been recorded. A study by Larson and Kitchell (1958) summarised the nerve supply to the external reproduction area by noting that the central origin of nerves concerned with supplying the external genitalia can be divided into cranial, middle, and caudal parts. The nerve supply of this area is important as damage can impair the bull's ability to copulate (Beckett *et al.* 1978). A simple version of the innervation is that the pelvic plexus supplies sympathetic and parasympathetic fibres to the pelvic genitalia and to the penis (Ashdown and Hancock 1968).

The preputial muscles (cranial and caudal) receive their motor nerve supply from branches of the lateral thoracic nerve (Larson and Kitchell 1958; Larson *et al*. 1961; Hofmeyr 1987). This nerve originates from the ventral branches of C8, Th1 and Th2 (Larson *et al.* 1961), but was also described as arising from the brachial plexus in the axilla (Larson and Kitchell 1958; Ashdown and Pearson 1973; Hofmeyr 1987). It has also been stated that ventral branches of several thoracic and lumbar spinal nerves supply the preputial muscles (Trotter and Lumb 1958), further confirming the varied information on the innervation of the anatomy of the genitalia of the bull.

The retractor penis muscles are supplied proximally by the middle hemorrhoidal nerve (Larson and Kitchell 1958) and distally by the dorsal nerve of the penis (Larson and Kitchell 1958; Hofmeyr 1987). Several small branches of the dorsal nerve of the penis also enter the retractor penis muscles at the distal curve of the sigmoid flexure (Beckett *et al*. 1978). The retractor muscle of the penis is also innervated proximally by the terminal part of the caudal rectal nerve (Hofmeyr 1987). A simplified description is that sacral nerves supply motor fibres to the muscles of the penis (Ashdown and Hancock 1968).

The sensory nerve supply to the body and glans of the penis are the dorsal nerves of the penis (Larson and Kitchell 1958; Beckett *et al.* 1978; Hofmeyr 1987) that originate from the pudendal nerves at the ventral aspect of the ischial arch (Beckett *et al.* 1978). This supply was described as sacral (Ashdown and Hancock 1968) and as sympathetic fibres of the pudic nerve (Trotter and Lumb 1958). Bilateral dorsal penis neurectomy abolished the ability of the bull to locate the vagina during service attempts, and if the vagina was accidentally located, the bulls were still unable to ejaculate. Unilateral neurectomy did not abolish the ability to copulate. This suggests that in cases of trauma, one nerve could be severed without abolishing the bull's ability to copulate (Beckett *et al.* 1978). The sensory nerve supply to the prepuce includes the cranial preputial (rising from the ventromedial branches of T13, L1 and L2), the middle preputial (from the caudal branch of the inguinal nerve) and the caudal preputial nerves (from the superficial perineal branch of the pudendal nerve) (Larson and Kitchell 1958; Hofmeyr 1987).

<u>Methods of defining the conformation of external reproductive structures in the bull</u>

This thesis aimed to confirm some of the causes and the significance of the causes of preputial prolapse and preputial eversion in *Bos indicus* and *Bos indicus* derived bulls. To achieve this, the possible predisposing causes needed to be identified in the literature. Any suggested predisposing structures could be objectively measured and studied in relation to preputial eversion or preputial prolapse in *Bos indicus* and *Bos indicus* derived bulls.

External reproductive structures in the bull have been objectively measured by many authors with a view to defining the conformation of the bull and relating these measurements to reproductive performance. For example, a study by Lagos and Fitzhugh (1970) showed that all the sheath measurements observed except eversion score tended to increase with age although these regressions on age were not statistically significant at $P < 0.05$. Some of the external reproductive structures measured by different authors are discussed below to show the range of measurements used by authors to objectively measure the bull external reproductive organs and associated structures. Such a variety of measurement techniques in the literature suggests that the best universal measurements that are related to reproductive problems have not yet been found. Other possibilities should therefore be investigated.

In previous studies sheath area was calculated by photographing each animal in front of a grid of known measurements from a standard distance (Franke and Burnes 1985; Hoogenboezem and Swanepoel 1995). Some authors have used a more subjective measurement (a sheath score) to estimate sheath area (Bertram *et al.* 1997). This score was assessed using the recording format used in the Australian national BREEDPLAN validation project where 1 = an extreme pendulous sheath to 9 = an excessively trim sheath. Sheath size and shape of sheath are also classified as part of the Brahdex evaluation system in South Africa (Swanepoel and Hoogenboezem 1993) although details of the method were not included in the publication.

Sheath depth has been defined as the vertical distance from the edge of the sheath at the preputial orifice to the abdominal wall (Bertram *et al.* 1997; McGowan *et al.* 2002). Other groups have described this as sheath length (Lagos and Fitzhugh 1970; Swanepoel and Hoogenboezem 1993) or prepuce length (Smith *et al.* 1981; McGowan *et al.* 1998). A lot of confusion exists because the term sheath length is described as the distance from the front of the scrotum to the preputial orifice (Smith *et al.* 1981) which is a completely different measurement to the others.

As part of the Brahdex evaluation system in South Africa, sheath conformation is classified on a ten point scale (Swanepoel and Hoogenboezem 1993). Seven criteria were used to develop this system and these included the vertical distance from ground to the orifice and the shape of the sheath including navel fold.

The preputial cavity is about 35 to 40 cm long and about three cm in diameter (Getty 1975) though no breed information was presented with these figures. In other studies by Bellenger (1971) *Bos indicus* breeds have been found to have a significantly greater total prepuce length (54.8cms) than *Bos taurus* breeds (49.3cms). This information was calculated from data on 58 slaughtered bulls and the breed difference was significant. Of the *Bos taurus* breeds examined, polled breeds (Poll Hereford, Poll Shorthorn and Angus) had greater mean prepuce length than horned Hereford and Shorthorn although the differences were not statistically significant in the study. This prepuce measurement was from the tip of the glans penis to the preputial orifice with the penis fully extruded after slaughter. Another method of measuring prepuce length was to determine the length of the epithelium by the use of a probe inserted to the reflection (Long and Hignett 1970; Van Den Berg 1984). Other authors also measured the length of the penile prepuce and total prepuce but the technique was not recorded (Bellenger 1969).

The preputial orifice has been defined to be located about 5cm caudal to the umbilicus and is also only large enough to admit a finger readily (Getty 1975). However, others have quoted an average measurement of 2-4 cm in diameter, although no breed information was given (Roberts 1971). In separate studies, the internal diameter of the preputial orifice was measured using callipers with a subjectively determined degree of tension against the internal wall (Lagos and Fitzhugh 1970). The external circumference of the sheath at the preputial orifice was measured along the hairline around the preputial orifice. Internal diameter and external circumference should be related as the diameter and circumference of a circle but base breed differences were found which may have been due to breed differences in hide thickness. No confirmation of this possibility was reported. A similar measurement of the half-circumference of the preputial orifice taken after slaughter with internal callipers was reported (Long and Hignett 1970). Also as part of the Brahdex evaluation system in South Africa orifice diameter was measured (Swanepoel and Hoogenboezem 1993). Circumference of the orifice was also measured with dividers (Van Den Berg 1984).

Preputial eversion at rest was scored by Lagos and Fitzhugh (1970). *Bos indicus* derived bulls were placed in groups of 35 to 40 and allowed to stand at rest. They were continually observed for 1 hour and classified according to the estimated extent of exposed prepuce. Bulls were not scored when they were urinating as this changed the scoring. The 4 classes were; no exposure, slight (<3cms), moderate (3-8cms) and extreme (>8cms), the maximum score for each bull being used in this analysis. They used this score in their analyses and found that the eversion score was related to the sheath depth.

The penis has also been measured in mature bulls and the total length of the flaccid penis was found to vary from about 90 cm, particularly in *Bos taurus* breeds, to about 110 cm in *Bos indicus* breeds or crosses (Hofmeyr 1987). Although both *Bos taurus* and *Bos indicus* bulls develop preputial prolapse, the difference in length of the penis may still be important as the mechanisms for preputial prolapse may vary between the breeds.

Other measurements included umbilical cord or navel thickness score which was assessed on a scale of 1 = approximately 0.5 cm to 5 = 3.0 cm (Bertram *et al.* 1997). The 'rosette' or inverted fold of skin in the sheath at the external interface of the umbilical cord was recorded as 0 = absent, 1 = small and 3 = large (an inverted semi circle about 5cm diameter) (Bertram *et al.* 1997). These were measured as they are closely associated with the sheath and their size may be an indicator of preputial problems.

Sequence of preputial abnormalities

Preputial pathology presents as a variety of clinical conditions due to varying aetiology and pathogenesis (Wolfe 1986). Conditions seen in a study of 172 cases of preputial injuries included preputial lacerations, abscessation, and stricture with phimosis and preputial prolapse with preputial haematoma (Memon *et al.* 1988).

Lacerations of the prepuce must be considered as part of a complex because it can lead to a series of conditions with many possible sequelae. Because of the irritation caused by the laceration and the fact that it is an area that can remain quite contaminated by environmental pathogens, oedema, cellulitis, abscessation, and scar tissue formation can occur due to the laceration. Depending on the extent of the lesion and the position of the penis, these conditions can lead to phimosis, paraphimosis, or adhesions (Walker and Hull 1984).

Other authors had similar descriptions and Walker and Vaughan (1980) stated that the pathogenesis of preputial abnormalities is insidious and self aggravating. Small abrasions of the prepuce cause oedema of the prepuce that predisposes to prolapse with subsequent bruising and laceration (Walker and Vaughan 1980; Hofmeyr 1987). This leads to erosions, abscessation and fibrosis (Walker and Vaughan 1980).

During mating, young bulls may repeatedly mate females in oestrus until the penis and prepuce becomes erythematous and excoriated, creating a traumatic balanoposthitis which may lead to prolapse (Wolfe 1986). In one retrospective study, records on 368 bulls with genital conditions were examined to determine cause and it was determined that the age at which inflammation of the prepuce occurred was during the most active period of breeding activity (Amaya Posada 1979). Lacerations at the reflection of the prepuce onto the penis generally occur during copulation and some have stated that this injury is seen in hard thrusting young bulls (Rice 1987), which may lead to further problems in high libido bulls that continue to breed and exacerbate the problem.

One sequence observed started with posthitis and ulceration of the prepuce. Infection could then enter the traumatised epithelium leading to inflammation and prolapse. This area is then exposed to further trauma (Donaldson and Aubrey 1960). Other work indicated that laceration with phimosis is the most common type of preputial laceration (Walker and Vaughan 1980).

Other authors stated that phimosis may be congenital or acquired, the latter being more common. Adhesions within the sheath can also be congenital or acquired and simple adhesions can be severed but multiple adhesions are usually difficult to treat (Gibbons 1956).

Initial trauma is not always required to initiate the sequence leading to preputial abnormalities. Under certain circumstances in susceptible bulls the degree of protrusion may become too much to be retracted. Gravity then interferes with venous drainage which leads to oedema. Because the prepuce does not retract, the surface then dries and becomes irritated leading to thromboses, infarction, ulceration and infection. If left untreated, necrosis and gangrene could be the end result (Arthur 1964).

Penis and preputial abnormalities may be linked and this is seen when there are successive contractions of the ischiocavernous muscle after tearing the tunica albuginea of the penis forcing blood into the subcutaneous areas forming a haematoma and often causing a secondary prolapse of the prepuce. Some authors stated that this secondary prolapse is seen more commonly in polled bulls that have poorly developed caudal preputial muscles (Walker and Vaughan 1980). Some highlighted the importance of this secondary problem and stated that haematomas in the region of the penis are exceedingly common (Hofmeyr 1987).

Factors predisposing to preputial prolapse

Breed differences in preputial prolapse.

Studies to date have indicated that breed of bull may influence occurrence of preputial prolapse, indicating that heritability plays a role in the aetiology of abnormalities of the sheath or the associated predisposing mechanisms (Venter and Maree 1978; Memon *et al.* 1988). The effect of breed is also a contentious issue and findings and ideas vary widely. Lagos and Fitzhugh (1970) highlighted that the apparent variation in the predisposition to prolapse observed among breeds resulted from surveys or experiments that were not designed to eliminate the influences of extraneous sources of variation. More quality research is needed to clarify these breed differences.

The prevalence of preputial problems reported in some breeds only reflects the proportion of that breed in that area (Desrochers *et al*. 1995). Reference population data are required to determine the significance of breed involvement. Breeds that have been reported to present with preputial problems include: Brahman (Mosaheb *et al*. 1973; Memon *et al.* 1988; Bruner and Van Camp 1992), Brangus (Memon *et al.* 1988; Baxter *et al*. 1989; Desrochers *et al*. 1995), Beefmaster (Memon *et al.* 1988; Baxter *et al.* 1989), Santa Gertrudis (Lenert 1956; Donaldson and Aubrey 1960; Larson and Bellenger 1971), Angus (Wheat 1951; Milne 1954; Baxter *et al.* 1989), Simmental (Desrochers *et al*. 1995), Hereford (Donaldson and Aubrey 1960; Arthur 1964), Africander (Hofmeyr 1968), Jersey (Hofmeyr 1968), Friesian (Hofmeyr 1968), Red Sindi (Hattangady *et al.* 1968) and Poll Hereford (Milne 1954; Walker 1966). This range demonstrates the extent of the issue and confirms the importance of any research in this condition that may clarify the differences in breed incidence.

Bos taurus type bulls were more commonly affected with preputial injury (82.5%) than *Bos indicus* bulls (18%) in a study of 51 cases seen in a US veterinary hospital (Desrochers *et al*. 1995). Individual breeds most affected were; Angus (45%), Simmental (12%) and Brangus (10%). These results are countered by the fact that the predominant breeds seen were Angus (27%), Hereford (22%) and Simmental (17%). It was further stated that the proportion of *Bos taurus* breeds (82%) to *Bos indicus* breeds (18%) affected was in proportion to the breed population in Kansas. So although the incidence of preputial prolapse varied between individual breeds in this area, *Bos indicus* and *Bos taurus* bulls were proportionally affected.

Many researchers presented only population estimates of, rather than specific, total numbers of bulls affected with preputial prolapse from the different breeds. The number of bulls with preputial injuries from the Brangus, Brahman and Beefmaster breeds was higher than in the nine other breeds included in a survey by Memon *et al.* (1988). They clarified this by stating that this could be an indication of the breeds' proportion of the total cattle population in the Louisiana and Oklahoma areas as the population data was not available.

Studies showing no difference in incidence of preputial injuries amongst breeds were limited. Most of the 25 head with preputial prolapse obtained from a sample of 550 bulls at an abattoir were Brahman or Brahman derived bulls (Mosaheb *et al*. 1973). Breed break-up in the total number was not presented and may have given a clearer picture of the breed influence. The cattle in this study came from North Queensland and the Northern Territory where an increasing proportion of the cattle may be expected to be Brahman infused in 1973 when the paper was written.

Over a four year period in Townsville, cases of posthitis were seen by Donaldson and Aubrey (1960) in 19 Santa Gertrudis bulls, two Santa Gertrudis derived bulls, three Zebu derived bulls, one Hereford bull and one Zebu steer. At the time of the study the population of Santa Gertrudis and Brahman was very low in North Queensland with the principal breeds being

Shorthorn and Hereford. Although small numbers were involved and no statistical analysis was presented, the author referred to, but did not directly state, a high incidence in Santa Gertrudis bulls.

Cases of surgical conditions of the prepuce were seen by Hofmeyr (1968) in four Herefords, two Africanders, three Santa Gertrudis, 13 Brahmans, one Jersey and one Friesian. Although not statistically analysed, Africanders were very popular in South Africa in 1963, but Brahmans were present in relatively small numbers and Santa Gertrudis were uncommon (Hofmeyr 1968). After considering the breed proportions and relating this to the proportions presented with surgical conditions of the sheath, Hofmeyr (1968) felt the Brahman breed had a higher incidence of preputial injury that required surgical correction, which indicated a possible weakness of the breed when managed in South Africa, due to harsher conditions. Although bred to thrive under similar environmental conditions as the Africander, the pendulous nature of the preputial skin in Brahman breeds has been maintained. Hofmeyr (1968) acknowledged that the difference between the two breeds may well lie in the fact that the imported representatives of the Brahman breed were obtained from a population that had been selected in a relatively protected physical environment.

Breed differences in preputial eversion.

Preputial eversion is important because it has been anecdotally linked to preputial injuries and most studies show breed differences in preputial eversion tendencies. Preputial eversion has been noted in Brahman (Johnson and Williams 1968; Supple-Kane 1969; Long and Rodriguez Dubra 1972), Brahman derived (Gibbons 1956; Supple-Kane 1969; Long 1969), polled breeds (Monke 1976; Klug *et al.* 1979; Ott 1986), Hereford (Long 1969) and in horned Friesians (Supple-Kane 1969). Although no population data were given, Supple-Kane (1969) stated that preputial eversion is also very common in the Sahiwal and the Boran in Kenya.

The incidence of preputial eversion was recorded in 244 bulls of 13 British breeds. Twenty-eight (85%) of 33 polled bulls everted whereas only three (1.4%) of 211 horned bulls did so (Long 1969). This included 10 of 11 Angus (91%), 9 of 12 Polled Herefords (75%) and 1 of 46 horned

Herefords (1.4%). In this study it was found that there seemed to be a clear relationship, as far as British breeds were concerned, between polling and eversion of the prepuce. Analyses of the figures revealed a highly significant odds ratio of 388. This relationship was not absolute and Long (1969) stated that the variation may have been related to heterozygosity because some of the polled bulls were known to be heterozygotes. If this was not always the case, and some evidence suggests that homozygous polled non-everting bulls do exist, then it may be possible to select strains of polled bulls free of this condition. On two estancias in Argentina, Long and Rodriguez Dubra (1972) recorded the incidence of preputial eversion in 487 bulls from 11 breeds was greatest in polled European breeds and Zebu breeds. Only low numbers were observed in many of these breeds and the source population data given was that breeds in which preputial eversion was found to be common were the predominant breeds in the area.

A study by Lagos and Fitzhugh (1970) used least squares means and regression coefficients to show a significantly lower average preputial eversion score for bulls whose dam was Shorthorn compared with bulls from Hereford, Angus and Red Angus dams. Lagos and Fitzhugh (1970) felt this supported a lack of evidence incriminating the Shorthorn breed in preputial prolapse.

Ott (1986) stated that eversion was found to some degree in all naturally polled bulls and in *Bos indicus* bulls but not in horned animals (although horned *Bos indicus* bulls were not mentioned in the last part of the statement). Wolfe (1986) stated that *Bos indicus* bulls had a higher incidence of eversion than other breeds. In other horned breeds e.g. Santa Gertrudis and Brahman, eversion has been reported to be common (Long 1969).

From the literature the breeds affected by preputial problems can be categorised into two main groups;

- *Bos indicus* and derived breeds
- Polled *Bos taurus* breeds

Each group has many different associated risk factors and should generally be considered separately.

Age

Preputial prolapse is seen in bulls of various ages but not often recorded in any animals under one year of age. Affected bulls were usually identified after they had been mated to cows and many authors reported the condition more commonly in younger bulls (Amaya Posada 1979; Wolfe 1986; Rice 1987). Even with authors who quoted a large range of ages, the average age still indicated that the condition was more common in young bulls (Memon *et al* 1988; Baxter *et al.* 1989; Desrochers *et al.* 1995). In a study of 172 bulls with preputial injuries, Memon *et al.* (1988) recorded a range of one to twelve years with a mean of 3.5 years. In this study, 85% of the bulls with preputial prolapse or posthitis were *Bos indicus* or *Bos indicus* derived bulls and age was not correlated with breed. Baxter *et al.* (1989) recorded a range of one to seven years with a mean of 3.5 years in 33 bulls with preputial prolapse. In this study, 97% of the bulls were *Bos indicus* or *Bos indicus* derived. A similar low mean age (2.5 years) was recorded by Desrochers *et al.* (1995) in a study of 51 bulls with preputial injuries. The ages ranged from one to five years of age and 82.3% of the bulls were *Bos taurus*.

Interestingly, a northern Australian abattoir survey looking at preputial prolapse found that most (76%) affected bulls were mature (3.5 to 7 years of age) and 24% were old (>7years of age) (Mosaheb *et al.* 1973). A reasonable proportion (22%) of the cattle in this study were classified as young (< 3.5 years) compared with 59% classified as old. This later prevalence may reflect the age of first breeding usage of bulls in this study. Further analysis of the prevalence within these age groups showed that older bulls were less affected than mature bulls (2% compared with 11%).

If predisposing factors related to preputial problems could be confidently identified in bulls before they reached puberty then susceptible bulls could be culled before use and the incidence of clinical preputial prolapse could be greatly reduced. This would reduce production loss where bulls failed to get calves and more importantly the bulls prone to the conditions could be culled before they had the opportunity to pass these heritable traits to the next generation.

Season

Some authors noted a seasonal pattern of preputial problems and linked this to the breeding season. This may reflect the possibility that many bulls are injured while breeding. Arthur (1964) reported that prolapse was a condition of the grazing animal whilst in the company of bulling heifers or cows and all cases occurred in the summer months. A study by Memon *et al.* (1988) further supported this finding by noting a seasonal pattern of injuries occurring mainly during the breeding season from April to August with a peak in June. When examining hospital cases, Desrochers *et al.* (1995) reported a seasonal incidence of preputial injuries with peaks during the period of May to July (53%) and November to February (33%). These coincided with the spring and autumn breeding season.

Donaldson and Aubrey (1960) stated the incidence of posthitis and prolapse of the prepuce was not associated with seasonal pasture fluctuations. Other studies, however, noted direct pasture links in groups of Angus and Hereford that were affected while grazing subterranean clover dominated pasture, which could be due to a possible phyto-oestrogen effect (Larson and Bellenger 1971). Correa *et al.* (1978) also reported possible nutritional effects predisposing to preputial problems where a higher incidence of preputial inflammation occurred in bulls fed on high planes of nutrition compared to natural pasture fed bulls. This study of 1096 bulls in 17 different establishments postulated that the lesions are due primarily to production of ammonia by *Corynebacterium*. Further studies would be needed to clarify the association of seasonal pasture fluctuations with the incidence of preputial prolapse.

Structures predisposing to preputial pathology

Many factors are reported to be associated with preputial problems in bulls. Therefore, it is important that these are correctly identified for the different breed types, as early recognition of bulls predisposed to prolapse could prevent later-life breeding problems. Arthur *et al.* (1982) stated that in general, preputial lesions occur at two sites. The more common is at the segment of mucosa close to the preputial orifice that is everted and traumatised. The other site is near the area of attachment of the preputial skin to the body of the penis. Other structures, where variation may predispose bulls to preputial problems, are the sheath (control, depth or pendulousness), prepuce (length, volume or eversion) and the preputial orifice (size or ability to constrict).

Sheath control, which is defined as the ability to lift the orifice, was seen as a factor in the aetiology of posthitis with resulting preputial prolapse in bulls (Donaldson and Aubrey 1960). No data were collected to analyse this observation in this study. Without sheath control, Wolfe (1986) highlighted the observation that if the penis cannot be raised to the level of the vulva of the cow the bulls will be impotent without pathology.

A long or pendulous sheath was identified as a factor that may lead to preputial problems in bulls, as described by many authors (Ganesakale, Ramaswamy and Wilson 1964; Johnson and Williams 1968; Zemjanis 1970). Long (1969), however, observed that pendulous sheaths may not necessarily be the cause of eversion in British breeds as it was noted Friesian bulls which rarely evert generally have a more pendulous sheath than those of Angus bulls.

Larson (1986) stated that Polled bulls, which tend to chronically evert the prepuce but have a sheath that is not pendant, do not seem to have an increased incidence of traumatic preputial disease.

Sheath problems seen in *Bos indicus* cattle may be related to sheath depth. Swanepoel and Hoogenboezem (1993) stated that Zebu breeds have more skin than *Bos taurus* breeds in the sheath area and this occurs in both sexes and varies in size and shape. Support for this idea came from Hofmeyr (1987) who noted that the sheath depth in the Nelore is more like that in *Bos taurus* and preputial prolapse in not a problem in this breed.

Preputial structure is also a factor which leads to preputial problems (Lenert 1956; Walker and Hull 1984; Ott 1986) and some authors suspect preputial length is a major contributing factor (Bellenger 1971; Klug *et al.* 1979; Van Den Berg 1984). Memon *et al.* (1988) supplied evidence to the contrary and stated that the Africander breed has a longer prepuce than the Brahman and the incidence of preputial prolapse is low in the Africander but is high in the Brahman. However, in the Zebu breeds the length of the prepuce plays a major role in preputial prolapse (Klug *et al.* 1979). This was in agreement with Wolfe (1986) who found that bulls of the *Bos indicus* breeds have a more pendulous prepuce that averages 5.5cms longer than in *Bos taurus* breeds (Wolfe 1986). Possibly the preputial length may be a factor in the development of preputial prolapse in some breeds.

Van Den Berg (1984) measured 373 bulls of different breeds in South Africa, where Brahmans numerically dominate, and found that the overall length of the prepuce from the orifice to the fornix of the Brahman and Africander breeds exceeds that of all other breeds. In the Africander breed, however prolapse of the prepuce is virtually unknown suggesting prepuce length is not the determining factor in the development of preputial pathology. This may be supported by information provided by Long and Hignett (1970) who found that preputial length measurement after slaughter did not show a significant difference between everting and non-everting bulls. This suggests that the length of the prepuce is not important in the development of preputial prolapse or preputial eversion but more research is needed to determine if both these findings apply for *Bos indicus* and *Bos taurus* bulls.

Arthur (1964) reported that bulkiness of the prepuce is related to prolapse in bulls. This was in contrast to results from dissections in *Bos taurus* bulls that showed there was no difference in the mean preputial volume between horned bulls (which do not commonly evert) and polled bulls (Long and Hignett 1970). No information on prepuce bulkiness was found for *Bos indicus* bulls.

Eversion of the prepuce was seen to be a major predisposing factor in preputial pathology by many authors (Donaldson and Aubrey 1960; Ott 1986; Larson 1986), and was confirmed by Monke (1976) who stated that most cases of prolapse requiring surgery have been in breeds known to evert. In contrast, a study of 244 bulls of 13 British breeds, it was noted that health records revealed no greater incidence of preputial disease in bulls that everted than in those which did not (Long 1969). Unfortunately, no analysis was presented from these records. These results, however, were further supported by a study of 487 bulls where eversion of the prepuce was found to be of little clinical significance by determining that the presence of preputial ulcers was statistically unrelated to eversion (Long and Rodriguez Dubra 1972).

In a study of 244 bulls of 13 British breeds, it was determined that eversion occurred concurrently with any activity and was seen commonly during times of particular excitement or during urination and defaecation but was seen less frequently during grazing and rumination (Long *et al.* 1970). The duration of a single preputial eversion and the amount of epithelium protruded varied widely, both between and within bulls and could vary from a continuous eversion and retraction in one movement to one eversion of 15 minutes (Long *et al.* 1970). The extent ranged from 1.2 cm to 10.0 cm (Long *et al*. 1970; Ott 1986).

There have been variable reports of contributions of the muscle groups that control movement of the penis and prepuce to the occurrence of preputial eversion. For example, polled bulls are more susceptible to eversion due to a heritable weakness of the caudal and cranial preputial muscles (Rice 1987; Bruner and Van Camp 1992) or to the degree of control exercised by these muscles (Arthur 1964). Other literature states that the predisposition to preputial prolapse involves breeds of bulls that have incomplete development or absence of the caudal prepuce muscle (Walker and Vaughan 1980; Wolfe 1986). The effectiveness of the cranial preputial muscles also varies between breeds and individuals within a breed (Wolfe 1986). When musculature was divided up into breeds it was found that in polled breeds, especially polled Herefords and Angus, the caudal preputial muscles are absent or rudimentary often leading to chronic preputial prolapse (St. Jean 1995).

Long and Hignett (1970) dissected 30 prepuces of British breed beef and dairy bulls to look at anatomical differences in the prepuces of everting and non-everting bulls. When observed before slaughter all seven of the polled bulls examined were seen to evert but only one of the 19 horned bulls showed signs of eversion although one was not examined prior to slaughter.

The difference between these bulls was statistically significant. Well developed cranial muscles of the prepuce were present in all 30 bulls dissected and the horned bulls all had well-developed caudal preputial muscles but these muscles were absent in all of the polled bulls. The one horned bull to evert may not have everted until old age as it was 15 years old at examination and the eversion may have been associated with neural or muscle degeneration (Long and Hignett 1970).

Another view was stated by Klug *et al.* (1979) that eversion is very common in Angus bulls due to individual connective tissue weakness or similar defects in the prepuce. This was supported by a study performed on six young Friesian and one young Jersey bull which found that in some bulls, in the absence of muscular control of both prepuce and penis, eversion did not occur (Ashdown and Pearson 1973). It was presumed that the structure of the sheath and its attachments were sufficient to retain preputial tissue within the superficial fascia of the ventral abdominal wall. In 1987, Hofmeyr (1987) found that no observations had been published concerning investigation of the caudal preputial muscles of *Bos indicus* bulls. At that stage it was uncertain whether the muscles in *Bos indicus* bulls prone to prolapse are different from those in bulls that are not.

Walker (1980) stated that preputial prolapse occurs chiefly in bulls of *Bos indicus* derivation and it is predisposed in these animals because their pendulous prepuce favours gravitational oedema and fibrosis. This often is further aggravated by the absence or incomplete development of the caudal muscles of the prepuce (Walker 1980) or because these caudal preputial muscles in the Brahman are underdeveloped with poor tone (Memon *et al.* 1988). Van Den Berg (1984) supported this with dissection of one Brahman (and this was acknowledged as too few to be definite by the author). In this study the author concluded that the preputial muscles and retractor penis muscles in Brahmans are underdeveloped with poor tone.

However, Bellenger (1971) performed measurement studies on 58 slaughtered bulls, and found certain clear preputial anatomical breed differences but the study included only two *Bos indicus* breeds and selection procedures for the cases were not given. Although only 13 *Bos indicus* bulls were examined, the study concluded that for *Bos indicus* breeds, preputial prolapse appears to be related to prepuce length rather than caudal preputial muscle absence as the horned *Bos indicus* bulls have caudal preputial muscles.

Reporting from a study of three polled and two horned bulls and a study involving dissection of 30 prepuces, Long and Hignett (1970) and Long *et al.* (1970) suggested that the absence of a caudal preputial muscle in polled bulls allowed the epithelium to be pushed out of the orifice by the advancing penis. From this it was concluded that eversion is related to penis movement. But a study of 244 bulls of 13 British breeds observed that eversion occurs at micturition when the penis is non-erect and around service when the penis is erect. The conclusion drawn from this by Long *et al.* (1970) is that eversion is related to penis movement, but it is not related to penis erection.

Penis position was considered as a possible contributing factor for preputial eversion. Preliminary studies indicate that polled bulls do not retract the penis as far into the prepuce as do horned bulls (Long and Hignett 1970). When examining five bulls from four different breeds, Long *et al.* (1970) found the position of the glans penis at rest was highly variable between bulls. In the three polled bulls there was a correlation between penis position and eversion. Eversion accompanied forward movement of the glans and was not related to erection. Hofmeyr (1987) also stated that, at rest, the penis occupies the caudal third of the preputial cavity, especially in *Bos taurus* breeds. In Brahman and Santa Gertrudis, however, the penis often lies much further forward.

Evidence from surgery showed that following bilateral myotomy of the retractor penis muscles the penis was always found to be near the orifice of the sheath (Ashdown and Pearson 1973) but not prolapsing (Hofmeyr 1967). This shows that after the operation, tissues other than the retractor muscles must be responsible for preventing prolapse of the penis (Hofmeyr 1967). There was no eversion of the prepuce but after service the penis was not readily returned to the sheath (Ashdown and Pearson 1973).

The preputial orifice has been identified as a contributing factor causing preputial abnormalities with some authors reporting size of the orifice as the main factor (Van Den Berg 1984; Rice

1987; Memon *et al.* 1988). The size of the preputial orifice varies between breeds (Wolfe 1986; Hofmeyr 1987) and individuals within a breed (Wolfe 1986). Hofmeyr (1987) compared the breeds and stated that in *Bos taurus* the orifice is just big enough to permit the erect penis to slide through. In these animals the sheath tends to be short and pendulous, the opening cranioventral and closed. In the Africander and Nelore (*Bos indicus*), the length of the sheath is intermediate and the opening tends to be even smaller than in *Bos taurus* bulls, leaving minimum room between the erect penis and edge of the opening. In other *Bos indicus* breeds the depth of the sheath is greater and pendulous and the opening appreciably wider and flabby (Hofmeyr 1987). The extreme examples of the wider preputial orifice are in Brahmans and Santa Gertrudis bulls where the preputial orifice can easily admit three fingers. Memon *et al.* (1988) further confirmed this and stated that the Brahman has a considerably larger preputial orifice than do the Afrikaner and European breeds. Van Den Berg (1984) measured 373 bulls of different breeds (in an area in South Africa where Brahmans numerically dominate) and found that the preputial orifice is largest in the Brahman. Other areas for possible differences were examined and Long and Hignett (1970) observed and slaughtered 26 bulls and found that the orifice measurement showed no significant difference between everting and non-everting bulls.

Neurectomy of the lateral thoracic nerves paralysed the muscles of the prepuce and resulted in eversion of the prepuce in three (two Friesians, one Jersey) out of seven young bulls (six Friesians, one Jersey). Myotomy of the caudal muscles of the prepuce failed to produce lasting eversion of the prepuce in any of four bulls. Ashdown and Pearson (1973) concluded that in some bulls the cranial muscles of the prepuce are important in preventing eversion of the prepuce, probably by their sphincteric action on the orifice of the sheath. In this study Ashdown and Pearson (1973) found Friesians and Jerseys have powerful sphincters at the sheath orifice but in most Brahman bulls the sphincter does not have the ability to contract (Van Den Berg 1984).

The predisposition of these structures to injury (Lenert 1956; Walker and Hull 1984; Baxter *et al.* 1989) may lead to pathology of the prepuce. The most common injuries are at mating

(Walker 1970; Amaya Posada 1979; Amstutz 1981) or are incidental (Hofmeyr 1967; Supple-Kane 1969; Frank 1959).

Heritability and correlations of external reproductive structures

Correlations;

Excess skin along the ventral surface of the bull has been studied and discussed by many. Some simplify the problem, as did Smit (1994) in stating that there is not one “good or positive” trait that is correlated or associated with excessive skin. By selecting against excessive sheath in bulls in a herd in southern Africa, it was observed in the cows in the herd that: 1) there was a dramatic reduction in cervical and uterine size; 2) prolapses decreased; 3) navel infections in calves virtually disappeared; 4) umbilical hernias decreased; and 5) there was a remarkable improvement in both the udder and udder attachments as well as an improvement in the size of the teats. Unfortunately, no data were presented in the article to show the extent of these changes (Smit 1994).

Hoogenboezem and Swanepoel (1995) found a low correlation (0.31) between sheath size and average daily weight gain. Therefore, reducing sheath size in the herd would lead to a reduced average daily gain. In their study this was shown by dividing 55 Santa Gertrudis bulls into above the group average sheath area and below the average and comparing their weights. This method of selection into groups may have just grouped larger bulls with larger sheaths and smaller bulls with smaller sheaths into separate groups. Results in this study also revealed that post weaning growth did not account for a significant amount of variation in sheath area. Although no heritabilities were given, a high heritability for sheath area was stated. From the results of this cohort study, these data show that selection could be effective in reducing sheath area but it could be antagonistic with pre and post weaning growth (Hoogenboezem and Swanepoel 1995). Similar results were shown when weaning weights were taken and correlated with sheath score by McMurray and Turner (1994) who scored 295 Beefmaster calves from two herds. The correlation coefficient was - 0.26 indicating that as sheath score increases (sheaths become less pendulous) there is a decrease in weaning weight.

More evidence was provided when genetic correlations were found between sheath area and birth weight, average daily gain and weaning weight (0.23 ± 0.35, 0.58 ± 0.25, 0.52 ± 0.27). As the heritability of sheath area is moderately high (stated as 0.45±0.13), the results suggest selection could be effective in reducing sheath area but would be antagonistic to preweaning growth traits. Further results from this study show that because of the relatively low phenotypic correlations between sheath area and preweaning growth rate (0.27) and weaning weight (0.29), continued emphasis on increased growth rate or weaning weight could generally be maintained with careful attention to avoiding large sheath areas through independent culling level or index selection procedures (Franke and Burnes 1985).

In a study of 113 (3/4 Santa Gertrudis, 1/4 Brahman) bulls by Lagos and Fitzhugh (1970) the authors found sheath depth was significantly (P<0.05) related (0.33) to the eversion score. Sheath depth was measured as the vertical distance from the ventral edge of the sheath at the orifice to the abdominal wall. Eversion score was based on extent of exposure from no exposure, to slight (less than three cm), to moderate (three to eight cm) and extreme (greater than eight cm). After adjustment for age, a small non-significant negative correlation (r=-0.14) between body weight and the eversion score was found so selection for weight in these breeds would not be expected to increase the frequency of eversion. No significant correlation (-0.03) was found between body weight and sheath depth. This was comparable to Bertram *et al.* (1997) who discovered that after measuring many bull external anatomical reproductive features, that only navel width was correlated with live weight (P<0.01 at two and two and a half years old respectively). Navel width was measured from the ventral measurement of the orifice to the intersection of the anterior curvature of the sheath.

A possible benefit of bulls with excess underline skin was seen when results from a study Santa Gertrudis bulls (n = 40; 2 years of age) on one property in Texas by Smith *et al.* (1981). The study showed that correlations between physical measurements of reproductive soundness and fertility were low. Sheath depth (the distance from the abdomen to the orifice) was the only physical parameter significantly (p<0.05) correlated to percent pregnant of oestrous females (PE rate; r = -0.38) or percent pregnant of females mated (PM rate; r = 0.36). This may be related to the correlation of sheath depth to body weight and scrotal circumference despite these not being correlated to the increased fertility rates. Other physical parameters included in the study were body weight, masculinity score, scrotal circumference and the sheath length (from the scrotum to the orifice). In this study masculinity score also increased ($P<0.05$) as the sheath depth increased but a concomitant increase in PM rate was not obvious. From the study the author indicated that the subjective evaluation of bulls for masculinity as a means of predicting fertility is questionable.

A similar result was seen in a large scale research program in Northern Australian herds using Santa Gertrudis, 5/8th *Bos indicus* and *Bos indicus* bulls (Holroyd *et al.* 1998). Sheath depth was positively related to calf output at three of the six sites. Body weights were not given for this study. Bulls judged to have excessively pendulous prepuces also were not mated so there was not enough variation in the data to allow accurate expression of this trait as a predictor of calf output.

A total of 487 bulls were studied from an area where *eversion* was common and Long and Rodriguez Dubra (1972) found no correlation between frequency of eversion in the sires (n=5) and frequency of eversion in the sons (n=36) nor between the percentage of time sires and their sons everted the prepuce. The authors had considered that frequency and duration of eversion rather than the length of epithelium everted to be more important but no data were given to support this. Results showed that selection against frequency and duration of eversion did not reduce the problem in the offspring (Long and Rodriguez Dubra 1972). Lagos and Fitzhugh (1970) reported a different result where analysis of 113 bulls used in a study gave a paternal half-sib estimate of heritability of eversion score (extent of eversion) of 0.35 ± 0.3 with a high standard error. Therefore culling sires with a predisposition to evert would apparently reduce the frequency of this characteristic in the breeding population.

Sheath characteristics were measured and serving capacity tests performed by Bertram *et al.* (1997) looking to find correlations. Santa Gertrudis bulls (n = 287) from four Queensland herds were assessed by this group and they found a poor relationship between sheath depth and width and the number of mounts and serves that a bull achieved in serving capacity tests. They also found that mean sheath score varied little across age groups. As should be expected, many of the sheath measurement were correlated e.g. sheath width and depth for bulls in two age groups: 2 years ($P < 0.01$) and 2.5 years ($P < 0.01$). Because they describe a similar structure, sheath depth and sheath score were negatively correlated at all ages ($P < 0.01$). When adjusted for age, sheath depth was negatively correlated with sheath score and number of interests ($P < 0.01$ and $P < 0.05$ respectively) and positively correlated with sheath width, rosette and navel thickness score ($P < 0.01$ and $P < 0.05$ respectively).

Bertram *et al.* (1997) also used a rosette score which was based on the inverted fold of skin in the sheath at the external interface of the umbilical cord and is recorded as 0 = absent, 1 = small and 3 = large (greater than five cm diameter). They found that mean navel thickness score and rosette score varied little across age groups. In some age groups of bulls (2 years and > 3 years) they found navel thickness score and 'rosette' score were positively correlated ($P < 0.01$ and $P < 0.01$, respectively). In two year olds, 'rosette' score was positively correlated with sheath depth ($P < 0.01$). When adjusted for age, 'rosette' score was positively correlated with navel thickness score ($P < 0.01$) and negatively correlated with serves ($P < 0.05$). After consideration of these results they found that the serving capacity of the bull is not strongly related to the common sheath characteristics that they measured (Bertram *et al.* 1997).

Heritability;

Heritability of sheath area of 0.45 (SE = 0.13) was statistically estimated from data obtained from 439 Brahman and 7/8th Brahmans and it was within the range quoted in the literature obtained by Franke and Burnes (1985). It was similar also to McMurray and Turner (1994) who scored 295 Beefmaster calves from two herds for sheath score to determine the heritability of this trait. After statistical adjustment to remove the effects of sex of calf and weaning weight the estimate was 0.40$\pm$ 0.08. From this the authors recommended selection for better sheath and navel flap score. Comparisons were done between sires and dams with different sheath/navel flap scores that indicated that lower scores for sire and dam do result in calves with lower (more pendulous) scores. These results indicate that selection against pendulous sheath can be practiced using the sire and dam scores. Although correlation figures indicated that cleaner sheath bulls had a lower weaning weight, multiple trait selection can be practiced to prevent this reduction in weaning weight.

Although no qualifying raw data were given or defects defined, an estimate of heritability of defects of the prepuce of 0.85 was calculated by Brinks (1972). This was from data collected over a 14 year period from 16 lines of Hereford cattle with a total of 798 bulls being studied. This was supported by a subjective statement provided by Hofmeyr 1987 that *prolapse* of the prepuce is undoubtedly hereditary.

Treatment and prevention of preputial problems

Consideration of treatment

Many authors (Larson and Bellenger 1971; Memon *et al.* 1988; Baxter *et al*. 1989) described treatment of preputial problems. Roberts (1971), however, stated that because prolapses are genetically predisposed it is probably undesirable to operate on these bulls. Early recognition of risk factors and selection against these factors offers the only long term satisfactory solution. The retrospective study of hospital records and published data conducted by Kasari *et al.* (1997) looked at cost effectiveness of medical and surgical treatment of beef bulls with preputial prolapse. Individual cases depended on treatment and replacement costs but usually it was more cost effective for owners to cull injured bulls than to treat bulls.

Prevention

One possible method of prevention of preputial problems is by removal of a triangle of skin of the sheath but this is not recommended as bull buyers may be misled and the operation could be regarded as unethical in veterinary practice (Bostwick 1980). Lagos and Fitzhugh (1970) also stated that there is a possibility that the predisposition to prolapse is inherited suggesting that continued breeding of affected sires, made possible by surgical correction, could increase the frequency of this defect.

Prevention of preputial prolapse is not possible under the extensive grazing conditions in Northern Queensland. However, the acute condition (before the formation of scar tissue) can be controlled in individual bulls by confining them to clean, covered facilities and only hand mating them so injuries can be monitored (Donaldson and Aubrey 1960). The best prevention of preputial problems is achieved through selection (Donaldson and Aubrey 1960; Rice 1987; Rao et al. 1988). Early recognition of bulls predisposed to prolapse would allow their removal from the breeding population and avoid breeding problems that often accompany prolapse. Objective measurements, if closely related to the tendency to prolapse, could be used to identify problem animals (Lagos and Fitzhugh 1970).

Summary

It is obvious from the literature that there is some uncertainty regarding the predisposing causes of preputial prolapse in *Bos indicus* and *Bos indicus* derived bulls. Many authors have logically suggested that the exposure of the sensitive preputial tissue during preputial eversion may lead to an increase in preputial prolapse. This relationship has not been confirmed and a significant longitudinal study that could examine considerable numbers of bulls and monitor their development over many years is needed to confirm this relationship.

Definitive studies of *Bos taurus* bulls have linked preputial eversion to polled bulls and their associated deficiency in the caudal preputial muscles. No similar definitive work in *Bos indicus* bulls has been performed. Anatomical studies are required to determine if the predisposing issues for preputial eversion are similar in *Bos indicus* bulls to the *Bos taurus* bulls if preputial eversion does predispose bulls to preputial prolapse.

Chapter 3.

Causes of bull wastage from northern Australian beef cattle herds

Introduction

There is a paucity of information available on the causes of bull wastage in northern Australia. Bull wastage represents a potentially significant financial loss to the northern beef industry and any insight into causes of wastage may lead to development and implementation of prevention measures. The work reported in this chapter identifies reasons for culling bulls in northern Australia and collates this information into a format which could be utilised to assist initial bull selection by determining the importance of the traits that lead to bull wastage. In this study, losses due to preputial prolapse have been highlighted to illustrate the importance of preputial prolapse to the northern Australian cattle industry.

Objectives

The objectives of this study were to:

- Document reasons for culling bulls in Northern Australia
- Categorise culling reasons into a format to assist bull selection
- Specifically investigate factors that may influence the occurrence of preputial prolapse.

Materials and methods

This study involved observations on bulls on eight cattle properties in northern Australia during one season (1998). The properties are located in north west Queensland and on the Barkly Tablelands in the Northern Territory. Many of the properties consist of predominantly Mitchell grass (*Astrebla* spp.) plains country with some river frontage country and some less fertile soils. The climate has a predominantly summer rainfall pattern that is affected by monsoonal influences. Average annual rainfall ranged from 288mm to 637mm on the properties. Bulls were usually kept with the cows throughout the year. Stocking rates varied from one adult cow equivalent to 15ha in some of the more fertile areas to one adult cow equivalent to 30ha in the less fertile areas.

On one property observations were continued for an additional two years (1999 and 2001). Properties owned by one large pastoral company were included in the study to achieve a higher degree of commonality in general management strategies and consistency in reporting. A large pastoral company that was likely to cooperate with the study and was situated in the area of interest was selected. Bull age structure and the total number of bulls on the eight properties were also recorded for three consecutive years (1998 - 2000). Age was estimated from the year brand on each bull. Breed of the culled bulls was also noted.

Bulls were visually assessed by the manager on each property and reasons for culling involving problems of the head, fore leg, hind leg, reproductive structures, back and other various reasons were recorded (Table 3.1). The data recording sheet was developed in consultation with the property managers and a senior Queensland government beef cattle extension officer. Terminology used in the survey was selected because it was routinely used by the cattlemen who were culling the bulls and recording the data (Table 3.1). The extension officer was also involved in ensuring there was a level of consistency of interpretation of the culling reasons by those recording the data. Categories of reasons for culling were selected to allow for more analysis of the data as the numbers involved are often too small to allow meaningful analysis when considering different ages, properties or breeds.

Table 3.1; List of possible reasons for culling bulls on the selected beef cattle properties.

Reason for culling
Various
• Aged but sound
• Aged & unsound
• Poor body condition
• Poor temperament
• Poor libido
• Poor body conformation
• Severe Buffalo Fly skin lesions
• Sound but surplus (not aged)
• Other
Head
• Pink-eye
• Other eye problem
• Jaw infection/abscess
• Other
Fore leg
• Hoof problem
• Leg injury
Hind leg
• Excessively straight hind leg (posty leg)
• Leg injury
• Hip injury
• Hoof problem
• [1]'Stringhalt'
• Arthritis
• Weak fetlock
Reproductive structures
• Testicular problem
• Preputial prolapse
• [2]'Heavy (or dropped)' sheath
• [3]'Broken penis'
• Other
Back
• Injury
• Arthritis
• Other

[1] Upward fixation of the patella

[2] Excessively pendulous sheath

[3] Penile haematoma

Statistical analysis

The data were analysed using the GenStat (ninth edition) (IACR – Rothamsted, Harpenden, Hertfordshire AL5 2JQ; distributed by Numerical Algorithms Group, Oxford) statistical package. Given the small numbers of bulls within each year group, comparing individual ages was not feasible, and thus age data were pooled into young (3-6 years) and older (7-10 years) bulls which had been culled for the main areas of interest including reproductive problems, leg problems (fore and hind leg problems were pooled) and preputial prolapse. The proportion of bulls culled by age category and culling category were compared using a two-sample binomial test (Table 3.10). Other specific culling issues that could not be logically combined could not be analysed because of the low numbers involved. The proportion of bulls classified by culling category and age was analysed using a generalised linear model with binomial distribution and logit link. The binomial denominator was the total number of bulls within these age limits and with a known reason for culling. The analyses assessed the effect of bull age, culling category and their interaction (Table 3.11).

There were 95 bulls culled for reproductive reasons. The proportions of bulls within each specific reproductive culling reason (as a proportion of the total number of reproductive culls) were compared using a generalised linear model with binomial distribution and logit link (Table 3.12).

Results

Data collected for the 1998 season from the eight cattle properties are presented in Table 3.2. The total bull population on the eight cattle properties in 1998 was 6040 (ranging from 498 to 1153 on individual properties). In 1998, 900 bulls (15%) were culled and the culling rate ranged from 4% (36 of 822 bulls) to 24% (191 of 810 bulls) on individual properties (Table 3.2). The primary reason for culling bulls in 1998 was for age (n = 557; 62%), with some culled as they were surplus to requirements (n = 43; 5%). The remaining 33% (n = 300) of bulls were culled for specific problems. The proportion of bulls culled for specific reasons assessed in this study only amounted to 5% (n =300) of the total number of bulls from all properties. Reasons for culling on the properties (Table 3.2) varied and this may reflect differences in management or environmental effects. Culling levels for reproductive structure problems are only for visible structures and do not reflect levels of reproductive problems that are not detected by visual means alone.

Table 3.2; Summary of number of bulls culled by culling reason in 1998 on eight commercial beef cattle properties in north west Queensland and the Barkly Tableland.

Reason for culling	Property									As a percentage of all bulls
	A	B	C	D	E	F	G	H	Total	culled for a specific reason
General conditions										
Poor body condition	19		2	1	2			3	27	9.0
Poor temperament	17	5	4	1	2	10	3	1	43	14.3
Poor libido	1				1				2	0.7
Poor body conformation		16	4		1		11	4	36	12.0
Severe buffalo fly skin lesions	1	1		5				1	8	2.7
Subtotal	39	22	13	7	7	10	14	9	116	**40.0**
Head										
Pink-eye		1						1	2	0.7
Other eye problem	2	1	3	1	1				8	2.7
Jaw infection/abscess		2	3						5	1.7
Other		1							1	0.3
Subtotal Head faults	2	5	6	1	1	0	0	1	16	**5.3**
Fore leg										
Hoof problem				1	3				4	1.3
Leg injury	5			2	2				9	3.0
Subtotal Fore leg faults	5	0	0	3	5	0	0	0	13	**4.3**
Hind leg										
Excessively straight hind leg (posty leg)	6	1		1	2		6		16	5.3
Leg injury	5	3	1	2	4		2	1	18	6.0
Hip injury	2		3	1				2	8	2.7
Hoof problem	2			1	1				4	1.3
[1]'Stringhalt'									0	0
Arthritis					1				1	0.3
Weak fetlock	1				5				6	2.0
Subtotal Hind leg faults	16	4	4	5	13	0	8	3	53	**17.7**
Reproductive structures										
Testicular problem	1		1		3		2	3	10	3.3
Preputial prolapse	1	5	12	9	3			2	32	10.7
[2]'Heavy (or dropped)' sheath	2	9				2	2	2	17	4.7
[3]'Broken penis'	6					8	22		36	11.9
Other									0	0
Subtotal reproductive faults	10	14	13	9	6	10	26	7	95	**31.7**
Back										
Injury									0	0
Arthritis									0	0
Other					1		6		7	**2.3**
Subtotal back faults	0	0	0	0	1	0	6	0	7	2.3
Total culled with specific problems	71	45	33	25	32	20	54	20	300	**100**
Non-specific culled bulls										
Aged but sound	49	34	81	101	3	63	55	171	557	
Sound but surplus (not aged)		1				37			38	
Other reasons	1		3		1				5	
Total bulls culled									900	
Total bulls on each property	946	498	1153	583	822	564	664	810	6040	
Percentage culled (%)	13	16	10	22	4	21	16	24	15	

[1] Upward fixation of the patella

[2] Excessively pendulous sheath

[3] Penile haematoma

Age data were collected on the culled bulls to determine the age when problems were detected in bulls on these extensively managed properties. Age of problem detection could be used to assist property managers understand which problems could be reduced by culling for age or which age groups of bulls need extra monitoring for development of problems. Many of the culling problems occurred throughout the age groups (Table 3.3) but more older bulls than younger bulls were culled for poor temperament or poor condition. Further analysis was done on age of reproductive problems. For the bulls with known age, the average age of the culled bulls was 8.1 years old. Variation was seen in the age structures of the bull populations (Table 3.4). An important management issue is the number of older bulls on all properties.

The two bulls culled for poor libido were Brahmans. Bulls culled for severe skin reactions to buffalo flies included five Brahmans, two Santa Gertrudis and one Charbray.

Table 3.3. Age profile of bulls culled in 1998 for various abnormalities across eight northern beef cattle properties.

	Age (years)										
	3	4	5	6	7	8	9	10	11	Unknown	Total
Various											
Poor body condition					4	3	13	4	1	2	27
Poor temperament	2	1	5	5	13	3	4	1		9	43
Poor libido					1					1	2
Poor body conformation	2	2	2	2	6	4	1			17	36
Severe buffalo fly skin lesions		1	2	1	3					1	8
Head											
Pink-eye		1								1	2
Other eye problem		1		1		2				4	8
Jaw infection/abscess				1	2					2	5
Other					1						
Fore leg											
Hoof problem	1			1						2	4
Leg injury	1	3	1		2	1				1	9
Hind leg											
Excessively straight hind leg (posty leg)		1		2	5		1			7	16
Leg injury	1	4	1	2	2	2	1	1		4	18
Hip injury				1	1	1	1			3	8
Hoof problem	1	2			1						4
[1]'Stringhalt'											0
Arthritis								1			1
Weak fetlock	2						1	3			6
Reproductive structures											
Testicular problem	1			1	1		1	1		5	10
Preputial prolapse	2	3	3		6	5	3	1		9	32
[2]'Heavy (or dropped)' sheath		2	1	1	5		4			4	17
[3]'Broken penis'	1	3	1	1	2	3	3			22	36
Back											
Injury											0
Arthritis											0
Other										7	7
Total (specific)	14	24	16	19	55	24	33	12	1	102	300
Non specific causes											
Aged but sound					55	146	102	173	7	74	557
Sound but surplus (not aged)			5	5	28						38
Other		1		1						3	5
Total culled	14	25	21	25	138	170	135	185	8	179	900

[1] Upward fixation of the patella
[2] Excessively pendulous sheath
[3] Penile haematoma

Table 3.4. Age structure of the bull population on each cattle property.

Bull age	Property A	B	C	D	E	F	G	H	Total	Percentage of bulls in each age group
2	106		86	140	28				360	6
3	100			81	118	28	24	124	475	8
4	312	98	195	40	101	70	109	146	1071	18
5	131	60	159	149	99	88	103	49	838	14
6	46	75	135	42	104	59	91	95	647	11
7	63	132	74	32	103	76	23	213	716	12
8	68	35	294	99	87	50	13	183	829	14
9	53	51	143		63		39		349	6
10+	67	47	67			113	192		486	8
Unknown					119	80	70		269	4
Total	946	498	1153	583	822	564	664	810	6040	100

The number of bulls culled with preputial prolapse in Table 3.5 includes three bulls primarily culled for another reason but they also had a preputial prolapse. Table 3.10 presents the findings of analysis of the difference between the number of young and older bulls with preputial prolapse and Table 3.11 summarises the findings of the analysis of the differences between the age groups for reproductive problems. Overall, 0.6% (35/6040) bulls were culled with preputial prolapse.

Table 3.5; Age distribution of bulls culled with preputial prolapse from each property during one year (1998).

	Property									Total number of bulls culled with preputial prolapse	Percentage of bulls in each age group with preputial prolapse
Age of bull	A	B	C	D	E	F	G	H	Totals		
2	1	1	3	2	1	0		15	23	1	4.3
3	5	2	0	2	4	1		0	14	2	14.3
4	8	6	1	4	3	3		0	25	3	12.0
5	5	2	0	5	0	9		0	21	3	14.3
6	4	6	3	3	2	7		0	25	0	0.0
7	21	19	0	5	2	35		56	138	6	4.3
8	13	2	8	105	3	39		0	170	5	2.9
9	51	27	31	0	3	23		0	135	4	3.0
10	11	10	35	0	6	3		120	185	2	1.1
11	1	5	2	0	0	0		0	8	0	0.0
Unknown	1	0	34	0	12	0	109	0	156	9	5.8
Totals	121	80	117	126	36	120	109	191	900	35	3.9

Although too few bulls from each breed were affected with preputial prolapse to perform a comparative analysis, the percentage of bulls culled for this problem (Table 3.6) for the main breeds (Brahman (4.1%) and Santa Gertrudis (2.8%)) provides an indication of the annual prevalence of preputial prolapse amongst bulls culled in the north Australian cattle industry.

Table 3.6; Summary of prevalence of preputial prolapse by breed and property.

Breed	Property A	B	C	D	E	F	G	H	Totals	Number of bulls culled with preputial prolapse	Percentage of bulls in each breed with preputial prolapse
Brahman	111			118	36		6		271	11	4.1
Charbray	3			5			1		9	2	22.2
Charolais	7					1			8		0.0
Santa Gertrudis		64	102			82	102	191	541	15	2.8
Santa Gertrudis cross		16				37			53	1	1.9
Angus			9						9	5	55.6
Murray Grey			6						6		0.0
Belmont Red				3					3	1	33.3
Total	121	80	117	126	36	120	109	191	900	35	

Total bull numbers from the eight properties were collected for a further two years and demonstrated that bull numbers were maintained at a consistent level despite the number of bulls culled (Table 3.7). Despite culling many bulls for age, the data show that the properties still kept many older bulls in the herds.

Table 3.7; Total numbers of bulls by age on all eight properties over a three year period 1998-2000.

All properties		Bull numbers	
Age (years)	1998	1999	2000
1	0	0	133
2	360	565	452
3	475	697	825
4	1071	851	1033
5	838	1005	789
6	647	763	982
7	716	578	698
8	829	540	441
9	349	357	211
10 and over	486	388	186
Unknown	269	0	0
Total	6040	5744	5750

Despite the general trend, (Table 3.7) bull age data from property A (Table 3.8) demonstrate a change in bull culling and bull replacement that achieved a reduction in the number of older bulls on this property after the initial bull cull survey was conducted.

Table 3.8; Total bull numbers on property A over the three years 1998-2000.

Property A	Number of bulls		
Age (years)	1998	1999	2000
1			133
2	106	208	163
3	100	146	193
4	312	119	134
5	131	294	109
6	46	105	256
7	63	32	46
8	68	49	
9	53	45	
10 and over	67	47	
Total	946	1045	1034

On property E, the age structure of bulls culled in this Brahman herd indicated that culling was highly variable between years (Table 3.9). Over the three years on property E, individual cull numbers for each age group for each year were too low for comparative analysis.

Table 3.9; Age structure of all bulls (Brahmans) culled from property E over three years.

	1998	1999	2001
Age (years)	Percentage	Percentage	Percentage
2	1	2	8
3	4	1	22
4	3	2	14
5	0	1	33
6	2	5	66
7	2	6	2
8	3	3	12
9	3	3	11
10	6	2	24
11	0	0	6

After the initial bull cull survey in 1998, only one property (property E) provided detailed culling information in the following years (1999 and 2001). During the initial survey the animal managers closely examined their bulls and culled any with problems that could interfere with their future function. The bull culling data from property E over three years demonstrated that it was consistently the older bulls that developed preputial prolapse (Figure 3.2) on this property that used Brahman bulls.

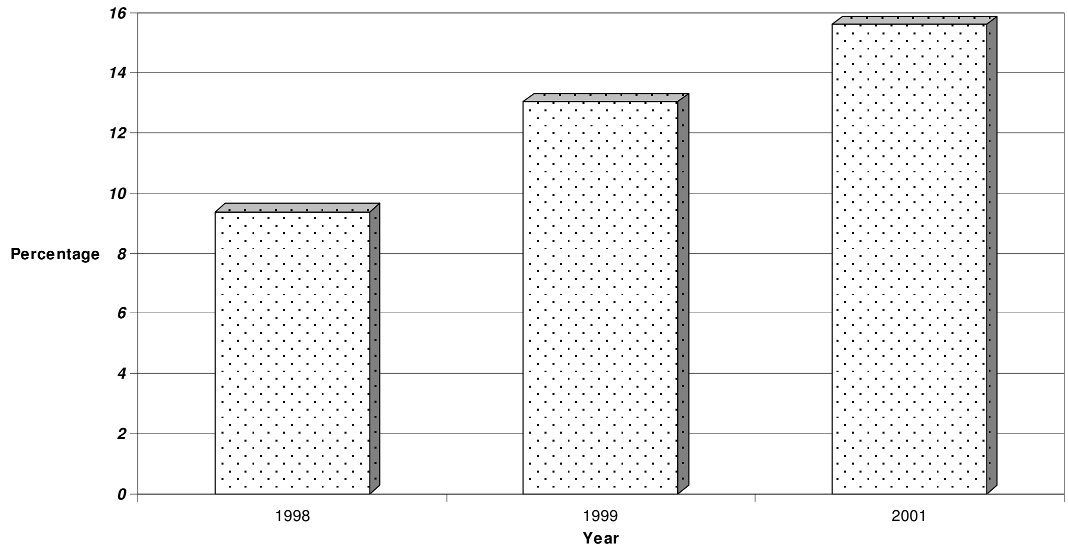

Figure 3.1; Percentage of culled bulls of all ages culled for preputial prolapse on property E over three years.

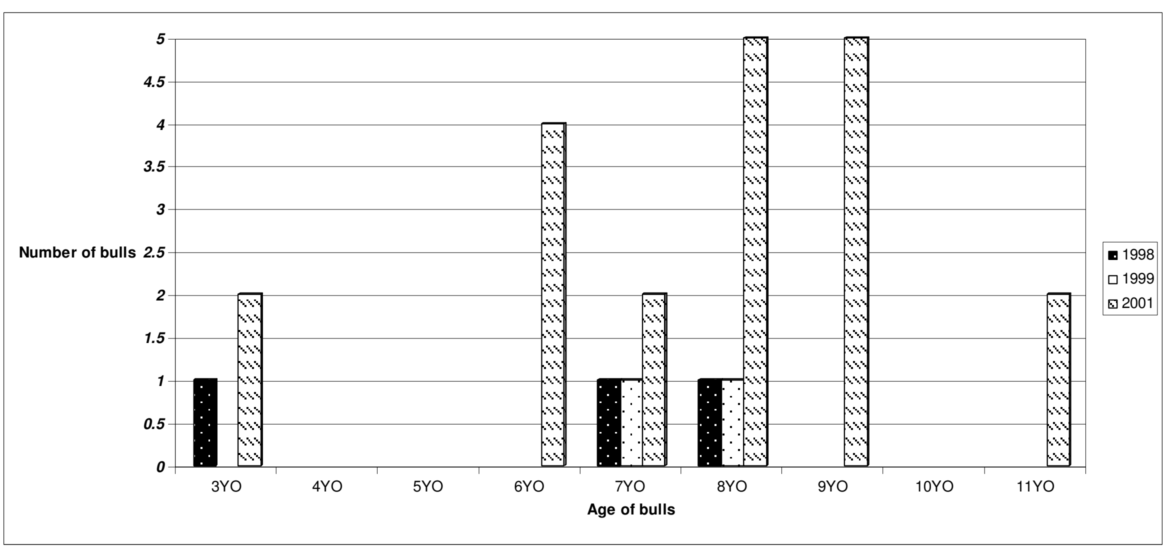

Figure 3.2; Numbers by age of bulls culled with preputial prolapse from property E over three years.

The interaction between bull age and culling category was significant (P<0.05) indicating that the proportion of bulls culled for leg, reproductive or other problems was not consistent across bull age (Table 3.10).

Table 3.10; Predicted frequency and SE of bulls culled for leg, reproductive and other reasons in relation to age at culling.

Age (years)	Leg	Other	Reproductive
3	3.1 ± 1.2 ^{abcde}	2.0 ± 1.0 ^{abc}	2.0 ± 1.0 ^{abc}
4	5.1± 1.6 ^{cdef}	3.1 ± 1.2^{abcde}	4.1± 1.4 ^{abcde}
5	1.0 ± 0.7 ^{a}	4.6 ± 1.5 ^{bcdef}	2.5 ± 1.1^{abcd}
6	3.1± 1.2^{abcde}	5.1± 1.6 ^{cdef}	1.5 ± 0.9 ^{ab}
7	5.6 ± 1.6 ^{cdef}	15.2 ± 2.6 ^{g}	7.1± 1.8 ^{ef}
8	2.0 ± 1.0 ^{abc}	6.1± 1.7 ^{def}	4.1± 1.4 ^{abcde}
9	2.0 ± 1.0 ^{abc}	9.1± 2.1 ^{fg}	5.6 ± 1.6 ^{cdef}
10	2.5 ± 1.1^{abcd}	2.5 ± 1.1 ^{abcd}	1.0 ± 0.7 ^{a}

Means followed by a letter in common are not significantly different at P=0.05

The individual cull numbers for each age group for each culling reason were too low for comparative analysis. Valid analysis between the age groups was possible when age groups were condensed into young and old bull categories and general cull reasons were compared. Older bulls were more likely to be culled for reproductive problems (and specifically preputial prolapse) compared to younger bulls (P< 0.05). No difference was found in the proportions culled for leg problems between younger and older bulls (P > 0.05; Table 3.11).

Table 3.11; Significance of age on culling for reproductive problems, leg problems and preputial prolapse.

	Young bulls (3-6 YO)			Older bulls (7-9 YO)			
	Number affected	Total number of bulls in the herds	Percentage	Number affected	Total number of bulls in the herds	Percentage	
Total culled for reproductive problems	20	3031	0.66	33	1894	1.74	P < 0.001
Culled for fore and hind leg problems	24	3031	0.82	19	1894	1.00	*NS
Culled for preputial prolapse problems	8	3031	0.26	14	1894	0.74	P < 0.05

* NS Not significant

Within the bulls culled for reproductive problems, preputial prolapse and penile haematoma were significantly more important than the other causes of culling (Table 3.12).

Table 3.12; Frequency of different causes of reproductive problems.

Reproductive problem	Number	Predicted percentage
Testicular abnormalities	10	10.5 ± 3.15 [a]
Preputial prolapse	32	33.7 ± 4.85 [b]
Excessively pendulous sheath	17	17.9 ± 3.93 [a]
Penile haematoma	36	37.9 ± 4.98 [b]
Total	95	

Means followed by a letter in common are not significantly different at P=0.05

Discussion

The work reported in this chapter was conducted to identify the reasons for culling bulls on large extensively managed properties in northern Australia. The information obtained can be used to assist initial bull selection as it determined the importance of the problems that lead to bull wastage. Eight properties (6040 bulls) were involved in the survey and it established that there were many older bulls in these herds. Preputial prolapse was an important issue for the industry as 35 bulls were culled with preputial prolapse in the year of the survey and despite a higher proportion being older bulls, many were younger bulls.

Based on these data we obtained in this study, we determined that only 15% of the bulls were culled in a year so at this rate most bulls remain in the herd for many years. Information was obtained on the significance to the northern Australian cattle industry of temperament, reactions to buffalo flies, visible reproductive problems and issues involving the legs. The figures obtained could be compared and used to prioritise bull selection options to reduce specific problems.

Culling percentages for the range of problems varied between properties and may represent differences in: breeds and sires used; management decisions regarding bull culling: or environmental conditions.

This survey shows that the rate of bull culling was approximately 15% for the year. At this level of culling, bull retention would average six years, which means that many bulls in these herds would be older bulls. These older bulls may have reduced fertility which could affect production efficiency in these herds. An Australian study involving a Northern Territory herd found that a high proportion of bulls over eight years old contributed to the erratic conception patterns (McCosker *et al.* 1989). Problems with older bull fertility were also reported in a Brazilian study where unsatisfactory reproductive performance was 12.2% for bulls aged 2-7 years but approximately 30% for bulls 8-10 years of age (Gottschall and Mattos 1997).

Most (n = 636; 88%) of the bulls culled were over six years old (where age was identified) (Table 3.3). Of the bulls over six year of age, 76% (n = 483) were culled for age. This percentage may actually be higher as many of the bulls where no age information could be found were culled for age and were likely to be older bulls. The average age of the culled bulls was 8.1 years old. This compares to an average age of 6.3 years for cull bulls seen at a NSW abattoir in 1971 (Bellenger 1971). Another Australian abattoir survey (WA) found that only 17% of the bulls with ages identified were over 7 years old and the average age of the culls was 4.4 years (Turnbull 1977). The differences are likely to reflect that bulls are culled at a younger age in more intensive cattle areas.

Although 15% of the bulls were culled in the year, only 5% of the bulls were culled for specific problems other than age. For the discussion, the percentages discussed will be percentages of each problem in relation to the bulls culled for specific problems.

Reproductive defects accounted for 32% (n = 95) of culls. These consisted mainly of damaged penises (n = 36; 12%) and preputial prolapse (n = 32; 11%). Sixty-one percent of the 36 bulls (22/36) culled for ‘broken penis’ were from one property (property G). This may reflect a variation in interpretation of the condition, a specific breed or strain issue or a localised problem leading to an abnormally high level in this herd. It may also suggest bulls were intermittently culled on assessment of their visual reproductive organs because, in this survey, five properties culled no bulls with penis problems. Research into the predisposing factors associated with these injuries is required before improvements in bull selection can be made. Of the total bulls culled for specific reasons, 6% (n = 17) were culled for heavy or dropped sheath. This could reflect injury to the sheath area, difference in sheath size accepted by the property management or a problem in some bulls as they become older. The level of reproductive problems may be understated in this survey. These bulls were only briefly visually examined and many reproductive problems may not be visible. A survey of culled bulls at a WA abattoir found that 34.3% of the bulls had pathological conditions affecting the testicles, epididymis, penis or prepuce (Bellenger 1971). Information from the owners of these bulls showed that many of the conditions were not identified in the live animal and the bulls were often culled for other reasons. As the bulls in this survey were not subjected to a bull breeding soundness examination annually it would be expected that many reproductive problems may be missed and the rates much higher than reported here.

Thirty-five bulls (12%) were culled with preputial prolapse (Table 3.5). This includes bulls where preputial prolapse was not selected as the primary reason for culling. Ages were known for 25 (71%) of these bulls and 8 (32%) of these were under six years old. This figure (35) is important as it quantifies the problem of preputial prolapse in the northern Australian industry. When expressed as a percentage (0.6%) of the total bulls in the herds it may be compared to other studies. Examination of 10940 bulls in Colorado by Carroll *et al.* (1963) detected (0.5%) with preputial abnormalities. Bulls in the Colorado study were mostly *Bos taurus* and the percentage was the result of examinations and not from culling of obvious problems but the study does give some comparison information. Those selecting bulls for use in northern Australia can use the figure from this survey to decide on the importance of selection against traits that may predispose to preputial prolapse and use this benchmark to monitor if the problem is increasing or decreasing. The result that 32% of the bulls culled with preputial prolapse were under six years old demonstrates that this problem is not confined to one age group and suggests that the predisposition to the condition may be multi-factorial.

Five of the nine culled Angus bulls (56%) were culled with preputial prolapse (Table 3.6). Such a high percentage of culled Angus bulls culled for preputial prolapse may indicate a problem in this breed relating to the high levels of preputial eversion seen in polled *Bos taurus* breeds (Long 1969). The higher numbers of Brahman and Santa Gertrudis bulls culled with preputial prolapse reflects the predominance of *Bos indicus* or Bos indicus derived cattle in these northern herds (McGowan *et al.* 2002). These breeds did not vary greatly from each other in percentage of cull bulls being culled for preputial prolapse and demonstrate lower levels (Brahmans 4% and Santa Gertrudis 3%) when compared to some of the minor breeds in the survey (Table 3.6).

Fore and hind leg issues were seen in 22% (n = 66) of the culled bulls. Most of these bulls (n= 53) had hind leg issues with injuries (n = 26) and conformation (n = 22) the most important issues. Most (n = 39) of the bulls culled for specific leg issues came from two properties. More attention may have been focused on legs on these properties or the terrain may have been more difficult and caused more leg issues to be detected. The figure of 66 bulls culled for leg issues will allow those selecting bulls for these extensive areas to determine the priority needed for selection for structural soundness.

The 7% culled for hind leg conformation means that initial bull selection could be improved in this area by closer inspection at time of purchase. When this figure is added to the 12% culled for poor general conformation and the 6% culled for large sheaths, improvements in initial bull selection by visual assessment of conformation is further indicated.

In this study, 75% of bulls (n = 27) culled for poor body conformation were from two properties. Unfortunately conformation is a very general term and this figure may represent differences in what is acceptable conformation between bull buyers and staff responsible for culling bulls. Conformational defects may be hidden by fat in young well fed bulls and it is reported that excess weight in bulls is one factor leading to joint problems (Lachowicz 1971). Selection of young bulls in paddock condition may reduce this problem.

Another area where initial bull selection may be improved is in selection for improved temperament. Fourteen percent (n = 43) of the bulls were culled for poor temperament but 63% (n = 27) of the bulls culled for temperament were culled from two properties. This may reflect individual variation in perception of acceptable temperament or may reflect a real difference in the bulls found on particular properties. Handling also has an influence on temperament and different terrain may mean that some properties need to place more emphasis on temperament. Even when bulls are initially selected on temperament, culling on temperament is still a priority in the extensive beef areas of Australia (Bortolussi *et al.* 2005b).

Poor body condition in bulls occurs due to many reasons and bulls with undetected health problems may present in poor condition. High libido bulls may also be in poor body condition and would be a loss to the industry to be culled. Bulls that have trouble coping with the harsh environmental conditions of northern Australia may also be in poor condition. In this study, 9% (n = 27) of bulls were culled for poor body condition. A substantial percentage of these, 70% (n = 19) were from one property which may reflect specific nutritional or health problems on that property or an increased selection pressure based on body condition by that particular manager.

Problems associated with the head made up 5% (n = 16) of the specific bull culls in this study. Abscesses and eye problems other than pinkeye were the most common reasons for culling, so there is little room for improved bull selection to make an impact in the head region as these issues would be more related to physical damage on the property. This figure is less than the 13.7% of cull bulls with keratitis seen at a NSW abattoir (Bellenger 1971). This difference probably reflects breed differences or may be due to differences in grass seed or other pasture problems. A study in Turkey showed there was a breed difference in eye disease with lens abnormalities in 30.3% of Holsteins and 12.4% of Brown Swiss beef cattle (Ouurtan *et al.* 2002). Pigment is a possible difference that may result in less eye problems particularly from sun damage (Ward and Nielson 1979). Less than one percent was culled due to pink eye which may also reflect breed differences in susceptibility and indicates few benefits in altering initial bull selection.

Only 3% (n = 8) of the bulls were culled for severe reaction to buffalo fly infestation. *Bos indicus* bulls may attract large numbers of buffalo flies and the low percentage may reflect the industry attitude that buffalo flies are not a serious problem in the extensive areas. Increased concern may have been detected on one property as 63% (n = 5) of the bulls culled for severe buffalo fly reaction were from one property. This may reflect a particularly sensitive strain of bulls on that property as four of the five bulls culled on this property were Brahmans but the origin of these bulls was not recorded. Despite the low numbers, a variety of breeds of bulls were culled for reaction to buffalo flies. No bulls over 7 years old were culled for reaction to buffalo fly reactions (Table 3.3). This may indicate that susceptible bulls were identified and removed earlier or that the older bulls become more resistant to the effects of the buffalo flies.

Of the total bulls culled, 96% (865/900) were Brahman, Santa Gertrudis or Santa Gertrudis cross bulls. The breed percentages of these herds was not recorded but the predominance of these breeds in the cull data most likely reflects the breeds commonly used in these areas. *Bos indicus* was the most commonly reported genotype in north Queensland, north west Queensland and north Northern Territory in a study of the northern Australian beef industry (Bortolussi *et al.* 2005a).

Total bull numbers on the eight properties were obtained for three years (Table 3.7). These numbers (6040, 5744 and 5750) indicate that the number of bulls did not vary greatly over the three years. After the collection of data in the first year, the number of bulls with unknown age was reduced to zero on all properties. The total number eight year old, nine year old and ten plus year old bulls was also reduced by the third year. On some properties there was a major shift to younger bulls and property A demonstrates this culling of older bulls to totally remove all bulls older than seven by the third year (Table 3.8).

Bull culling information was provided for property E over three years (Table 3.9) but this did not provide enough culled bulls to analyse the consistency of culling for specific problems over time. The percentage of bulls culled with preputial prolapse actually increased over the three years (Figure 3.1) but no conclusions were made as the numbers were low. Most of the bulls culled with preputial prolapse were between six years old and nine years old in each of the three years (Figure 3.2). This was similar to the information from the eight herds in the main study and demonstrates that this is a fairly constant ongoing issue in older bulls in this region.

Survey data were analysed to examine the relationship between age and leg, reproductive or other defects to see if there was an age pattern. This interaction showed that the proportion of bulls culled for problems in these general areas was not consistent across the different age groups ($P > 0.05$; Table 3.10). No obvious pattern was detected that may assist bull selection or influence further bull culling processes.

Within bulls culled for reproductive defects, the main reasons for culling were preputial prolapse and penile haematoma (significantly more than testicular problems or bulls with excessively pendulous sheaths; $P < 0.05$) (Table 3.12). This highlights the loss to the northern cattle industry and the importance of preputial prolapse and penile haematoma, but further research is needed to determine predisposing factors that may lead to these problems to assist initial bull selection.

This study provides quantitative information on the levels of some problems that are reasons for culling of bulls in the northern Australian beef herds. The results apply to Brahman, Santa Gertrudis and Santa Gertrudis cross bulls as these made up 96% of the bulls culled in this study. As only 15% of the bulls were culled in the year, it was determined that bulls need to be retained in the herd for many years at this level of culling. Because of some of the issues with older bulls in the herd, a higher culling rate should be considered. Improved bull selection could be applied to temperament as 43 bulls were culled for temperament. As 66 bulls were culled with leg issues some further research and selection pressure could be used to reduce this loss. Thirty-five bulls were culled with preputial prolapse. This has quantified the loss due to preputial prolapse and has demonstrated that it is a significant issue in the northern Australian beef herd.

Chapter 4.

A quantitative anatomical study of the sheath and prepuce of Santa Gertrudis bulls relative to the occurrence of preputial eversion

Introduction

No comprehensive studies of the anatomy and function of muscles associated with the sheath and prepuce in *Bos indicus* derived bulls have been reported. Similarly any differences in these muscles between polled or horned *Bos indicus* derived bulls, or between those that do or do not exhibit preputial eversion have not been adequately examined. Polled *Bos taurus* bulls are reported to have poorly developed caudal preputial muscles which are associated with preputial eversion in *Bos taurus* bulls (Long and Hignett 1970). A series of baseline studies are required to define the normal variation found in anatomy of the sheath and prepuce of *Bos indicus* derived bulls. Such information is necessary for an examination of the links between anatomical characteristics and subsequent problems developing in the sheath and prepuce. If any links could be identified they may be utilised to remove bulls predisposed to these problems and reduce wastage in the industry. This is particularly important as defects of the prepuce were found to be heritable in a large study by Brinks (1972). The present study examined the sheath, prepuce and associated structures in bulls of one *Bos indicus* derived breed (Santa Gertrudis) to establish such baseline data. Relationships between scoring systems for these organs used in the live animal, and measurements taken post mortem at an abattoir were also examined.

Objectives

To determine if there are differences in the sheath and prepuce musculature in *Bos indicus* derived bulls between polled and horned bulls and between those that evert their prepuces and those that do not.

Materials and methods

Animals

A total of 40 (n = 8 polled; n = 32 horned) bulls from a central Queensland Santa Gertrudis stud herd were included in this study. Bulls, (n = 1 two-year old; n = 39 three years old) were examined on-farm and visually scored by the owner for sheath depth, occurrence of preputial eversion and sheath skin thickness. All animals were reproductively and structurally sound, were all managed similarly and had been culled as excess to stud sale requirements.

Definitions used for the study

Sheath - The hair-covered skin appendage that supports and protects the penis along the ventral abdomen. It extends from the scrotum to the preputial orifice.

Prepuce - The hairless epithelium within the sheath that extends caudally from the preputial orifice, is reflected at the fornix, then extends cranially to attach at the base of the glans penis.

Preputial eversion – Temporary protrusion of a variable length of prepuce from the preputial orifice.

Farm scores

On-farm scores or assessments of the sheath were recorded by the owner, an experienced cattle judge, before the bulls were slaughtered. Bulls with scurs were classified as horned bulls for this study. Sheath depth was scored using the 9 scores (Figure 4.1) of the BREEDPLAN validation project scoring system (Agricultural Business Research Institute, Armidale). From these categories, sheath depth was classed for analysis as either “short” (BREEDPLAN score ≥ 3) or “long” (BREEDPLAN score < 3).

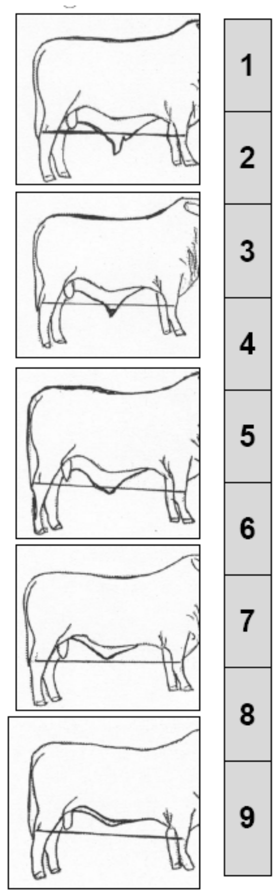

Figure 4.1; BREEDPLAN sheath scoring system.

Preputial eversion was scored as: 1 = none, 2 = slight (< 4 cm), 3 = moderate (4 to 8 cm) and 4 = excessive (> 8 cm). Sheath skin thickness was subjectively assessed as: 1 = thin, 2 = moderate and 3 = thick. This was a subjective, comparative, visual estimation of the thickness of the skin of the sheaths that is used within the industry to describe the sheath without performing any specific measurement.

Abattoir procedures

Bulls were slaughtered at a local abattoir where their external reproductive organs were collected and dissected as shown in Figure 4. 2. The organs were dissected within 12 h of slaughter and were measured and photographed. Hot carcase dressed weight (kg) was obtained from abattoir data.

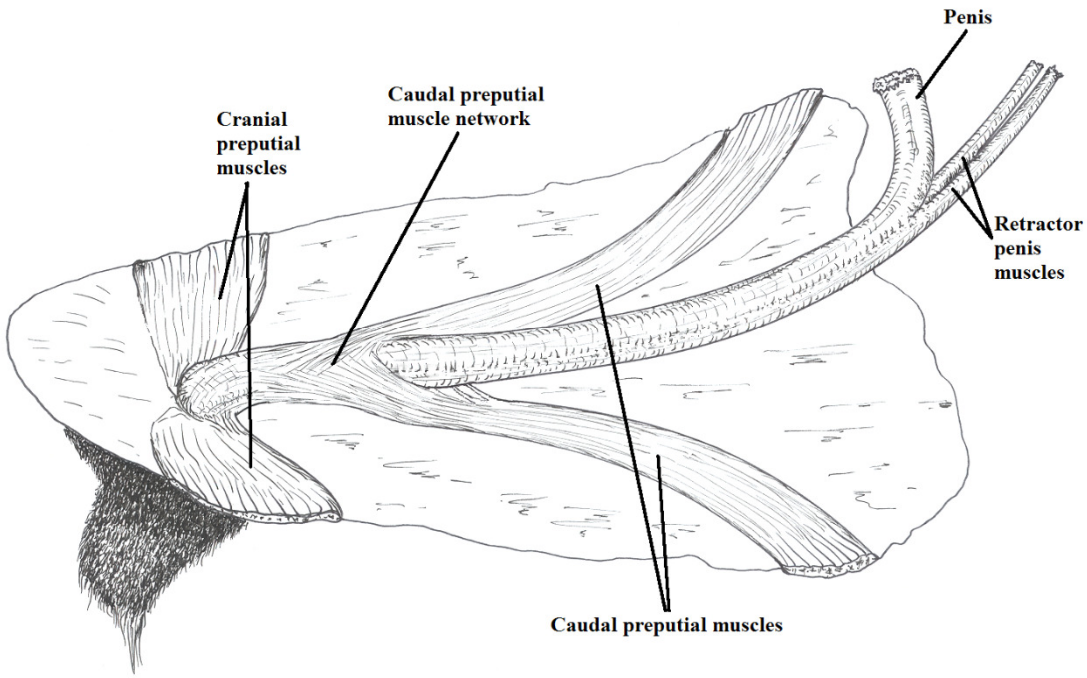

Figure 4.2; Diagram of the dissection indicating basic muscle positions.

Diagram by D Baker.

Organ measurements
Prepuce:

- *Preputial attachment to end of penis* (mm) - The penis was fully extruded and the distance from the point of attachment of the prepuce to the tip of the penis was measured.

- *Fornix to attachment* (mm) - The penis was fully extruded and the distance from the fornix (the point at which the surface of the mucosa changes from smooth to irregular) to the attachment of the prepuce to the penis was measured.

- *Preputial orifice to fornix* (mm) - The penis was fully extruded and the connecting prepuce allowed to relax. The distance from the orifice (defined as the hair junction) to the fornix was measured.

- *Preputial orifice to fornix* (*detached*) (mm) - The prepuce was dissected from the penis and orifice and was suspended and measured from the hair line at the orifice to the fornix.

- *Total length of prepuce* (mm) - The detached prepuce was suspended and measured.

- *Prepuce weight* (g) - The detached prepuce was weighed.

Muscles of the penis and prepuce:

- *Vertical thickness of retractor penis muscle* (mm) – Dorso-ventral measurements of the muscle were taken with a ruler just posterior to the insertion of the muscle onto the penis.

- *Width of retractor penis muscle* (mm) – The lateral transverse measurement was taken immediately posterior to the insertion of the muscle onto the penis.

- *Vertical thickness of caudal preputial muscle* (mm) - This dorso-ventral measurement of the muscle was taken midway along the body of the muscle.

- *Width of the caudal preputial muscle* (mm) - From a set distance above the organs, photographs were taken. From these photographs, the lateral transverse diameter of the caudal preputial muscle was measured midway between the orifice and the base of the scrotum using the ruler included in the photographs.

  Caudal preputial muscle network - The caudal preputial network was scored from photographs. Scores ranged from 1 to 5 (Appendix 2). (1 = network absent or one to two muscle strands from each muscle present, 2 = network of three muscle strands, 3 =

network of four muscle strands, 4 = dense network of more than four muscle strands, 5 = broad dense network of more than four muscle strands). For analysis purposes, a 'small network' was defined as a network of three or less caudal preputial muscle strands visible on the dorsal surface surrounding the prepuce. A 'large network' was defined as four or more strands.

Penis measurements:

- *Dorso-ventral diameter of penis* (mm) and the *lateral transverse diameter of the penis* (mm). These were measured immediately proximal to the insertion of the retractor penis muscles.

- *Penis length* (mm) - The suspended penis was measured from the tip of the penis to the distal boundary of the ischiocavernosus muscle.

- *Weight of penis* (g) – For weighing, the penis was transected at the distal end of the ischiocavernosus muscle.

Sheath skin measurements:

- *Thickness at the preputial orifice* (mm) - Calipers were inserted into the orifice and the thickness of the skin at a distance of two cm from the orifice was measured.

- *Umbilicus measurement* (mm) – The width of the umbilical cord remnant was measured and included the double layer of skin of the sheath that covers the cord remnant.

- *Sheath skin thickness* (mm) - The skin thickness was measured with calipers near the midpoint between the orifice and the base of the scrotum. This was a single skin thickness measurement taken after dissection.

- *Sheath skin area to weight ratio* (sq mm/g) - A rectangular area of hide midway between the preputial orifice and the base of the scrotum was removed. The area was determined and the sample weighed.

Preputial orifice:

- *Preputial orifice diameter* (mm) - A conical object was inserted firmly into the orifice and released to obtain a standard pressure on the orifice. The measured distance along the cone at the orifice was converted into the calculated diameter.

Statistical analysis

Relationships between the anatomical measurements, carcase weight, and scores were examined. The *Statistix* package (Analytical Software, Tallahassee, FL, USA) was used to compute tests of association, ANOVAs and correlations.

Due to the low frequencies of many of the abattoir and on-farm score values, each of the five scores were collapsed to two-valued scores and selected 2x2 cross-tabulations were calculated from these. Where all four frequencies in the margins of a 2x2 table were greater than 10 the chi-square test of association was used, but otherwise the Fisher-Irwin exact test tail probability was calculated.

For each of the 20 abattoir measurements and for each of the five on-farm and abattoir scores, a one-way analysis of variance (ANOVA) was done in which the score (or the collapsed score) values were taken to be treatment levels in a one-way analysis of variance. Treatment significance was tested (F-test) at the 5% level.

Possible relationships among abattoir measurements were examined by calculating a matrix of all possible pairwise simple correlation coefficients.

Results

In this study, horn status was not significantly correlated with sheath depth, occurrence of preputial eversion or caudal preputial muscle network score (Table 4.1). Although not significant, there was a trend for caudal preputial muscle width and for weight of the prepuce to be greater in polled than horned bulls (Table 4.2).

Table 4.1; Numbers of animals by horn status for classifications of sheath depth, preputial eversion and the caudal preputial muscle network.

Classification	Sheath depth		Preputial eversion		Caudal preputial muscle network	
	Short	Long	No	Yes	Small	Large
Horned	15[a]	17	18	14	17	15
Polled	4	4	3	5	3	5
	P = 1.00		P = 0.44		P = 0.69	

[a] Results are given as the number of bulls in each category

Table 4.2; Relationship between horn status, size of the caudal preputial muscle, and length and weight of the prepuce and penis.

		Caudal preputial muscle		Prepuce		Penis	
		Width (mm)	Vertical thickness (mm)	Total length (mm)	Weight (g)	Length (mm)	Weight (g)
Classification	N	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Horned	32	40 ± 17	4.3 ± 2.0	369 ± 52	174 ± 50	1100 ± 66	883 ± 92
Polled	8	50 ± 8	3.6 ± 1.7	390 ± 71	201 ± 50	1120 ± 41	866 ± 104
		P = 0.12	P = 0.3	P = 0.3	P = 0.7	P = 0.5	P = 0.7

A significant relationship (*P* < 0.05) between sheath depth and occurrence of preputial eversion was found. Significantly more bulls with longer sheaths everted their prepuces than bulls with shorter sheaths (Table 4.3).

Table 4.3; Relationship between sheath depth and preputial eversion.

	No eversion	Eversion
Short sheath	14	5
Long sheath	7	14
	P < 0.05	

In terms of other relationships, the occurrence of preputial eversion was not significantly associated with size of the preputial orifice, length or weight of the penis, any of the caudal preputial muscle measurements, or with carcase weight or skin measurements (*P* > 0.05). However, occurrence of preputial eversion was significantly (*P* < 0.05) related to the distance from the preputial orifice to the fornix (measured while the prepuce was attached to the penis) but not to any of the other preputial length measurements (Table 4.4). Bulls that exhibited preputial eversion had shorter preputial orifice-to-fornix measurements than those that did not. Eversion was not, however, significantly related to the caudal preputial muscle network (*P* > 0.05; Table 4.5) and sheath depth (score) was not significantly correlated with carcase weight (P > 0.05).

Table 4.4; Relationship between occurrence of preputial eversion and preputial measurements.

		Preputial orifice to fornix (mms)		Total length of prepuce (detached)(mms)	
	Sample size	Mean	Standard deviation	Mean	Standard deviation
No eversion	21	268.6	34.1	366.7	40.4
eversion	19	266.8	58.1	380.2	69.4
			P = 0.9		*P* = 0.45
		Fornix to attachment (mms)		Preputial orifice to fornix (detached) (mms)	
	Sample size	Mean	Standard deviation	Mean	Standard deviation
No eversion	21	103.0	15.8	192.3	28.3
eversion	19	95.3	21.1	166.6	49.9
			P = 0.2		*P* > 0.5

Table 4.5; Relationship between the size of the caudal preputial muscle network and the occurrence of preputial eversion.

	No eversion	Eversion
Small network	11	9
Large network	10	10
P = 0.75		

Data (mean; SD; range) on the various measurements undertaken in the study are summarised in Table 4.6. For comparative purposes, data from other similar studies are also shown. These data from bulls not affected by preputial prolapse are recorded to provide baseline measurements from *Bos indicus* derived bulls of this age.

Table 4.6; Mean, SD and normal range of various measurements taken in 40 Santa Gertrudis bulls aged 2-3 years.

	Mean	SD	Normal range [a]	Previously published measurements
Prepuce				
Preputial attachment to end of glans (mm)	121	10	100-142	Tip to orifice 548mm, *Bos indicus* (Bellenger 1971)
Fornix to attachment (mm)	99	19	62-137	
Preputial orifice to fornix (mm)	180	42	97-263	
Preputial orifice to fornix (mm) (detached)	268	46	156-360	
Total length (mm) (detached)	373	56	261-485	Total length of the prepuce plus the glans penis 548mm,
Weight (g)	179	51	77-281	
Muscles of the penis and prepuce				
Vertical thickness of retractor penis (mm)	9.8	1.9	6.1-13.5	
Width of retractor penis (mm)	16.2	2.9	10.4-22.0	
Width of caudal preputial (mm)	42	16	10-74	
Vertical thickness of caudal preputial (mm)	4.2	2.0	0.4-8.0	
Penis				
Dorso-vental diameter (mm)	30.8	1.7	27.4-34.2	
Lateral transverse diameter (mm)	35.2	1.8	31.5-38.9	40-50mm (Roberts 1971); 25-40mm (Trotter and Lumb 1958)
Length (mm)	1104	61	981-1229	1100mm, *B indicus* and crosses (Hofmeyr 1987);
Weight (g)	880	90	700-1060	
Sheath skin				
Thickness at preputial orifice (mm)	9.7	1.7	6.3-13.1	
Umbilicus measurement (mm)	32	5	23-42	Up to 50mm (Bertram *et al.* 1997)
Thickness (mm)	6.7	1.6	3.6-9.9	
Area to weight ratio (sq mm/g)	97	15	68-127	
Preputial orifice diameter (mm)	51	4	43-59	20mm (Sisson 1975); 20-40mm (Roberts 1971);
Hot carcase dressed weight (kg)	373	39	295-451	

[a] Normal range calculated as 2 standard deviations each side of the mean, normal distribution assumed

The lateral diameter of the penis was significantly correlated with dorso-ventral diameter (r = 0.40, *P* < 0.05), the two penis weight measurements (r = 0.68, *P* < 0.001 and r = 0.63, *P* < 0.001) and each of the two preputial orifice-to-fornix measurements (r = 0.39, P = 0.01 and r = 0.52, P < 0.001). As would be expected, the weight of the penis was significantly (r = 0.68, *P* < 0.001) correlated with its length. However lateral diameter of the penis bore no significant relationship to the width or vertical thickness of the retractor penis muscle (r = 0.31, *P* = 0.055 and r = 0.31, *P* = 0.051 respectively). The diameter of the penis and the width and vertical thickness of the retractor penis muscles were not significantly related (*P* > 0.05) to the horned status, the caudal preputial network score or to the width of the caudal preputial muscle. Although the size of the penis increased with increasing carcase weight (r = 0.33, *P* < 0.05), neither penis length, nor either of its diameters was individually significantly correlated with carcase weight.

Discussion

In the eight poll *Bos indicus* derived bulls in the present study, polled bulls (homozygosity was not known) did not have a significantly higher preputial eversion score, sheath score, penis length or penis weight compared to horned bulls (Tables 4.1 and 4.2). The polled characteristic had no significant impact on width, vertical thickness, or the network of caudal preputial muscle bands. Although the difference was not significant, the average caudal preputial muscle network was more extensive in polled than in horned bulls. This is different to the situation in *Bos taurus* bulls where it has been suggested by some (Rice 1987; Bruner and Van Camp 1992) that polled *Bos taurus* bulls are susceptible to preputial prolapse because of a heritable weakness of the cranial and caudal muscles of the prepuce.

There have not been any observations published on the caudal preputial muscles in *Bos indicus* bulls (Hofmeyr 1987). There is no indication from the literature to confirm whether there is any difference in the anatomy of the caudal preputial muscles in *Bos indicus* bulls that display or do not display preputial eversion or develop or do not develop preputial prolapse.

Preputial eversion score in the present study was not significantly ($P > 0.05$) related to the size of the caudal preputial muscle or to the size of the caudal preputial muscle network (Table 4.5). In our study, 10 of 20 bulls (50%) with a large caudal preputial muscle network exhibited preputial eversion compared to 9 of 20 (45%) bulls with a small muscle mass. This lack of difference indicates that the caudal preputial muscle network is not important in determining if a *Bos indicus* derived bull everts its prepuce or does not evert its prepuce. This is important as it highlights the difference with the current literature on polled *Bos taurus* bulls where Long and Hignett (1970) dissected 30 prepuces of British breed beef and dairy bulls and observed all seven of the polled bulls everted their prepuces but only one of the 20 horned bulls everted its prepuce. After slaughter of these *Bos taurus* bulls, dissection of the reproductive organs demonstrated that the horned bulls all had well-developed caudal preputial muscles but these muscles were absent in all of the polled bulls. Other authors also related this caudal preputial muscle deficiency to preputial prolapse and suggested that the predisposition to preputial prolapse involves breeds that have incomplete development or absence of the caudal preputial muscles (Walker and Vaughan 1980; Wolfe 1986). The difference between the breeds may be because most *Bos indicus* bulls have a much longer sheath than most *Bos taurus* bulls and may have developed different preputial control methods.

Cranial preputial muscles were present in all 40 bulls examined in this study, but were not measured as no consistent site for measurement remained on the organs provided by the abattoir.

In the literature, sheath has been described in many ways (Donaldson and Aubrey 1960; Walker and Hull 1984). For the purpose of this discussion it is assumed that sheath size, sheath score, sheath area and the degree to which the sheath is pendulous are similar and can be generally compared as these terms similarly describe the sheath. In the present study, sheath score was not significantly related to carcase weight ($P > 0.05$). This would suggest that selection against a more pendulous sheath will not impact on the growth rate of Santa Gertrudis bulls. This finding contradicts much of the earlier literature where more pendulous sheaths have been linked to heavier cattle or greater body weight gains in *Bos indicus* and *Bos indicus* derived cattle (Franke and Burnes 1985; Hoogenboezem and Swanepoel 1995). Franke and Burnes (1985) examined 439 Brahman and Brahman derived cattle and found sheath area was correlated to pre-weaning growth traits. In the present study the absence of any relationship may reflect selection over time within the herd against more pendulous sheaths while concurrently selecting for increased growth rates within this herd. Results from other studies were in agreement with the present study with no significant correlation between body weight and sheath depth in *Bos indicus* derived bulls (Lagos and Fitzhugh 1970; Bertram *et al*. 1997). In the study on yearling bulls by Lagos and Fitzhugh (1970), no correlation between body weight and preputial eversion score was found after data were adjusted for age.

Findings from this current study illustrate that preputial eversion was more common ($P < 0.05$) in bulls with more pendulous sheaths than in bulls with less pendulous sheaths (67% versus 26%; Table 4.3). This was in agreement with a previous study that found that sheath depth was significantly correlated with eversion score (Lagos and Fitzhugh 1970). If preputial eversion is an important factor leading to preputial prolapse, then the present study further confirms that culling of bulls with excessively pendulous sheaths should reduce the incidence of preputial prolapse. Eversion of the prepuce is stated as a major predisposing factor in preputial injury and infection (Johnson and Williams 1968; Supple-Kane 1969; Walker 1980). Others have found that most cases of preputial prolapse requiring surgery have been in breeds in which preputial eversion is common (Monke 1976). However, in another study there was no greater incidence of preputial disease in *Bos taurus* bulls that displayed preputial eversion than in those which did not (Long 1969). This was supported by a study of 487 *Bos indicus and Bos taurus* bulls in which the presence of preputial ulcers that may predispose to prolapse was statistically unrelated to eversion (Long and Rodriguez 1972).

Eversion score in this study was not significantly related to the detached prepuce weight or to any of the detached preputial length measurements. This supports studies comparing preputial length measurements after slaughter, where there were no significant differences between bulls that displayed preputial eversion and those that did not (Long and Hignett 1970). It had been suggested that size of the prepuce may influence the probability of preputial prolapse (Arthur

1964). Some authors quantified size by measuring preputial length and indicated that an increased preputial length was a major factor that predisposes bulls to preputial prolapse (Hofmeyr 1968; Klug *et al.* 1979). In contrast, Memon *et al.* (1988) stated that preputial length alone was not the cause of prolapse. Definitive studies observing large numbers of *Bos indicus* derived bulls are needed to clarify the significance of the relationship between preputial measurements and preputial prolapse.

Eversion score was not significantly related to orifice diameter in the present study ($P < 0.05$) which confirms another study, where there was no significant difference in orifice measurement between everting and non-everting bulls (Long and Hignett 1970). However, some authors (Van Den Berg 1984; St Jean 1995) indicated that orifice diameter was a contributing factor in prolapse. A larger preputial orifice may be related to a higher risk of injury of the prepuce due to increased exposure of the prepuce at the orifice and thus, may not necessarily be related to prolapse due to eversion.

The size and weight of the penis was recorded to establish a normal range in young Santa Gertrudis bulls (Table 4.5). A normal range may be used as a reference by later studies to determine if penis size is a factor in preputial prolapse.

Sheath skin measurements and scores were collected to confirm the relationship that has been suggested between skin thickness and an increase in preputial eversion or preputial prolapse (Smit 1994). These relationships were not supported by the present study where eversion was not significantly related to any of the sheath skin measurements.

The overall aim of the research was to identify measurements that can assist the selection of bulls to reduce the incidence of preputial prolapse in the industry. Preputial prolapse costs the industry in lost function of bulls, treatment costs, welfare concerns and the requirement of extra replacement bulls. There was no evidence that polled *Bos indicus* derived bulls in this herd had poorer preputial muscle development than did horned *Bos indicus* derived bulls, or that they everted their prepuces further than horned bulls. This is different to the situation in polled *Bos taurus* bulls but may reflect the limited genetic composition in this one herd, the different mode of inheritance of the poll trait in *Bos indicus* cattle or the unknown homozygosity of these bulls. We also determined that preputial eversion was related to low sheath score, which may justify selection against *Bos indicus* bulls with excessively pendulous sheaths if eversion leads to an increase in preputial injury or infection. Selection for breeding bulls with less pendulous sheaths needs to be implemented as part of the selection program in bull breeding programs. Eversion of the prepuce was not related to the apparent degree of caudal preputial muscle development or to the caudal preputial muscle network score. Eversion of the prepuce was also not related to the length of the prepuce so further work is needed to establish the causes of preputial eversion and to determine the pathogenesis of preputial prolapse in *Bos indicus* derived bulls so bulls susceptible to preputial prolapse can be identified early and removed from breeding programs.

Chapter 5.

A study of the anatomy of the external genitalia of Santa Gertrudis bulls with chronic preputial prolapse

Introduction

Preputial prolapse is perceived within the beef industry to be a cause of significant financial loss (Copland 1989). It has been suggested that *Bos indicus* and *Bos indicus* derived bulls should be culled for many reasons that are thought to be associated with an increased risk of developing chronic preputial prolapse. This includes culling bulls with excessively pendulous sheaths or bulls in which preputial eversion regularly occurs (Donaldson and Aubrey 1960; Walker 1970). This is particularly important as abnormalities of the prepuce were found to be heritable in a large study by Brinks (1972).

Previous studies of *Bos taurus* bulls have shown that polled *Bos taurus* bulls have a deficiency in the caudal preputial muscles when compared to horned bulls. Of the prepuces from 30 *Bos taurus* bulls that were examined, all those from horned bulls had well developed caudal preputial muscles; however these muscles were absent from all of the polled bulls. All seven polled bulls were seen to evert but only one of the horned bulls (Long and Hignett 1970). It was suggested that the caudal preputial muscles were important in preventing preputial eversion in the horned bulls. Similar information for *Bos indicus* and *Bos indicus* derived bulls is not available.

Objectives

Therefore, the objective of this study was to describe the anatomy of the sheath, prepuce and penis of Santa Gertrudis (*Bos indicus* derived) bulls affected with chronic prolapse of the prepuce to determine whether any anatomical characteristics were associated with prolapse of the prepuce.

Materials and methods

Animals

The external reproductive organs of 32 Santa Gertrudis bulls affected with chronic preputial prolapse were collected from a south east Queensland abattoir. Hot standard carcase weights were obtained from the abattoir and information on the horn status, age and history of the bulls was obtained from the owners. Bulls were from properties in north-eastern Australia and were between two to ten years of age. In this study, 'old' bulls were classified as being over six years of age. Eight of the bulls were polled and 15 were horned, but horn status information was not available for the remaining nine bulls. The organs were examined in an anatomy dissection area at the University of Queensland within 12 hours of slaughter and were measured and photographed. Muscle terminology is based on Getty (1975).

Anatomical measurements

Prepuce and penis

For the measurements in this study, the prepuce is defined as the hairless epithelium and associated tissues extending from the preputial orifice to its attachment on the penis .All measurements were done using a standard 300 mm ruler.

1. *Vertical thickness of retractor penis muscle* (mm) – The dorso-ventral thickness of the muscle just posterior to the insertion of the muscle onto the penis.

2. *Width of retractor penis muscle* (mm) – The transverse thickness immediately posterior to the insertion of the muscle onto the penis.

3. *Vertical thickness of caudal preputial muscle* (mm) – The dorso-ventral thickness midway along the body of the muscle.

4. *Width of the caudal preputial muscle* (mm) - The transverse thickness of the caudal preputial muscle midway between the preputial orifice and the base of the scrotum.

5. *Caudal preputial muscle network* score (1 - 5) - The network was scored as follows: 1 = network absent or only one to two muscle strands from each muscle present, 2 = network of three muscle strands, 3 = network of four muscle strands, 4 = dense network of more than four muscle strands, 5 = broad dense network of more than four muscle strands (See Appendix 2).

6. *Vertical diameter of penis* (mm) and the *lateral diameter of the penis* (mm) – These were measured immediately proximal to the insertion of the retractor penis muscles.

7. *Penis length* (mm) - The penis was freely suspended and then measured from the tip of the penis to the distal boundary of the ischiocavernosus muscle.

8. *Weight of penis* (g) – The penis was transected at the distal end of the ischiocavernosus muscle and then weighed on desk scales.

Sheath

1. *Sheath skin thickness* (mm) - The single skin thickness was measured with calipers near the midpoint between the preputial orifice and the base of the scrotum after removal of the skin from the organs.

Statistical analysis

For statistical analysis of the preputial muscle network score, a ‘small network’ was defined as a network of three or less caudal preputial muscle strands visible on the dorsal surface surrounding the prepuce. A ‘large network’ had four or more strands.

Due to low frequencies of the score values, each of the scores was collapsed to two-valued scores and then selected 2 x 2 cross-tabulations were calculated from among the scores. Where all four frequencies in the margins of a 2 x 2 table were greater than ten, the chi-square test of association was used but otherwise the Fisher-Irwin exact test tail probability was calculated.

For each of the measurements and for each of the scores, a one-way analysis of variance (ANOVA) was done in which the score (or collapsed score) values were taken to be treatment levels in a one-way analysis of variance. Treatment significance was tested (F-test) at the 5% level.

Relationships among abattoir measurements were examined by calculating a matrix of all possible pairwise simple correlation coefficients. The *Statistix* package (Analytical Software, Tallahassee FL) was used to compute tests of association, ANOVAs and correlations.

Results

The mean age of the bulls was 6.1 years ± 2.1. Polled bulls (819 ± 88 kg) were of similar liveweight to horned bulls (841 ± 133 kg). The majority of horned bulls had a large caudal preputial muscle network, whereas the majority of polled bulls had a small caudal preputial muscle network (Table 5.2). Significant differences were found between horned and polled bulls for sheath skin thickness, vertical thickness of the caudal preputial muscle and width of the caudal preputial muscle only (Table 5.3). When relationships between the size of the penis and associated penis muscles were analysed, the width and vertical thickness of the retractor penis muscle was found to increase significantly ($P < 0.05$) with increasing weight of the penis and the increasing diameter of the penis.

Table 5.1; Summary of the mean (± SD) preputial, penis and sheath measurements from 32 Santa Gertrudis bulls affected with chronic preputial prolapse.

	Mean	SD
Muscles of the penis and prepuce		
• Vertical thickness of retractor penis muscle (mm)	10.9	2.6
• Width of retractor penis muscle (mm)	20.3	4.0
• Width of caudal preputial muscles (mm)	40.0	33.2
• Vertical thickness of caudal preputial muscle (mm)	4.0	2.2
Penis		
• Vertical diameter (mm)	32.3	3.0
• Lateral diameter (mm)	36.3	3.2
• Length (mm)	1160	80
• Weight (g)	1150	220
Skin		
• Sheath skin thickness (mm)	7.3	1.5
Bull weight		
• Hot standard carcase weight (kg)	462	68
• Live weight (kg)	825	118

Table 5.2; Frequency of bull age and caudal preputial muscle network score groups by horn status for bulls affected with chronic preputial prolapse.

Horn status	Caudal preputial muscle network		Age	
	Small	Large	≤ 6 years old (Younger)	> 6 years old (Older)
Horned	1	11	7	8
Polled	6	1	6	1
P value	< 0.05		0.16 n.s.	

*Network scores and age data were not available for all the study bulls so total numbers vary for each analysis.

Table 5.3; Comparison of means between preputial, penis and sheath measurement from horned and polled bulls affected with chronic preputial prolapse.

Horn status		Sheath skin thickness (mm)		Vertical thickness of the caudal preputial muscle (mm)		Width of the caudal preputial muscle (mm)
	n	Mean ± SD	n	Mean ± SD	n	Mean ± SD
Horned	15	8.0 ± 1.5	15	5.0 ± 1.5	11	46.4 ± 21.3
Polled	7	6.6 ± 0.7	5	2.5 ± 2.9	5	4.0 ± 8.9
P value		< 0.05		< 0.05		< 0.05
		Retractor penis muscle width (mm)		Vertical thickness of retractor penis muscle (mm)		Vertical diameter of the penis (mm)
	n	Mean ± SD	n	Mean ± SD	n	Mean ± SD
Horned	15	20.0 ± 5.4	15	10.8 ± 3.6	15	32.6 ± 3.0
Polled	8	20.5 ± 2.2	8	11.0 ± 1.3	8	32.8 ± 2.1
P value		0.8 n.s		0.9 n.s.		0.9 n.s.
		Lateral diameter of the penis (mm)		Penis length (mm)		Weight of penis (g)
	n	Mean ± SD	n	Mean ± SD	n	Mean ± SD
Horned	15	36.0 ± 3.1	15	1152 ± 87	15	1157 ± 260
Polled	8	34.8 ± 2.8	8	1188 ± 63	8	1158 ± 169
P value		0.4 n.s.		0.3 n.s.		0.9 n.s.

*Not all measurements were able to be performed on all of the bulls identified as horned or polled.

Table 5.4; Summary of significant correlations between hot standard carcase weight and penis and penis muscle measurements.

Measurement	r value	P value
Weight of the penis	0.65	< 0.001
Length of the penis	0.42	< 0.05
Lateral diameter of the penis	0.57	< 0.01
Vertical diameter of the penis	0.47	< 0.05
Width of the retractor penis muscle	0.47	< 0.05

Discussion

The anatomy of Santa Gertrudis bulls affected with preputial prolapse was examined to determine if any structures could be identified that might predispose to this condition. Bulls affected with chronic preputial prolapse could be separated into two main categories; horned bulls, a majority of which had well developed caudal preputial muscles and thicker sheath skin; and mostly young polled bulls, a majority of which had poorly developed caudal preputial muscles (Tables 5.2 and 5.3). This may be important as polledness has been reported to be associated with preputial eversion in *Bos taurus* bulls (Long and Hignett 1970; Rice 1987; Bruner and Van Camp 1992). These authors reported that polled *Bos taurus* bulls have poorly developed caudal preputial muscles. If there is a link between increased eversion and a higher incidence of preputial prolapse, this could explain the increased proportion of preputial prolapses which has been reported in polled *Bos taurus* bulls (Desrochers *et al.* 1995). Although only small numbers of *Bos indicus* derived bulls with preputial prolapses were sampled in this study, the frequency of affected polled bulls was higher than the frequency of polled bulls in the breed. Horn status was identified in 23 of the bulls. Of these 23 bulls, eight (35%) were identified as polled and 15 (65%) were horned. This is compared to the industry figures of 5% of Santa Gertrudis bulls being polled when figures are taken from a semen price list (Beef Breeding Services 1999) and 15% in the 2002 BREEDPLAN progeny recording data from the Santa Gertrudis Breeders' (Australia) Association. A higher than expected proportion of polled Santa Gertrudis bulls affected with preputial prolapse could indicate that the polled gene is associated with a defect that increases the risk of development of preputial prolapse in polled bulls.

The link between polled bulls and a deficiency of the caudal preputial muscle may not be universal in all *Bos indicus* derived bulls. From the chapter four study of the anatomy of the caudal preputial muscles in normal bulls, it was concluded that some polled Santa Gertrudis bulls have well developed caudal preputial muscle networks.

Polledness was not related to the size of the retractor penis muscles or to the length, size or weight of the penis. There is no indication that the increased frequency of preputial prolapse seen in these polled bulls is due to larger penises or to a deficiency in the size of the retractor penis muscles. Polled bulls without preputial prolapses were dissected in the chapter 4 study and a similar lack of any relationship was found. Polledness in the chapter 4 study was also not related to the size of the retractor penis muscles or to the length, size or weight of the penis. No other comparative studies of the relationship between horn status in *Bos indicus* derived bulls and penis or penis muscle size are available.

The size or weight of the penis has been considered by some in the cattle industry to be a possible predisposing factor for preputial prolapse with larger penises thought to predispose to preputial prolapses (Want 1999). Many of the organ measurements recorded in this study were significantly related to the weight of the bull. As carcase weight increased so did penis length, weight and diameter and width of the retractor penis muscles.

Comparing the results of this study with the results of the study of normal bulls in chapter 4, the penises of the bulls with preputial prolapses were heavier for their size and length than the penises of the normal bulls. Bulls with preputial prolapses in the present study (n = 26; 462kg hot standard carcase weight) were 24% heavier than the normal bulls (n = 40; 373kg hot standard carcase weight) in the previous study. It was also noted that the average weight of bull penises for affected bulls was 31% more (n = 32; 1150kg) than penises of unaffected bulls in the chapter 4 study (n = 40; 880kg). However, the dimensions (diameter and length) of the penises in the present study were less than 5% greater than in the normal bulls of the previous study. This may be a reflection of a normal age effect on the penis rather than a possible factor contributing to preputial prolapse, as the bulls in this study were older (averaging six years old) compared to the unaffected bulls in chapter 4 that averaged three years old.

We were able to determine that measurements of the retractor penis muscle were positively correlated with penis measurements. No retractor penis muscle deficiency was found as the muscles increased in size in bulls with larger penises. These muscles were measured as they have been previously reported to be underdeveloped in Brahmans (Van Den Berg 1984) so could be linked to preputial prolapse.

The age of the prolapsed bulls at the time of slaughter is a reflection of the age of onset of the preputial prolapse. Most bulls were sent to slaughter soon after preputial prolapse was detected. Preputial prolapse was seen more frequently in younger polled bulls compared with horned bulls. Only one polled bull was classified as 'older' compared to more than half of the horned bulls. For the analysis, younger was defined as 6 years old or younger. Six years old was the average age of the bulls in this study. Although this was not a statistically significant result, data suggest that factors causing preputial prolapse in polled bulls generally affected those bulls at a young age. This may be related to a congenital deficiency in the size and development of the caudal preputial muscles of polled bulls.

A previous northern Australian abattoir survey examined preputial prolapse and found that most (76%) affected bulls were between the ages of 3.5 and 7 years, and that 24% were older (Mosaheb *et al.* 1973). These findings are very similar to the present study where 65% of the affected bulls were between the ages of 3.5 and 7 years and 26% were older. Other studies have showed a 3.5 years average age of bulls affected with preputial prolapse but both these studies (Memon *et al.* 1988; Baxter *et al.* 1989) examined bulls presented for treatment and did not include bulls with preputial prolapse that were culled without treatment. This is a different situation to the extensive areas of northern Australia.

Despite the polled bulls with preputial prolapse being younger than the horned bulls, the average age of the bulls with preputial prolapse was 6.1 years and this is similar to the chapter three finding that the average age of bulls culled for preputial prolapse in northern Australia was 6.7 years old. The consistency of these findings supports the information on age of development of preputial prolapse in *Bos indicus* derived bulls in Australia although further analysis of the differences between polled and horned bulls provides additional understanding.

Sheath skin measurements were performed to confirm the relationship that has been suggested between sheath skin and an increased risk of preputial prolapse (Baxter *et al.* 1989). Polled bulls in the present study had significantly thinner skins than horned bulls. This may reflect the younger age of the polled bulls in this study although the age difference may not account for the difference as there was no difference in live weight, penis or retractor penis muscles between the polled and horned bulls (Table 5.3). The thicker skin in these prolapsed horned bulls may be significant but was not compared to the skin of the sheaths of horned bulls that did not exhibit chronic prolapse of the prepuce. Sheaths with thicker skin may be heavier and may extend lower and the chapter 4 study showed that bulls with more pendulous sheaths everted their prepuces more than bulls with less pendulous sheaths and this may have been a factor contributing to preputial prolapse.

Despite more pendulous sheaths being identified in chapter four as being linked to an increase in preputial eversion, sheaths were not scored in the present study. Although this could have provided a stronger link between sheath size and the possibility of developing preputial prolapse, the sheaths of these bulls with preputial prolapse were distorted to different extents due to the varying weights of the preputial prolapses.

As eversion may be an important factor in the aetiology of preputial prolapse, causes of preputial eversion other than the deficiency in the caudal preputial muscles in some polled *Bos indicus* derived bulls and excessively pendulous sheaths in *Bos indicus* derived bulls need to be investigated. Any further identified relationships to preputial eversion could then be used to improve bull selection and reduce the incidence of preputial prolapse

Chapter 6.

Relationship between the position of the penis and preputial eversion in *Bos indicus* derived bulls

Introduction

It has been suggested that eversion of the prepuce is a major predisposing factor in preputial injury and infection (Monke 1976; Larson 1986) but there is a paucity of published information validating this association and limited data confirming factors that predispose bulls to preputial eversion.

Most reported cases of preputial prolapse requiring surgery have been in breeds known to display eversion of the prepuce (Monke 1976). These have included Brahmans, Santa Gertrudis, Angus, Polled Herefords and occasionally Herefords. This association was not universally observed: in a study of 244 bulls of 13 British breeds, records revealed no greater incidence of preputial disease in bulls that displayed eversion of the prepuce than in those which did not (Long 1969). Although a range of ages and breeds were observed in this study, the bulls were housed at artificial insemination centres and the bulls were mostly tethered. During the study, these bulls would not have been exposed to the trauma associated with natural mating and would not have been exposed to harsh environmental conditions that may damage an exposed prepuce.

Preputial eversion is considered to be related to a deficiency of the caudal preputial muscles in *Bos taurus* bulls (Long and Hignett 1970) but there are no published research data that demonstrate this relationship in *Bos indicus* and *Bos indicus* derived bulls. It is possible there may be differences between *Bos taurus* and *Bos indicus* bulls in causes of preputial eversion.

Objectives

The objective of the study is to determine if preputial eversion is related to the position of the penis in *Bos indicus* derived bulls, and to examine factors that may affect this relationship.

Materials and methods

Animals

Thirty-two Droughtmaster bulls ranging in age from 10 to 130 months from two south-east Queensland properties were examined. There were 13 bulls from one property and 19 from the other property. Nine of the bulls were polled, 16 were scurred (with horn-like growths in the same location as horns), and seven were horned. Sire data from these bulls were also collected. Two of the bulls did not evert their prepuces and were not included in the analysis. One of these was a horned bull that was able to constantly contract the preputial orifice towards the abdomen making the position of the penis in relation to the preputial orifice difficult to accurately assess. When the bull did relax his sheath during rectal examination, the glans penis was not observed to be close to the preputial orifice. This bull was excluded from the analysis as no preputial eversion was measured. Sheath measurements from this bull were within the range measured from the other bulls.

Measurements

The bulls were examined while restrained in a cattle crush. The distance from the tip of the glans penis to the preputial orifice was measured externally with a flexible measuring tape, the tip of the glans penis being located visually (by its impression in the sheath) where possible, or by palpation. The position of the tip of the glans penis was found to constantly change and an average of 19 repeat measurements within one hour were recorded for each bull while the bull remained in the cattle crush. Simultaneous measurements of the length of preputial eversion from the preputial orifice were recorded with a flexible measuring tape except in two bulls where preputial eversion was not observed. These repeated measurements were used to establish the relationship between the length of preputial eversion and the position of the tip of the glans penis in the sheath. To establish an accurate relationship, these paired measurements were taken quickly especially after palpation, which sometimes initiated contraction of the penis and prepuce. Measurements for all bulls except Bull 1 were recorded on one day only.

Measurements on Bull 1 were repeated three weeks apart to determine if the measurements were repeatable at a different time. Data for the two days for this bull were combined for further analysis.

Two standard measurements were defined: the length of preputial eversion when the tip of the glans penis was at the preputial orifice and the minimum distance of the tip of the glans penis from the preputial orifice when no preputial eversion was evident. These measurements were obtained by extrapolating the regression lines for each bull to the intersection with the Y and X axes respectively.

The depth of the sheath of each bull was measured as the vertical distance from the ventral abdominal wall to the preputial orifice.

Definitions

The definitions of the sheath, prepuce, and preputial eversion are as provided in chapter 4.

Statistical analysis

All statistical analyses were performed using *Genstat* 9th Edition (IACR – Rothamsted, Harpenden, Hertfordshire AL5 2JQ; distributed by Numerical Algorithms Group, Oxford). The bull is the independent experimental unit. Repeated measurements for each bull were used in the regression analysis to estimate the relationship between the distance of the tip of the glans penis from the preputial orifice and the length of preputial eversion. These regressions were then compared using grouped regression analysis. There were significant differences between intercepts but not slopes. To assess whether the difference in intercepts could be attributed to the property (two levels), sire (18 levels), horn status (three levels) or age (three levels, < 18 months, 19 to 29 months and > 29 months) the intercept term in the grouped regression was replaced by each of these factors in turn. Due to considerable confounding of these factors, they could not be assessed simultaneously in the model. Eighteen different sires were involved in the study so the effects of individual sires (sire effects) were difficult to statistically confirm.

Correlations between the length of preputial eversion and other sheath measurements were calculated.

The age groups were selected to differentiate between young bulls (< 18 months old) and older bulls (> 29 months old). Sufficient numbers of bulls in each of these age groups enabled valid analyses.

Results

Repeat regression analyses of the relationship between distance of the tip of the glans penis from the preputial orifice and the length of preputial eversion for Bull 1 were not significantly different ($P < 0.05$, Figure 6.1) at the two different measurement times. There was a constant linear relationship ($P<0.001$, Table 6.1) between distance from the tip of the glans penis to the preputial orifice and the length of preputial eversion across nearly all bulls, with individual bulls having significantly ($P<0.001$: $r^2=0.36$) different intercepts (Figure 6.2). The estimated Y intercept (constant) for each animal was then tested against possible factors. The difference between intercepts could not be fully explained by differences in factors such as property ($P = 0.362$: $r^2=0.03$), sire ($P = 0.487$: $r^2=0.62$), or the presence of horns ($P = 0.059$: $r^2=0.19$, Figure 6.3). Age was significant ($P = 0.005$: $r^2=0.33$): however a linear model was inappropriate so an exponential model was adopted to examine this relationship (Figure 6.4). Significant ($P<0.001$: $r^2=0.36$) linear relationships were found between the length of preputial eversion when the tip of the glans penis was at the preputial orifice and the depth of the sheath (Figure 6.5).

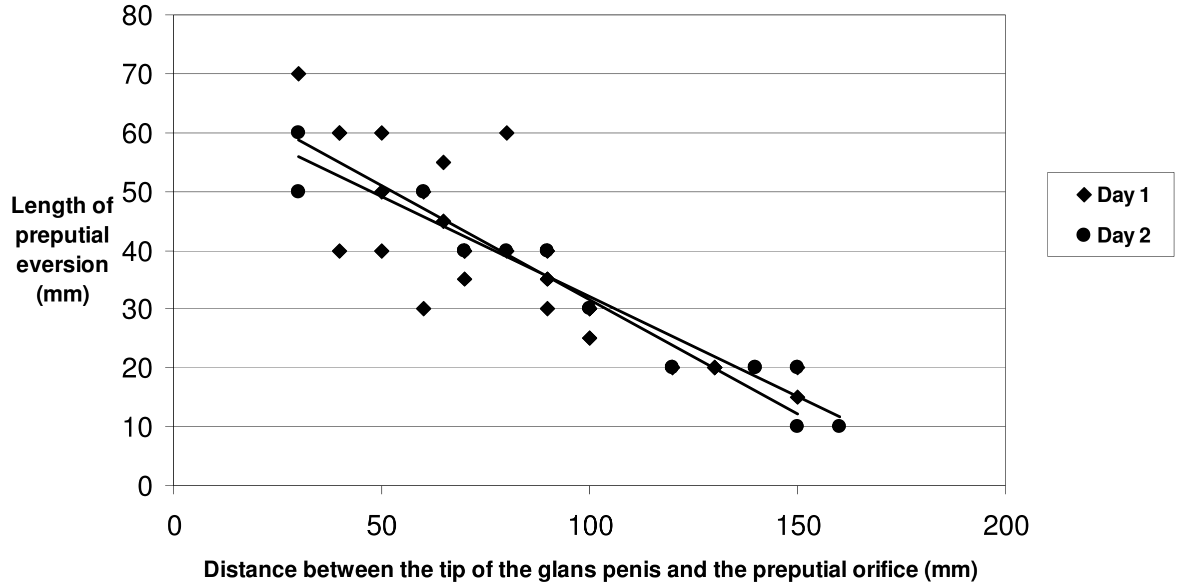

Figure 6.1; Relationship between length of preputial eversion and position of the tip of the glans penis relative to the preputial orifice for Bull 1 on two different days.

Table 6.1; Relationship between length of preputial eversion and position of the tip of the glans penis relative to position of the preputial orifice for individual bulls, and physical characteristics of the bulls that exhibited eversion.

Bull	Number of	Age (Months)	Farm	Sire	Horn	Sheath	Constant	Slope	r^2	Prob
1	50	16	1	1	H	200	68.7	-0.3661	0.84	<0.001
2	30	19	1	2	H	180	64.34	-0.3817	0.86	<0.001
3	36	16	1	1	H	220	100.24	-0.3821	0.87	<0.001
4	8	17	1	3	S	150	65.78	-0.341	0.69	0.01
5	14	16	1	3	P	150	67.61	-0.3356	0.68	<0.001
6	33	17	1	4	P	170	77.19	-0.3975	0.93	<0.001
7	21	13	2	5	P	170	72.69	-0.3151	0.82	<0.001
8	17	11	2	6	S	170	68.42	-0.2867	0.75	<0.001
9	17	11	2	6	H	160	74.22	-0.3344	0.88	<0.001
10	21	24	2	5	S	185	70.86	-0.3115	0.81	<0.001
11	23	22	2	7	P	200	81.84	-0.3455	0.74	<0.001
12	15	39	1	6	S	220	100.32	-0.3485	0.87	<0.001
13	16	28	1	6	S	170	80.61	-0.2274	0.65	<0.001
14	13	26	1	8	P	190	120.1	-0.4728	0.76	<0.001
15	16	24	1	9	S	165	83.73	-0.4211	0.88	<0.001
16	14	27	1	6	S	140	61.97	-0.3217	0.76	<0.001
17	14	20	2	6	P	230	112.65	-0.3413	0.83	<0.001
18	4	10	2	10	S	175	51.76	-0.171	0.82	0.097
19	14	22	2	11	S	215	135.8	-0.5155	0.71	<0.001
20	10	30	2	5	S	250	88.6	-0.2927	0.77	<0.001
21	12	34	2	6	S	215	100.49	-0.3315	0.85	<0.001
22	20	24	2	12	S	180	77.92	-0.3554	0.92	<0.001
23	21	26	2	13	H	220	46.75	-0.2506	0.88	<0.001
24	20	24	2	14	P	180	58.17	-0.3607	0.77	<0.001
25	18	23	2	15	H	175	66.66	-0.3828	0.93	<0.001
26	19	23	2	14	P	185	97.66	-0.3553	0.90	<0.001
27	28	130	2	16	S	205	121.93	-0.4515	0.85	<0.001
28	17	32	2	17	S	195	110.41	-0.4354	0.91	<0.001
29	14	M	2	M	S	200	55.31	-0.1676	0.77	<0.001
30	25	81	2	18	S	240	106.64	-0.293	0.95	<0.001

M missing data

H horned, S scurred and P polled.

The constant is the length of preputial eversion when the tip of the glans penis is at the preputial orifice.

Table 6.1 indicates possible related factors (age, farm, sire, sheath depth and horn status) and summarises the relationship between the position of the tip of the glans penis and the associated length of preputial eversion.

Although there was some variation in the slopes of the relationships (Table 6.1), a low variance ratio of 3.82 shows that the relationship between preputial eversion length and the position of the tip of the glans penis was similar among these bulls.

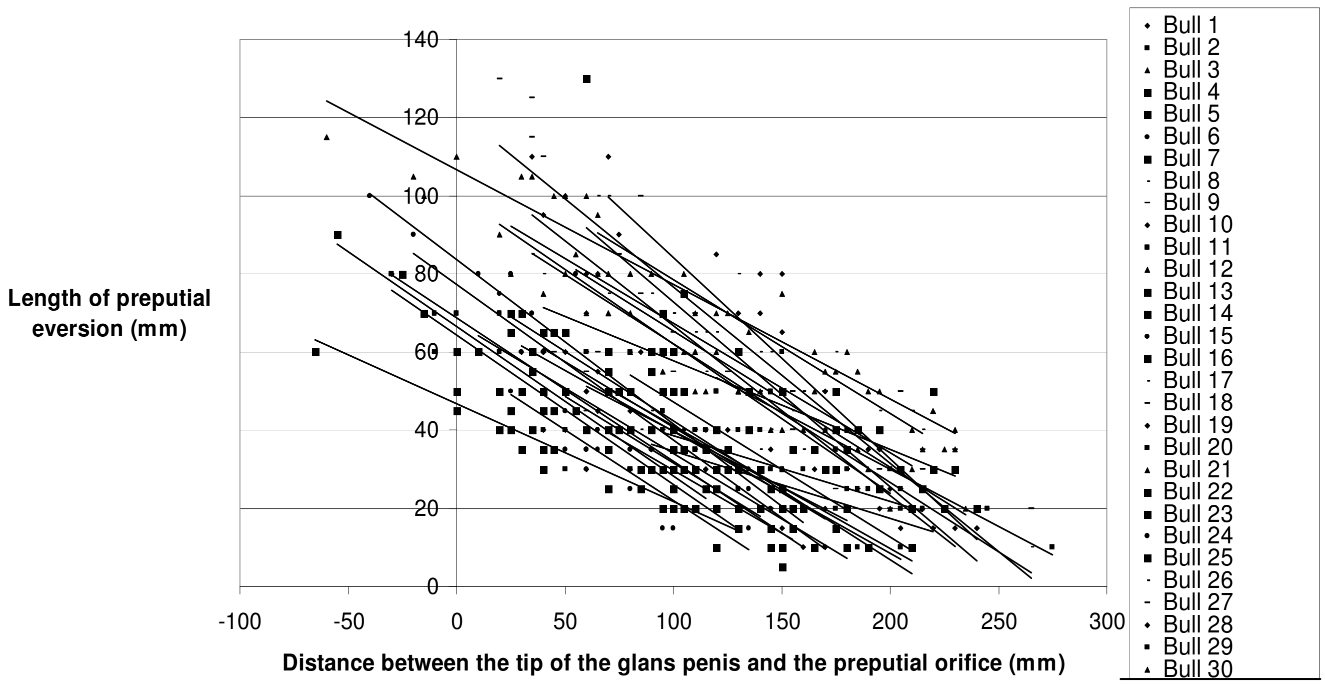

Figure 6.2; Individual regression lines for the relationship between the length of preputial eversion and position of the tip of the glans penis relative to the preputial orifice for all bulls in the study.

Regression analyses (Figure 6.2) demonstrated that bulls had similar slopes (relationships between the position of the tip of the glans penis and length of preputial eversion relative to the preputial orifice) but had different intercepts (length of preputial eversion when the tip of the glans penis was at the preputial orifice, or the minimum distance of the tip of the glans penis from the preputial orifice when no preputial eversion was visible).

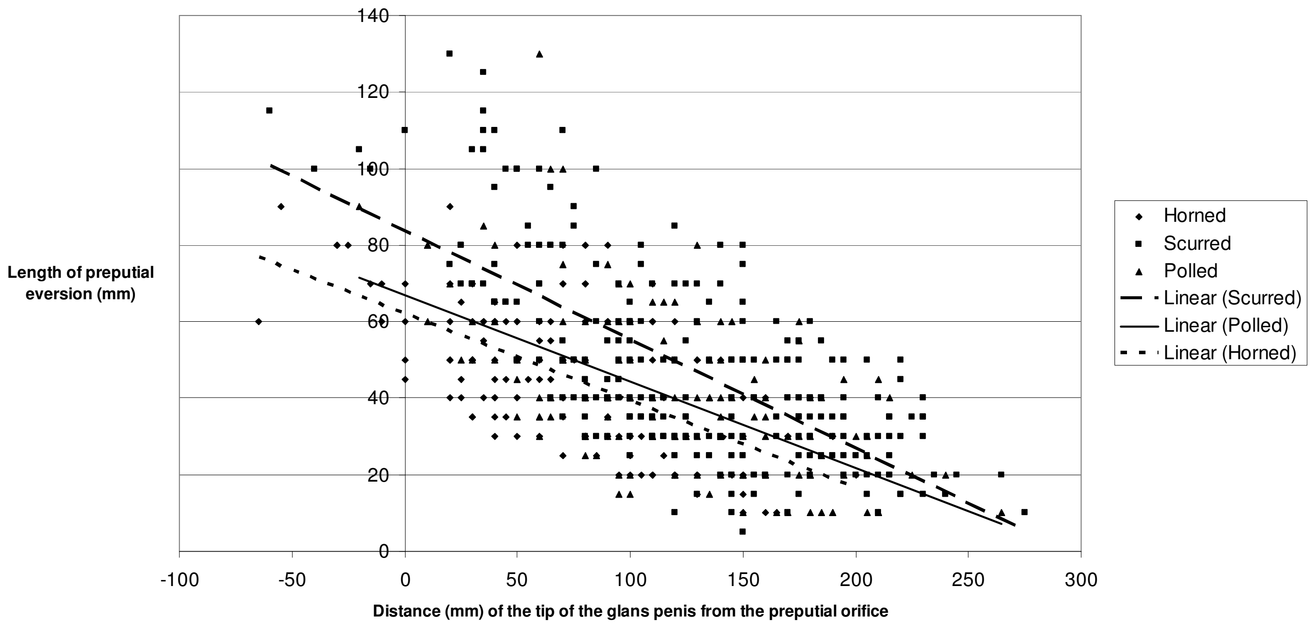

Figure 6.3; Relationship between length of preputial eversion and position of the tip of the glans penis relative to the preputial orifice for bulls of different horn status.

Differences in the relationship between the length of preputial eversion and the position of the tip of the glans penis relative to the preputial orifice for bulls with different horn status were not significant (Figure 6.3).

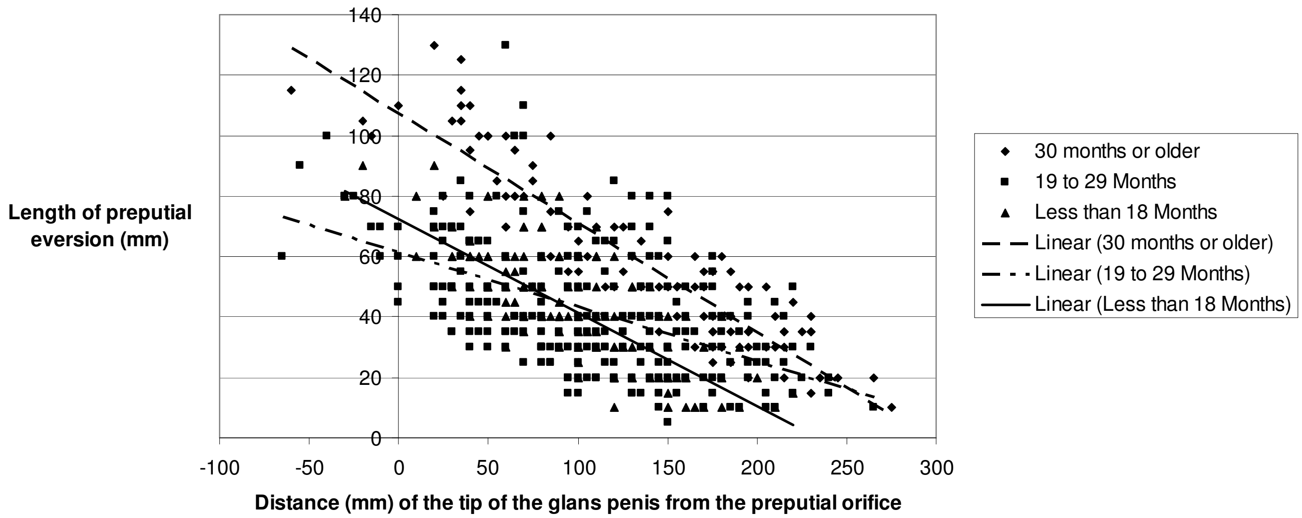

Figure 6.4; Relationship between length of preputial eversion and position of the tip of the glans penis relative to the preputial orifice for the different age groups of the bulls.

Significant differences were found in the relationships between the length of preputial eversion and the position of the tip of the glans penis for bulls of differing ages (Figure 6.4). Older bulls had a greater length of preputial eversion for the corresponding position of the tip of the glans penis in the sheath than the younger bulls.

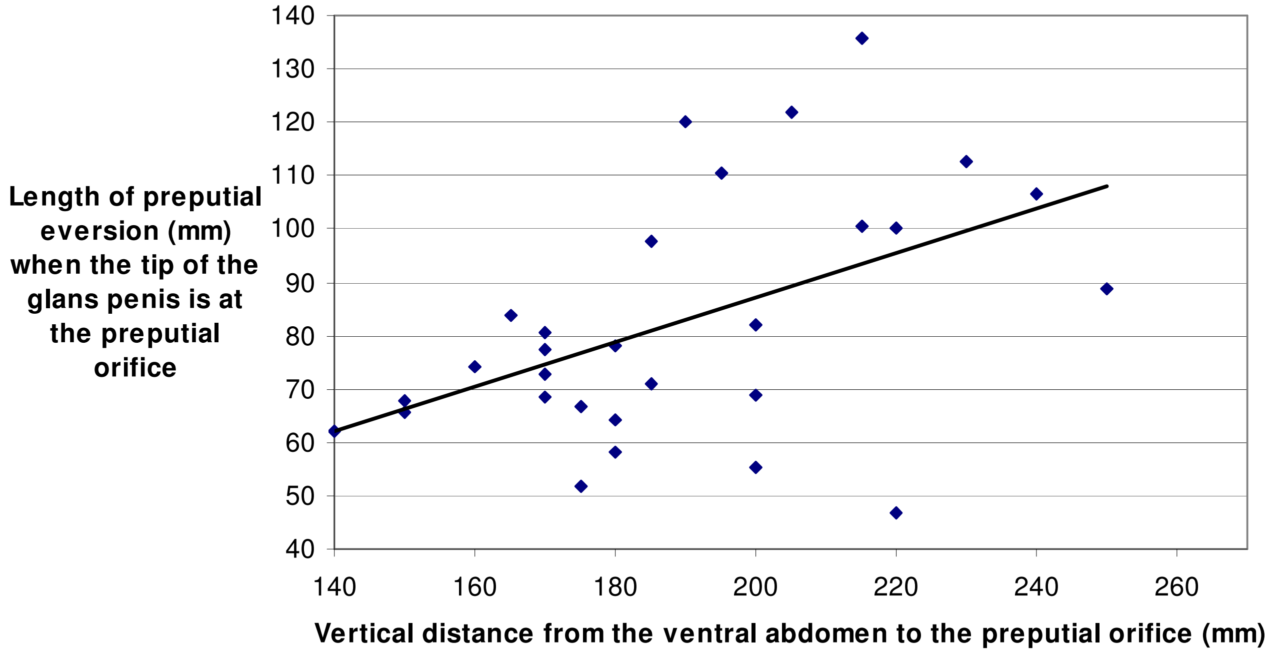

Figure 6.5; Relationship between length of preputial eversion when the glans penis is at the preputial orifice and vertical distance from the ventral abdominal wall to the preputial orifice.

The length of preputial eversion (when the tip of the glans penis had moved down the sheath to become level with the preputial orifice) was greater in bulls with more pendulous sheaths (Figure 6.5).

Discussion

This live animal study demonstrates for the first time a relationship between position of the penis and length of preputial eversion. The varying length of preputial eversion was significantly related to the corresponding distance of the tip of the glans penis from the preputial orifice, and demonstration of this relationship was repeatable when measurements were taken at different times. This finding confirms comments by Wolfe (1986) that preputial retraction occurs secondarily to penis retraction.

There are conflicting reports regarding the involvement of the caudal preputial muscles in preputial eversion. Ashdown and Pearson (1973) found that the caudal preputial muscles appeared to not participate in eversion to any significant extent in *Bos taurus* bulls. Other authors (Aubrey and Butterfield 1970; Getty 1975; Trotter and Lumb 1958) supported caudal preputial muscle involvement in the movement of the prepuce. These authors, however, did not distinguish between *Bos taurus* and *Bos indicus* bulls or between horned or polled bulls, which may explain the differences in the literature.

In *Bos taurus* bulls, the caudal preputial muscles are absent in polled, but present in horned bulls, and correspondingly, polled bulls evert their prepuce while horned bulls do not (Long and Hignett 1970). In a study of 244 bulls of 13 British breeds, 28 (85%) of 33 polled bulls exhibited preputial eversion whereas only three (1.4%) of 211 horned bulls did so (Long 1969), suggesting a clear relationship, between polledness and eversion of the prepuce in British breeds. This relationship between horn status and preputial eversion has not been reported in *Bos indicus* bulls, and the present study found no significant effect of horns on the relationship between length of preputial eversion and the distance of the tip of the glans penis from the preputial orifice.

It is likely that when present, caudal preputial muscles may have some effect on preputial movement. Long and Hignett (1970) and Long *et al*. (1970) suggested that in the absence of caudal preputial muscles, eversion is related to penis movement. The results of this present study support this suggestion and confirm a major effect of penis movement on preputial eversion in *Bos indicus* derived bulls.

In these *Bos indicus* derived bulls the penis moved constantly and was related to a constantly varying length of preputial eversion. This contrasts with earlier reports of a constant position of the glans penis at rest (Long *et al*. 1970), and may reflect breed differences, as that study involved only *Bos taurus* bulls. Constant movement of the prepuce meant that it was not meaningful to give a standard measurement of preputial eversion length, because each eversion episode was not constant in its maximum length. As preputial eversion was linearly related to the position of the penis in the sheath, standardised measurements of preputial eversion were possible when related to a standard position of the penis. The two standardised measurements developed were the length of preputial eversion when the tip of the glans penis was at the preputial orifice, and the minimum distance of the tip of the glans penis from the preputial orifice when no preputial eversion was visible. These standardised measurements can be used to detect relationships between preputial eversion and other measurements in bulls.

There was a significant relationship between the length of preputial eversion when the tip of the glans penis is at the preputial orifice and the vertical distance from the preputial orifice to the abdomen (Figure 6.5) endorsing the findings of Lagos and Fitzhugh (1970), who found eversion score was related to sheath depth. This relationship may be important if a pendulous sheath is a contributing factor in preputial prolapse, as stated by some authors (Monke 1976; Larson 1986). The relationship may not be significant in *Bos taurus* bulls as Friesian bulls, which rarely exhibit eversion of the prepuce, generally have a more pendulous sheath than those of Angus bulls that exhibit preputial eversion more commonly (Long 1969). However, it must be recognised that when compared with *Bos indicus* and *Bos indicus* derived bulls, *Bos taurus* bulls have much less pendulous sheaths.

This study also showed that older bulls everted a greater length of prepuce compared to younger bulls when their glans penis moved to the preputial orifice. These effects of age are important considerations for bull owners making culling decisions. If increased length of preputial eversion is related to increased preputial pathology then this presents another reason to cull older bulls.

In the present study, sire effects (differences due to individual sires) were not found to influence the relationship between length of preputial eversion and position of the tip of the glans penis, but only a small sample size from each sire was examined. Further studies are required involving more bulls per sire to test this effect more rigorously.

The position of the glans penis has been demonstrated in this study to be a major factor in length of preputial eversion in *Bos indicus* derived bulls and may have a greater influence on preputial eversion than the caudal preputial muscles. These findings highlight important differences between *Bos taurus* and *Bos indicus* derived bulls in factors that influence preputial eversion.

Chapter 7.

A study of the involvement of abdominal muscles in the position of the penis and prepuce within the sheath of *Bos indicus* derived bulls

Introduction

Preputial prolapse is a problem seen in many bulls (Walker and Hull 1984) and various studies have been conducted to establish the causes of this condition (Donaldson and Aubrey 1960; Lagos and Fitzhugh 1970). Many of these studies have concentrated on physical structures closely associated with the external reproductive organs but some of the factors involved in the development of preputial prolapse in *Bos indicus* and *Bos indicus* derived bulls are still unknown. When these factors are ultimately identified, cattle producers will be in a position to identify and remove young bulls with the propensity for development of preputial prolapse, thus preventing or reducing the prevalence of the condition and its associated economic losses.

In the literature, many closely related physical structures of the external reproductive organs are implicated in preputial prolapse and preputial eversion. For example, the pendulousness (depth) of the sheath has been identified as a problem in *Bos indicus* bulls (Memon *et al*. 1988; Bruner and Van Camp 1992). However, a holistic approach requires consideration of the involvement of other structures not in the immediate area, such as the abdominal muscles.

Work in humans has demonstrated that the abdominal support muscles assist in many pelvic and other functions, such as urination, defaecation, forced expiration, coughing and parturition (Getty, 1975). In humans, two deep muscles, multifidus lumborum and transversus abdominus, activate together to form a corset that stabilises and supports the lumbo-pelvic region (Richardson and Cull 1995; Markwell 2002; Markwell 2001; Ward *et al.* 2009). A deficit or dysfunction in the multifidus lumborum muscle has been identified in human patients with acute low back pain (Hides *et al.* 2001; Markwell 2001).

These muscles also influence more distant activities, as there is co-activation of the abdominal and pelvic floor muscles in functional activities such as head and shoulder raising (Sapsford *et* *al.* 2001). The thoracolumbar fascia is thought to be responsible for functionally integrating these apparently unrelated anatomic structures (Vleeming *et al.* 1995). Ultrasound provides a sensitive technique to detect changes in cross-sectional area associated with dysfunction of these muscles (Getty 1975; Raadsheer 1994; Juul-Kristensen 2000; Hides *et al.* 1994; Hides *et al.* 1996).

Despite the differences in stance between cattle and humans, many of the anatomical connections are similar (Lansman and Robertson 1992), and established concepts of human back muscle function are valid for quadruped mammals (Schilling *et al.* 2005). Muscles of the abdomen are connected to the thoracolumbar fascia in the pelvic area (Sapsford *et al*. 2001), which is also connected to the external reproductive organs and associated muscles extending from the pelvic area. Despite different neural control, poor tone or development of these abdominal muscles may cause relaxation of the fascia and result in a pathological extension of some of the external reproductive organs. However, a functional relationship between abdominal musculature and pelvic function has not been investigated in bulls.

Eversion of the prepuce has been shown to be related to movement of the penis (chapter 6). As the penis moves down the sheath towards the preputial orifice, preputial eversion commences and lengthens in response to continued movement of the penis down the sheath. The retractor penis muscles control the movement of the penis, and are connected to the thoracolumbar fascia. It is possible that poor abdominal muscle tone may be associated with poor tone in the thoracolumbar fascia, which may in turn affect tone in the retractor penis muscles. Less toned retractor penis muscles may cause the penis to be positioned more distally within the sheath, resulting in greater eversion of the prepuce. Specific muscles in bulls that support and stabilise the pelvic area, as well as function in association with external reproductive organs, include the transversus abdominus, the obliquus internus abdominis, and the multifidus lumborum.

<u>Objective</u>

The objective of the study, as part of a larger study of the external reproductive organs in *Bos indicus* bulls, was to investigate the relationship between specifically identified abdominal muscles that control pelvic function and the position of the penis within the sheath and preputial eversion.

<u>Materials and Methods</u>

Animals

Droughtmaster bulls (n = 20; age: 10 – 130 months) from two properties in SE Queensland were examined. Each bull was weighed and scored for horn status (horned, polled, or scurred). Horn status was obtained from pedigrees, where possible, and confirmed during a physical examination. Data on age and sires of the bulls were also obtained from pedigrees.

Measurements

Bulls were first examined free standing in yards and observed during urination. It was then noted whether each bull lifted its tail or did not lift its tail during urination. This action was specifically noted, as the need to lift the tail to urinate could reflect a need to strain during urination, which could be indicative of a deficit in the transversus abdominus muscle. This action would be easy to identify in live bulls.

The bulls were also examined while restrained in a cattle crush. The distance from the tip of the glans penis to the preputial orifice was measured externally with a flexible measuring tape. The tip of the glans penis was located visually, where possible (by its impression in the sheath), or by palpation. The position of the tip of the glans penis was found to constantly change and repeated measurements within one hour were recorded while the bull remained in the cattle crush. Simultaneous measurements of the length of the preputial eversion from the preputial orifice were recorded where eversion was present.

A measurement of the sheath (vertical distance from the ventral abdominal wall to the preputial orifice) was included to determine the relationship with preputial eversion for each bull.

Subcutaneous fat depth was measured (mm) using an ultrasonic scanning device. Fat scans were taken at the 12th/13th rib and P8 rump sites, as in abattoirs, fat depth is measured at these sites. Scan measurements at both sites help to better describe liveweight measurements and allows assessment of whether the difference in liveweight is due to muscle or fat (Sundstrom 1999). These measurements were used in this study to account for differences in fat levels between bulls.

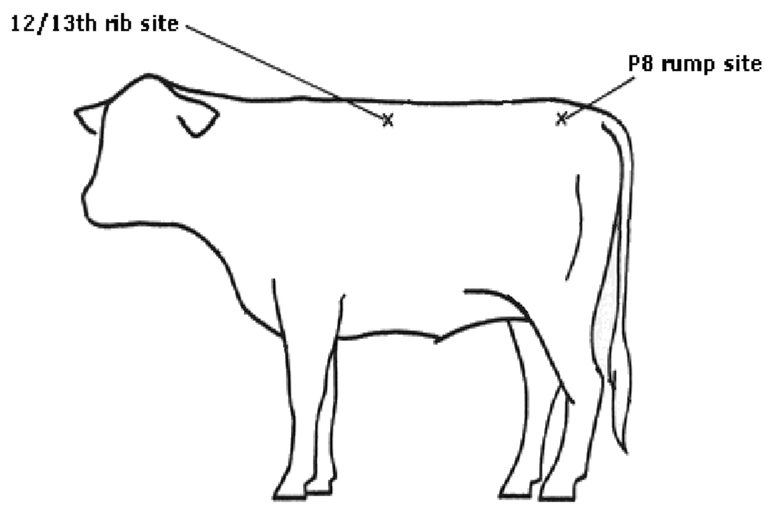

Figure 7.1; Ultrasound measuring positions (Adapted from McKiernan and Sundstrom 2000).

Measuring techniques and positions were developed so bulls could be examined to determine relationships between abdominal muscle measurements and preputial eversion, curvature of the backline and pendulousness of the sheath.

Cross-sectional thickness of selected abdominal muscles was measured by ultrasonography. A linear array ultrasound machine (Aloka SSD-500V) utilising a rectal probe (5MHz. UST-587T-5.0), and an external probe (3.5 MHz. UST-5035-3.5) was used to develop a measuring technique that could reliably measure some abdominal muscles, especially the transversus abdominus, that may be specifically involved in maintaining the tone of the thoracolumbar fascia. The skin was not shaved but lubricant was applied to the skin of the bulls before scanning. The probes were placed against the muscles at the sites described below so the thickness of the muscles could be determined. The anatomic terminology used was as described in Getty (1975).

The multifidus lumborum muscle thickness was measured at the level of the coxal tuber in the depression between L6 and the sacrum. The circumference of multifidus lumborum was also measured by ultrasonography.

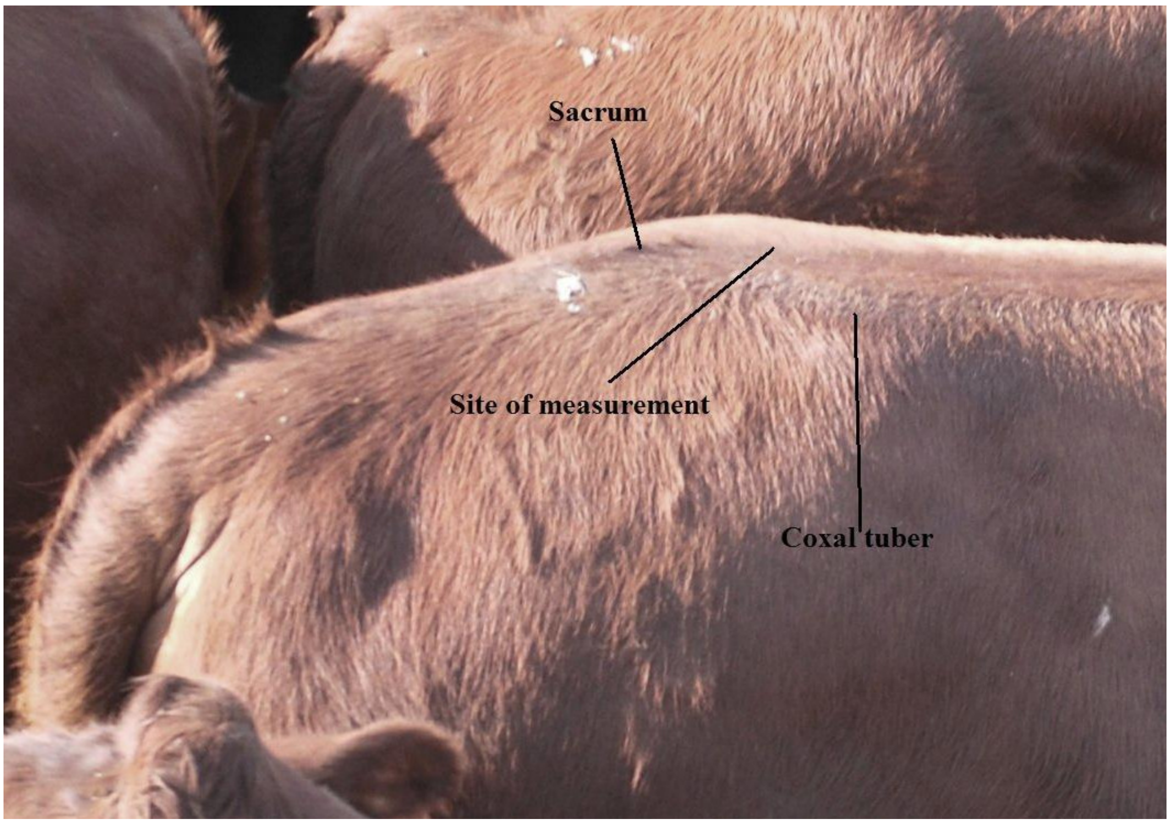

Figure 7.2; Position of measurement of the multifidus lumborum muscle.

The thickness of the obliquus internus abdominis muscle was measured at a point half way along the muscle bulge between the coxal tuber and the ribs. Minimal pressure was applied during this measurement as pressure affected the reading.

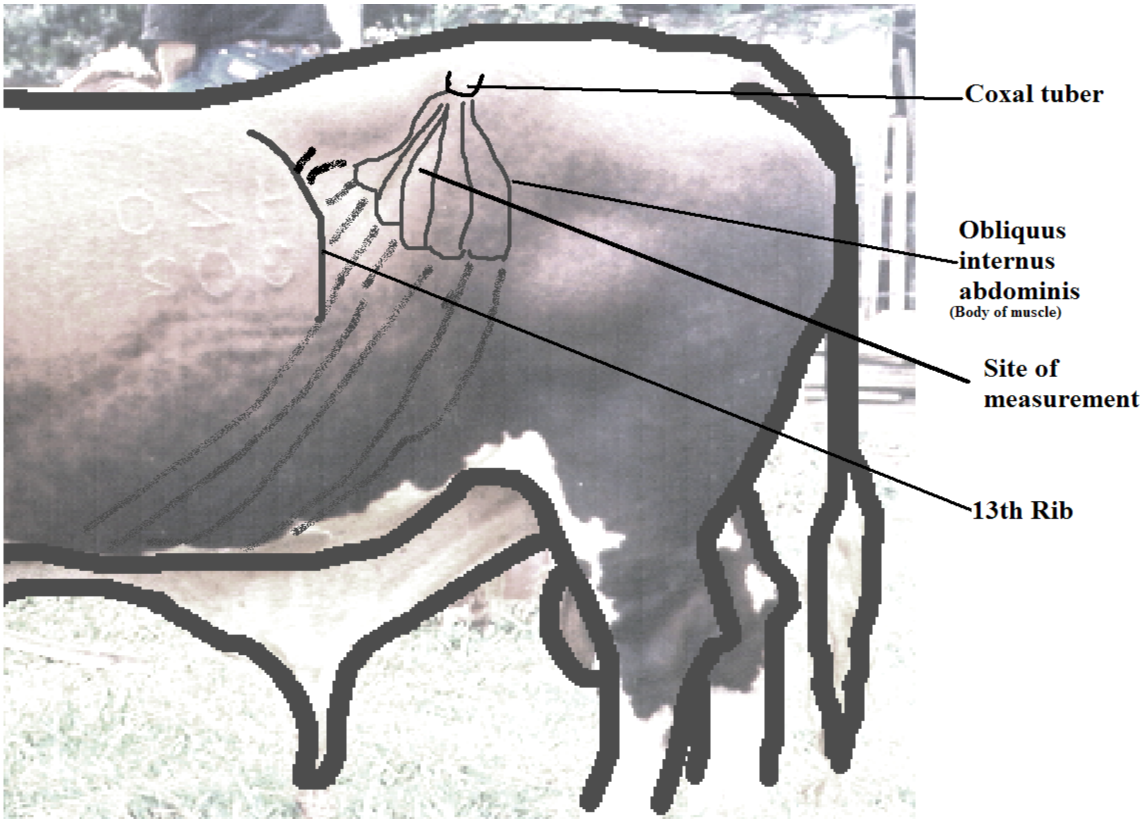

Figure 7.3; Position of measurement of the obliquus internus abdominis muscle.

The transversus abdominus was measured at the edge of the 13th rib and down until muscle became obvious. Multiple measurements were taken as the muscle depth changed in response to movement of other parts of the body. Maximum and minimum values were obtained and a ratio between these values was calculated.

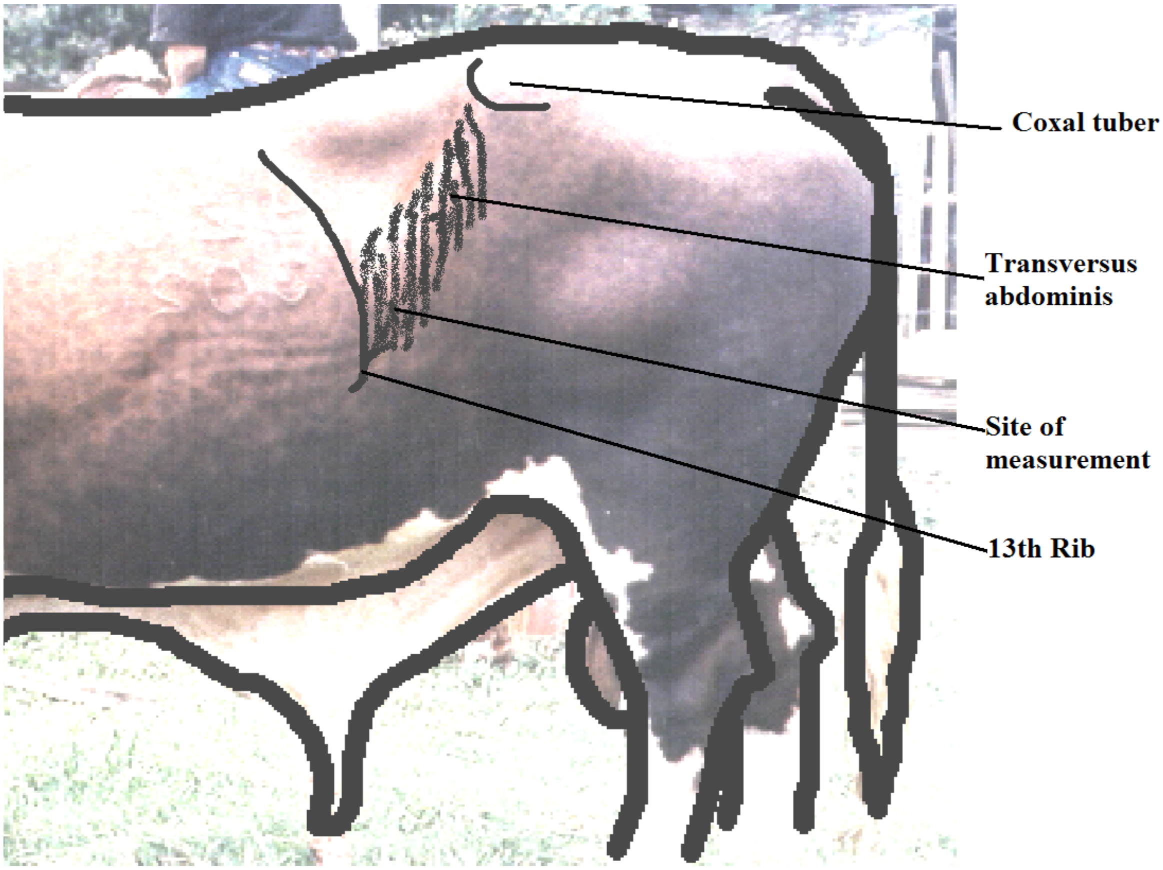

Figure 7.4; Position of measurement of the transversus abdominus muscle.

The rump height measurement was the maximum height (mm) measured between L3 (lumbar) and S3 (sacrum). The sites were palpated on each back line. The curvature of the back was noted between T6 (thoracic) and T12 and the back depth measurement (mm) was the maximum depth of the depression of the back between these points (Figure 7.5). These measurements were taken only when the bull was observed to be standing evenly on all four legs. A flexible ruler was used for these measurements. Flexible measuring devices have been shown to be reliable, quick and valid (reproducible to within 9% for the same observer (Burton 1986)) for measuring the shape of the lumbar spine, which may prove helpful in quantifying lumbar postures (Hart and Rose 1986), or assessing lumbar sagittal mobility (Burton 1986).

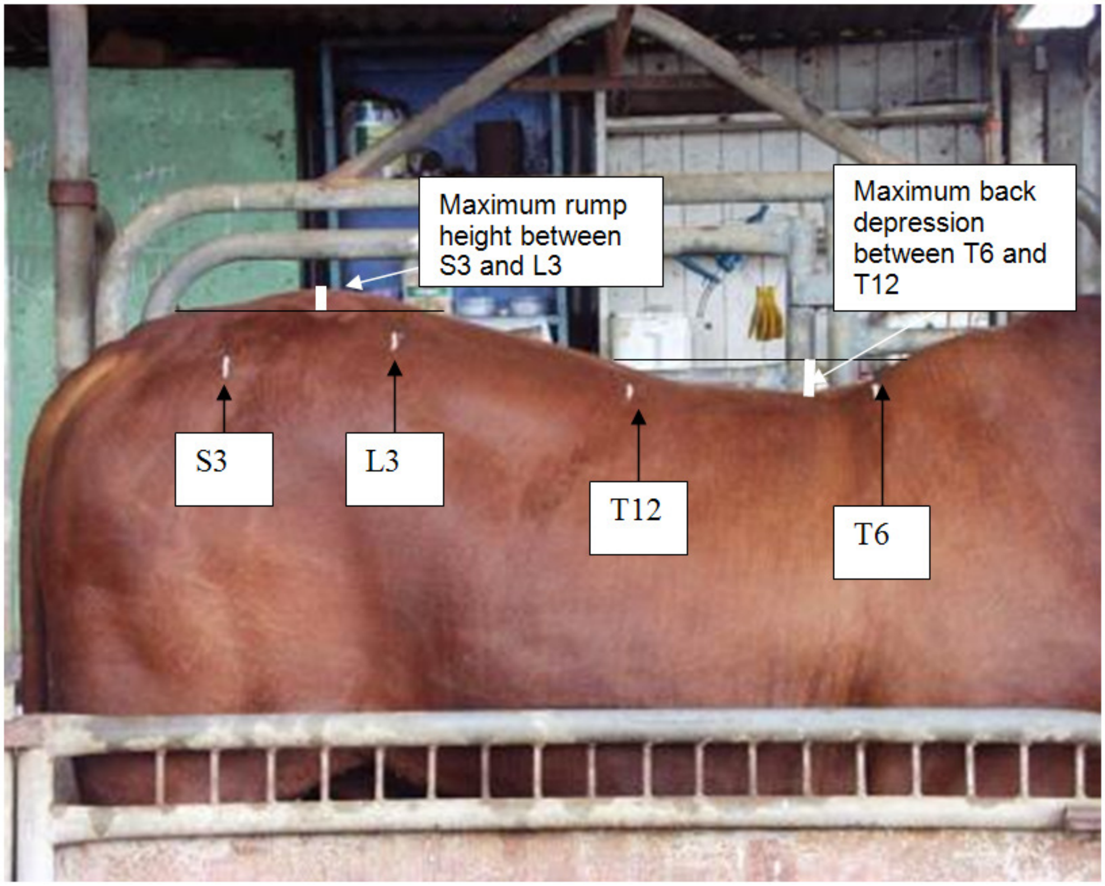

Figure 7.5; Position of backline measurements of the bulls. (The sites marked on the bull are indicators of the level of the site of the appropriate vertebral processes and are not on the actual site of measurement).

Definitions

Definitions of the sheath, prepuce and preputial eversion are provided in chapter 4.

Statistical analysis

All statistical analyses were performed using *Genstat* 11th Edition (IACR – Rothamsted, Harpenden, Hertfordshire AL5 2JQ; distributed by Numerical Algorithms Group, Oxford).

Initially, separate simple linear regressions (eversion length as the dependent variable and position of penis as the independent variable) were fitted for each bull to confirm previous results that this response was linear.

A grouped regression analysis was then performed to determine if:

- there were differences between intercepts and slopes for individual bulls,
- there was a common slope across bulls but different intercepts,
- there was a common intercept and slope for all bulls.

From this, the y intercept (the length of the preputial eversion when the glans penis was at the preputial orifice - a) and the slope (b) were calculated. The other intercept (x – the minimum distance from the glans penis to the preputial orifice when no eversion ($y = 0$) was observed) was calculated using $y = a + bx$.

Simple correlations were performed to test relationships between the sheath, abdominal muscle and backline measurements, and preputial eversion and penis position data. One-way analysis of variance was used to assess whether horn status and tail lift to urinate were factors related to the sheath, abdominal muscles, backline measurements and preputial eversion measurements.

Determination of the relationships between the measurements should take into account differences in weight, fat levels, age and sire. Correlations were calculated to investigate whether these factors impacted on the observed relationships between the sheath, abdominal muscle and backline measurements, and length of preputial eversion measurements.

Significant relationships from the above analyses were further investigated using multiple linear regression analysis.

Results

The external measurements of the bulls are presented in Table 7.1, including possible related factors that may affect the relationship between the size of the abdominal muscles and the actions of the penis and prepuce (weight, horn status, tail lift status during urination, sheath depth, fat depth, and age). Table 7.2 lists abdominal muscle measurements and the transversus abdominus ratio for the bulls in the study. Table 7.3 presents the variation recorded in back depth and rump heights as well as the data obtained for each bull when the penis movement recordings were correlated with preputial eversion measurements.

Table 7.1; Individual bull data for weight, age, horn status, fat measurements, sheath measurements and tail lift in relation to urination.

Bull	Weight	Polled (P) Horned (H) Scurred	Lift tail to	Sheath depth (mm)	P8 fat (mm)	R13 fat (mm)	Age (mth)
1	M	S	No	220	2.5	3.8	39
3	403	S	No	170	4.3	4.3	28
4	470	P	No	190	3.8	4.3	26
5	450	S	No	165	4.1	4.1	24
6	450	S	Yes	140	3.8	4.5	27
7	540	P	No	230	17.8	12.6	20
8	340	S	Yes	175	10	7.5	10
9	630	S	Yes	215	8.8	5.5	22
10	700	S	No	250	9.5	3.8	30
11	774	S	No	215	7.8	6.9	34
12	403	S	No	180	6	6	24
13	433	H	No	220	4.5	4.5	26
14	373	P	Yes	180	5.8	5.9	24
15	373	H	No	175	4.7	4.8	23
16	380	P	No	185	6	7.8	23
17	610	S	Yes	205	6.5	5.5	130
18	850	S	No	195	17.5	16.5	32
19	555	S	No	200	4.9	6.3	M
20	705	S	No	240	3.7	3.5	81

M – missing data

Horn status - H horned, S scurred and P polled.

Table 7.2;. Abdominal muscle thickness measurements (mm) on individual bulls.

Bull	Obliquus internus	Transversus	Transversus	Ratio of maximum to minimum	Multifidus	Multifidus lumborum
1	37.3	10.8	6.3	1.7	45	145
2	19	17.3	13	1.3	46	165
3	39.3	15.5	7.3	2.1	48	133
4	35.8	7	4.5	1.6	40	145
5	35	14.5	8.8	1.6	44	151
6	25.8	8.1	7.5	1.1	38	109
7	24.3	13.8	6	2.3	48	193
8	39.8	13.5	8.8	1.5	49	124
9	56.5	5.5	3	1.8	65	237
10	52.2	21.8	7	3.1	68	215
11	42.5	29.3	9.3	3.2	59	246
12	27.3	17.5	9.8	1.8	53	163
13	30	14.8	8.5	1.7	43	148
14	32.5	18.5	9.1	2	43	150
15	20	23.5	17.3	1.4	37	160
16	26	22.3	9.5	2.3	47	150
17	32.3	22.5	15	1.5	38	158
18	57.3	19.5	9.8	2	51	144
19	37.5	15.3	11.3	1.4	47	182
20	57.5	9.1	7.8	1.2	66	207

Table 7.3; Individual back and rump measurements and data from the correlation between penis movement and preputial eversion.

Bull	Back depth (mm)	Rump height (mm)	Intercept x	Slope	Intercept y
1	36	82	100.31	-0.35	288
3	31	40	80.61	-0.23	354
4	30	47	120.11	-0.47	254
5	6	82	83.73	-0.42	199
6	19	69	62.01	-0.32	193
7	26	47	112.61	-0.34	330
8	31	69	51.71	-0.17	302
9	30	35	135.81	-0.52	263
10	31	45	88.61	-0.29	303
11	33	64	100.49	-0.33	303
12	13	71	77.91	-0.36	219
13	0	48	46.75	-0.25	187
14	22	46	58.17	-0.36	161
15	20	62	66.66	-0.38	174
16	27	58	97.66	-0.36	275
17	36	57	121.93	-0.45	270
18	37	43	110.4	-0.44	254
19	36	55	55.31	-0.17	330
20	4	35	106.63	-0.29	364

The data obtained from the correlation of penis movement and eversion measurements were reasonable to good fits (percentage of variance accounted for ranged from 62.3 to 94.3; $P<0.001$) for all bulls except bull 10 (% variance accounted for was 72.2; $P=0.097$). However there were only 4 points for this bull and the significance level was below 10%. Therefore it is reasonable to conclude that all bulls followed a linear trend (Figure 7.5).

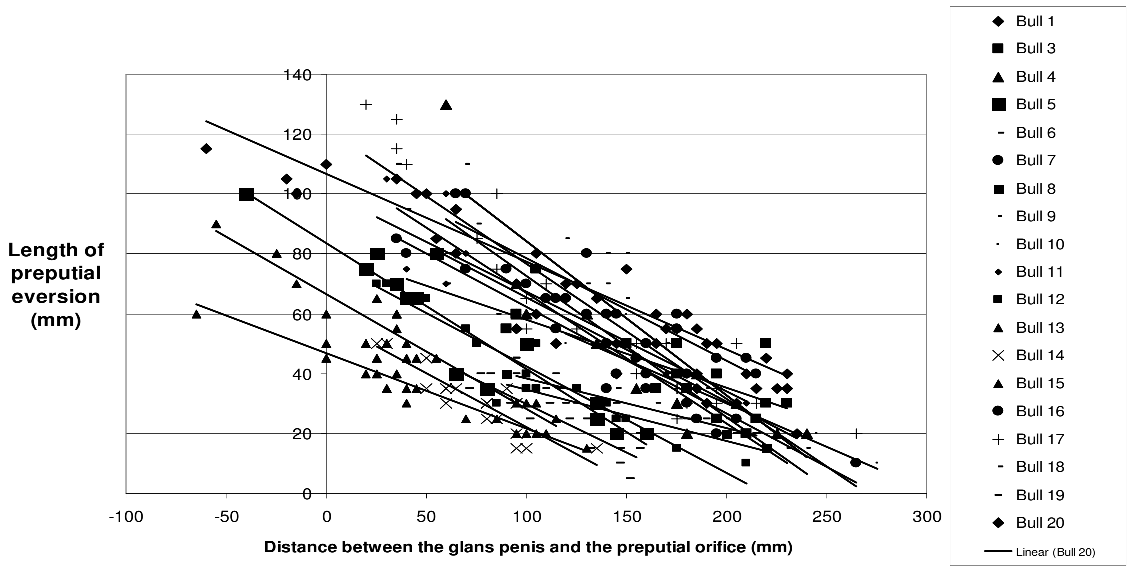

Figure 7.6; Regression of length of preputial eversion against position of the tip of the glans penis for all bulls in the study.

The analysis of the penis movement and preputial eversion length measurements showed there were significant differences between bulls in their slopes and intercepts (both P<0.001), indicating that the data for individual bulls was best analysed separately. Length of preputial eversion was related to the position of the tip of the glans penis in a linear fashion for these bulls but there was variation between the bulls. The intercepts (length of preputial eversion when the tip of the glans penis was at the preputial orifice and the distance of the tip of the glans penis from the preputial orifice when preputial eversion commenced) differed between the bulls. Although appearing similar in Figure 7.6, the slopes (relationships between the position of the tip of the glans penis and length of preputial eversion) differed between the bulls

Table 7.4; Pearson correlations indicating significant relationships between sheath depth, abdominal muscles thickness measurements, backline measurements and preputial eversion figures.

Measurement or figure	Measurement or figure	Significance level
Depth of sheath	Obliquus internus abdominis	*
Depth of sheath	Multifidus lumborum	**
Depth of sheath	Multifidus lumborum circumference	***
Depth of sheath	Intercept y	*
Obliquus internus abdominis	Transversus abdominus minimum	*
Obliquus internus abdominis	Multifidus lumborum	***
Obliquus internus abdominis	Multifidus lumborum circumference	*
Obliquus internus abdominis	Intercept y	*
Transversus abdominus maximum thickness	Transversus abdominus minimum	**
Transversus abdominus maximum thickness	Ratio of maximum to minimum measurements	**
Ratio of maximum to minimum thickness of transversus abdominus	Multifidus lumborum	*
Ratio of maximum to minimum thickness of transversus abdominus	Multifidus lumborum circumference	*
Multifidus lumborum	Multifidus lumborum circumference	***
Multifidus lumborum	Intercept y	*
Multifidus lumborum circumference	Intercept x	*
Intercept x	Slope	***

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

The backline measurements were not significantly related to any of the sheath, abdominal muscle or preputial eversion data. Table 7.4 presents the significant relationships between abdominal muscle measurements, sheath measurement, backline measurements and penis movement and preputial eversion data. Although relationships were initially determined to be significant, possible related factors that may affect these relationships need to be considered. Further analyses were performed (Tables 7.5 and 7.7) to determine which relationships were significant after accounting for the relevant factors (Table 7.8).

Table 7.5; Probability-values from analyses of variance for horn status and 'tail lift to urinate' factors and sheath, abdominal muscle thickness measurements, backline measurements and preputial eversion data.

	Horn Status	Tail lift to urinate
Sheath depth	0.953	0.143
Obliquus internus abdominis	0.019*	0.622
Transversus abdominus maximum	0.766	0.413
Transversus abdominus minimum	0.222	0.723
Ratio maximum to minimum measurements	0.767	0.125
Multifidus lumborum	0.138	0.491
Multifidus lumborum circumference	0.794	0.480
Back depth	0.134	0.345
Rump height	0.325	0.510
Intercept x	0.181	0.812
Slope	0.593	0.533
Intercept y	0.089	0.246

* represents $P<0.05$

From these analyses the only significant relationship found was between horn status and thickness of the obliquus internus abdominis muscle (Table 7.5). The 'tail lift to urinate' action was not related to any of the measurements. Table 7.6 shows the mean data for obliquus internus abdominis muscle measurements by horn status.

Table 7.6; Relationship between horn status and obliquus internus abdominis thickness measurements.

Horn status	n	Mean±SE
Poll	5	2.75±0.45 [a]
Horns	2	2.50±0.71 [a]
Scur	13	4.16±0.28 [b]

Means followed by a different letter are significantly different (P<0.05).

Table 7.7; Correlation coefficients between weight, age, and fat depth, and sheath, abdominal muscle thickness measurements, backline measurements and preputial eversion figures.

	Weight	Age	P8 fat	R13 fat
Sheath depth	0.595**	0.289	0.294	0.062
Obliquus internus abdominis	0.648**	0.145	0.279	0.156
Transversus abdominus maximum	0.174	0.139	0.176	0.215
Transversus abdominus minimum	-0.091	0.364	-0.145	-0.003
Ratio of maximum to minimum measurements	0.339	-0.218	0.422	0.257
Multifidus lumborum	0.581**	-0.024	0.273	0.026
Multifidus lumborum circumference	0.620**	0.120	0.226	-0.009
Back depth	0.328	0.076	0.297	0.301
Rump height	-0.403	-0.118	-0.212	-0.101
Intercept x	0.573*	0.403	0.306	0.219
Slope	-0.243	-0.217	-0.122	-0.125
Intercept y	0.408	0.246	0.216	0.109

* represents $P<0.05$, ** represents $P<0.001$.

Age and fat depth were not related to any of the other measurements, though weight was positively correlated with sheath depth, obliquus internus abdominis thickness, multifidus lumborum thickness, multifidus lumborum circumference, and intercept x (Table 7.7).

Table 7.8 summarises all of the significant relationships found between variables from simple correlation and ANOVA analyses and lists the factors identified through regression analyses that need to be accounted for in determining significance. Remaining significant relationships are identified in the final column.

Table 7.8; All significant relationships identified from simple correlation and ANOVA analyses, factors identified through regression analyses that need to be accounted for in determining significance and significant relationships after accounting for these factors using multiple linear regression analysis.

Measurement or figure	Measurement or figure	Corrected for:	Significant after correction
Depth of sheath	Obliquus internus abdominis thickness	Weight and horn status	
Depth of sheath	Multifidus lumborum thickness	Weight	Yes
Depth of sheath	Multifidus lumborum circumference	Weight	Yes
Depth of sheath	Intercept y	Weight	
Obliquus internus abdominis thickness	Transversus abdominus minimum thickness	Weight and horn status	Yes*
Obliquus internus abdominis thickness	Multifidus lumborum thickness	Weight and horn status	Yes
Obliquus internus abdominis thickness	Multifidus lumborum circumference	Weight and horn status	
Obliquus internus abdominis thickness	Intercept y	Weight and horn status	
Ratio of maximum to minimum thickness of transversus abdominus	Multifidus lumborum thickness	Weight	
Ratio of maximum to minimum thickness of transversus abdominus	Multifidus lumborum circumference	Weight	
Multifidus lumborum thickness	Multifidus lumborum circumference	Weight	Yes
Multifidus lumborum thickness	Intercept y	Weight	
Multifidus lumborum circumference	Intercept x	Weight	
Intercept x	Slope	Weight	Yes**

* Internal abdominal oblique = 2.387 + 0.00495 weight – 1.500 transversus abdominis minimum

(% variance a/c for = 53.8; P<0.001))

Weight (P=0.002) Transversus abdominis minimum (P=0.021)

**Intercept x = -9.7 + 0.0743 weight – 170.8 slope

(% variance a/c for = 64.7; P<0.001)

Weight (P=0.012) Slope (P<0.001)

After accounting for the relevant factors, significant relationships were found between thickness of multifidus lumborum and multifidus lumborum circumference, and between intercept x and the slope (Table 7.8). Both of these were expected: a thicker muscle should have a greater circumference, and the slope of the graph determines the intercepts. In addition, the depth of the sheath was significantly related to both the thickness and circumference of the multifidus lumborum, and the obliquus internus abdominis thickness was significantly related to the thickness of both the transversus abdominus minimum and the multifidus lumborum.

There were 13 different sires for the 19 bulls (one unknown). Due to the lack of replication for the majority of the sires, the effect of sire could not be properly determined and therefore sire effects have been ignored.

Correlations were investigated between fat depth measurements and the physical, measurable structures on the bull (sheath, back and rump). No significant correlations were found (Table 7.9).

Table 7.9; Correlations (with probability values) between fat depth measurements and sheath, back and rump measurements.

Fat depth measurement site	Backline measurement	Correlation (r)	p-values
P8	back depth	0.297	0.204
P8	rump height	-0.212	0.369
P8	depth of sheath	0.294	0.208
R13	back depth	0.301	0.197
R13	rump height	-0.101	0.673
R13	depth of sheath	0.062	0.796

Discussion

This study investigated a novel concept that abdominal muscles in bulls may play a role in external reproductive organ movement. Functional links between supporting abdominal muscles—specifically the transversus abdominus, obliquus internus abdominis, and multifidus lumborum—and the structures and functions of the external reproductive organs were examined in *Bos indicus* derived bulls.

After adjusting for weight, statistically significant correlations were found between the depth of the sheath and the thickness and circumference of the multifidus lumborum. This relationship suggests that the multifidus lumborum muscles are functionally linked to the structures in the sheath area, stimulating the development of larger multifidus lumborum muscles in response to a more pendulous sheath.

After adjusting for confounding factors, statistically significant correlations were also found between muscle thicknesses of the obliquus internus abdominis and both the multifidus lumborum and the transversus abdominus minimum. These findings are not surprising considering the anatomical and functional connections between these muscles.

The transversus abdominus originates from the deep lumbar fascia, and the obliquus internus abdominis attaches to the lumbar fascia, as does the superficial abdominal fascia. The aponeurosis of the latter muscle forms part of the abdominal tunic (Getty 1975), and a portion of it enters the inguinal canal, forming part of the fascia of the penis in the male (Getty 1975). In ruminants it is well developed (Getty 1975) and links these muscles to the external reproductive organs (Basmajian 1974; Getty 1975). These muscles function to compress the abdominal viscera (Getty 1975), and may affect the functioning of the prepuce, as the caudal preputial muscles also have fibres that unite on the abdominal wall (Getty 1975). The multifidus lumborum muscles insert on the lumbar spinous processes (Kaigle 1995), which may link the muscle to the external reproductive organs as the penis retractor muscles originate from the caudal vertebrae (Getty 1975).

After accounting for the relevant factors (weight, fat measurements, age and sire) and possible related parameters (horn status; lifting tail to urinate), no relationship was found in this study between the abdominal support muscles and the data derived from the penis movement and preputial eversion measurements. This result was unexpected, given the anatomical relationships between the abdominal support muscles and external genitalia. However, these comparisons were initially significant, before adjustment for confounding factors, suggesting a relationship which should be investigated in a larger study involving more bulls.

In this study, the obliquus internus abdominis muscle thickness was related to horn status, with scurred animals having larger muscles than horned or polled bulls. However, the numbers of polled and horned bulls were small compared to those with scurs, suggesting that this result should be confirmed with a larger cohort of animals. A link between preputial eversion and caudal preputial muscle deficiency has been demonstrated in polled *Bos taurus* bulls, which display more preputial eversion than horned *Bos taurus* bulls (Long and Hignett 1970). Horn status in the current study was not related to sheath or preputial eversion data, which confirms that there are differences in the causes of preputial eversion between *Bos taurus* bulls and *Bos indicus* derived bulls.

A part of this study investigated possible links between the backline of the bulls and fat measurements, abdominal muscles, sheath depth, penis movement and preputial eversion figures. If the shape of the backline gave any indicators of abdominal tone, increased sheath depth, or reflected any issues relating to penis movement or preputial eversion, it was important to consider if the level of fat in the animal affected these backline measurements. Excess body fat in humans has a flexion effect on posture (Gilleard and Smith 2007) and causes back pain (Peltonen *et al.* 2003). However, fat levels in the bulls were not found to be related to curvature of the spine or sheath measurements in this study.

The shape of the back may reflect muscular support as Getty (1975) found that rupture of the prepubic tendon occasionally occurs in the ox and results in a relaxation of the abdominal musculature and a concave appearance to the dorsum. In this study, the shape of the back was not related to the size of the abdominal muscles and could not be used to predict the size of these muscles in normal bulls. Furthermore, neither the shape of the backline, nor the rump measurements were found to have any influence on the penis to preputial eversion relationship.

It was hypothesised that simultaneously lifting the tail to urinate may be associated with 'straining', in compensation for a smaller transversus abdominus muscle, which normally assists urination by compressing the abdominal viscera. The action of the multifidus lumborum along the dorsal median aspect of the tail extends the tail and may offer support to the abdominal muscles (Getty 1975). However, the 'lift to urinate' behaviour showed no relationship to sheath depth, abdominal muscles, backline measurements or to preputial eversion data. This behaviour may simply be an unlocking mechanism that allows urination when the rectum is full.

The beef industry considers that the muscling of the bull is reflected in the shape of the rump. This study investigated links between the height of the rump (as an objective measure of rump muscling) and the abdominal support muscles. Rump height was not related to any of the abdominal support muscles measured in this study so could not be used to predict the size of these muscles.

The pendulousness (depth) of the sheath has been identified as a factor related to reproductive problems in *Bos indicus* bulls (Memon *et al*. 1988; Bruner and Van Camp 1992) and was related to more preputial eversion in *Bos indicus* derived bulls in chapters 4 and 6. In this study, sheath depth was not related to the points derived from the penis movement and preputial eversion measurements. The relationship between preputial eversion and sheath depth was initially found to be significant but was not found to be significant after adjusting for weight. The results presented in chapter 6 were not adjusted for weight. The relationship was adjusted for age in the chapter 6 study, but body weight was not considered to significantly affect preputial eversion or sheath depth as analysis in chapter 4 did not demonstrate any relationship. Larger numbers of bulls were examined in chapters 4 and 6 than in this study which suggests that further studies with a larger cohort of bulls are needed to verify the relationship.

Greater preputial eversion in *Bos indicus* derived bulls has been linked to a higher incidence of preputial prolapse, which represents a loss to the beef industry. The previous chapter (chapter

6) demonstrated that preputial eversion in *Bos indicus* derived bulls is related to the position of the penis in the sheath. This study aimed to understand what may influence the extent of the movement of the penis so measurements could then be used in bull selection to reduce preputial eversion in these bulls.

Chapter 8.

General discussion and conclusions

This work examines preputial problems which are one of the most common conditions affecting the ability of bulls to mate (Memon *et al.* 1988). These problems are common in *Bos indicus* and *Bos indicus* derived bulls but these types of cattle need to be utilised in many areas as they are better adapted to the tropical and sub tropical areas of the world (Swanepoel and Hoogenboezem 1993).

The survey for this thesis illustrates the importance of preputial prolapse to the northern cattle industry. A total of 35 bulls were culled with preputial prolapse from a population of 6040 bulls in one year. Although this only represents about 0.6% of the total bulls per year, preputial prolapse is a condition that causes a significant production loss and it also represents an obvious welfare problem. It is important to determine the extent of the preputial problems within the industry to give perspective to any industry recommendations. With the level of culling (15%/year) detected in the survey, it was determined that most bulls were being kept for an average of six years. This presents a problem relating to the development of preputial prolapse as there would be many older bulls in these herds and 65% of the bulls culled with preputial prolapse were over six years old. It also highlights an industry practice of retaining older bulls in the herd which has other management and production implications.

There were many suggested predisposing causes of preputial prolapse in *Bos indicus* or *Bos indicus* derived bulls in the literature. Two of the main causes were stated as pendulous sheaths (Ganesakale, Ramaswamy and Wilson 1964; Zemjanis 1970) and increased amounts of preputial eversion (Donaldson and Aubrey 1960) although very few studies attempted to confirm these suggested causes.

A pendulous sheath was identified early as a possible predisposing cause of preputial prolapse and it was reported by Walker (1970) that selective breeding against pendulous sheaths was meeting with some success in reducing the problem. It was also noted that pendulous sheaths may not necessarily be the cause of eversion in British breeds as it was noted by Long (1969) that Friesian bulls which rarely evert generally have a more pendulous sheath than those of Angus bulls which often evert. The probable difference in causal factors leading to preputial problems between *Bos taurus* and *Bos indicus* derived bulls creates confusion in the literature. This study examines links between pendulous sheaths and preputial function only in *Bos indicus* derived bulls.

From the literature it was determined that preputial eversion in *Bos taurus* bulls is mainly seen in polled bulls which have smaller caudal preputial muscles (Long and Hignett 1970). The situation in *Bos indicus* or *Bos indicus* derived bulls was not clarified as little work has been done in this area. Some authors suggested that a similar situation to *Bos taurus* bulls existed (Memon *et al.* 1988). The anatomical study on normal *Bos indicus* derived bulls in this thesis found that there was no evidence of poorer preputial muscle development or more preputial eversion in polled bulls than in horned bulls. Eversion of the prepuce was not related to caudal preputial muscle development in any of the bulls (including the horned bulls). This did agree with some authors (Dyce *et al.* 1987) who stated that the actions of the caudal preputial muscle remain unclear and their function is described as being of uncertain importance. Also in the literature, myotomy of the caudal preputial muscles did not produce lasting eversion of the prepuce (Ashdown and Pearson 1973). These muscles must have some effect on the prepuce as the report also stated that when the caudal preputial muscles are stimulated, the outer layer of the prepuce and the surrounding fascia are pulled caudally.

In this study it was also found that bulls with more pendulous sheaths displayed significantly more preputial eversion than those with less pendulous sheaths. The relationship between preputial eversion and sheath score may justify selection against *Bos indicus* derived bulls with pendulous sheaths if preputial eversion leads to an increase in preputial injury or infection. This relationship between preputial eversion and preputial prolapse has not been confirmed and studies by Long and Rodriguez Dubra (1972) reported eversion of the prepuce to be of little clinical significance. They found the presence of preputial ulcers was statistically unrelated to eversion in *Bos taurus* breeds. This could be quite different to the situation in *Bos indicus* or *Bos indicus* derived bulls.

Analysis also showed that the diameter of the preputial orifice was not significantly related to preputial eversion score. The results agree with other literature which also showed no significant preputial orifice differences between everting and non-everting *Bos taurus* bulls (Long and Hignett 1970). One complicating factor in the role of the preputial orifice is the sphincteric action of the cranial preputial muscles which may be more active in some breeds (Ashdown and Pearson 1973; Van Den Berg 1984) but this was not investigated in this study.

Preputial eversion in *Bos indicus* derived bulls was not related to caudal preputial muscle development or to the polled state as in *Bos taurus* bulls. Occurrence of preputial eversion was also found not to be related to an increased length of the prepuce. The only significant relationship was between bulls exhibiting preputial eversion and a shorter preputial orifice-to-fornix measurement. The anatomical study suggested a relationship between preputial eversion and movement of the penis in these bulls. This was also reported by Long, Hignett and Lee (1970) but limited numbers were involved in their study. A further study was developed to examine this relationship.

The penis constantly moved within the sheath in *Bos indicus* derived bulls and was not found resting in any one position when examined in two studies. A method to objectively measure the relationship between penis movement and preputial eversion was developed for the study. Analysis showed that preputial eversion in these *Bos indicus* derived bulls was linearly and consistently related to position of the penis. It was determined that the position of the penis is a major factor in preputial eversion and is more important than the presence or absence of the caudal preputial muscles in *Bos indicus* derived bulls.

After determining that preputial eversion is related to the position of the penis in the sheath and the relationship can be measured for each bull, factors affecting the movement of the penis were considered. A holistic approach to this work considered structures not closely associated with the external reproductive organs as structures other than those in the immediate proximity may be involved in preputial eversion. Work in humans demonstrated that the abdominal support muscles assist in many pelvic functions and the variation in these muscles can be measured by ultrasound (Raadsheer 1994; Juul-Kristensen 2000). These supporting muscles should have an effect on the muscles of interest in the bulls as the retractor penis muscles originate from the vertebra (Trotter and Lumb 1958; Ashdown and Pearson 1973) and the caudal prepuce muscles have the connecting fascia as part of their origin (Ashdown and Pearson 1973). This study used the method developed to objectively measure the relationship between penis movement and preputial eversion from the previous study. Penis movement and preputial eversion were measured to find a relationship between these abdominal muscles and the individual variation seen in the relationship between penis movement and preputial eversion. From the study it was determined that none of these abdominal muscle measurements could be used to predict future preputial problems in the bulls.

The relationship between increased preputial eversion and preputial prolapse in *Bos indicus* or *Bos indicus* derived bulls appears logical but has not been confirmed. The anatomical study of Santa Gertrudis bulls with preputial prolapse did not clarify the relationship and found that bulls with preputial prolapse were either horned bulls with no caudal preputial muscle deficiency or young polled bulls with a significant caudal preputial muscle deficiency. No obvious cause of preputial prolapse in the horned bulls was determined from the dissections and previous sheath depth measurements and preputial eversion history was not available.

No link was found between polled bulls and any deficiency in the caudal preputial muscles or preputial eversion in the normal *Bos indicus* derived bull study. In the literature however, the link was confirmed in *Bos taurus* bulls (Long and Hignett 1970). The anatomical study of *Bos indicus* derived bulls affected with preputial prolapse showed that young polled bulls were deficient in caudal preputial muscles. This was not seen in the horned *Bos indicus* derived bulls with preputial prolapse in the study. This suggests that there is a link in some *Bos indicus* derived bulls between the polled gene and a deficiency of the caudal preputial muscles that could predispose these bulls to preputial prolapse. It also confirms that there are other causes in *Bos indicus* derived bulls that lead to preputial prolapse that are not related to the horn gene or a deficiency in the caudal preputial muscles.

The deficiency of the caudal preputial muscles in these young polled *Bos indicus* derived bulls that developed preputial prolapse may have caused these bulls to evert more as seen in polled *Bos taurus* bulls. It could be hypothesised that this would support a link between preputial eversion and preputial prolapse.

The anatomical study that did not find a link between polled bulls and eversion or a deficiency in the caudal preputial muscles was conducted on bulls from one herd. This may reflect that within the *Bos indicus* derived breeds there are genetically related polled bulls that do not have any caudal preputial muscle deficiency. This may have been achieved through selection.

The relationship between sheath depth and preputial eversion suggested in the literature was confirmed in two of the studies in this thesis.

The cause of preputial prolapse in *Bos indicus* derived bulls may be multifactorial as no one cause appears obvious. This thesis examined many aspects of preputial eversion in *Bos indicus* derived bulls and examined aspects of confusion in the literature associated with breed differences relating to preputial eversion. Unfortunately the scope of the work did not extend to a significant longitudinal study that could examine considerable numbers of bulls and monitor their development over many years. A longitudinal study specifically monitoring the development of preputial prolapse is needed to provide evidence as to which factors are significant in the development of preputial prolapse. The many findings related to preputial eversion could help develop the factors that could be measured in a longitudinal study. If preputial eversion was found to be one of the major factors predisposing bulls to preputial prolapse many of the findings in this thesis could be utilised to reduce preputial eversion.

The message to the beef industry when buying *Bos indicus* derived bulls is to avoid bulls with excessively pendulous sheaths and be careful when selecting polled *Bos indicus* derived bulls.

The beef industry should be aware that there are herds of polled *Bos indicus* derived bulls that do not appear to have any caudal preputial muscle deficiency.

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Appendices

Appendix 1. Examples of sheath scores

Examples of sheath variation seen in *Bos indicus* derived bulls.

BREEDPLAN 7-8 sheath score Sheath hangs at 45^{o} angle, depth up to about 15cm, moderate umbilicus.

BREEDPLAN 5-6 sheath score

Sheath hangs at 45^{o} angle, slightly more pendulous than a small sheath (score 7-8), with depth less than 20cm, and larger umbilicus.

BREEDPLAN 1-2 sheath score

Sheath hangs at up to 90^{o} angle, excessive looseness and length of umbilicus, sheath depth at or below hock-knee horizontal line, often with eversion of the preputial mucosa.

Appendix 2. Examples of caudal preputial muscle network scores

Photos of the exposed normal bull reproductive organs as collected at the abattoir.

From a set distance above the dissected organs, photographs were taken of each organ.

The caudal preputial muscle network score was scored from photographs as follows:

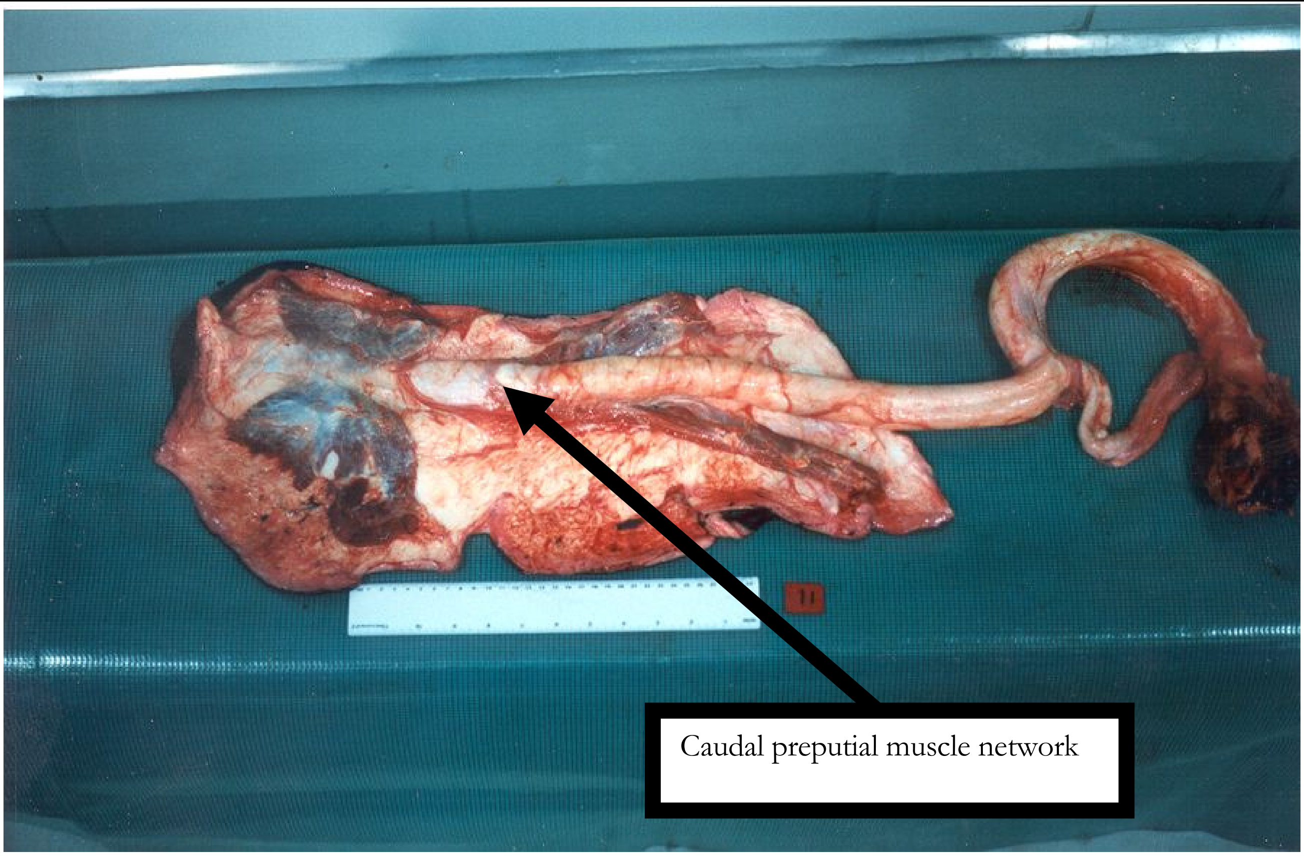
1 = Network absent or one to two muscle strands from each muscle present

2 = Network of three muscle strands

3 = Network of four muscle strands

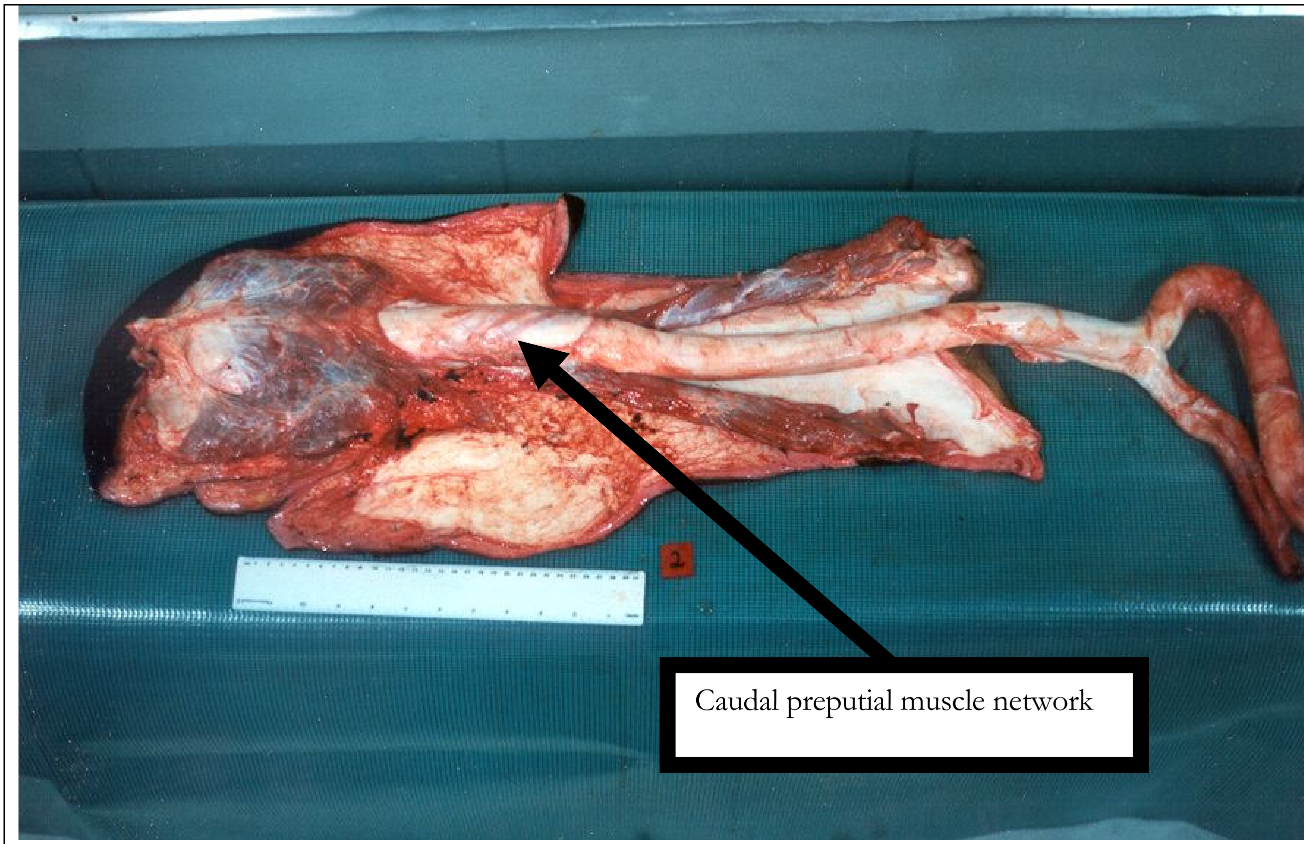
4 = Dense network of more than four muscle strands

5 = Broad, dense network of more than four muscle strands



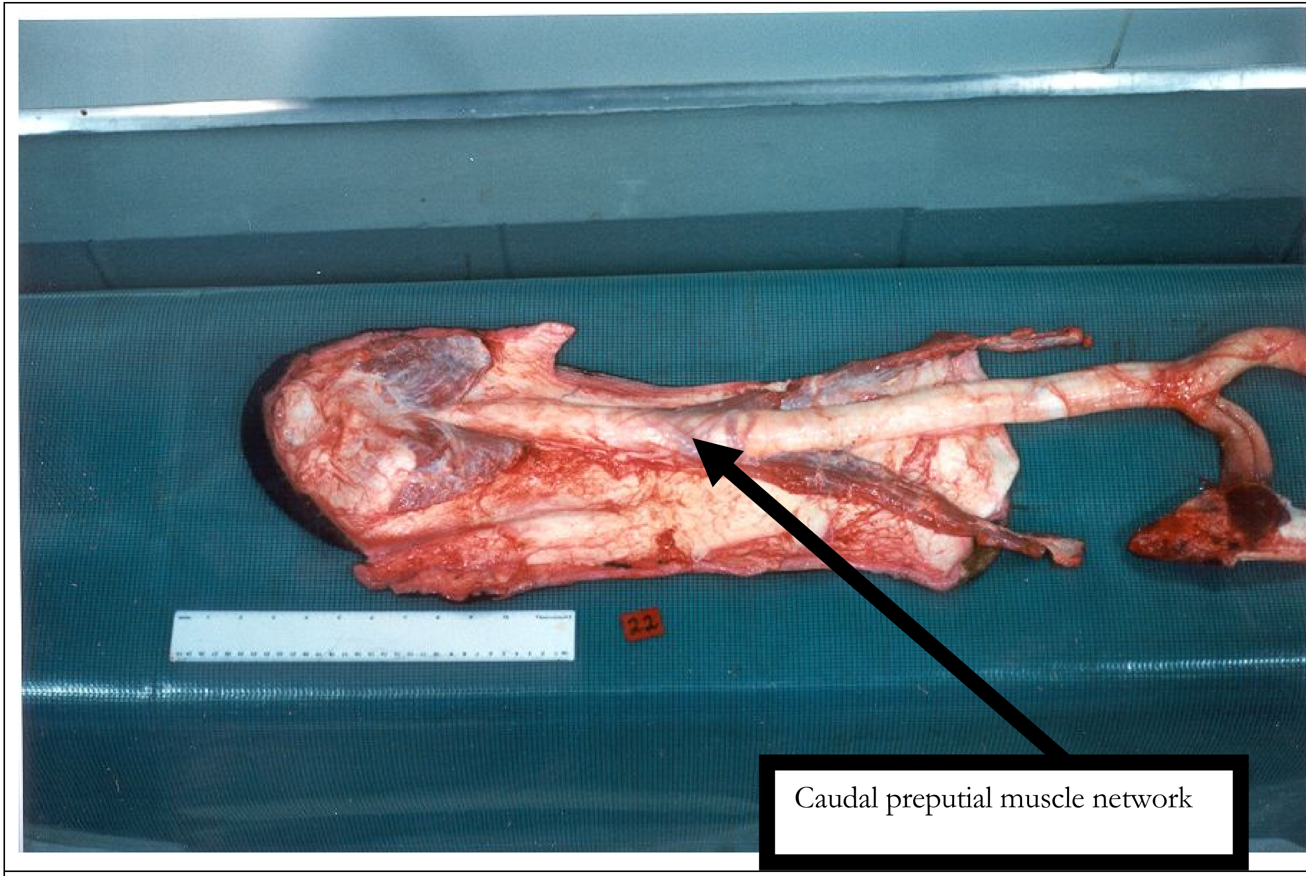
Bull 11

Caudal preputial muscle network score = 1



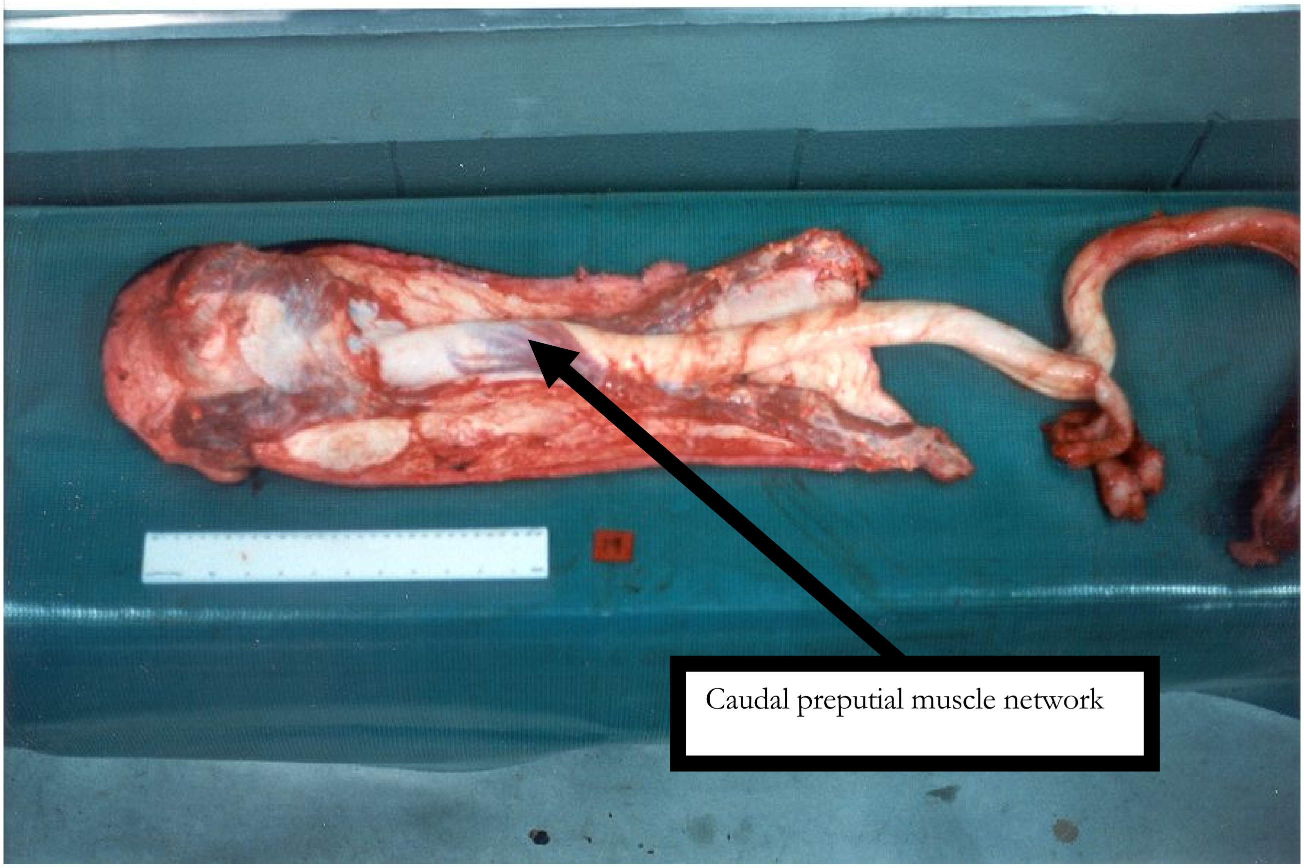
Bull 2

Caudal preputial muscle network score = 2



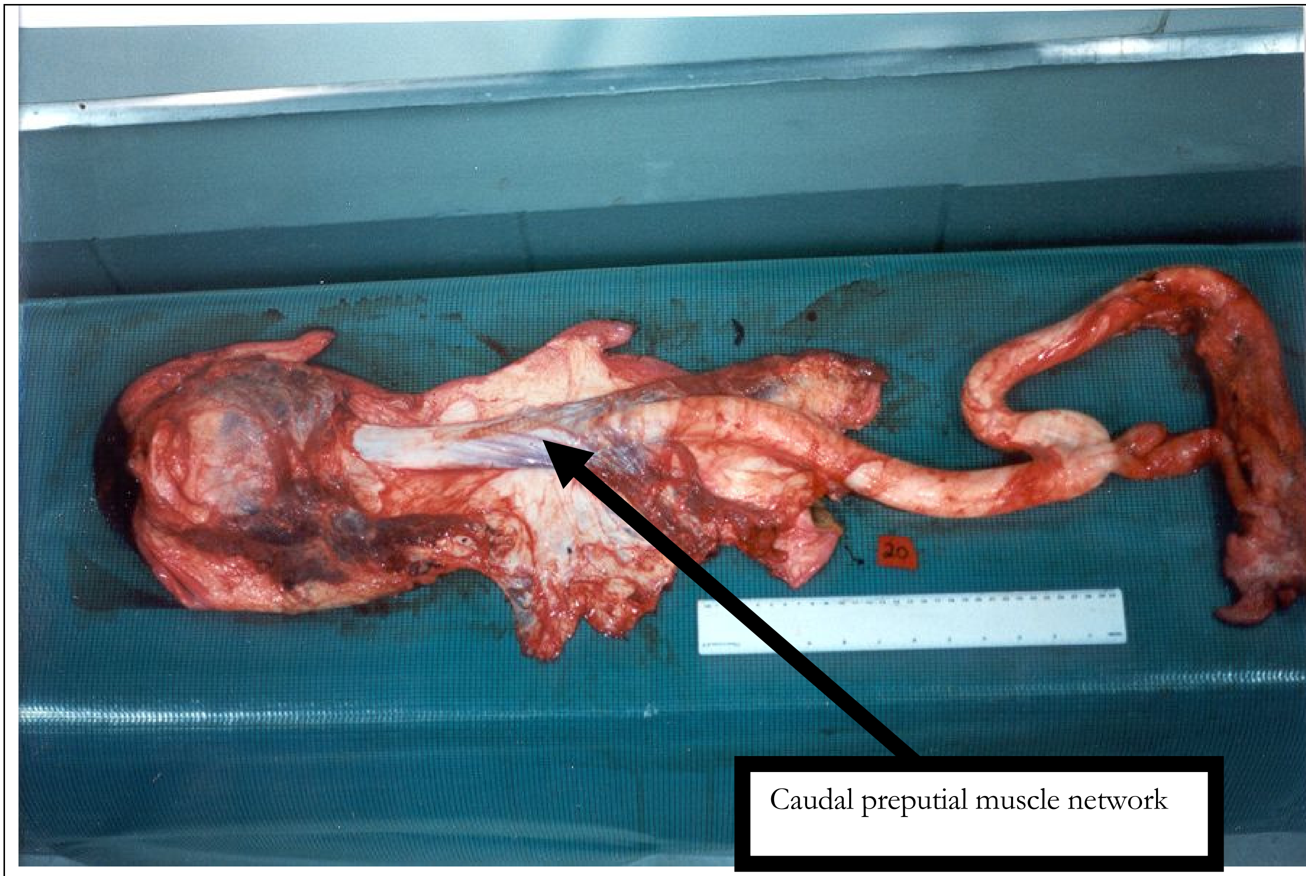
Bull 22

Caudal preputial muscle network score = 3



Bull 19

Caudal preputial muscle network score = 4



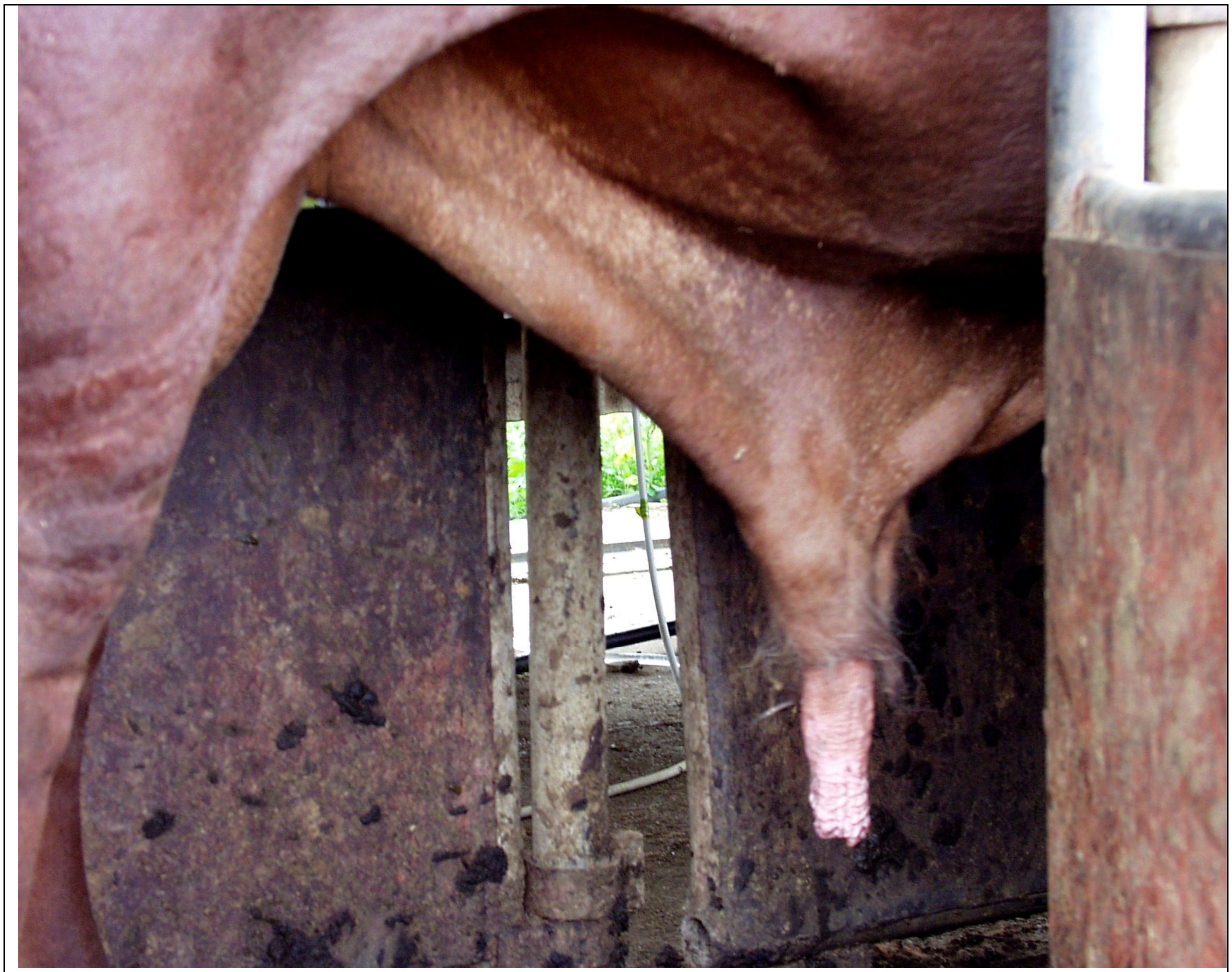
Bull 20

Caudal preputial muscle network score = 5

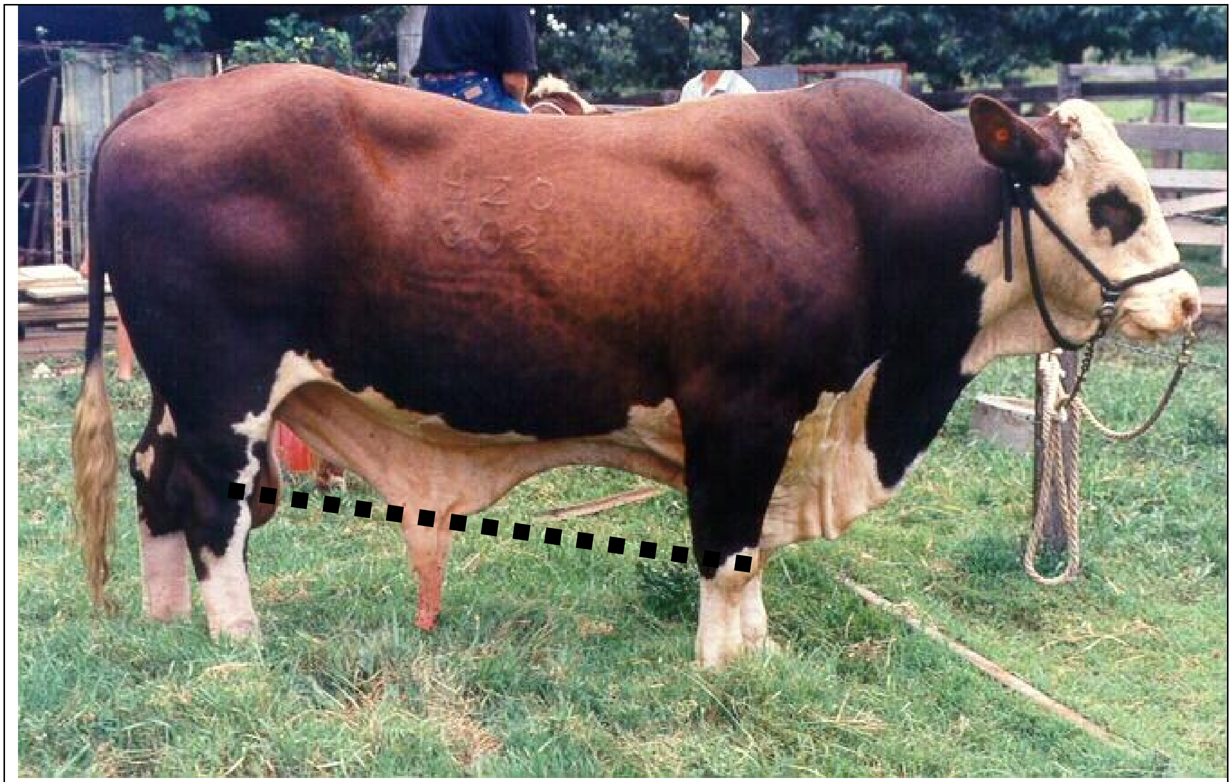
Appendix 3. Examples of preputial eversion

Examples of various stages of preputial eversion in *Bos indicus* cross bulls.

Preputial eversion < 5cm



Preputial eversion > 10cm



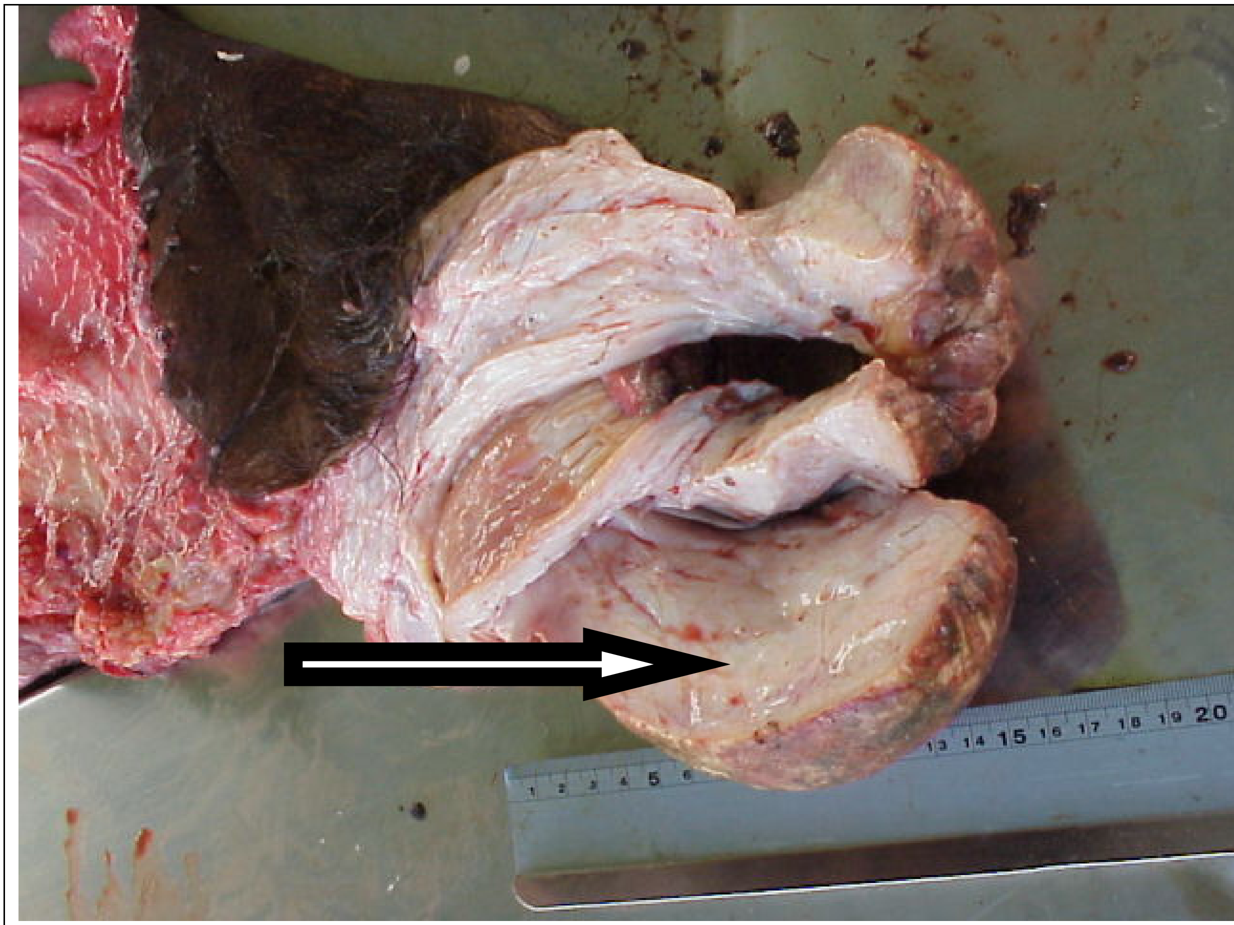
Very long preputial eversion with preputial orifice obviously below the ‘knee-hock’ line

Appendix 4. Examples of preputial prolapse

Photos of chronic preputial prolapse from Santa Gertrudis bulls.

Preputial prolapse with extensive superficial excoriation

In some cases of chronic preputial prolapse the tip of the penis can still protrude



Chronic preputial prolapse showing extensive fibrous tissue formation.