A COMPARISON OF TWO
EQUINE CASTRATION
TECHNIQUES

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Cover image: Equine castration under general anaesthesia using a Sand’s emasculators.

Courtesy Dr Bryan Hilbert
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Certificate of Authorship

I hereby declare that this submission is my own work and to the best of my knowledge and belief, understand that it contains no material previously published or written by another person, nor material which to a substantial extent has been accepted for the award of any other degree or diploma at Charles Sturt University or any other educational institution, except where due acknowledgement is made in the thesis. Any contribution made to the research by colleagues with whom I have worked at Charles Sturt University or elsewhere during my candidature is fully acknowledged. Chapter 3 has been published in the Australian Veterinary Journal as a peer reviewed paper.

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Christopher Owens 3rd August, 2018
Chapter 3 has been published in a peer-reviewed veterinary journal as outlined below. Christopher Owens was responsible for composing the manuscript, however the collaborating authors contributed to the critical revision of the article and approved the final manuscript for publication.

I, Kristopher Hughes (senior author), sign on behalf of the collaborating authors to confirm the above statement and consent to the inclusion of the publications in this thesis.

Kristopher Hughes 3rd August, 2018
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Ethics Approval

Animal Care and Ethics

Animal care and ethics approval was attained prior to data collection. The Animal Care and Ethics Committee, Charles Sturt University approved the study protocols. The protocol numbers issued with respect to this project were ACEC 13/005 (Part 2: Chapter 4) and ACEC 14/053 (Part 3: Chapter 5).

Human Ethics

Human ethics approval was attained prior to distribution of the questionnaire (Part 1: Chapter 3). The Faculty of Science Ethics in Human Research Committee reviewed and approved the research proposal. The protocol number issued with respect to this project was 400/2014/42.
Publications and Conferences

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Glossary of abbreviations

BID: bis in die (twice a day) BTW: bodyweight

cm: centimetre

IM: intramuscular

IV: intravenous

mg/kg: milligrams per kilogram

min: minute

mL: millilitres

mmHg: millimetres of mercury

PO: per os (via the mouth)

TIVA: total intravenous anaesthesia
Abstract

Castration of horses is among the most common surgical procedures undertaken in equine veterinary practice worldwide. It is most frequently performed to reduce masculine behaviour in horses that are not intended or suitable for breeding. Less common indications for castration include testicular disease, including neoplasia, orchitis or trauma, inguinal hernias or torsion of the spermatic cord. Equine castration is traditionally performed with surgical emasculators, and can be undertaken using closed, semi-closed or open techniques in the standing horse after sedation, or in the recumbent animal after induction of general anaesthesia. Although castration is frequently performed in routine practice, complications of the procedure are common. Post-operative complications range from those that are inconvenient to the owner and cause discomfort to the animal such as swelling and infection, to those that are financially costly and immediately life-threatening such as evisceration or marked haemorrhage. The wide variety of intra and post-operative protocols available to the equine surgeon is testament to the on-going search for ways to improve outcomes with castration. The scientific literature contains conflicting information on outcomes and risk of complications with surgical considerations such as whether to perform castrations using an open or closed technique, in the recumbent or standing horse, with or without primary closure of the skin incision, a certain variation of emasculator or with or without ligation of the vaginal tunic and spermatic cord. Finally, examination of practitioner preferences for equine castration between veterinarians in different regions would be valuable as this information may improve understanding of contemporary castration practices and outcomes.

Recently, the Henderson castration instrument has emerged as another option for castration of horses, and opinions have been divided regarding the efficacy and safety of this method in horses. It is important that the Henderson instrument is subjected to scientific evaluation in a controlled manner for determination of surgical outcomes and comparison with conventional equine castration techniques which rely on emasculcation. As such, the aims of the research presented in this thesis were to:
(i) Collect information on the habits, impressions and preferences of Australian equine veterinarians performing castration, their experiences with the Henderson instrument and the rates and types of complications they have experienced when using various methods of castration via a nationally-delivered questionnaire.

(ii) Compare outcomes and complications of castration using a surgical emasculator with the Henderson castrating instrument in a clinical study.

(iii) Observe and report the effects of surgical emasculators and the Henderson instrument on the spermatic cord and internal inguinal ring at the time of surgery.

This is the first study to describe and analyse the castration preferences and outcomes experienced by Australian equine veterinarians (Part 1) and to directly compare castration of horses using the Henderson castrating instrument or emasculators (Parts 2 and 3). Comparison between the two techniques was undertaken using a multifaceted approach that involved determination of clinical outcomes and complications (including those occurring intra-operatively, immediately post-operatively [24 hours] and at longer-term post-operative follow-up [3 months]) in a prospective cohort study (Part 2) and laparoscopic and post-mortem examination of the inguinal and vaginal rings, vaginal tunic and spermatic cord (Part 3).

The results of the questionnaire study found that while there are geographical differences compared to studies performed in North America and the United Kingdom in terms of surgical preferences, the rates and types of complications experienced are consistent with those previously reported in other countries. This information provides insight into the current castration techniques, preferences and outcomes of Australian veterinarians and epidemiological data to further the understanding of associations between particular castration methods and types and rates of complications, which may contribute to moving the industry closer to a gold standard for castration.

The results of the clinical surgical study indicate that the types and rates of complications seen with the Henderson castrating instrument are similar to those with semi-closed castration using the surgical emasculators. Despite this finding, for future investigation of equine castration techniques a larger study involving the Henderson instrument may be warranted as the
observational study (Part 3) revealed that in some horses, the Henderson castrating instrument resulted in the tearing of the internal inguinal ring and vaginal ring.

This thesis provides valuable contributions to the epidemiological understanding of equine castration in the Australian context, and has added important knowledge in the form of a prospective study of both the emasculator and Henderson instruments in a prospective cohort study. The observational study should form the impetus to continue investigating the effects of the Henderson instrument on the spermatic cord and inguinal ring in order to develop conclusions about these observed changes that may have implications for horse welfare.
Chapter 1: Introduction

Castration is used for the management of male horses to prevent reproductive capacity and decrease hormonally-driven behaviours such as aggression. It is done by surgical removal of testes and epididymis and is the most commonly performed equine surgical procedure\(^1,2\). Complications are common with equine castration being reported as the most common source of malpractice claims for equine veterinarians\(^3-5\). Complications have been reported to occur in up to 60% castrated horses\(^6-8\). Post-operative complications range from the very mild, almost expected issues, such as slight post-operative swelling through to more moderate complications such as infection, to immediately life-threatening events like serious haemorrhage or evisceration\(^3\).

Emasculators have been the Industry standard for approximately the last hundred years\(^9\). Considerable research has been done to improve outcomes following castration, almost all of the reported studies examine the use of this instrument\(^4,5,7,10-16\). Therefore, most reports of complication rates and types in the literature relate to castrations using the surgical emasculator. Many clinicians also ligate the vessels in the spermatic cord in order to prevent haemorrhage and to close the vaginal tunic (out-pouching of the peritoneum) that connects the scrotum to the abdomen through the inguinal ring. In the late 1990s the Henderson technique was introduced for castration of horses\(^17\). This device clamps on to the spermatic cord and attaches to a power drill. It occludes the vessels and removes the testis via torsion. Early anecdotal reports suggested that this method is related to fewer complications and is a faster technique to perform than when emasculators are used. However, there are little data from scientific assessment of this technique, and no studies directly comparing the surgical emasculator to the Henderson instrument.
Objectives

The objectives of this study were to:

1. Collect and analyse the perceptions of veterinarians performing equine castrations in Australia regarding techniques, preferences and outcomes.
2. Investigate how commonly veterinarians were using the Henderson castrating instrument, and their experiences with the method.
3. Investigate potential associations between veterinarian demographics, patient signalment, castration methods, techniques and complications.
6. Observe the effect of castration using either the Henderson instrument or surgical emasculators on the internal inguinal ring and spermatic cord by direct visualisation at the time of surgery.

These objectives were achieved by:

1. Using a questionnaire to collect information from Australian veterinarians about their perceptions and experiences with both techniques.
2. Performing a clinical study to compare the rates and types of complications of each technique for equine castration in a prospective cohort study.
3. Performing castrations on intact male horses with pre-existing conditions holding a grave or hopeless prognosis and simultaneously evaluating the testicular artery and inguinal rings via laparoscopic visualisation and subsequently by post-mortem examination.
Thesis Structure

This thesis is compiled in accordance with Charles Sturt University recommendations for a professional doctorate by publication. Chapter 2 is a comprehensive literature review of published information surrounding castration of horses including variations in instrument and technique, post-operative preferences, complication types and rates, surveys and evidence-based surgery.

Chapter 3 consists of a paper published in The Australian Veterinary Journal in January 2018 entitled ‘A survey of equine castration techniques, preferences and outcomes among Australian veterinarians’. This chapter reports epidemiological data on Australian equine veterinarians performing castration.

Chapter 4 consists of a manuscript in preparation for submission to The Equine Veterinary Journal entitled ‘A prospective study comparing the outcomes of horses undergoing castration using either the Henderson castrating instrument or emasculators’. This chapter compares types and rates of complications that are associated with castration using the Henderson castration instrument and surgical emasculators in a prospective randomised clinical study.

Chapter 5 consists of a manuscript in preparation for submission to Veterinary Surgery entitled ‘Comparison of Two Castration Techniques in the Horse Using Direct Laparoscopic Observation of the Internal Inguinal Ring and Spermatic Cord at the Time of Surgery’. This chapter describes the results of an observational study visualizing what happens to the spermatic cord and inguinal ring at the time of surgery when castration is performed with either emasculators or the Henderson Castrating Instrument.

Chapter 6 consists of an exegesis reflecting on the contributions of this thesis to the literature and the veterinary profession.
References

Chapter 2 Literature Review
2.1 Introduction

Castration is the removal of the testis, epididymis, and spermatic cord containing the afferent and efferent blood supply, and lymphatics. The goal of castration is to remove the tissue that gives reproductive and behavioural capacities of the stallion with minimal tissue trauma and optimum haemostasis. This involves the removal of the testis, as well as the head, body and tail of the epididymis, and haemostasis of the testicular artery and pampiniform plexus and the associated cutaneous and muscular vessels. Ideally this should be done in a way that minimizes local trauma, haemorrhage and infection of the surgical site, and ascending infection through the vaginal tunic that directly communicates with the peritoneum and prevention of herniation or evisceration of abdominal contents via the vaginal tunic through the inguinal ring. Despite being one of the most commonly performed equine surgical procedures in both field and hospital setting\textsuperscript{1,2}, complications are common and range from swelling of the surgical site to life threatening complications such as evisceration and severe haemorrhage. Due to the highly vascular nature of the anatomy, the dependent position of the incision, and the direct communication between the abdomen and the scrotal contents, there are a number of serious complications that can occur. As a result it is not only the most commonly performed equine surgical procedure but the most common cause of malpractice claims against veterinary practitioners in America\textsuperscript{3-5}.

The industry standard for the castration of horses is based on the use of the surgical emasculator (Figure 2.1.1)\textsuperscript{6}. This instrument is applied to the spermatic cord and (based on the variant of emasculator) it either simultaneously crushes and cuts the spermatic cord and vessels, or these structures are cut manually at the discretion of the surgeon after being crushed, thereby removing the testis and clamping the blood vessels to prevent haemorrhage. Wide variation has been reported among veterinarians in surgical technique and peri-operative preferences with the use of emasculators\textsuperscript{4,5,15}. Examples include choice of emasculator variant\textsuperscript{4,18}, approach\textsuperscript{3,19}, ligation\textsuperscript{20,21}, intra testicular use of local anaesthetic\textsuperscript{10,11}, having the patient standing or recumbent\textsuperscript{3,7}, use of peri-operative antimicrobials\textsuperscript{4} and anti-inflammatory drugs\textsuperscript{12}, whether to perform the surgery closed, open, or semi closed\textsuperscript{3,4,7}, and whether perform
primary closure of the skin\textsuperscript{13,19}, Numerous studies have sought to associate surgical techniques and peri-operative preferences with complications in the hope of improving outcomes. Frustratingly, these studies have often produced conflicting results.

In the mid-1990s, an alternative instrument to the traditional surgical emasculator emerged: the Henderson castrating instrument (Figure 2.1.2)\textsuperscript{17}. Originally devised in the United States for castration of cattle, the instrument has been adapted for use in horses and has found some popularity among equine veterinarians\textsuperscript{22}. The Henderson instrument is applied to the spermatic cord, and the instrument is in turn attached to a battery-operated drill. Using the drill, the testis and cord are rotated until the twisted cord breaks, removing the testis and causing occlusion of
the vessels in the cord. Because the structures are twisted and effectively obliterated, no ligature is placed around the spermatic cord and associated vessels.

Figure 2.1.2 Henderson castrating instrument Stone Manufacturing & Supply Kansas City MO.

Proponents of the Henderson instrument claim that it is a faster and more technically simple method, and have claimed that it carries the same or lower complication rates than using surgical emasculators\(^\text{22}\). However, there are little data available for the assessment of use and complications of the Henderson technique in horses. Post-surgical complications of castration have been reported\(^\text{12,14,20}\), but these studies have invariably assessed castration techniques utilizing the surgical emasculator. Further, there have been no prospective studies comparing castration using the Henderson instrument to the castration using the surgical emasculator.

### 2.2 Functional Anatomy

The testes (Figure 2.2.1) originate in the abdominal cavity and under normal circumstances, descend into the scrotum within 2 weeks after birth. The main functions of the testes are the production of testosterone and spermatozoa. The head, body and tail of the epididymis are responsible for storage, maturation and transport of spermatozoa. The head of the epididymis is located at the cranial pole of the testis. The body of the epididymis is attached to the dorsal border of the testis by loose connective tissue. The tail of the epididymis is located at the
caudal pole of the testis and transitions to the ductus deferens, which is responsible for transportation or spermatozoa, via the accessory sex glands, to the urethra\textsuperscript{23}.

The spermatic cord contains the testes’ afferent and efferent vascular and nerve supply, lymphatics, and the ductus deferens. In order to maintain appropriate testicular temperature, heat exchange occurs between the testicular artery and vein at the pampiniform plexus. The cremaster muscle is attached to the outside of the spermatic cord. The function of the cremaster muscle is to retract and lower the testis as part of its thermoregulatory mechanism. The mesorchium is a fibrous sheath responsible for supporting the structure of the spermatic cord\textsuperscript{24}.

Once descended, the testes are located in the scrotum, allowing the testes to be distant from the body’s core temperature. The scrotum is comprised of four layers, from external to internal: skin, tunica dartos, scrotal fascia and vaginal tunic (common vaginal tunic). The tunica dartos is a layer of smooth muscle and connective tissue, constriction and relation of which allows for raising
and lowering the testes. The scrotal fascia is loose connective tissue which facilitates movement of the testes within the scrotum. The vaginal tunic is an evagination of the peritoneum which extends through the inguinal canal and consists of two layers: the parietal layer and a visceral layer. The parietal layer (or tunica vaginalis communis) is continuous with the parietal peritoneum and lines the vaginal tunic. The visceral layer (tunica vaginalis propria) covers the spermatic cord, testis, and epididymis. As it is a continuation of the peritoneum it provides communication between the abdomen and the scrotum. The origin of the vaginal tunic is the vaginal ring, which is a thickening of the peritoneum that lies deep to the internal inguinal ring. The vaginal tunic travels through the internal and external inguinal rings (the inguinal canal), to the scrotum. The internal inguinal ring is a slit bordered by the internal abdominal oblique muscle, the rectus abdominis, the prepubic tendon and the inguinal ligament. The external inguinal ring is a slit in the external abdominal oblique muscle, approximately 10-12cm long in light breed horses, which is oriented in a craniolateral to caudomedial direction. Multiple structures are located within the inguinal canal, including the spermatic cord, the genitofemoral nerve, the external pudendal vasculature and the efferent lymphatic vessels from the superficial inguinal lymph nodes.

2.3 Anatomical Aberrations

2.3.1 Cryptorchidism

If one or both testes fail to descend through the vaginal ring in an appropriate time frame, the horse is termed a cryptorchid. If the epididymis, but not the testis, has descended through the vaginal ring, the horse is termed a partial cryptorchid. A further variation is the ‘high flanker’ or ‘inguinal cryptorchid’, where the testis is located in the inguinal canal. Unilateral cryptorchid horses are fertile but exhibit reduced production of sperm however bilateral cryptorchids are sterile due to hypoplasia of the seminiferous tubules caused by the increased temperature the testis is subjected to. The influence of breed on the predisposition to cryptorchidism in horses remains uncertain, although some authors consider the prevalence of the condition to be higher in Percherons, American Saddlebreds, American Quarter Horses and crossbreeds in comparison to other breeds. In addition, in a large retrospective study of 604 cryptorchid cases in horses,
Quarter Horses were significantly over-represented in comparison to other breeds, suggesting that breed may be associated with predisposition to the condition\textsuperscript{26}.

The aetiology of cryptorchidism in animals and humans remains unknown but is thought to be multifactorial\textsuperscript{27} with a number of genetic, endocrine, epigenetic and environmental factors that are thought to play a role\textsuperscript{28,29}, and a number of sources suggest that it is an hereditary condition\textsuperscript{30-32}. In horses, unilateral cryptorchidism is most common, although bilateral cryptorchidism may also occur in a minority of cases\textsuperscript{26}. While unilateral cryptorchidism of the left or right testes occurs with similar frequency, the location of the testes is influenced by the side of the horse\textsuperscript{30,33,34}. On the left side, abdominal retention is more common than inguinal retention of the testes, while on the right side, inguinal retention of the testes most frequently occurs. In horses with bilateral cryptorchidism, abdominal retention usually is present\textsuperscript{26,34}.

\textbf{2.3.2 Testicular tumours}

Testicular tumours are germinal (seminoma, teratoma, teratocarcinoma, embryonic carcinoma) or non-germinal (Sertoli cell tumours, Leydig cell tumours) with Seminomas and teratomas being the most commonly diagnosed testicular tumour\textsuperscript{35}. Seminomas can be malignant or benign, however, the malignant variety are more prone to metastases. Teratomas are typically benign and consist of multiple tissues whose embryologic origins are different from that of the tissue in which they arise. Therefore, teratomas can be bone, cartilage, brain, respiratory or glandular epithelium.

\textbf{2.4 Evolution of Castration}

Castration has been performed in order to control reproductive capacity and behaviour since the domestication of animals. The first recorded veterinarian was in Sumeria in 2300 BC where castration was routinely performed to quieten and fatten bulls and stallions\textsuperscript{36}. The basic horse castration clamp remained unchanged from Roman times until the 19\textsuperscript{th} century with the advent of emasculators. These original clamps were clamps made of either iron or wood, and were used
to hold the testes distal to the body in order to cut them with a separate blade, or a disposable wooden peg that was left on the cord to crush it, and drop off at a later time. These remained in use until the 20th century when they were made from stainless steel.

2.4.1 The Surgical Emasculator

The industrial revolution allowed design and manufacturing improvements resulting in the basic design of the surgical emasculator types used today. The basis of this device is a pair of jaws that both crush and sever the cord either simultaneously or crush first then cut.

Today, the surgical emasculator is the industry standard for surgical castration of horses. There are a number of variations available, but they are all based around the same design and function. The surgical emasculator crushes and cuts the connection between the testis and the body, thereby removing the testis and clamping the blood vessels to prevent haemorrhage. The commonly used emasculator variants are the White’s, the Reimer, Serra and Sand’s models. The White’s improved emasculators feature crushing jaws and cutting blade that act simultaneously. The Reimer emasculators feature a separate handle to control the blade. This design feature is considered safer by users because the surgeon can’t inadvertently cut the cord before it is properly crushed. However, the Reimer’s can be difficult to use because of the extra handle. The Sand’s emasculator has the same advantages in that there is no cutting blade that is automatically engaged as part of the emasculator, but there is no extra handle so cutting must be done manually. The Serra variant has curved jaws so that the cord is evenly crushed, and the grooves on the crushing blades are oriented parallel to the cord so that transecting the cord inadvertently when trying to crush is less likely. A recent study reported that testicular arteries that had been crushed with Reimer emasculators resisted significantly higher pressure than those with Serra. During open castration, however there was no difference when castration was performed via the closed technique.

In a survey of equine castration complications carried out in North America, Moll et al. (1995) found that all 560 respondents used surgical emasculators as part of their castration protocol.
The majority of surgeons used three variants of surgical emasculators: the White’s improved, the Serra, and the Reimer’s. When assessing surgical bleeding, significantly more haemorrhage was reported by vets using the Reimer’s emasculators in comparison to the Serra’s emasculators. This finding is difficult to explain given the Reimer’s instrument provides a more controlled transection of the spermatic cord, as the cutting blade is activated by the surgeon once the cord is crushed, whereas the Serra’s instrument transects and crushes the cord at the same time. This is the only study that has evaluated emasculator types for equine castration. The study by Moll et al (1995) was undertaken in North America and prior to the commercial availability of the Henderson castration tool and is unlikely to reflect current emasculator tool preference in Australia.

2.4.2 Variations in surgical technique available to emasculator method

2.4.2.1 Open versus Closed

Surgical castration can be performed via three general techniques which vary regarding the vaginal tunic; closed, ‘semi’ or ‘half’ closed, and open. For the closed technique the vaginal tunic is not incised and is removed in the emasculation. For the open technique, the vaginal tunic is incised and the testis and spermatic cord are removed, the vaginal tunic is left open. The semi-closed technique involves opening the tunic to expose the testes but including it in the emasculation. It has been stated previously that the closed and semi-closed techniques are advantageous as the removal of vaginal tunic decreases the incidence of postoperative complications such as septic funiculitis. In a survey of equine castration complications, respondents reported that the open technique was used most frequently, with lower rates of infection, oedema, and excessive swelling than the half-closed technique. However, a retrospective study reported significantly more complications with the semi-open technique compared with the closed technique. The open technique was not evaluated in this study. Rosanowski et al. (2017) reported a 70% complication rate in 250 horses castrated using the open standing technique, which is substantially higher than previous reports. In an earlier retrospective study of castration outcomes, Kilcoyne et al (2013) reported that of all variables measured only the choice of open vs closed method had a significant effect on the rate of
complications: the odds of a complication was nearly 5 times greater with semi-closed castration in comparison to closed castration. Identification of a superior method remains unclear as the results of these studies are inconsistent. Comparison is difficult as the interpretation of complication magnitude varies between these studies. Finally, primary skin closure at castration has also been advocated by a number of sources\textsuperscript{13,39-41}, however open drainage of the incisions combined with exercise remains the treatment of choice for clinicians despite this evidence\textsuperscript{4,6}.

In addition to the choice of open, closed or semi closed technique, a number of approaches have been described in the literature. By far the most commonly reported is the scrotal approach\textsuperscript{4}. Further sub-variations of this approach include two parallel incisions 1-2cm either side of the median raphe and remove one testis via each incision. Other surgeons prefer to perform a scrotal ablation, resulting in only one incision and increased capacity for drainage post-operatively\textsuperscript{4}. Some surgeons have employed an inguinal approach to castration and claim that it is related to significantly lower complications with a reported complication rate of 2.1\%\textsuperscript{19,42,43}. It has been theorised that the inguinal approach negates the need to traumatise the soft tissues surrounding the vaginal tunic with the scrotum\textsuperscript{19}.

\textbf{2.4.2.2 Ligation}

A number of studies have investigated ligation of the spermatic cord, vaginal tunic, or a combination of the two options. Moll et al. (2005) reported a significantly higher rate of infection from respondents who ligated, but no increase in rates of haemorrhage or oedema. While the reported frequency of post-operative haemorrhage was no different, the volume of blood observed was significantly less in ligated horses.

Conversely, Kilcoyne et al. (2013) reported no significant association between use of ligatures for either intraoperative haemorrhage or post-operative complications. Similarly, in an earlier study\textsuperscript{14} comparing non-sutured and sutured castration using surgical emasculators, the authors reported a 22\% complication rate in horses castrated without ligation of the vessels and only a 6\% complication rate in horses castrated with vessel ligation, suggesting that ligation may not be a risk factor for post-operative complications. Recently, the use of a multifilament transfixing
ligature used with a closed technique did not result in a higher complication rate than a closed technique without ligation or castration with primary closure. Comino et al (2016) went further to assess the properties of two knot types used in ligation, comparing the novel giant knot to the traditional transfixing knot. The Giant knot is a type of sliding half hitch where, as opposed to a surgeon’s knot (2 turns of the suture followed but a single twist thrown where the suture ends are pulled parallel to the suture line, with equal tension) described by the authors as a one way self-locking sliding knot with 4 overhand half hitches. Comnio et al. (2016) did not find a significant difference in arterial bursting pressure between the knots, but they did report that the giant knot required less suture material than the transfixing knot. This study presented interesting findings, however due to the ex-vivo nature of the study, the clinical significance of these findings remains to be seen.

2.4.2.3 The Henderson Castrating Instrument

While a number of studies have been published evaluating post-surgical complications of castration using emasculators, there are little data evaluating the Henderson technique in horses, and to date there have been no prospective studies comparing the Henderson technique to the emasculator technique. Proponents of the Henderson instrument claim that it is a faster and more technically simple method for the surgeon with very low complication rates. One paper reported nil complications out of 150 horses castrated with the Henderson tool, minimal to no bleeding, with no appreciable tissue trauma. In a retrospective evaluation of the outcomes of 252 horses castrated with the Henderson instrument, a 10.7% complication rate was reported, and increasing age was significantly associated with the likelihood of complications. In that study, horses under the age of 4 years had a complication rate of 8.3%, while horses over the age of 4 years had a complication rate of 21.3% and two horses (0.8%) subjected to euthanasia: one due to wound botulism and one due to evisceration. The rigor of this study suggests that these complication rates are more accurate. Although this is a markedly higher complication rate than was suggested in the original paper on the use of the instrument (no complications), it is at the low end of what has been reported for emasculator castration and therefore makes a promising argument in favour of use of the Henderson castrating instrument.
2.4.2.4 Other techniques for equine castration

Testicular artery ligation under laparoscopic guidance using Filshie clips resulted in incomplete avascular necrosis of the testicular tissue in some patients and in three of twelve patients there was no avascular necrosis\(^{48}\). Rijkenhuizen et al. (2018) reported on the castration of 15 unilateral cryptorchid stallions using combined laparoscopic and conventional techniques. Intra-abdominal ligation of both spermatic cords was undertaken laparoscopically. The descended testis were removed using laparoscopically-assisted abdominal transection of the spermatic cord and a modified open method with the horse standing, while for the abdominal testes, the cord was not transected and the testes was left in situ\(^{16}\). In that study low rates of intra and post-operative complications were reported and the scrotal incisions healed with no swelling or exudate. Turner et al. (2015) presented the ‘Equitwister’, a hand driven version of the Henderson castrating instrument to the AAEP in 2015, for use in developing countries due to its reported ease of use and low cost. The authors reported no complications\(^{49}\).

2.4.2.4.1 Chemical Sterilisation

Although not a popular choice amongst clinicians, immunologic castration techniques can be employed. Stallions can be immunised against luteinising hormone-releasing hormone and gonadotrophin releasing hormone. Repeated immunizations are required to supress testicular function and sexual behaviour and unfortunately the immunization has a highly variable effective period\(^{50}\).

2.4.2.4.2 Patient Positioning

Castration of horses can be performed either with the patient standing or recumbent. A previous study in the United Kingdom reported that 29% of respondents performed all equine castrations under general anaesthesia in the field, 13% performed all castrations using standing sedation, and 0.7% performed all castrations under general anaesthesia in hospital with surgical facilities\(^{14}\). The majority of respondents performed some castrations in standing horses and some castrations after general anaesthesia of the patient. In that study, the complication rates associated with these surgical preferences were not investigated. In a retrospective study of
castration methods in the United States\textsuperscript{6}, no significant difference in complication rates between horses castrated under general anaesthesia or standing sedation was found. However, the authors of that study reported that additional anaesthesia was associated with a significant increase in the frequency of complications\textsuperscript{6}. One explanation for this finding may be that additional anaesthesia was linked to the use of the semi-closed technique. The semi-closed castration technique is more technically demanding and requires increased tissue handling and a longer duration of surgery, which may increase the likelihood of complications\textsuperscript{4}.

**Use of intra-testicular local anaesthetic**

Portier (2009) reported a significant decrease in the number of additional incremental IV boluses required under total intravenous anaesthesia in horses undergoing castration when intra-testicular lignocaine was administered suggesting that there is an element of nociceptive stimuli present in castration, even under general anaesthesia. As such the use of lignocaine may be of benefit both on ethical grounds to minimise pain in these animals, and to improve post-operative outcomes, since additional complications have been associated with longer anaesthetic lengths in castrated horses\textsuperscript{11,20}. The 1995 United states retrospective revealed the that only 40\% used local anaesthesia during castration under general anaesthesia\textsuperscript{6}. Price et al. (2005) reported similar findings from their questionnaire-based review of castration in the United Kingdom where only 49\% of respondents used local anaesthetic in addition to standing sedation or recumbent anaesthesia. The findings of these papers may suggest an impression that there is low or no pain associated with the castration procedure or potentially a belief that the pain experienced by the patient does not have a negative impact on the post-operative outcomes and recovery from the procedure. Recently, intraoperative heart rates, post-operative pain scores and cytokine levels were found to be significantly lower in horses receiving local mepivacaine compared with horses in the control group\textsuperscript{51}. Stucke et al. (2014) reported that intraoperative injection of mepivacaine into the spermatic cord resulted in lower postoperative subjective pain measures when compared with flunixin alone. These findings support the use of intra-operative local anaesthetic during castration procedures in horses to improve quality of anaesthesia and reduce post-operative pain. Moreover, the use of local anaesthetic does not appear to have appreciable
adverse effects as a recent study reported no association between intra-testicular lignocaine and development of complications after castration\textsuperscript{20}.

To date, there has been no consensus statement on the ideal combination of techniques among options available. Surgical techniques used for equine castration vary between clinicians, due to individual preferences based on experience, personal belief, available literature and available facilities and resources.

2.4.4 Post-operative Preferences
2.4.4.1 Analgesia

Although the majority of clinicians provide pre-operative analgesia in the form of systemically-administered flunixin meglumine or phenylbutazone, veterinarians vary in their post-operative analgesic protocols. Perhaps surprisingly, given the frequency of swelling following the procedure\textsuperscript{6,14,19,20,52}, the dependent location of the incision, and the rich innervation of the anatomy, the Moll et al. (1995) and Price et al. (2005) surveys revealed that only 51\% and 46\% of veterinarians respectively did not administer post-operative analgesia. An alternative to the more commonly used flunixin meglumine and phenylbutazone is meloxicam, which can be administered orally. In a recent study, administration of meloxicam was reported to reduce the perceived discomfort in horses following routine castration compared to horses receiving no post-operative analgesia\textsuperscript{53}. It is also important to note that the results of the studies that report low use of pain relief for castration are now 15 and 25 years old and could represent an industry attitude to equine analgesia that has since evolved.

2.4.4.2 Hydrotherapy

Hydrotherapy of the surgical site is a common post-operative recommendation and may be a logical addition as it is expected to result in vasoconstriction, removal of discharge, reduction in inflammatory mediators and decreased surgical site oedema\textsuperscript{4}. However the use of cold-hosing post-operatively may also have adverse consequences in horses after castration. Paradoxically in the survey of equine practitioners in the USA, horses receiving cold-hosing post-operatively were
reported to have increased rates of swelling and infection post-operatively in comparison to horses that did not receive hydrotherapy\textsuperscript{6}. One possible explanation is that overzealous hydrotherapy could traumatise surgical site or possibly force water and debris into the incision. Alternatively, these observations may be a reflection that owners performing hydrotherapy would have the opportunity to monitor the surgical site more closely, which may result in recording bias. Further assessment of the beneficial or detrimental effects of hydrotherapy in horse after castration is warranted, particularly with consideration of technique used.

2.4.4.3 Post-operative confinement and exercise

Although movement is recommended to reduce post-operative oedema, the majority of veterinarians choose to maintain patients on stall rest for 24 hours post-operatively. This is presumably to allow for close monitoring of complications such as haemorrhage, prolapse of tissue and evisceration before turning the horse out for limited exercise\textsuperscript{3}. Anecdotally, following a period of twenty-four hours of stall rest, the majority of patients are permitted to be turned out in a small paddock. Some veterinarians prefer to advise the client to exercise the horse daily, either via walking or lunging\textsuperscript{4}, to facilitate drainage from the surgical incisions and reduce post-operative swelling.

2.4.4.5 Antimicrobials

The available literature regarding the administration of perioperative antimicrobials for castration is challenging and reports of infection rates and whether antimicrobials are indicated are problematic to interpret due to the myriad of intra and post-operative preferences that have been used in different studies and the methods used to collect the data. Considering castration from a theoretical standpoint, on one hand it has a number of characteristics that suggest antimicrobial administration is not indicated for castration. It is a relatively brief elective procedure generally requiring short anaesthetic episodes with a low incidence of life threatening infection related complications. As such castration could justifiably be performed without prophylactic antimicrobials or a single preoperative dose\textsuperscript{54}. Conversely, in reality it is often not performed in the controlled setting of a surgical theatre under general anaesthesia, but in a
paddock or stable where accurate preparation of the surgical site and the surgeon’s hands, and prevention and even recognition of breaks in sterility are logistically difficult. Post-operatively the surgical site is traditionally left to heal by second intention giving the procedure the classification of clean-contaminated leaving the site vulnerable to infection not only from the surrounding skin above the incision on the flanks and on the legs adjacent, but from the nearby urogenital and GI tracts. While not often life threatening when treated in a timely fashion infection is recognised as a common post-operative complication (37%)\(^7\), which can lead to serious sequelae such as scirrhouos cord.

The literature seemingly reflects the complexities of the question of whether antimicrobial administration is justified. The use of antimicrobial drugs in the pre- and post-operative management of horses undergoing castration is controversial. Moll et al. (1995) reported that 56% of veterinarians administered antimicrobials prior to performing a routine castration and that there were fewer post-operative complications when antimicrobials were utilised pre-operatively in comparison to horses that did not receive antimicrobial drugs. Conversely, only 21% of horses in a more recent retrospective study\(^20\) were administered antimicrobial drugs pre-operatively and there was no significant difference in complication rates between horses that did and did not receive antimicrobial drugs. In other studies\(^7,14\), pre-operative antimicrobial drug administration was given as part of the standard peri-operative protocol, precluding the assessment of any drug effect on post-castration complication development. Nevertheless, in one of these studies, the majority of 250 Thoroughbred horses that had standing castration received peri-operative antimicrobial drugs; however, a high rate of surgical site infection occurred (36.7%), and most affected horses required an extended course of antimicrobial drugs in the post-operative period\(^7\). Also, low rates of infection post-castration have been reported in studies where perioperative antimicrobial administration was used infrequently or not at all\(^2,8,47\), bringing into question whether antimicrobial use is indicated in horses that undergo elective castration. Collectively, the results of these studies\(^2,6-8,20,47\) indicate that other factors, such as surgical technique and housing environment are also involved in the predisposition to post-operative infection, rather than a sole effect of antimicrobial drug use. To the authors’
knowledge, no studies focused on the use of post-operative antimicrobial drugs in horses that have undergone castration have been conducted at this time. Such a study would be beneficial.

2.4.4.6 Isolation from female horses

The process of spermatogenesis last 60 days\(^4\); therefore, it is perhaps logical that recently castrated geldings should be isolated from mares for this time period. Taking into account practical considerations, many clinicians recommend a period of segregation from mares of only 2 days since after two days ejaculates are highly unlikely to contain sufficient spermatozoa for pregnancy\(^56\). However sources have stated that 20% to 30% of horses castrated before sexual maturity still displayed stallion-like sexual behaviour and aggression toward horses, and 5% were aggressive toward people in a stallion-like manner\(^57\) meaning that segregation for longer periods may be prudent for herd safety.

2.5 Complications

Post-surgical complications of castration include excessive swelling, haemorrhage, evisceration, infection, seroma formation, peritonitis, inadvertent penile damage, hydrocoele formation, and continued stallion-like behaviour\(^5\).

The variations in surgical technique that exist for equine castration may influence the development of post-operative complications. When castration is performed with the horse standing, the potential complications of general anaesthesia (including hypotension, trauma during recovery, corneal ulceration) are avoided. Conversely, castration of the recumbent horse provides easier and safer access to the surgical site. With consideration of open or closed techniques, incision of the parietal tunic (open technique) allows direct visualisation of anatomical structures, while preservation of the parietal tunic (closed technique) is faster but requires more dissection of tissue. An additional surgical consideration is ligation of the spermatic cord and vessels: this procedure contributes to haemostasis, lessening the risk of haemorrhage. Conversely, not ligating the cord and vessels avoid the retention of foreign material in the surgical site which may act as a nidus of infection.
There are a number of published studies that have been undertaken with the objective of collecting epidemiological data to determine the optimal technique for the safe castration of horses. Despite these attempts, there remains a lack of consensus amongst the studies on the ideal combination of surgical techniques for castration.

Previously authors have collected data using retrospective case series, prospective case series, randomised clinical trials, surveys and questionnaires, as well as anecdotal evidence. There has been wide variation in the findings of studies with overall complication rates reported between 6.9% and 60%. This variation may be explained not only by differences in surgical techniques across studies, but other non-surgical influences such as study factor and the study design. For example, while retrospective hospital records were used by Kilcoyne et al. (2013) to gain information about complication rates in castration, Price et al. (2005) relied solely of the opinions of veterinarians. As well as this, measured variables such as excessive haemorrhage, swelling and infection, and parameters used to measure these variables varied between studies and were frequently not defined.

Between studies of outcomes of horses that have undergone castration, authors have differed in what are considered to be complications. Kilcoyne et al. (2013) reported mild swelling as the most common complication following castration, whereas Rielly and Cimetti (2005) reported no complications. However in the latter study, castrated horses were reported to develop surgical site swelling that could be minimized with the administration of nonsteroidal anti-inflammatory drugs, suggesting that the authors did not consider swelling a complication. Mason et al. (2005) measured post-surgical complications by the cost or scale of the interventions required to treat them. Other papers relied on impressions respondents had of apparently undefined terms such as ‘excessive haemorrhage’.

In the absence of an industry wide consensus for describing or measuring complications, meaningful comparison of these studies is problematic. With this in mind, it is likely that the
recent large scale study that reported an overall complication rate of 10.2\%^{20}, and the UK study which identified an overall complication rate of 15.2\%^{14} was found provide important information of the complication rates for castrated horses, as both included consideration of surgical techniques, including standing and recumbent procedures, open and closed castration techniques and whether the scrotal incisions were left open to heal by second intention or closed primarily.

2.5.1 Swelling

Swelling has been reported as the most common complication associated with routine castration\(^{2,6,12,14,19,20,52}\), and some authors describe post castration preputial and scrotal oedema as inevitable\(^{5}\). Marked swelling following surgery is most likely due to haemorrhage, lack of wound drainage, inadequate post-operative exercise, lack of lymphatic drainage, surgical trauma or infection\(^{3,58}\). Various post-operative protocols have been used by owners and veterinarians to prevent or minimise swelling. Walking or trotting the patient for a number of days post-operatively, cold hosing (hydrotherapy), use of non-steroidal anti-inflammatory drugs (NSAID’s) and antimicrobials are commonly employed\(^{5}\) yet there are little data to suggest a superior combination treatment options.

Kilcoyne et al (2013) reported that swelling developed 2-8 days post-surgery with a mean of 5.6 days. This is consistent with previous reports that swelling usually peaks at 3 to 6 days post-surgery and subsides at 9 days post surgery\(^{3,20,59,60}\). In one study, excessive swelling was significantly reduced in castrations performed using the closed technique compared with the open and semi-closed techniques\(^{6}\). Rosanowski et al. (2017) reported 70% incidence of swelling in a trial using the open technique\(^{7}\). Moll et al. (1995) also reported that approximately half of respondents routinely used NSAID’s post castration.

2.5.2 Haemorrhage

Excessive haemorrhage is described by various sources as a steady stream of blood from the scrotum for more than 15-60 minutes\(^{3,5,14,58,59}\). Carmalt et al. (2008) reported that excessive
haemorrhage accounted for approximately one third of complications. The source of excessive haemorrhage is presumably the testicular artery\textsuperscript{3,61-63}, and occurs due to ineffective crushing and/or ineffective ligation of the testicular artery. Excessive haemorrhage can also arise from the inadvertent laceration of a branch of the pudendal vein\textsuperscript{59}.

Embertson (2008) recommends leaving emasculators in place during crushing for 2-3 minutes and/or double ligation of the spermatic cord when employing suture to minimise the occurrence of this complication\textsuperscript{58}. Comino et al (2016) compared the leakage pressure of the testicular artery when applying a ligature, and compared the transfixing knot with the giant knot and rather than identifying a difference between the two knots types, they found that leakage pressure was higher when the castration was performed open regardless of suture pattern.

Packing the surgical site with sterile gauze may be effective for minor bleeding but is not usually appropriate for management of more substantial haemorrhage. It has been reported that anaesthesia of the horse to facilitate recumbent identification and ligation of the bleeding vessel or vessels is prudent with substantial haemorrhage as it is often difficult to effectively ligate the cord in the standing horse\textsuperscript{3,5,58,60}. Searle et al. (1999) suggests that in cases where ligation or emasculation of the cord is not possible, long forceps can be passed into the inguinal canal to clamp the bleeding vessel, and left for 12-24 hours to allow thrombosis to occur. An alternative approach in this situation is to pack the dead space created by the surgery with gauze swabs and suture them to the skin. The skin is then closed temporarily and the swabs removed 24 hours later\textsuperscript{58,64}. Improved outcomes in horses with haemoperitoneum that have been treated with aminocaproic acid have been reported\textsuperscript{65,66}; however evidence for the efficacy of the drug in controlling haemorrhage in horses, including after castration, is scarce. A number of recent case reports have also described laparoscopic cauterization of the testicular artery as a treatment for post castration haemorrhage\textsuperscript{62,63}. This is potentially promising as an alternative to the traditional treatment of locating and ligating the spermatic cord either standing or recumbent; however, neither group were able to locate the source of the haemorrhage via laparoscopy nor the
eventual treatment (ligation of the spermatic cord) could feasibly have been achieved if laparoscopic equipment was not available.

2.5.3 Sepsis

In studies of equine castration, sepsis is frequently reported as the second most common complication after excessive swelling\textsuperscript{6,14,20}. Rosanowski (2017) reported funiculitis as the second most common complication (behind swelling) at 36.7%. Funiculitis (inflammation of the spermatic cord) is usually a septic process\textsuperscript{3} and is thought to be the result of intraoperative contamination including the placement of a contaminated ligature, or can be extension of scrotal infection\textsuperscript{6,60}. Schumacher (1996) suggested that ligation of the spermatic cord increases the risk of septic funiculitis but Mason et al. (2005) found that standing non sutured castrations had significantly higher rates of sepsis than the recumbent sutured technique, although it is difficult to accurately interpret the significance of suture material in Mason’s study since it was not the only variable that differed between the sutured and non-sutured surgical groups. Chronic infection of the spermatic cord with \textit{Staphylococci}, also known as scirrhous cord, is treated via surgical resection of the infected and thickened cord, antimicrobial therapy and appropriate drainage\textsuperscript{3}. With the horse anaesthetised and in dorsal recumbency, blunt dissection is used to isolate the cord from healthy tissue, and the cord is re-emasculated proximally or ligated and transected. The wound is then left open to heal by second intention\textsuperscript{3,5,58}. A significantly lower infection rate amongst horses routinely treated with antimicrobials was identified along with a significantly higher infection rate and rate of excessive swelling in horses treated with hydrotherapy routinely\textsuperscript{6}. However, this finding may however be due to observational bias as the horses receiving hydrotherapy were likely being more closely observed. They also reported that only 3 of 560 respondents did not recommend some form of exercise regimen post castration. Embertson (2008) states that exercise creates movement of the tissues prolonging the opening of the tissues and facilitates drainage through the scrotal incisions\textsuperscript{58}. 
2.5.4 Hydrocoele

A hydrocoele can form months or years following castration and is a painless accumulation of fluid in the vaginal tunic\(^3\,\text{58}\). It often appears as fluid in the scrotum that can be digitally reduced into the abdominal cavity. Treatment is not necessary unless the swelling is so large it interferes with ambulation, or for aesthetic reasons. The scrotum can be incised, the tunic bluntly dissected and the vaginal tunic emasculated\(^3\). Moll et al (1995) reported a 0.26% occurrence of hydrocoele.

2.5.5 Evisceration

Evisceration or ‘eventration’ is a relatively rare but serious complication of castration with a reported long term (> 1 year) survival rate of 44%\(^5\,\text{52}\). Because the vaginal tunic is a continuation of the peritoneal cavity, there is potential for abdominal contents to travel through the inguinal canal into vaginal tunic within the scrotum. If this occurs post surgically when the scrotum has been incised, it can result in evisceration. It generally occurs within 4 hours of surgery but can occur up to 6 days following surgery\(^3\). The rate of evisceration has been reported similarly by a number of authors in the past and ranges from 0.2-2.96%\(^1,\text{6}\). A study of draught colts reported a much higher rate of small intestinal evisceration at 4.8%\(^6\,\text{7}\). The tissue that is involved in the evisceration is most commonly small intestine (67%) with the remainder made up with omentum (33%)\(^6\,\text{7}\). Torre et al (2013) presented the first documented case of post castration evisceration of small intestine through the femoral canal rather than the inguinal ring\(^6\,\text{8}\). The authors suggested that the breach in continuity between the peritoneum and abdominal fascia that is required for this problem to occur may be caused by rupture of the abdominal fascia during recovery from general anaesthesia.

2.5.6 Peritonitis

Mild transient peritonitis is a common sequel of routine castration, as the peritoneal cavity is opened during castration. However, septic peritonitis following castration is rare\(^5\). Schumacher et al. (1988) reported non-septic peritonitis as diagnosed by peritoneal fluid analysis in 15 of 24 horses\(^6\,\text{9}\). No signs other than fever were reported to have been present in these cases. Because of the often mild clinical signs that have been associated with non-septic peritonitis, it is possible
that it has been underreported in other studies which reported only 5 cases of peritonitis of 23,229 castrations\textsuperscript{6}, or other studies that did not attempt to capture peritonitis as a complication\textsuperscript{14,20}.

2.5.7 Penile damage
Penile damage is an uncommonly reported complication and usually occurs iatrogenically\textsuperscript{5}. Moll et al (1995) is the only study to have included investigation of this complication and reported penile damage in the form of paralysis in 1 out of 23,229 cases.

2.5.8 Continued masculine behaviour
Despite a main motivation for performing castration being the elimination of ‘stallion-like’ behaviours\textsuperscript{12,19}. Castration does not always abolish or prevent masculine behaviour in geldings\textsuperscript{3}. It was once believed that incomplete removal of epididymal tissue was the cause of unwanted behaviour in castrated horses and animals with persistent stallion-like behaviour were often referred to as having been ‘cut proud’ on the assumption that remaining epididymal tissue was responsible. However, epididymal tissue contains no cells capable of producing the androgens responsible for such behaviour\textsuperscript{5}. In cases where surgical error is to blame for continued stallion like behaviour, it is more likely that the incorrect structure may have been removed at the time of surgery. Given the considerable anatomical variation of the testis and associated structures, a large epididymis can be mistaken for a small testis and removed leaving the androgen producing testis behind. If an abdominal testis is left inadvertently in cases where the epididymis is descended but the testis is retained and the epididymis is mistaken for a small testis, androgen producing cells of the testis are still present\textsuperscript{5}. However surgical error may be overly ascribed as the cause of this post-operative frustration since up to 30% of castrated horses display stallion like behaviour regardless of whether they were castrated before or after puberty\textsuperscript{57}. Regardless of the suspected cause of persistent stallion-like behaviour if the castration history is obscure, hormonal testing, rectal palpation, and transabdominal and transrectal ultrasound can be employed to diagnose a retained testis\textsuperscript{3}.
2.6 Approach to Clinical Research

2.6.1 Evidence-based Surgery

The ultimate goal of evidence-based surgery is to improve surgical and perioperative care in order to achieve best outcomes for the patient\textsuperscript{70}. A number of past papers have employed clinical trials to investigate castration complications\textsuperscript{8,10}. While evidence-based surgery has made massive improvements in the last 50 years\textsuperscript{70}, it still lags behind the medical research field significantly\textsuperscript{71}, and collection of meaningful and constructive data in the field of surgery presents unique challenges compared with other medical research\textsuperscript{70}. Surgical innovations are complex and prone to rapid modifications in early stages of development\textsuperscript{72}, placebo controls are almost always unethical and therefore unfeasible in surgical investigations, and there can be marked variation in surgeon skill, both between surgeons and within an individual surgeon over time. As well as these factors there are often individual anaesthetist and surgeon preferences that may not be able to be controlled which make results difficult to compare.

For randomised controlled trials (RCT), clear and detailed reporting of the flow of participants through each stage is required for transparency and assessment of the validity and generalisability of the study findings\textsuperscript{73} and is best achieved by inclusion of a flow diagram (Figure 2.6.1). In general, the number of participants, assessment for eligibility, randomisation and allocation and number of participants included in analyses can be practically conserved. However, reasons for exclusion prior to randomisation, the number of participants who received the allocated intervention, were lost to follow up and those included in the main analysis are often less clearly recorded\textsuperscript{74}. Despite these limitations, randomized controlled trials (RCT) represent the most rigorous method for evaluation of surgical techniques\textsuperscript{75}. Even if a true controlled trial is not feasible, clinical trials are still of value to the literature and should be planned and run with the most rigorous adherence to the fundamental principles of RCT\textsuperscript{72}. As outlined by Diener et al. (2012), prior review of the literature is necessary to determine whether the research question has previously been answered. To achieve a meaningful contribution to the literature, sample sizes should be calculated. In addition, the protocol should be developed
in a transparent fashion, the trial should be centrally randomized to account for comorbidities, co-medications and individual variables between subjects.

The timing of randomisation is controversial as some authors suggest that it occur as close to the time of intervention as possible to reduce the chance of non-randomization due to preference cancellation or clinical events, while others suggest that early randomization is important as it gives patients the best chance of true randomization\textsuperscript{70}. Blinding in surgical trials is aimed at participants (owners) and assessors. Surgeons cannot be blinded, but the assessor should be blinded. In veterinary surgery as compared to human surgery, blinding of the patient is not necessary as patient interpretation and experience cannot be measured. Overall, Diener et al. (2012) proposed that in surgical trials, the researcher should aim to blind as many involved individuals as possible. Standardisation of surgical care including the protocol, and perioperative treatments is imperative. Variations in surgical skills, learning curve, surgeon and anaesthetist preferences should be analysed (if not able to be controlled) to search for significant effects on results.

\textit{Figure 2.6.1 CONSORT flow diagram from Schultz et al 2010 available at} \url{http://www.consort-statement.org/consort-2010}
2.6.2 Subjective Measures and Observations

In veterinary research, it is common and often necessary to employ observational grading scales of clinical information that are inherently subjective. It has been stated that these types of data are prone to misreporting and misinterpretation in the literature leading to unjustified conclusions by the authors\(^7\). However, they are important in veterinary clinical research and can form a valuable aspect of the research if it is analysed and interpreted correctly.

Subjective grading scales are commonly employed in veterinary research to evaluate the degree of severity of clinical findings. Previous equine castration investigations have employed one or more ordinal scales to grade complications in terms of interventions required for complications\(^6\), when complications occurred and what interventions were required\(^14\), mild, moderate and severe swelling, colic, suture dehiscence, respiratory infection, fever, seroma and haematoma\(^19,20\). The complications in Mason et al (2005) were identified by billing records and defined by the level of intervention required\(^14\).

In order to avoid collecting and presenting misleading data when using clinical grading systems, and to present meaningful and useful data using subjective scales, one must firstly assess the grading system appropriately, and second, apply appropriate data presentation and analysis.

In assigning grading systems, the data must be identified as either nominal or ordinal (quantitative or qualitative). This is a fundamental point of confusion among collectors of data and those receiving results as data presented in the form of a numbered grading system can often be subjectively assigned, non-linear or continuous data that has been arbitrarily assigned a number on a scale. Though these scales may have been devised by consensus and are considered ‘official’ such as the Havermeyer laryngeal function scale or the AAEP lameness scale, these scales are still inherently subjective in nature. The limitation with these data is that the interval between each grading scale is arbitrary in terms of its clinical meaning.
Boden (2011) suggests that in order for clinical grading scales to be useful, the grades within the system must be objectively assigned, the system must be independently measured for intra- and inter-observer repeatability and validated with respect to a particular clinical outcome. These requirements for grading scales can be achieved via appropriate data analysis.

2.6.3 Questionnaires and Surveys

2.6.3.1 General use of surveys in research

Surveys have been used to capture information on surgeon perspectives in both human and veterinary medicine\textsuperscript{77-80}. A properly designed and implemented survey can be a powerful tool for the quantification of the distribution of different characteristics of a population from only a small percentage of the wider population\textsuperscript{81}.

Past authors have employed survey studies to capture practices relating to veterinary castration and its post-operative complications\textsuperscript{6,12,16,20,82}. Dillman (1991) outlines a framework to neutralise the pitfalls of survey research that are namely non-coverage error that arises when members of a population are not covered by the sampling frame. A non-coverage error may occur if a survey samples members of a certain professional society that not all members of the population are a part of and therefore not represented in the results thus skewing the representation of a population. A non-response error may also skew the results of a survey if too small a response rate is gained therefore not being representative of the target population, or if significant sections of the population have a low response rate changing their representation. Measurement error can be minimized by providing the best opportunity for the survey questions to be answered correctly, through intuitive and robust question design, and ease of experience for the respondent. Schleyer and Forrest (2000) note that internet based surveys allow researchers to contact sample individuals with minimal time and in geographic populations that are often rare and dispersed.
2.7 Conclusion

The options available to the equine clinician for the castration of horses continues to increase in number. As is often the case with any veterinary procedure or treatment, this reflects the fact that no gold standard methods for the surgical procedure or the associated perioperative protocols have been determined. Due to frequency with which this procedure is performed at all levels of equine practice, and the substantial number of commonly occurring complications after castration, ranging from inconvenient to immediately life threatening, further research of castration techniques, outcomes and risk factors for complications is required, with the goals of improved welfare outcomes for patients and financial outcomes for owners.

The Henderson castrating instrument represents a castration method that is simple to perform, has low establishment costs and very little specialised equipment or training required, which makes the method attractive and applicable to clinicians of all types of practice. The results of recent studies suggest that it has potential to become a safe alternative to emasculator castrations with similar rates of complications\textsuperscript{47}.

The surgical emasculator remains the industry standard for castration. While the majority of previous studies have assessed complication rates of castrations through the use of this instrument, much remains uncertain about best practice in terms of emasculator variant, technique, approach, and perioperative protocols. Efforts are required to provide the veterinary profession with improved understanding and knowledge of approaches to castration in horses, with a goal of achieving consensus on what constitutes best practice for equine castration for evidence-based decision making. Improvements may be reflected by introduction of new methods, scientific assessment of new and current methods in terms of surgical outcomes and determination of factors that may increase the risk of post-castration complications in horses.
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Chapter 3: A survey of equine castration techniques, preferences and outcomes among Australian veterinarians

Appendix 1 [Equine castration complications: a brief review of the rate and type of complications (Owens et al 2015)] is located at the end of this thesis. It was used to provide awareness of the upcoming questionnaire to Australian veterinarians which was used to collect data for chapter 3.

The questionnaire is located at the end of the thesis in appendix 2.
Chapter 4: A prospective study comparing the outcomes of horses undergoing castration using either the Henderson castrating instrument or emasculators

Manuscript prepared in preparation for submission to Equine Veterinary Journal
A prospective study comparing the outcomes of horses undergoing castration using either the Henderson castrating instrument or emasculators

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4.1 Abstract

**Objective** To compare intra-operative and post-operative outcomes in horses castrated using a surgical emasculator technique or the Henderson castrating instrument.

**Study Design** Prospective cohort study

**Methods** One Hundred and eighty client owned horses were randomly assigned to castration by either emasculator or the Henderson castrating instrument. Post-operative complications before discharge from the hospital or in the immediate post-operative period at the property where the animals were kept were recorded. Post-operative photographs of the surgical site were taken at 24 hours and scored by two blinded observers using an ordinal grading scale. Clients of each horse were contacted by telephone 7, 14, 28 and 84 days after castration and asked questions about complications.

**Results** Ninety-four castrations were done using emasculators and 86 using the Henderson instrument. There were 15 breeds represented. Anaesthetic time and surgery time were both significantly shorter for horses castrated via the Henderson method (P <0.001). The median (range) surgical and anaesthetic times for the Henderson method were 15 (7-35) minutes and 27 (11-82) minutes respectively, while the median (range) surgical and anaesthetic times for the traditional method were 25 (10-60) minutes and 44.5 (15-87) minutes, respectively. Surgical technique was not associated with development of post-operative or post-discharge complications in castrated horses, with the exception of a significant association at the univariate level between tissue eversion from the surgical site and use of the Henderson instrument. For development of any complication after castration, location (field/operative theatre) was retained in the multivariable model (OR = 2.69, P = 0.008). In the multivariable models for complications in the post-operative period, body weight (OR = 1.01, P = 0.001) was retained for any complication and weight (OR = 1.02, P = 0.009) and surgery time (OR = 1.07, P = 0.048) were retained for post-operative swelling. In the multivariable models for complications in the period after discharge from hospital, anaesthetic maintenance (gaseous/TIVA) (OR = 0.21, P = 0.015) and swelling post-discharge (OR = 8.45, P = 0.002) were retained for development of haemorrhage and any post-operative complication (OR = 8.14, P <0.001) and haemorrhage after
discharge from hospital (OR = 9.51, P = 0.001) were retained for development of swelling. The rates of complications across both methods were swelling (56%), haemorrhage (5.3%), tissue hanging from the incision (3.3%), infection (1%), and evisceration (0.55%) with an overall complication rate of 84%.

**Main Limitations:** Post-discharge complication information relied on owner observations and risk of recall bias. Risk of confounding bias during analyses.

**Conclusion:** Horses castrated with the Henderson castrating instrument had similar rates and types of complications as previously reported for emasculator complications.

**Keywords:** equine; complications; post-operative

4.2 Introduction

Castration of horses is performed in all types of equine practice yet post-operative complications are common, and range from problems such as swelling, infection, seroma formation, peritonitis, inadvertent penile damage, hydrocele formation, and continued stallion-like behaviour, to those that are immediately life-threatening, including evisceration and major haemorrhage. The reported prevalence of complications after castration is most often between 7-37.7%2,6,14,20,83, although a recent study of open castration in standing horses reported 60% of horses developed complications7. Post-operative complications not only have welfare implications for the patient but can come at considerable financial cost to the owner and veterinarian4,14. The ‘traditional’ mainstay of equine castration has been the emasculator. The emasculator is essentially a large haemostat that crushes the spermatic cord and associated vessels with a variable blade configuration. The most common types are the Serra which has a blade that automatically cuts as the cord is crushed, the Reimer that has a separate lever to engage the blade by the surgeon, and the White’s improved which does not contain a blade, meaning the surgeon must use a separate scalpel or scissors to remove the testis from the body6.
Wide variation in surgical technique and perioperative preferences has been reported among veterinarians using emasculators\(^6,12\) and numerous studies have sought to associate technique with complications in an effort to improve outcomes. These studies have sometimes reported conflicting results as to the gold standard emasculator type\(^6\), approach\(^{19,43}\), use of ligature on the spermatic cord\(^8,15\), use of local anaesthetic\(^{10}\), patient position (standing or recumbent)\(^{14}\), use of peri-operative antimicrobials\(^6\) and/or anti-inflammatory drugs\(^84\), whether to perform the surgery closed, open, or semi closed\(^6,20\), and whether to perform primary closure of the skin\(^{39,40}\).

The development of the Henderson instrument\(^{17}\) has introduced a unique method of castration that can be used on horses. The plier-like jaws of the Henderson instrument are applied to the spermatic cord that is still enclosed within the vaginal tunic. The handle of the instrument is then attached to a battery-operated, variable speed drill and the instrument is rotated until rupture of the cord occurs, achieving removal of the testis and distal portion of the spermatic cord\(^{22}\). Haemostasis is achieved by sealing of vessels by torsion of the vaginal tunic and spermatic cord, as opposed to the crushing action of emasculators. Ligation of the spermatic cord with suture material is not possible after use of the Henderson instrument. Initial reports have suggested that castration using the Henderson instrument is faster than castration using emasculators, and that it carries fewer and less serious complications\(^{22,85}\). A recent retrospective study of 252 horses castrated using the Henderson instrument reported an overall complication rate of 10.7%, but found that complications were more likely to occur in horses over 4 years old, suggesting that factors in addition to surgical technique may influence the development of complications after castration.

Some clinicians have expressed reservations about the instrument and anecdotally, the use of the Henderson instrument has been associated with higher rates of evisceration after castration\(^83\). Despite these observations, a recent retrospective study of castrations performed using the Henderson instrument showed no association between the Henderson castrating instrument and evisceration. However, a randomised comparison of outcomes of castration using emasculators or the Henderson instrument has not been reported previously. The
objectives of this study were to (1) compare intra-operative and post-operative outcomes in horses castrated using an emasculator protocol with horses castrated using the Henderson castrating instrument and (2) determine risk factors for complications, in a prospective cohort study. We hypothesised that the Henderson castration technique would be associated with fewer complications than emasculcation and that important post-operative complications would be associated with specific risk factors.

4.3 Materials and Methods

4.3.1 Study Design

A sample size calculation, based on power of 80%, α value of 0.05 and detection of a 10% difference in complication rates between the two surgical methods, returned a required sample size of 180 horses (90 horses per group). Horses of any breed or age that had normal cardinal parameters and both testes descended in the scrotum and without concurrent scrotal or preputial injuries were included in the study. Horses that were febrile or had abnormal testis, scrotal or preputial injuries, were excluded from the study. Each horse recruited to the study was randomly allocated to one of the two treatment groups (Henderson group, emasculator group) at the time of surgery using an Excel random number generator. All horses were client-owned and patients of the Veterinary Clinical Centre, Charles Sturt University. The study was approved by the Charles Sturt University Animal Ethics Committee (Protocol No. 13/005).

4.3.2 Preoperative Protocol

Physical examination findings, including heart rate, respiratory rate, rectal temperature and gingival colour, capillary refill time, abdominal auscultation and scrotal palpation, signalment (age and breed), body weight, and any comorbidities were recorded for each horse. Thirty to 60 minutes before surgery, all horses were given tetanus toxoid (1 mL i.m.), phenylbutazone (2.2 mg/kg bwt i.v.) and procaine penicillin (22 mg/kg bwt i.m.). Horses were usually discharged from the hospital 24 hours after surgery. Post-operatively, the horses were treated with phenylbutazone (2.2 mg/kg bwt p.o. BID) and procaine penicillin (22 mg/kg bwt i.m. BID) for 3 days.
4.3.3 Anaesthetic protocol
Anaesthetic protocols were at the discretion of the faculty anaesthetist and were in three groups: total intravenous anaesthesia (TIVA), gaseous anaesthesia using isoflurane, or desflurane administered under positive pressure ventilation. Horses were premedicated with acepromazine (0.02mg/kg bwt i.v.) and general anaesthesia was induced by administration of a combination of xylazine (1.0 mg/kg bwt i.v.) and ketamine (2.2 mg/kg bwt). Intraoperative crystalloid fluids (Hartmanns solution) and dobutamine (0.5-20ug/kg bwt/min) were administered, as required, to maintain mean blood pressure above 70mmHg. All other anaesthetic treatments and development of any complications were recorded.

4.3.4 Surgical protocols
After induction, the horses were positioned in dorsal recumbency, and the inguinal region and scrotum were surgically prepared with chlorhexidine and alcohol solutions. The hind limbs and surgical site were drapped routinely. Surgery was performed by a veterinarian (faculty clinician or resident) and a final year veterinary student. In all horses, two skin incisions approximately 8-10 cm long were made parallel and 1-2 cm either side of the median raphe. Horses then underwent one of the two castration methods depending on the random allocation.

4.3.5 Emasculator group
The skin incision was continued through the subcutaneous tissue and vaginal tunic to expose the testis, epididymis and spermatic cord and 15millilitres of 2% lignocaine was injected into the body of each testis and directed towards the spermatic cord.

The ligament of the tail of the epididymis was identified at the attachment to the vaginal tunic, and a haemostat was applied across the tunic and the ligament was transected. The spermatic cord was identified and 2 large Carmalt forceps were applied transversely across the cord, followed by application of Reimer emasculators to the cord distal to the Carmalt forceps. A single transfixing ligature using USP 2 polydioxanone material was tied into the crush in the cord made by the most proximal clamp. Once securely ligated, the blade handle of the Reimer emasculators
was engaged and the testis was removed. The remaining Carmalt forceps and emasculator were removed from the spermatic cord. The cord was checked for haemorrhage prior to replacement within the tunica. The subcutaneous tissue surrounding the tunic and cremaster muscle was then checked for haemorrhage. Any redundant fat or subcutaneous tissue protruding from the incision was removed using Metzenbaum scissors.

4.3.6 Henderson group

The skin incision was continued through the subcutaneous tissue but not through the vaginal tunic of the testis. Fifteen millilitres of 2% lignocaine was injected into the body of the testis directed towards the spermatic cord. Scrotal fascia was stripped in a proximal direction from the exteriorised testis using a dry gauze surgical swab. The Henderson castrating instrument was attached to a variable speed cordless drill (Hitachi DS 18DFL). The jaws of the Henderson instrument were clamped across the spermatic cord just proximal to the testis. The tip of the instrument was placed inside the scrotal skin incision in a distal to proximal orientation, aligned with the spermatic cord. The drill was engaged, rotating the clamp at a slow to moderate speed in a clockwise direction with no tension applied until the cord ruptured allowing removal of the testes and distal portion of the cord.

For all horses, intra-operative surgical findings recorded were primary surgeon, anaesthetic type, duration of anaesthesia, duration of surgery, concurrent procedures in the same anaesthetic, location (theatre or field), anaesthetist, intra-operative complications and treatments.

4.3.7 Post-operative protocol

At the end of surgery, horses were recovered either in the hospital recovery room or on grass if the procedure was done in the field. Post-operative photographs of the surgical site were taken the following day before discharge from the hospital (approximately 24 hours following surgery) or at the property where the castration was done. Any post-operative complications and the treatments required before discharge from the hospital or in the immediate post-operative period at the property where the animals were kept were recorded. The 24 hours post-operative
photographs of the surgical site were scored by two blinded observers (BH, GT) using an ordinal scale (0: no visible swelling, 1: swelling is restricted to scrotal incisions and/or there is eversion of incisions, 2: swelling of incisions AND of scrotum OR prepuce, 3: swelling of incision AND of scrotum AND prepuce, 4: swelling of incision, scrotum, prepuce and distortion of anatomy). Observers also noted any evidence of haemorrhage, purulent discharge or tissue hanging from the incision. Both observers were blinded to the identity of the horses for all photographs and scoring of the photographs was undertaken a minimum of 6 weeks after completion of the surgical component of the study. For all horses, any post-operative complications (swelling, haemorrhage, evisceration, tissue hanging from the incision site, fever, colic, penile damage) and treatments prior to discharge (in the first 24 hours following surgery) were recorded.

4.3.8 Follow-up

Clients of each horse were contacted by telephone 7, 14, 28 and 84 days after the castration procedure and asked questions about the presence, severity and treatments of any swelling, haemorrhage, infection, evisceration, inappetence, fever, abdominal pain, stallion-like behaviour, or any other comments or observations. Questions were a combination of multiple choice, interval scale and open-ended questions, with the opportunity to provide additional comments if necessary. The follow-up phone questionnaire used when contacting owners to determine the development of post-operative complications is provided in Appendix 3.

4.3.9 Data Analysis

After checking the data for errors, descriptive statistics were performed using Microsoft Excel (2013). For continuous data, median and range were calculated. Comparisons between the two surgery groups were performed for age, breed, body weight, surgeon, anaesthetist, anaesthetic maintenance method, presence of co-morbidities and surgery location. For categorical variables, Pearson’s Chi-square test or Fisher’s exact test was used, while for continuous variables, the Mann-Whitney test was used as data were non-normally-distributed (Shapiro-Wilk test). For each period (post-operative [<24 hours after surgery], post-discharge [≤ 3 months after surgery] and both [post-operative and post-discharge]) and for each complication category (any,
haemorrhage, swelling, fever, infection, surgery site tissue eversion), potential associations with explanatory variables were assessed by use of univariate analyses: for categorical variables, Pearson’s Chi-square test or Fisher’s exact test was used, while for continuous variables, univariate logistic regression was performed. All complications were considered as binary (yes/no) outcome variables. Variables with P<0.2 were included in multivariable logistic regression models with backwards elimination of the least significant variables until only variables with P≤0.05 remained. Plausible and clinically-relevant two-way interactions between variables were considered in each model. Agreement between observers for rating of surgical site appearance was assessed using the Spearman rank coefficient and the weighted Cohen Kappa statistic. All analyses were performed in R (version 3.4.2) and significance was set at P≤0.05.

4.4 Results
4.4.1 Demographics
Of the 213 horses castrated by the Veterinary Clinical Centre between 04/02/13 and 12/06/15, 180 were eligible based on inclusion criteria and owner consent. Of 180 castrations performed, 94 were done using emasculators and 86 were done using the Henderson instrument. There were 15 breeds represented, the most common being Standardbreds (56/180; 31%), polo horses (42/180; 23%), and Thoroughbreds (26/180; 14%) (Table 4.4.1.1). The median age was 13 months (range: 6 weeks to 6 years). There were 7 surgeons, with one surgeon (CO) performing the majority of the surgeries (121/180; 67%). Anaesthesia was performed by Faculty anaesthetist staff, or students under the supervision of veterinarians when castrations were performed in the field.

There were no significant differences in horse age, weight or breed, anaesthetist, surgeon, or anaesthetic protocol between the Henderson and emasculator groups. A significantly higher proportion of emasculator castrations than Henderson castrations were performed in a theatre (P = 0.02), and significantly more Henderson castrations were performed with final year veterinary students administering anaesthesia (as compared to anaesthetist staff) (P = 0.035).
Anaesthetic time and surgery time were both significantly shorter for horses castrated via the Henderson method (P <0.001). The median (range) surgical and anaesthetic times for the Henderson method were 15 (7-35) minutes and 27 (11-82) minutes respectively, while the median (range) surgical and anaesthetic times for the traditional method were 25 (10-60) minutes and 44.5 (15-87) minutes, respectively.

Four horses had comorbidities for which other surgical procedures were performed at the same time: removal of a fractured incisor (n=1), surgical repair of an umbilical hernia (n=1), interdental wiring to repair a fracture of the rostral mandible (n=1) and laryngoplasty and ventriculocordectomy for treatment of left recurrent laryngeal neuropathy (n=1).

Thirteen horses were discharge from the hospital before 24 hours (on the day of the surgery) and no photos of the surgical sites were taken. For the 167 horses from which photos of the surgical sites were obtained, there was significant correlation between observer rating scores of surgical site appearance (Spearman rank correlation coefficient: 0.714, P <0.001). The weighted Cohen Kappa statistic (0.61, 95% confidence interval: 0.42-0.79) represented fair to good agreement between raters.

4.4.2 Complications

The rates of complications were swelling (56% 101/180), haemorrhage (5.3% 10/180), tissue hanging from the incision (3.3% 6/180) infection (1% 2/180), evisceration (0.55% 1/180), and overall (84% 151/180). Results of the univariate analyses for associations between explanatory variables and post-operative complications and post-discharge complications are presented in Tables 4.4.2.1 and 4.4.2.2, respectively. Castrations performed using the Henderson method were significantly more likely to have the post-operative complication of connective tissue hanging from the incision (P = 0.05) and tissue hanging from the incision including evisceration (P = 0.023). Technique was not associated with development of any other complication, post-operatively or post-discharge. In the post-operative period, univariate analyses revealed that animal age, bodyweight, anaesthetic time and surgery time were most frequently associated with
development of complications (P < 0.2) (Table 4.4.3.1). Increases in age, bodyweight and surgery times were significantly associated with development of any post-operative complication and post-operative swelling (P < 0.05). Horses that experienced intraoperative anaesthetic or surgical complications were more likely to exhibit post-operative complications.

Horses were significantly more likely to be treated for post-operative complications if they experienced haemorrhage (P < 0.001), tissue eversion (P < 0.001) or evisceration (P < 0.001), but not surgical site swelling. In the multivariable models, body weight was retained for development of any complication (odds ratio [OR] = 1.01, P = 0.001), body weight (OR = 1.02, P = 0.009) and surgery time (OR = 1.07, P = 0.048) were retained for post-operative swelling and treatment for post-operative complications (i.e. in addition to the standard perioperative treatment protocol) was retained for both haemorrhage (OR = 51.0, P < 0.001) and tissue eversion (including evisceration) (OR = 1.71, P < 0.001) (Table 4.3.3).

In the post-discharge period, several factors were associated with development of complications, determined by univariate analyses (Table 4.3.2). For the development of any complication, anaesthetist (student/staff) (OR = 0.33, P = 0.017) and any post-operative complication (OR = 9.17, P < 0.001) were retained in the multivariable model. For the development of haemorrhage, anaesthetic maintenance type (Gaseous/TIVA) (OR = 0.21, P = 0.015) and swelling (OR = 8.45, P = 0.002) were retained in the final multivariable model, while for swelling, any post-operative complication (OR = 8.14, P < 0.001) and post-discharge haemorrhage (OR = 9.51. P = 0.001) were retained in the final multivariable model (Table 4.3.4).

When the development of any complication, irrespective of timing (post-operative and post-discharge) was considered, univariate analyses revealed several factors associated with the outcome (Table 4.3.2). In the final multivariable model, only location (field/operative theatre) was retained as significantly associated with development of a complication after castration (OR = 2.69, P = 0.008) (Table 4.3.4).
4.5 Discussion

This prospective cohort study reported on 94 emasculator castrations and 86 Henderson instrument castrations and is the first study to compare outcomes between the two castration techniques. While there were no significant differences in complication rates between the two castration techniques, several factors were found to be significantly associated with development of complications in horses undergoing castration. These results contribute to the understanding of the outcomes of castration techniques in horses and may contribute to evidence-based approaches to equine castration and communication with horse owners.

The overall complication rate for this study for both techniques combined was 84%. When divided, the overall complication rate for emasculator castrations was 85.2%, and 83.3% for Henderson instrument castrations. There was no significant difference between the rate of complications for each instrument. While these are much higher overall complication rates than previously reported, this is the first prospective cohort study of its kind and the strict observation and characterisation of any of post-operative complications including mild swelling may explain the much higher overall rate of complications compared to previous studies.

In our study, use of the Henderson instrument resulted in significantly shorter surgery and anaesthesia times in comparison to the emasculator technique. It is well known that increased surgical times are associated with increased risk of complications. One aspect of our emasculator protocol was the placement of a transfixation ligature, which would increase the surgical time. In addition, the time required for adequate crush of the cord and initial haemostasis would result in longer surgical and anaesthetic times, compared to the Henderson technique. Once attached to the cord, the Henderson instrument takes only a number of seconds to remove the testis when rotated at a moderate speed. Although post-operative swelling was more likely with increasing surgical time in this study, there was no statistically significant association between the slower emasculator method and post-operative swelling or other complication types. Although no horse developed neuromuscular complications in this study, prolonged recumbency is a reported risk factor for post-operative myopathy and neuropathies.
and prolonged castration times, particularly in field settings, should be avoided to minimise adverse patient outcomes. In addition, horses that experienced intraoperative anaesthetic or surgical complications were more likely to exhibit post-operative complications (P = 0.012), emphasising the importance of good surgical planning, efficient use of surgical time and minimising of preventable intraoperative complications.

In our study, rates of complications were not significantly different between the Henderson and the emasculator techniques. While several studies have described complication types and rate of occurrence after emasculator castration\textsuperscript{2-4,6} (including swelling, haemorrhage, evisceration, infection, fever, peritonitis, hydrocele and scirrhous cord formation), there are few reports of complications associated with the Henderson technique in horses. In one study, the Henderson instrument was reported to be associated with almost no complications and no post-operative swelling, leading the authors to conclude that the technique may be associated with lower risk of complications compared to emasculator techniques\textsuperscript{22}. Conversely, other authors have reported concern among clinicians that the Henderson instrument can be associated with an increased rate of evisceration compared with emasculator castrations\textsuperscript{83}. In this study we found that the rate of swelling was 56%, haemorrhage was 5.3%, tissue hanging from the incision was 3.3%, infection was 1%, and evisceration was 0.55%. The overall complication rate for the Henderson instrument in our study was 84% which is much higher than a recent retrospective of 252 Henderson castrations which reported an overall complication rate of 10.7%\textsuperscript{47}. In the current study, univariate analysis revealed that castration using the Henderson instrument was more likely to be associated with the outcome of connective tissue hanging from the wound (P = 0.05) and tissue hanging from the wound including evisceration (P = 0.023) in comparison to the emasculator technique. While castration technique was not retained in the final multivariable model, the method of castration and possible association with complications warrants consideration and further investigation. While unproven, it is possible that the twisted tissues from the action of the Henderson instrument may be prone to untwisting of the cord and tunic remnants potentially leading to these tissues hanging from the wound, or evisceration.
In the current study, the likelihood of complications overall, and specifically swelling, increased as the horse increased in age and increased in weight. This finding is similar to a recent retrospective study\textsuperscript{47}, where the odds of a post-operative complication was greater in horses of 4 years of age or greater, compared to younger animals. It is possible that the effects of age and weight are inter-related, namely that weight increases as the horse ages in years until it reaches adulthood. As an animal ages and grows in size, there is greater tissue mass, larger testis and associated vasculature and possibly enlargement of other important structures, including the inguinal rings. It follows that the rate of complications, especially swelling increase as the horse ages. Further, greater age and/or bodyweight may also influence perturbations to local fluid shifts and tissue fluid homeostasis, with greater risk of local fluid accumulation and postoperative swelling. The findings in the current and previous study\textsuperscript{47} may suggest that castration of horses at an earlier age may be advantageous as the odds of complications is reduced.

In the horses of the current study, the overall rate of swelling was 56%, with similar rates between the Henderson technique (52%) and emasculator (60%). This rate of swelling is notably higher than in several previous studies\textsuperscript{6,7,14,83}; however, in one recently reported study, 70% of horses developed swelling following castration using a standing open method\textsuperscript{7}. One possible explanation for high rates of swelling in both the current study and that of Rosanowski et al. (2018) is that unlike previous studies, the observation of complications was prospective, and not reliant on retrospective records. In the current study, photographs of the surgical area were collected 24 hours following surgery for review at a later time, and a standard assessment protocol was followed while the horses were in the hospital. When the documented complications in our study were divided into post-operative (pre-discharge), and post-discharge (phone follow up) and were assessed alone, the rates of complications were different.

Kilcoyne et al (2013) reported that swelling developed 2-8 days post-surgery with a mean onset of 5.6 days. This is consistent with previous reports that swelling usually peaks at 3 to 6 days after surgery and subsides at 9 days after surgery\textsuperscript{3,20,59,60}. Horses in this study were discharged from hospital at 24 hours to 3 days post-surgery: as such, a higher rate of swelling was expected from
the follow-up phone responses than observed in the pre-discharge observations. However, contrary to these assumptions, the follow up phone responses reported lower swelling than for pre-discharge. This unexpected finding may be due to a combination of recall bias, and tendency to under-report minor complications (in comparison to immediately life-threatening complications) such as mild to moderate swelling, mild incisional haemorrhage or a small amount of connective tissue hanging from the surgical incision. In addition, detection of post-operative swelling (prior to discharge) was likely maximised due to the prospective nature of the study. When the follow up phone responses were separated from the pre-discharge observations, the reported rate of swelling, (the majority of which occurred at 0-3 days after surgery) was 30% for Henderson castrations and 37% emasculator castrations which are similar to a previous large retrospective study reporting a 25% swelling rate post operatively.20

The overall rate of haemorrhage was 5.3%, which is within the range of previously reported studies of equine castration6,20,83. There was no significant difference in the rate of haemorrhage between the two techniques. Similarly, evisceration was not related to either technique. There was only one incident of evisceration in the study of 180 horses (0.56%): similar rates of this life-threatening complication have been reported previously6,20,47. In this study, evisceration occurred in a castration performed with the Henderson instrument, which has been reported previously47; however, it must be recognised that this represents neither a significant difference between the two techniques, nor a rate of evisceration that is any higher than previously reported for any emasculator castrations (0.3-4.8% evisceration)20,47,60,67. While the a priori sample size calculation performed for this study was sufficient to provide 80% power to enable the detection of a 10% difference between complication rates in techniques with 95% certainty, it must be acknowledged that a much larger sample size beyond the scope of this study may uncover associations between castration technique and evisceration. Both haemorrhage and tissue hanging from the incision site were significantly associated with administration of post-operative treatment beyond the standard perioperative treatment protocol which indicates the potential severity of these complications and requirement for targeted treatment at the discretion of the attending clinician.
Previously, breed has been reported as a risk factor for complications with one recent paper citing breeds other than Thoroughbreds being at increased risk of complications. In our study at the univariate level, surgical site swelling was significantly associated with breed (P=0.022) and was more likely in warmbloods, Arabians and Clydesdales compared to polo horses, ponies, Thoroughbreds and Standardbreds. However, this association was lost at the multivariable level.

Higher rates of evisceration have been associated with Standardbreds and Draught breeds in past studies, however no such link was found in our study, which is keeping with a large retrospective published in 2013. In the current study, there were 8 Clydesdales and 56 Standardbreds and none of these horses developed evisceration. The one horse that did develop evisceration was a Thoroughbred which has traditionally not been associated with increased likelihood of this complication. This episode of evisceration in one horse resulted in a rate of 0.55% overall, or amongst the Henderson castrations, 1.2%. Both of these rates consistent with, or lower than rates in previously reported studies. The low rate of evisceration in our study may have also been influenced by use of ligation which has been reported to reduce the likelihood of evisceration after closed castration. While some authors suggest ligation is associated with increased risk of infection due to foreign body placement, low rate of infection in horses that underwent ligation of the vaginal tunic were found in study by Carmalt et al (2008) (0.76%) and the current study (1.1%). Furthermore, a recent large retrospective found ligation was not associated with the development of complications. As such, ligation may be a beneficial component of emasculator castration technique in horses.

A counterintuitive finding from the current study was that complications of any kind were 2.7 times more likely when castration was performed in an operating theatre. This is mostly likely a reflection of observation bias, as any horses castrated in the field were housed at owner properties rather than the hospital, where they may have been more closely observed. Similarly, odds of haemorrhage post-discharge were 5 times less likely with TIVA compared to gaseous maintenance. While physiological parameters and recovery differences may be implicated in this finding, it is much more likely that since the gaseous anaesthetics were largely done in the theatre, and TIVA was exclusively used for field castrations, the issue of observation bias would
be most likely to explain this difference. Interestingly, a previous study that compared field and theatre castrations reported complication rates of 22% in the field and 6% in the theatre. While this appears contrary to our findings, that study compared standing non-sutured castrations (field) with recumbent sutured and primary closure castrations (theatre), while all of the castrations in the current study were recumbent. As well as this, the findings of that study are consistent with recent evidence that standing castration can be associated with increased risk/numbers of complications, including 70% scrotal swelling, 24/7% seroma and 36.7% funiculitis.

In our study, a greater number of emasculator castrations were performed in a surgical theatre and a greater number of Henderson castrations were anesthetised by students: these findings may have influenced the likelihood of complications. Given that surgical facilities provide cleaner and more controlled surgical environments compared to field settings, and that less experienced operators (i.e. veterinary students) may make more mistakes in anaesthesia, it is possible that there was a bias towards increased and decreased rates of complications for the Henderson method and emasculator technique, respectively, in the current study. Conversely, observational bias may have increased the sensitivity for detection of post-operative complications in theatre castrations compared to field castrations, and given that there were significantly more Henderson castrations done in the field setting, it is possible that Henderson complications were underreported.

In this study, there was a relationship between the development of haemorrhage and swelling at the surgical site after horses were discharged from hospital (i.e. >24 hours post-operatively). The odds of a horse developing haemorrhage or swelling were 8-fold higher if another complication was present. This finding is not unexpected and suggests that surgical trauma to the scrotum and surrounding tissues may predispose to both altered haemostasis and accumulation of interstitial fluid, resulting in oedema. As such, this finding emphasises that minimisation of surgical trauma through adherence to sound principles of tissue handling are imperative during castration of horses.
One surprising finding was that despite a wide range of surgeon experience, including some castrations performed by students, the surgeon was not associated with development of complications. This was consistent with the findings of a previous paper\textsuperscript{14}, and may be explained not only by the fact that the procedure itself is a relatively simple one, but also that in our study, all inexperienced surgeons (students and interns) were heavily supervised and directed by an experienced surgeon.

A significant gap in the literature is the effect of post-operative protocols on outcomes. In order to minimize the number of variables in this study, these measures were not able to be examined, as a standardised peri-operative protocol was administered to every horse. All horses were treated with a standard peri- and post-operative antimicrobial and anti-inflammatory protocols. While significantly lower infection rates in animals administered antimicrobials was reported in a survey study of post-castration complications\textsuperscript{6} and botulism after castration has been reported\textsuperscript{7}, in another study, neither antimicrobial nor nonsteroidal anti-inflammatory drug treatment was significantly associated with development of complications\textsuperscript{3}. Similarly, in this study, all horses had intra-testicular lignocaine which has previously been shown to improve analgesia, reduce the number of anaesthesia top-ups and reduce post-operative pain and cytokine levels\textsuperscript{10,51,87}. As such, it was beyond the scope of this study to determine the potential beneficial or deleterious effects of lignocaine use. However, a recent past retrospective found that lignocaine was not associated with complication development including haemorrhage, swelling or infection\textsuperscript{20}.

A limitation of this study is that in order to gather information on outcomes following discharge from the hospital, it was necessary to use phone interviews with owners and trainers which relied on the recall of non-trained personnel in non-controlled environments, increasing the risk of recall bias. We sought to minimise these factors by developing and a standardised telephone survey (Supplementary Item) which was validated in a pilot study to ensure clarity and repeatability of questions. Despite these measures, it is likely that non-quantifiable under-
reporting of complications occurred; however, it is far less likely that severe complications (marked swelling, infection) and immediately life threatening complications, including marked haemorrhage and evisceration, would have been under-reported. Further, information bias may have occurred given the possibility of errors in classification of the post-operative or post-discharge complications. Given the study design, there was also a risk of confounding bias, where mixing of the effects of two or more factors may have occurred, resulting in observed observations of associations between an exposure factor and an outcome includes the effects of one or more extraneous factors. In our study, the likelihood of confounding was minimised through careful consideration of possible confounders and exposures for the outcomes of interest that were taken into account with the multivariable analyses used. One unexpected outcome that arose from this study was that significantly more emasculator castrations were performed in a theatre compared to Henderson castrations. Consequently, significantly more Henderson castrations were performed with final year veterinary students administering anaesthesia (as compared to anaesthetist staff), because castrations performed in the field were anaesthetised by veterinary students in keeping with the University’s field training program. When anaesthesia was provided by final year veterinary students, the odds of any complication after discharge were three-fold lower than when anaesthesia was provided by faculty staff. This finding cannot be explained and should be viewed with caution. It may reflect that students were more likely permitted to anaesthetise horses with quieter temperaments.

4.6 Conclusion
This study has shown the Henderson instrument to be significantly faster than emasculator castration, with no significant differences in the either the rates or types of complications between the two techniques. At the univariate level, the Henderson instrument was associated with tissue hanging from the wound, and swelling was more likely in warmbloods, Arabians, Clydesdales compared to polo horses, ponies, Thoroughbreds and Standardbreds. At all levels, the risk of complications increased as the horse aged. These associations may warrant consideration when performing castration of horses.
4.7 Authors’ declaration of interests
No competing interests have been declared.

4.8 Ethical animal research
The study was approved by the Animal Care and Ethics Committee of Charles Sturt University and had informed consent of the owners.

4.9 Source of funding
There were no sources of funding.

4.10 Acknowledgements
The authors would like to thank the anaesthesia staff, veterinary nursing and clinical staff and final year veterinary students of the School of Animal and Veterinary Sciences, Charles Sturt University, that were involved in this study.

4.11 Authorship
All authors contributed to the design of the study. Data collection was performed by Chris Owens and Bryan Hilbert. Data analysis was performed by Sharon Neilsen, Kristopher Hughes and Chris Owens. Chris Owens and Kristopher Hughes composed the article and all authors contributed to the critical revision of the article and approved the final manuscript for publication.

4.12 Manufacturers’ addresses
### 4.13 Tables

Table 4.4.1.1: Results of univariate analysis for associations between clinical factors and post-operative complications in 180 horses that have undergone elective castration

<table>
<thead>
<tr>
<th>Explanatory variables</th>
<th>Any postoperative complication</th>
<th>Post-operative haemorrhage</th>
<th>Surgical site swelling</th>
<th>Surgical site tissue eversion&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Surgical site tissue eversion&lt;sup&gt;2&lt;/sup&gt;</th>
</tr>
</thead>
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<td>Technique</td>
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<td></td>
<td></td>
<td>0.05</td>
<td>0.023</td>
</tr>
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<td>Breed: any</td>
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<td></td>
<td></td>
<td>0.167</td>
<td></td>
</tr>
<tr>
<td>Breed 2: breed groupings</td>
<td></td>
<td></td>
<td></td>
<td>0.022</td>
<td></td>
</tr>
<tr>
<td>Breed 3:</td>
<td></td>
<td></td>
<td></td>
<td>0.022</td>
<td></td>
</tr>
<tr>
<td>Draught/horse/pony</td>
<td></td>
<td></td>
<td></td>
<td>0.022</td>
<td></td>
</tr>
<tr>
<td>Age (months)</td>
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<td>0.14</td>
<td>0.146</td>
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</tr>
<tr>
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<td>0.006</td>
<td>0.075</td>
<td>0.084</td>
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</tr>
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<td>Surgeon</td>
<td></td>
<td></td>
<td></td>
<td>0.17</td>
<td></td>
</tr>
<tr>
<td>Surgeon/surgery</td>
<td></td>
<td></td>
<td></td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>resident/resident</td>
<td></td>
<td></td>
<td></td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>Surgeon/Resident</td>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Comorbidities</td>
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<td>0.035</td>
</tr>
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<td>Location</td>
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<td></td>
<td></td>
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<td>Location: theatre/field</td>
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<td>0.179</td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Anaesthetist/student</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anaesthetic time (min)</td>
<td>0.08</td>
<td>0.166</td>
<td>0.134</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surgery time (min)</td>
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<td>0.15</td>
<td>0.031</td>
<td>0.194</td>
<td>0.154</td>
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<td></td>
<td>0.14</td>
<td>0.097</td>
</tr>
<tr>
<td>Anaesthetic maintenance: gas/TIVA</td>
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<td></td>
<td></td>
<td>0.06</td>
</tr>
<tr>
<td>Anaesthetic or surgical complications</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Intra/immediate postoperative treatments

| Treatment for postoperative complication prior to discharge | <0.001 |
| Treatment for swelling prior to discharge | NA | NA |
| Treatment for haemorrhage prior to discharge | NA | NA |
| Treatment for tissue eversion prior to discharge | NA | NA | NA |
| Treatment for fever prior to discharge | NA |

*a* connective tissue or omentum, excluding eventeration; *b* connective tissue, omentum or eventration; NA = not applicable
Table 4.4.2.2: Results of univariate analysis for associations between clinical factors and development of complications after discharge of horses from hospital after elective castration.

<table>
<thead>
<tr>
<th>Explanatory variables</th>
<th>Outcome variables of interest</th>
<th>Any complication post-discharge</th>
<th>Haemorrhage post-discharge</th>
<th>Surgical site swelling post discharge</th>
<th>Any castration complication&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technique</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Breed: any</td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Breed 2: breed groupings</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.164</td>
</tr>
<tr>
<td>Breed 3: Draught/horse/pony</td>
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<td></td>
<td></td>
<td></td>
<td>0.123</td>
</tr>
<tr>
<td>Age (months)</td>
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<td>0.177</td>
<td>0.166</td>
<td>0.149</td>
<td>0.115</td>
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<tr>
<td>Body weight</td>
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<td>0.080</td>
<td>0.091</td>
<td>0.083</td>
<td>0.036</td>
</tr>
<tr>
<td>Surgeon</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surgeon/surgery</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>resident/nonsurgery resident</td>
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<td></td>
<td></td>
<td></td>
<td>0.194</td>
</tr>
<tr>
<td>Surgeon/Resident</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comorbidities</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Location</td>
<td></td>
<td>0.018</td>
<td>0.024</td>
<td>0.020</td>
<td></td>
</tr>
<tr>
<td>Location: theatre/field</td>
<td></td>
<td>0.005</td>
<td>0.010</td>
<td>0.007</td>
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</tr>
<tr>
<td>Anaesthetist</td>
<td></td>
<td>0.002</td>
<td>&lt;0.001</td>
<td></td>
<td>0.013</td>
</tr>
<tr>
<td>Anaesthetist/student</td>
<td></td>
<td>0.004</td>
<td>0.024</td>
<td>0.005</td>
<td>0.007</td>
</tr>
<tr>
<td>Anaesthetic time (min)</td>
<td></td>
<td>0.047</td>
<td>0.177</td>
<td>0.041</td>
<td>0.025</td>
</tr>
<tr>
<td>Surgery time (min)</td>
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<td>0.022</td>
<td>0.017</td>
<td>0.017</td>
<td>0.009</td>
</tr>
<tr>
<td>Anaesthetic maintenance</td>
<td></td>
<td>0.017</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anaesthetic maintenance: gas/TIVA</td>
<td></td>
<td>0.008</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anaesthetic or surgical complications</td>
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<td></td>
<td></td>
<td></td>
<td>0.127</td>
</tr>
<tr>
<td>Any post-operative complication prior to discharge</td>
<td></td>
<td></td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>NA</td>
</tr>
</tbody>
</table>
| Condition                        | Pre-discharge | Post-discharge | | | | | | Treatment for post-operative complication prior to discharge | 0.003 | 0.002 | NA | | | Treatment for swelling prior to discharge | 0.019 | 0.017 | | | Treatment for haemorrhage prior to discharge | 0.004 | 0.049 | 0.004 | | | Treatment for haemorrhage prior to discharge | 0.039 | 0.037 | NA | | | Treatment for tissue eversion prior to discharge | 0.013 | 0.012 | | | Treatment for tissue eversion prior to discharge | 0.039 | 0.037 | NA | | | Fever prior to discharge | NA | NA | <0.001 | NA | | | Haemorrhage post-discharge | NA | NA | <0.001 | NA | | | Swelling post-discharge | NA | <0.001 | NA | NA | | | Infection post-discharge | NA | 0.112 | NA | | | | | | | | | | | | Pre-discharge and post-discharge; NA = not applicable
Table 4.4.2.3: Results of multivariable logistic regression models of clinical factors associated with defined post-operative complications in 180 horses that have undergone elective castration

<table>
<thead>
<tr>
<th>Model</th>
<th>Variable</th>
<th>OR</th>
<th>95% CI</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Any complication</td>
<td>Weight</td>
<td>1.011</td>
<td>1.004-1.018</td>
<td>0.002</td>
</tr>
<tr>
<td>Haemorrhage</td>
<td>Treatment for post-op complication</td>
<td>51.0</td>
<td>7.07-463.51</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Swelling</td>
<td>Weight</td>
<td>1.016</td>
<td>1.004-1.030</td>
<td>0.009</td>
</tr>
<tr>
<td></td>
<td>Surgery time</td>
<td>1.071</td>
<td>1.001-1.150</td>
<td>0.048</td>
</tr>
<tr>
<td>Tissue Eversiona</td>
<td>Treatment for post-op complication</td>
<td>1.71</td>
<td>2.020-3.808</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

*aconnective tissue, omentum, eventration; OR = odds ratio*
Table 4.4.2.4: Results of multivariable logistic regression models of clinical factors associated with defined complications after discharge from hospital and any complication throughout the study period in 180 horses that have undergone elective castration

<table>
<thead>
<tr>
<th>Model</th>
<th>Variable</th>
<th>OR</th>
<th>95% CI</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Any complication postdischarge</td>
<td>Anaesthetist – staff ref</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Anaesthetist - student</td>
<td>0.33</td>
<td>0.12-0.78</td>
<td>0.017</td>
</tr>
<tr>
<td></td>
<td>Any post-operative complication</td>
<td>9.17</td>
<td>3.11-33.83</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Haemorrhage postdischarge</td>
<td>Anaesthetic maintenance – gaseous ref</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Anaesthetic maintenance – TIVA</td>
<td>0.21</td>
<td>0.05-0.70</td>
<td>0.015</td>
</tr>
<tr>
<td></td>
<td>Swelling post-discharge</td>
<td>8.45</td>
<td>2.45-39.28</td>
<td>0.002</td>
</tr>
<tr>
<td>Swelling post-discharge</td>
<td>Any post-operative complication</td>
<td>8.14</td>
<td>2.89-26.68</td>
<td>&lt;0.001</td>
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<tr>
<td></td>
<td>Haemorrhage post-discharge</td>
<td>9.51</td>
<td>2.73-44.29</td>
<td>0.001</td>
</tr>
<tr>
<td>Any castration complication(^a)</td>
<td>Location – field ref</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Location – operating theatre</td>
<td>2.69</td>
<td>1.32-5.78</td>
<td>0.008</td>
</tr>
</tbody>
</table>

\(^a\)Pre- and post-discharge; OR = odds ratio
Table 4.4.2.5: post operative swelling scores of photographs by blinded observers

<table>
<thead>
<tr>
<th>Horse</th>
<th>Rater 1</th>
<th>Rater 2</th>
<th>Horse</th>
<th>Rater 1</th>
<th>Rater 2</th>
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<th>Rater 1</th>
<th>Rater 2</th>
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<th>Rater 2</th>
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</thead>
<tbody>
<tr>
<td>1</td>
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<td>1</td>
<td>1</td>
<td>113</td>
<td>0</td>
<td>0</td>
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<tr>
<td>2</td>
<td>0</td>
<td>1</td>
<td>58</td>
<td>0</td>
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4.14 References

43. Riemersma D: Complication rate of castration of the horses using an inguinal approach in 554 cases, Proceedings, Proceedings of the European College of Veterinary Surgeons, 2005 (available from
Chapter 5: Comparison of Two Castration Techniques in the Horse Using Direct Laparoscopic Observation of the Internal Inguinal Ring and Spermatic Cord at the Time of Surgery

Manuscript prepared in preparation for submission to Veterinary Surgery
Comparison of Two Castration Techniques in the Horse Using Direct Laparoscopic Observation of the Internal Inguinal Ring and Spermatic Cord at the Time of Surgery

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Keywords: horse; castration, Henderson: vaginal ring; spermatic cord

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5.1 Abstract

Objective: To visualise the effect of castration using the Henderson instrument or surgical emasculators on the internal inguinal ring and spermatic cord by direct visualisation at the time of surgery.

Study Design: Observational case series.

Study Population: Four intact male horses with pre-existing conditions holding a grave or hopeless prognosis.

Methods: Horses were anesthetised and underwent castration. In combination with a Serra emasculator, the vascular cord was ligated and the vaginal tunic was transfixied for the removal of one testis, and the Henderson instrument was used for removal of the other testis. During each surgical procedure, the internal inguinal ring and contents were visualised by direct laparoscopy at the time of emasculation. The horses were subsequently subjected to euthanasia, and post-mortem examination of the inguinal canals, inguinal rings and contents was performed.

Results: When the Henderson instrument was used, laparoscopic examination revealed haemorrhage from the intra-abdominal vascular stump in all four horses, and in two horses, damage to the internal inguinal ring. At post-mortem examination, the surgical findings were confirmed, and it was also determined that the vaginal tunic was not securely closed using the Henderson instrument. There was no evidence of haemorrhage from the spermatic cord remnant, lack of closure of the vaginal tunic or damage to the inguinal rings associated with castration using the emasculator in any horse.

Conclusion: Veterinarians using the Henderson castration technique should be aware that in some horses, intra-abdominal haemorrhage, damage to the internal inguinal ring, and an insecure closure of the extra-abdominal vaginal tunic may occur, with implications for the possibility of post-operative complications.
5.2 Introduction

Most equine veterinarians have their preferred technique for castration of horses; however, the procedure is most commonly performed using the surgical emasculator\textsuperscript{6,12,83}. More recently, the Henderson castration instrument has been available to veterinarians, since its patent in 1997\textsuperscript{17}. Unlike the surgical emasculator, which achieves haemostasis and tissue occlusion via the crushing action of paired serrated jaws, the Henderson castrating instrument achieves haemostasis and closure of the vaginal tunic via torsion. The instrument is essentially a clamp that is attached to the spermatic cord within the closed vaginal tunic. The handle is then attached to a variable speed cordless drill, and rotated at moderate speed until the testis is separated from the body. The vaginal tunic contains the spermatic cord which is comprised of the afferent and efferent vascular and nerve supply, lymphatics, ductus deferens and internal cremaster muscle. The external cremaster muscle is attached to the caudo-lateral surface of the vaginal tunic. The external cremaster muscle, vaginal tunic and spermatic cord travel first through the internal inguinal ring, which is bordered cranially by the internal abdominal oblique muscle, ventromedially by the rectus abdominus muscle, prepubic tendon and inguinal ligament\textsuperscript{24}. These tissues then travel through the inguinal canal which terminates at the external inguinal ring that is formed by a slit in the external abdominal oblique muscle, and into the scrotum. The afferent blood supply is in the form of the testicular artery, a branch of the descending aorta, and the efferent vasculature consists of the pampiniform plexus that supplies the spermatic vein which usually joins the caudal vena cava on the right side and the left renal vein on the left side\textsuperscript{24}. Given the prominent vasculature of the testis, improper haemostasis can lead to severe life-threatening haemorrhage\textsuperscript{4}. The vaginal tunic is a continuation of the peritoneum from the abdomen at the internal inguinal ring and consequently is a direct communication between the abdomen and the scrotum. In the immediate post-operative period, this communication can predispose to the life-threatening complication of evisceration of abdominal contents through the castration incision.

Early observational reports suggested the Henderson technique to be faster than emasculator castration with few to no complications\textsuperscript{22}. More recently, a retrospective study of outcomes of equine castration using the Henderson instrument reported a similar rate of overall
complications as has been reported for emasculator castrations (10.7%\textsuperscript{47} and 6.9-25%\textsuperscript{6,8,20}, respectively), and the risk of complications increasing with increasing horse age (21.3% in horses over 4 years old)\textsuperscript{47}. A survey of Australian veterinarians reported an impression of decreased swelling and infection, but increased risk of evisceration among veterinarians that had used the Henderson instrument\textsuperscript{83}. Further to these findings, it was the clinical impression of the authors that the Henderson instrument sometimes obliterated the vaginal tunic rather than resulting in closure (Owens et al., unpublished observations). The current study was undertaken to compare the gross structural changes to the spermatic cord and the external and internal inguinal rings that occurred at the time of surgery when the Henderson technique or a conventional emasculator castration technique was used. We hypothesised that the vaginal tunic would be securely closed using traditional castration, while the vaginal tunic of horses castrated with the Henderson instrument would not be securely closed.

5.3 Materials and Methods

5.3.1 Study Design
Stallions of any breed or age, with both testes descended in the scrotum and without concurrent clinical reproductive abnormalities, presented to the Veterinary Clinical Centre, Charles Sturt University between January 2013 and December 2015 for euthanasia because of serious disease not involving the reproductive system that was associated with a grave prognosis, were eligible for inclusion. Informed client consent was obtained for all horses included in the study and ethics approval was granted by the Charles Sturt University Animal Care and Ethics Committee (approval number: 14/053).

5.3.2 Anaesthetic Protocol
Horses were pre-medicated with acepromazine (0.02 mg/kg bwt IV) and general anaesthesia was induced by administration of a combination of xylazine (1.0 mg/kg bwt IV) and ketamine (2.2 mg/kg bwt IV). General anaesthesia was maintained under positive pressure ventilation and inhalational delivery of desflurane, sevoflurane or isoflurane at the discretion of the attending anaesthetist. Intraoperative polyionic isotonic crystalloid fluids (Hartmann’s solution) and
dobutamine were administered, as required, to maintain mean blood pressure above 70 mmHg. At the completion of surgery, the horses were subjected to euthanasia by intravenous administration of 75.0 mg/kg pentobarbitone sodium.

5.3.3 Surgical Protocol
The horses were positioned in dorsal recumbency and the ventral abdomen and scrotum were surgically prepared in a routine fashion. After draping, the patient was moved into the Trendelenburg (head down) position, and a single 1 cm laparoscopic portal was made through the skin and umbilical scar. The abdomen was insufflated via a 10 mm diameter, 20 cm long laparoscopic cannula (Dr Fritz Tuttlingen, Germany) to approximately 12-15 mmHg. A 0-degree, 10 mm diameter, 30 cm long rigid telescope (Stryker, Sydney, Australia) was introduced through the cannula for direct visualisation of the right and left internal inguinal rings (Figures 5.4.1 and 5.4.2). The horses were then castrated using the emasculator technique on the left testis and Henderson technique on the right testis.

5.3.4 Emasculator Technique
A 10 cm skin incision was made on the ventral aspect of the scrotum approximately 1.5 cm lateral to the midline. The skin incision was continued through the subcutaneous tissue and vaginal tunic to expose the testis, epididymis and spermatic cord and fifteen millilitres of 2% lignocaine was injected into the body of the testis and directed towards the spermatic cord. The ligament of the tail of the epididymis was identified at the attachment to the vaginal tunic, a haemostat was applied across the tunic and the ligament was transected. The spermatic cord was identified and two large Carmalt forceps were applied transversely, followed by application of Serra emasculators distal to the Carmalt forceps. A single transfixing ligature using USP 2 polydioxanone material was tied into the crush of the most proximal clamp. Once securely ligated, the blade handle of the Serra emasculators was engaged and the testis was removed. The remaining Carmalt forceps and emasculator were removed from the spermatic cord. The cord was checked for haemorrhage prior to replacement within the tunic. The subcutaneous tissue surrounding the tunic and external cremaster muscle was then checked for haemorrhage.
Any redundant fat or subcutaneous tissue protruding from the incision was removed using Metzenbaum scissors.

5.3.5 Henderson Technique

A 10 cm skin incision was made on the ventral aspect of the scrotum approximately 1.5 cm lateral to the midline. The skin incision was continued through the subcutaneous tissue but not through the vaginal tunic of the testis. Fifteen millilitres of 2% lignocaine was injected into the body of the testis, directed towards the spermatic cord. Scrotal fascia was stripped in a proximal direction from the exteriorised testis using a dry gauze surgical swab. The Henderson castrating instrument (Stone Manufacturing and Supply, Kansas City, MI) was attached to a variable speed cordless drill (Hitachi DS 18DFL). The jaws of the Henderson instrument were clamped across the spermatic cord just proximal to the testis. The tip of the instrument was placed inside the scrotal skin incision in a distal to proximal orientation, aligned with the spermatic cord. The drill was engaged rotating the clamp at a slow to moderate speed in a clockwise direction with no tension applied until the cord twisted and separated from the body.

5.3.6 Post-mortem examination Protocol

Each horse was subjected to gross post-mortem examination of the internal and external inguinal rings, and the remnants of the spermatic cord, vaginal tunic and associated connective tissue.

5.3.7 Data Analysis

For comparison of gross evidence of tissue damage, haemorrhage and adequacy of closure of the vaginal tunic between the two surgical methods, descriptions methods were used.
5.4 Results

A total of 4 horses were eligible for this study. There were two Thoroughbred horses and two Standardbred horses. Horses were aged from 9 months to 9 years. All horses had 2 normal descended testes. Horse 1 was a 2 year-old Thoroughbred colt, 530 kg bwt, with chronic uveitis. Horse 2, a 9 year-old Thoroughbred stallion, 450kg bwt, had type 2 cervical vertebral stenotic myelopathy. Horse 3, a 9 month-old Standardbred colt, 285 kg bwt, had osteochondrosis lesions in the left femoropatellar joint. Horse 4 was a 10 month-old Standardbred colt, 180 kg bwt, with bilateral central blindness.

5.4.1 Observational results

5.4.1.1 Henderson technique

5.4.1.1.1 Laparoscopic visualisation

When castration was undertaken using the Henderson instrument, the vascular bundle of the spermatic cord was observed to break and retract into the abdominal cavity through the vaginal ring soon after the spermatic cord was disrupted. The twisting effect of the Henderson technique on the vaginal tunic and spermatic cord could not be appreciated during intra-abdominal examination via laparoscopy. When the Henderson instrument was used, the contents of the spermatic cord were twisted and torn, and tended to retract into the abdomen through the internal inguinal ring associated with a small amount of haemorrhage. In two horses (Horses 2 and 4), use of the Henderson instrument caused a tear of the inguinal rings and damage to the vaginal ring (Figures 5.5.2 & 5.5.3).

5.4.1.1.2 Post-mortem examination

In all horses, the spermatic cord proximal to placement of the Henderson instrument was twisted tightly with the external cremaster muscle (Figure 5.5.4). While the twisted stump of the retained portion of the spermatic cord proximal to the instrument initially appeared closed, careful manipulation of the tissue revealed that the cavity of the vaginal tunic was only loosely closed (Figure 5.5.5). I agree with Dr Boden that some information provided in the Discussion is better placed in the Results section. The twisted cord of the removed tissues was firmly closed and
difficult to unravel (Figure 5.5.5). During castration using the emasculator method, little change at the level of the internal inguinal ring was visualised except for moderate tugging on the spermatic cord as the testes were exteriorized for the procedure. However, in two of the four horses, the stump of the spermatic cord and tunic was observed to retract to the internal inguinal ring almost immediately after release by the surgeon.”

The twisted cord of the removed tissues was firmly closed and difficult to unravel (Figure 5.5.5). Careful examination of the tissues outside the abdomen revealed that the twisted proximal remnant of the cord was a mixture of cremaster muscle and vaginal tunic (Figure 5.5.4). Unexpectedly, the combined tunic and cremaster muscle tissue that remained attached to the abdomen was easily unravelled to reveal the cavity of the vaginal tunic which communicates with the abdominal cavity.

5.4.1.2 Routine castration technique

5.4.1.2.1 Laparoscopic visualisation

In all horses, the ligated vascular bundle of the spermatic cord retracted through the internal inguinal ring into the abdomen, there was no appreciable haemorrhage and the vaginal and inguinal rings remained intact (Figure 5.5.6).

5.4.1.2.2 Post-mortem examination

In all horses the stump of the spermatic cord that was removed from the body remained transfixed and ligated. No haemorrhage from the spermatic cord, or tearing of the vaginal or inguinal rings or associated tissue was observed.
5.5 Discussion

This is the first study to directly observe the inguinal and vaginal rings of horses during the castration procedure. Important differences between surgical methods were observed with implications for post-operative complications, including haemorrhage and tearing of the internal inguinal ring and vaginal ring in horses castrated using the Henderson method, whereas complications associated with castration using surgical emasculators were not observed in any horse.

In the current study, castration using the Henderson instrument resulted in the spermatic cord to break and retract into the abdomen. In addition, the combination of vaginal tunic and cremaster muscle that remained after removal of the tests was easily unravelled, providing direct access to the abdominal cavity. This finding may serve as a timely reminder for the cautious surgeon to apply an Allis tissue forceps or similar instrument to the stump in order to be able to retrieve it to facilitate review of haemostasis before conclusion of the procedure. Haemorrhage is an important complication after emasculator castration and has been reported to account for 1/3 of post castration complications, with some horses requiring surgical intervention to achieve haemostasis and fluid therapy for improved haemodynamic function.

It must be recognised that due to the small sample size and observational nature of this proof of concept study, no conclusions can be drawn regarding the lack of complications seen in this set of emasculator castrations. In addition, it is important to note that the method employed in the current study included ligation of both the spermatic cord and vaginal tunic. While recent papers have found no association between ligation and increased risk of complications such as infection, ligation has been suggested to decrease haemorrhage volume when compared to castration without ligation, while possibly increasing the rate of surgical site infection.

In the current study, castration using the Henderson instrument resulted in the spermatic cord to break and retract into the abdomen. In addition, the combination of vaginal tunic and
cremaster muscle that remained after removal of the tests was easily unravelled, providing direct access to the abdominal cavity.

The implications of these observations are twofold: first, and of greatest concern, is that evisceration could occur via the open vaginal tunic\textsuperscript{3} and second, in the case of the twisted remnants retracting into the abdomen, undetected intraabdominal haemorrhage via the testicular artery could occur if the twisted remnants unravelled. It is important to note that these potential complications is also true for castrations using surgical emasculators, especially using the open method. Haemorrhage has been reported to account for a third of all castration complications due to insufficient haemostasis of the testicular artery or damage to the pudendal vessels\textsuperscript{8}. Additionally, there was a small amount of intra-abdominal haemorrhage associated with castration using the Henderson technique in each horse. While marked haemorrhage did not occur in the horses used in this study, the potential for haemorrhage or evisceration due to the easily unravelled cord remnants remains possible.

In two horses, the twisting action of the Henderson instrument appeared to damage the internal inguinal and vaginal rings (Figures 5.5.1 & 5.5.2). From our observation, there are two mechanisms by which this appears to occur. As the cord and vaginal tunic are twisted and compacted into one area, within the inguinal ring, the volume of the flattened tissue expands. This mechanical action may then create an expanding force that is applied to the inguinal ring. As the lateral aspect of the ring is against the horse’s leg, all of the expansion is likely to occur in a medial direction resulting in the bulky knot of tissue exerting pressure at the cranial and medial aspects of the ring. In addition, the twisting of the spermatic cord may inadvertently incorporate adjacent connective tissue, with subsequent tension and tearing of the tissues at the level of the inguinal region (Figure 5.5.3). In most horses, this small amount of tearing would be inconsequential and unbeknown to the surgeon or the owner. Further, when performing cryptorchidectomy, a common technique is to digitally ‘expand’ the internal inguinal ring\textsuperscript{4}. Not all surgeons close the external ring following this procedure and not every horse suffers severe consequences. While it was beyond the scope of this study to determine the clinical importance
of the damage we observed to the internal inguinal ring, or the potential rate of occurrence in a larger population, it remains possible that it could predispose the horse to evisceration. In a recent retrospective study of Henderson instrument castrations, the rate of evisceration (0.4%)\textsuperscript{47} was similar to rates in previous studies of castration using emasculators (0.2\textsuperscript{6,8,85}; however, in our recent survey of Australian equine veterinarians, there was an impression of increased rates of evisceration with the Henderson instrument\textsuperscript{83}.

The principle of clamping small vessels and twisting the haemostat until it breaks free from the tissue is an accepted technique that has previously been described in surgical texts. In the application of the Henderson instrument, the technique of vessel trauma and closure has been mechanised, and the vessels are larger and the consequences of failure are potentially more serious.

Previous rates of complications in horses after castration have been reported at approximately 10\%\textsuperscript{85,20}. In one study, horses three years of age and older were five times more likely to develop complications than horses two years of age or younger\textsuperscript{85}. Similarly, in another study, horses over 3 years of age had a significantly greater chance of complications in comparison to younger horses\textsuperscript{20} and in a recent randomised clinical study of 180 horses undergoing castration, the likelihood of complications increased as the horse’s age increased (Owens et al, unpublished data).

Schroeder et al. (2014) has proposed one of the advantages of the Henderson instrument, and a reason for fewer intra-operative and postoperative complications, was the technique of spinning and “tying” the vessels of the spermatic cord together with the vaginal tunic. Reilly and Cimetti similarly reported that the Henderson instrument results in sealing of the vaginal tunic, and as a result communication with the abdomen is virtually eliminated\textsuperscript{22}. In both of these studies, this conclusion was based on clinical impressions alone, without the addition of close intraoperative visualisation of the tissues. In light of the findings of the current study, further evaluation and
consideration of the effects of the Henderson technique on the cremaster muscle, vaginal tunic and spermatic cord is warranted.

5.6 Conclusion

The results of this small study suggest that if damage to the inguinal ring does occur while using the Henderson instrument, it may predispose the horse to evisceration. In addition, the assumption that the vaginal tunic, and the testicular artery are securely 'sealed' may not be correct and horses may be predisposed to post-operative complications, including haemorrhage and evisceration. As this was a terminal study, we were unable to determine if the intra-operative findings would be associated with the development of complications. Further clinical investigation of a larger sample size is warranted to investigate these observations.
5.7 Acknowledgements

The authors would like to acknowledge the assistance of veterinary nurses Stacy Ryan and Anna Dennis and the anaesthesiology team of Chris Quinn, Leah Bradbury and Leigh Ladd.

5.8 Disclosure

The authors declare no conflict of interest related to this report.
Figure 5.4.1: Appearance of the normal right internal inguinal ring and contents before surgery (Horse 2).
Figure 5.4.3: Appearance of the normal left internal inguinal ring before surgery (Horse 3).
Figure 5.5.1: Appearance of the left internal inguinal ring and contents after castration using the Henderson instrument (Horse 2).
Figure 5.5.2: Appearance of the torn internal inguinal ring after castration using the Henderson instrument (Horse 4).
Figure 5.5.3: Appearance of the torn internal inguinal ring after castration using the Henderson instrument (Horse 3).
Figure 5.5.4: Opening the vaginal tunic proximal to the location of placement of the Henderson instrument (Horse 3).
Figure 5.5.5: Appearance of the spermatic cord proximal to the site of placement of the Henderson instrument (Horse 3)
Figure 5.5.6: Appearance of the right internal inguinal ring after routine castration using emasculation (Horse 3).
5.10 References


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Chapter 6 Exegesis
6.1 In search of a gold standard for equine castration

Castration is the most commonly performed equine surgical procedure\textsuperscript{4}, and is considered a fundamental skill for equine veterinarians at all levels of equine practice, yet there are frequent and varied complications of the procedure. These include swelling, haemorrhage, evisceration, infection, seroma formation, peritonitis, inadvertent penile damage, hydrocoele formation and continued stallion-like behaviour\textsuperscript{5}. Complications after castration can also result in malpractice claims against equine practitioners\textsuperscript{64}.

Swelling, mild persistent bleeding, hydrocoele or seroma formation, herniation of omentum, continued stallion-like behaviour\textsuperscript{5} have the potential to develop into life-threatening situations, but primarily they result in added cost of extra treatments\textsuperscript{14}, protracted recovery times and longer return to work, and frustration for trainers and owners. More immediately life-threatening complications such as marked haemorrhage and evisceration, and development of peritonitis have a clearer impact on the morbidity and mortality of the patient and illustrate how seriously the surgical process of equine castration should be taken.

Efforts to minimize complications are evident in the numerous variations that have been developed and described for castration instruments and intraoperative and post-operative protocols. Clinicians have developed a number of options not only for the instrument’s configuration, but when applying the emasculators to the cord either within the closed vaginal tunic (closed technique), which has the advantage of being faster, and not exposing contents to contamination, or opening the tunic and applying the emasculators directly to the cord (open technique), which has the advantage of allowing full visualisation of the structures to be emasculated and reduces the volume of tissue within the crush, or opening the tunic, inspecting the structures, then applying the emasculators to the tunic and cord (semi-closed technique). Further, the application of a ligature to either the cord or the tunic or both in the interest of haemostasis and security against evisceration is available to the surgeon.
An alternative to the use of an emasculator that is growing in popularity is the Henderson castrating instrument. The Henderson instrument is comprised of a pair of studded curved jaws that are attached in a perpendicular alignment across the spermatic cord that is still enclosed in the vaginal tunic. Whereas the surgical emasculator achieves haemostasis and closure of the vaginal tunic via sustained clamping and crushing, The Henderson instrument is attached at the handle to a variable speed cordless drill, and rotated at a moderate speed until the torsion of the cord achieves closure of the tunic, crushing of the tissues, haemostasis and ultimately separation of the testis from the body²².

Beyond the choice of instrument variation, castration can also be performed with the horse standing, or recumbent after induction of general anaesthesia and a decision can be made as to whether local anaesthetic is injected into the testes to improve analgesia. In addition, there are a host of post-operative preferences including administration of antimicrobial, analgesic and anti-inflammatory drugs, whether to exercise or confine the horse, hydrotherapy through the use of cold hosing, and length of time to keep the patient separate from other horses.

These preferences tend to be strongly held beliefs among clinicians, often with regional or experience influenced differences⁶,¹² yet there are limited data regarding specific castration techniques in terms of outcomes and complications.

6.1.2 Comparison of reported equine castration complications and their rates: differences and challenges

Overall complication rates in previous studies of equine castration outcomes range from 6.9 – 70%⁶,⁷,⁴⁷,⁶⁴. This wide range is only partly explained by the diverse pre, intra and post-operative options used in these studies. It is also likely to be a result of the numerous outcome variables that can be measured, the wide variation in their definition measurement, and variation in study design. A prominent example is post-operative swelling. It has largely been reported as the most common complication which most commonly peaks around 5 days post-surgery³,⁵⁹,⁶⁰,⁶⁴. Yet some authors regard swelling as ‘inevitable’ and do not include it as a complication unless they consider
it excessive\textsuperscript{14}. This approach then of course calls into question what the definition of ‘excessive’ is. One author reported no post-castration complications when using the Henderson technique, but stated that post-operative swelling could be minimized by administration of nonsteroidal anti-inflammatory drugs, suggesting that swelling was not considered a complication in this study\textsuperscript{22}. This inconsistency in perception of what constitutes a complication is also true of haemorrhage and infection, and a definition for what is considered excessive is seldom provided\textsuperscript{6}. Regardless of the complication or outcome factor, robust design and analysis of clinical grading systems are often lacking. As a result, studies are seldom directly comparable, making comparison of post-operative complication rates and risk factors between studies problematic.

Further difficulty in direct comparison in outcomes results from the wide variety of study designs of varying quality that have been employed, including retrospective case series\textsuperscript{7,8,14,19,20,47,52,85}, clinician surveys\textsuperscript{6,12}, ex vivo experiments\textsuperscript{10} and prospective trials\textsuperscript{10,16,44,53}. While some authors have obtained complication rates from hospital records\textsuperscript{20,47} or even prospective studies\textsuperscript{44}, others have relied solely on the observation and opinion of veterinarians in reporting outcomes\textsuperscript{6}.

Some authors have reported impressions that the Henderson instrument is faster and safer than castration using emasculators\textsuperscript{22}. Additionally in a recent retrospective study\textsuperscript{47}, similar complication types and rates to previous descriptions of emasculator castration\textsuperscript{6} were reported, suggesting surgical equipment selection may not influence development of castration complications. However, to date, no prospective studies have been performed comparing outcomes of an emasculator to the Henderson instrument, nor has an investigation of the effects of the Henderson instrument on the spermatic cord and associated tissues been performed beyond speculation as to the efficacy of the method.

The United Kingdom and USA have been represented in collection of data regarding clinicians’ preferences surrounding castration\textsuperscript{6,12}, providing information from these countries, including the perceived complication types and rates. As yet, no such investigation of the Australian equine
veterinary community has been performed. Important research objectives of this thesis were to (i) provide information regarding castration among Australian veterinarians in terms of both preferences, beliefs and perceived outcomes, (ii) compare the outcomes of the Henderson technique to the emasculator technique in a single prospective cohort study and (iii) observe the effects of the Henderson and emasculator instruments at the time of surgery at the level of the spermatic cord and internal inguinal ring.

6.2 Contribution of the research to the scientific literature: Chapter 3
6.2.1 Profiles of equine castration in Australia

The research presented in Chapter 3 of this thesis provided new information regarding the castration techniques, preferences and outcomes among Australian equine veterinarians. The findings revealed similarities and highlighted points of difference with castration preferences in the United Kingdom and USA. Information on the preferences, habits and outcomes of veterinarians in Australia performing castration of horses was not previously available and this study has provided new and important information to improve the understanding of equine castration with a national emphasis.

Our research objectives were achieved via an online survey using the Survey Monkey website. The survey was developed and validated using a ten-respondent pilot study. Anonymity of responses was ensured by disabling collection of IP address information of respondents, and the anonymising measures were clearly explained to respondents in an introductory article published in the Australian Equine Veterinarian (Appendix 1) promoting involvement in the survey, and a written pre-amble introducing the survey, in order to minimize concern regarding the collection of potentially sensitive or damaging information such as complications types and rates that clinicians may experience. The survey was made available to members of the Equine Veterinarians Australia (EVA) in a link contained in 3 editions of the fortnightly E-newsletter, personalised invitation to practices and follow-up email reminders. Further, the questionnaire study received approval for the study from the CSU Faculty of Science Ethics in Human Research
Committee, representing external scrutiny and assurance that the study was undertaken without risk to the participants.

The survey population was the 1050 members of the EVA, and the survey contained 39 questions divided into 6 sections (Appendix 2), which sought information from respondents regarding castrations they had performed in the previous 12 months. The 6 sections of questions were clinician demographics, positioning and location of procedure, techniques and complications of emasculator castrations, techniques and complications of the Henderson instrument, perioperative preferences, and any other comments. In addition to descriptive results from the study, Fisher’s exact tests were used to determine associations between ligation and complications, and generalised linear models with a negative binomial family were used to determine associations between count response variables and categorical independent variables.

Approximately 5330 castrations over the course of one year were included by the respondents from a geographical distribution that reflected the distribution of equine veterinarians registered in each Australian state. The profile of respondents was in line with that reported by a published survey of Australian equine veterinary employment. Respondents were generally experienced veterinarians in practices with a high proportion of equine caseload, and the most common profile was a veterinarian who performed most or all castrations in the field, with the horse recumbent using general anaesthesia, using emasculators, without use of ligation via the open technique. This being said, there was still wide variation in responses and preferences among respondents, confirming the lack of consensus among clinicians regarding the optimum combination of castration techniques previously described in survey studies. Similar to equine veterinarians in the UK and USA, most respondents in our study performed castrations in the field. However, in contrast to the profile of the UK veterinarian, where the majority of castrations were reported to be performed with the horse standing and sedated, only 7% of castrations amongst Australian veterinarians were reported to have been performed standing.
In contrast to the USA study\textsuperscript{6}, the majority of Australian respondents performed castrations using the open technique, while American respondents indicated a more even distribution of open and semi-closed techniques. It was beyond the scope of the study to clarify the reasons for these differences, however it may reflect tradition, regional differences and undergraduate teaching. Interestingly, these points of difference did not appear to influence complication rates: the complication rates reported by the respondents in our study were similar to those reported in the UK\textsuperscript{12} and USA\textsuperscript{6} in previous surveys, with swelling reported at 25\%, haemorrhage at 5\% and infection at 5\% in the current study. This were important finding for clinicians in both Australia and overseas, as the choice of standing versus recumbent castration has anecdotally been a point of contention and concern in clinical decision making. For example when weighing up whether to anaesthetise a fractious stallion, or concerns about administering general anaesthesia to a horse with a cardiac arrhythmia of ambiguous clinical significance. The finding that complication rates across these studies were equivocal will be a useful addition to the decision-making information for veterinarians in clinical practice.

In our study, 10\% of veterinarians surveyed used the Henderson instrument, and attributed this choice to their impression that it carried less severe complications, less swelling than using an emasculator and was faster. This information provides useful information from clinicians in ambulatory practice about experience with the early uptake of the instrument that could not otherwise be captured in a more robust prospective study performed in hospitals. The low number of respondents that had used the instrument means it is important to interpret the results with caution, and it is unknown whether the impressions of these respondents is based on substantial first-hand experience with the instrument or the anecdotal reputation of the instrument as having low complications. Conversely, those that chose the emasculator for castrations cited familiarity with the technique and the most common determining factor for technique selection, although some respondents reported concern of evisceration as a reason not to use the Henderson instrument. However, in this study, the only technique that was significantly associated with evisceration based on respondents’ impressions was the open method of castration.
Despite previous reports that hydrotherapy using cold hosing was associated with increased rates of swelling and infection\textsuperscript{6}, no such association was found in the current study, although there was an association between cold hosing and the perception of haemorrhage. In both the current study and the previous study\textsuperscript{6}, it may be that rather than cold hosing being associated with greater incidence of swelling, infection or haemorrhage, the act simply facilitated closer inspection of the surgical site, possibly allowing clinicians and owners to recognise otherwise unnoticed complications. The finding that cold hosing was not associated with swelling and infection is useful to clinicians when choosing post-operative recommendations. There is inevitably passionate discussion between horse owners regarding the best way to care for horses after the surgery and veterinarians can find themselves having to defend recommendations. Clients may be concerned that they could be responsible for jeopardising the outcome of the surgery because of administering this common post-operative intervention. This study has added more information to guide veterinarians in their recommendations.

\textbf{6.2.2 Survey response rates among Australian veterinarians}

Robust techniques were employed in an attempt to achieve a high response rate including a clear, concise validated survey designed to be intuitive, easy to follow that was not overly long, and was easy to access and return. We sought the assistance of the EVA who distributed the survey with a paid, one time subscription to advertise the survey in three editions of the online newsletter and we sought prenotification of the survey population via an introductory article, phone follow-ups and personalised invitations to practices failed to increase the response rate. Despite these, we received a response rate of only 13.1\% of the target population. The comparatively small pool of respondents compared with studies performed in USA\textsuperscript{6} and UK\textsuperscript{12} may partially explain the low response rate, however the impact of survey fatigue, as has been recognised in other highly surveyed groups\textsuperscript{90} in an era where clinicians are exposed to surveys of all kinds including product and industry surveys may also have contributed. It would be prudent to investigate not only the phenomenon of survey fatigue amongst Australian equine veterinarians, but to investigate ways to gather important epidemiological information in the
face of these social and communication changes. Access to a database of Australian veterinarians of multiple disciplines and qualification levels, limited to researchers executing high-quality epidemiological research using robust methods, could be of benefit to future questionnaire studies of the Australian veterinary industry. In addition, the possible use of social networking platforms for generation of epidemiological data could be considered for future studies.

6.2.3 Attitudes of equine veterinarians to post-operative pain

In a recent study of equine veterinarians, 67% of respondents scored the pain associated with castration between 4/10 and 7/10, and a further 20% of respondents scored it as low as 1/10 or as high as 10/10, and a 2006 study reported that most respondents considered castration a low pain procedure. These results reflect a lack of professional agreement on pain associated with the procedure, and uncertainty regarding the place of anaesthesia and provision of analgesia for this procedure. The current study found that fewer than half of the respondents administered analgesia following castration and only one quarter of respondents administered pain relief prior to surgery. This was a surprising finding since evidence supporting the standardised use of anaesthesia and analgesia for castration of horses is mounting, as intra-testicular lignocaine has been shown to decrease the number of additional total intravenous anaesthesia boluses required, reduce cremaster muscle tension and cardiovascular changes, reduce post-operative pain scores and cytokine levels. In addition, post-operative nonsteroidal anti-inflammatory drug administration reduces the display of painful behaviours and physiological responses. As such, the concept of castration as a painful procedure that warrants anaesthesia and analgesia as standard practice by Australian veterinarians is possibly unrecognized in our industry, and this study has helped to uncover more evidence that education of Australian veterinarians on this point may be prudent to improve animal welfare.

6.2.4 Prudent use of antimicrobial drugs by Australian equine veterinarians

The nature of the castration procedure makes administration of antimicrobials highly justifiable, if not necessary. The procedure opens a route into the peritoneal cavity from the incision which is usually left to heal by second intention, the surgical site is located adjacent to the urogenital
and gastrointestinal openings, and in this study the overwhelming number of castrations were performed in the field. However, the benefit of prophylactic antimicrobial administration remains undetermined. In one study in which equine practitioners in the USA were surveyed, there was a significantly lower infection rate in horses administered antimicrobial drugs in comparison to that did not receive treatment, suggesting a benefit of antimicrobial treatment in reducing the risk of post-operative complications. However, in a more recent retrospective study of equine castration performed by one practice, prophylactic antimicrobial treatment was not associated with development of complications. In the current study, only 75% of respondents administered antimicrobials, and of greatest concern, there were large variations in dose rates and intervals of commonly used antimicrobial drugs in equine practice, including procaine penicillin. The variation in dosing regimens was both within and between respondents. Reasons for adjustment of dose rate and interval that were cited included how concerned they were over the likelihood of infection, or the severity of the infection. While these responses do not represent all Australian equine veterinarians, the surprising lack of basic prudent use of antimicrobials would be beneficial to further investigate and highlight for the education of our industry. Also, our findings are supported by recent studies that demonstrate that equine practitioners in Australia do not always adhere to recommendations underpinning sound antimicrobial stewardship, including those regarding use of prophylactic antimicrobial administration in surgical patients.

6.2.5 Study Limitations

It is important to consider the limitations of this study. The small response rate of 13% of the target population may have resulted in selection bias, including non-response bias where there may be important differences in perceptions and approaches between responders and non-responders. As such, it is possible that the internal validity of the study may have been influenced by the type of responder. Responders were required to recall information regarding all the castrations they had undertaken over a 12 month period and it is likely that some errors in information provided (recall bias) is likely. In addition, confounding bias through the mixing of effects of two or more factors may have influenced the study results, including biased assessment.
of associations between exposure and outcome factors. Efforts were made to limit confounding bias by careful consideration of all possible exposure factors. Nevertheless, confounding in the statistical models cannot be discounted.

6.2.6 Post-operative recommendations require further investigation

Post-operative recommendations among veterinarians were found to be prescriptive and yet highly variable, which is consistent with the study of equine castrations in North America\(^6\). Like the debate surrounding post-operative cold hosing discussed in section 6.2.1, a trend that emerged from this study was the recommendation that horses should be confined for 24 hours followed by turnout or enforced exercise. Despite the popularity of this recommendation, it was not associated with any difference in the rate or type of complications. Furthermore, apart from the perception that hydrotherapy using cold hosing is linked with haemorrhage in our study and swelling and infection in a previous study\(^6\), no post-operative recommendations were associated with either increased complications or protective effects. To our knowledge, post-operative recommendations following castration have not been investigated in a prospective study, and a study of this nature would be a valuable addition to the information from published surgical trials and intraoperative studies.

6.3 Prospective comparison between Henderson instrument and emasculator techniques for equine castration

Chapter 4 presented the results of a prospective cohort study comparing castration using surgical emasculators to castration using the Henderson instrument. The objectives of the study were to compare the surgical outcomes including complication types and rates and surgical duration for the Henderson castrating instrument and surgical emasculators in a prospective clinical study of horses presented for castration to a single facility (Veterinary Clinical Centre). Surgical technique was allocated by randomisation prior to castration to avoid selection bias. The study provided important contributions to the profession and expansion of the knowledge of castration complications as it was the first study to directly compare the Henderson technique with a conventional emasculator method. The results of this study can be used by veterinary surgeons
in the process of evidence-based clinical decision-making for castration approaches and communication with clients regarding complication types, rates and risk factors.

Surgical emasculators have been the industry standard for castration of horses since the advent of modern veterinary surgery. Common to all contemporary surgical emasculator variants (White’s improved, Sand’s, Serra, Reimer) is that haemostasis of the spermatic cord vasculature, and closure of the vaginal tunic are achieved via the crushing action of two jaws. Where the surgical emasculator achieved haemostasis and vaginal tunic closure through clamping and perpendicular pressure, the theory behind the Henderson castrating instrument is that torsion of the tissue will result in stable occlusion of the vasculature and close the vaginal tunic. As such, the Henderson technique for equine castration was proposed as an alternative method for equine castration that, through the tight torsion of the spermatic cord and vaginal tunic, may reduce the risk of important post-operative complications, including haemorrhage and evisceration.

In the absence of prospective scientific evaluation of the Henderson castration technique in horses and growing popularity of the method, initial information regarding surgical outcomes was based on anecdotal or descriptive reports. These initial reports were conflicting, with reports of overwhelmingly good outcomes, or condemnation of the instrument as dangerous, seemingly in equal measure. One early report claimed a 0% complication rate associated with the Henderson method, with minimal to no bleeding, no appreciable tissue trauma. However, some veterinarians consider the instrument puts horses at risk of evisceration after castration, as reported in the publication presented in Chapter 3. Recently, the complication types and rates associated with castration of horses were determined in a retrospective study of 252 castrations performed using the Henderson castration instrument. In that study, the authors reported a 10.7% overall complication rate which is similar with previous reports of other castration methods (7-37.7%), although a recent study of open castration in standing horses found 60% of horses developed complications. Based on the results of this retrospective study, the authors concluded that the Henderson castrating instrument is an acceptable alternative for
equine castration and that the method was neither protective for nor associated with higher proportions of specific complications compared with reports of other castration methods\textsuperscript{47}. However, these authors did report that horses over 4 years of age were at significantly higher risk of complications than those under 4 years of age at the time of castration\textsuperscript{47}, suggesting animal-level factors may be associated with development of complications in horses after castration. While the study of Hinton \textit{et al.} (2018) suggested that the Henderson castrating instrument is associated with similar types and rates of complications to those encountered with emasculators, the study design did not allow for direct comparison between the techniques and relied on medical records to derive clinical data. The prospective study described in Chapter 4 provides a valuable contribution to the understanding of the Henderson technique in horses, both in terms of complications encountered and also direct comparison with a commonly used a semi-closed emasculator castration technique. The results provided further evidence that both techniques are associated with similar rates of post-castration complications which can be used by veterinary practitioners when deciding on castration methods. Extending the existing knowledge, the study provided evidence of additional surgical and animal factors that may predispose to development of complications.

As well as assessment of novel methods like the Henderson instrument, associations between pre, intra, and post-operative preferences and various complications have been sought by numerous authors in an attempt to minimise morbidity and mortality surrounding equine castration. These include emasculator variation\textsuperscript{6}, approach\textsuperscript{19,43}, ligation of the spermatic cord\textsuperscript{6,15}, use of local anaesthetic injected into the testis and/or spermatic cord\textsuperscript{10}, patient position (standing or recumbent)\textsuperscript{14}, use of peri-operative antimicrobial drugs\textsuperscript{6} and non-steroidal anti-inflammatory drugs\textsuperscript{84}, whether to perform the surgery closed, open, or semi-closed\textsuperscript{6,20} and whether to perform primary closure of the skin\textsuperscript{39,40}. Although the described castration method variations available to the equine surgeon present opportunities to improve surgical outcomes, there is no industry/professional consensus statement and no standard practices for any of these preferences. Different study designs and the lack of agreement on preferred castration approaches precludes meaningful assessment of surgical outcomes (including complications) and
relationships to treatment variables between studies. Most often, information on rates and types of complications has come from small case series of a novel aspect of castration such as primary closure of the skin\textsuperscript{19,39,42}, an inguinal approach\textsuperscript{19} ligation of the vaginal tunic\textsuperscript{8}, that have not been controlled for the many variations available in the performing of castration, or information comes from larger retrospective studies that usually rely on hospital records\textsuperscript{14,20,47} where complications are not defined and ordinal scales have not been validated. Notwithstanding these limitations, some studies have provided evidence of breed-specific risks for important complications after castration. In a large retrospective study of routine castration in Draught-horse colts, using either closed or open emasculator methods\textsuperscript{2}, the rates of evisceration (4.8%) and omental herniation (2.8%) warranted concern as being unacceptably high and prompted revision of the surgical technique. In a subsequent study by the same research group\textsuperscript{8}, modification of the closed emasculator technique by incorporating ligation of the vaginal tunic in Draught-horse colts resulted in a marked reduction in the comparative rate of evisceration (0.76%), indicating that in Draught horse breeds, technique selection is important. In a recent study of castration of horses with the Henderson castrating instrument, a breed effect was also noted: in comparison to Thoroughbred horses, Warmblood horses, Arabians and ‘other breeds’ had increased odds of having a complication. The evidence in these studies\textsuperscript{2,47,95} that animal and surgical factors may be associated with risk of post-castration complications, provided a basis for further investigation of associations between clinical factors that increase or decrease the odds of developing complications in the current study.

6.3.1 Contribution of the research to the scientific literature: Chapter 4

The research in Chapter 4 is the first randomised prospective comparison of the Henderson castrating instrument with the more traditional emasculator method of castration of horses, representing important contributions to knowledge of equine castration. The study provided valuable information regarding the hitherto little-known outcomes of the Henderson castrating instrument and has extended the understanding of complications that may arise with this method in the prospective study. In addition, the study generated new data to contribute to the existing literature on the outcomes associated with emasculator-based castrations in horses:
both in terms of comparisons to previous emasculator castration studies and the comparison to
the Henderson instrument. Additionally, among castration studies, to the authors’ knowledge, it
is the first study of the outcomes of equine castrations that utilizes a standardised ordinal scale
for assessment of the appearance of the surgical sites, which provide clearly defined outcome
measures that have potential for use in future studies, allowing comparison between studies and
analysis of procedures for the prevention and management of post-operative complications.

In this study, the most striking difference between the two techniques was that the Henderson
instrument method was significantly faster, and therefore produced significantly shorter surgery
and anaesthetic durations. It is accepted that increased surgical times are associated with
increased chance of complications including post-operative neuropathies and myopathies\textsuperscript{1,46}
surgical site infection and reduced recovery scores with prolongation of anaesthesia. Further, in
our study, horses that experienced intraoperative anaesthetic or surgical complications were
more likely to exhibit post-operative complications (\(P = 0.012\)) reminding surgeons that
techniques that reduce time in surgery are likely to have benefits in terms of reducing patient
morbidity and are worth considering in pre-surgical planning of castration in horses. In addition
to reducing patient morbidity, faster surgical times when using the Henderson castrating
instrument, in comparison to conventional emasculator castration methods, may contribute to
the uptake of this recently described method by clinicians\textsuperscript{83}: ease of use and reduced surgical
time make it a more convenient method for the busy equine practitioner, and in practice where
reduced surgical times mean that more procedures can performed in a given space of time, this
aspect may translates to financial and time management advantages for the clinician.

Despite the considerably polarised opinions on the safety of the Henderson instrument
expressed by veterinary clinicians in Australia to the research team and also conflicting claims
that the Henderson instrument was associated either with increased life-threatening complications\textsuperscript{83} or alternatively with virtually no damage to tissues and no serious complications\textsuperscript{22}, the rates and types of complications experienced in our clinical study were not
significantly different between the emasculator and Henderson techniques. The overall
complication rate reported in our study (84%) is substantially higher than reported previously in several studies of castration using emasculators\textsuperscript{2,8,14,20} and the Henderson instrument\textsuperscript{22,47}. The most meaningful comparison for the Henderson instrument is a recent retrospective study of 252 horses castrated that reported an overall complication rate of 10.7\%\textsuperscript{47}. While these two rates appear incomparable, the prospective nature of our study, combined with a strict inclusion of any complication, including very mild swelling may explain why this study reported such a high complication rate compared with the previous study of the Henderson technique\textsuperscript{47}. Similarly, most retrospective studies of castration using emasculators reported overall complication rates between 10.2-27.6\%\textsuperscript{2,6,64}, and in prospective studies, complication rates of 6-22\% have been reported\textsuperscript{8,14}. While these collective findings may suggest a substantially greater complication rate and associated animal morbidity in the current study in comparison to previous studies, varying study design may, at least in part, explain the differences. In fact, after swelling, which occurred in 78\% (emasculator 83\%, Henderson 74\%) of horses, the next most frequent complication was haemorrhage at 5.3\% (emasculator 83\%, Henderson 74\%) followed by tissue hanging from the incision at 3.3\% (emasculator 0\% Henderson 7\%), infection at 1\% (emasculator 1.0\%, Henderson 1.1\%), and evisceration 0.55\% (emasculator 0\%, Henderson 1.2\%). With the exception of swelling, these rates, both overall, and for the individual techniques are consistent with the rates and types of complications previously reported\textsuperscript{6,14,20}. The higher rate of swelling in the current study, in comparison to most of the previous studies, likely reflects the prospective study design that included careful detection and recording of any post-operative swelling which was an a priori outcome of interest. The median post-operative swelling score was 1 for both raters (range 0-3 and 0-4 for rater 1 and 2, respectively), indicating that in the majority of horses, the degree of swelling was mild. Indeed, some authors consider mild swelling to be normal after castration and did not record this event as a complication\textsuperscript{22}. More recently, in a study of open standing castration in Thoroughbred racehorses in Hong Kong, 70\% of the horses developed swelling\textsuperscript{7}. This rate of swelling is consistent with our study, and it may reflect a low threshold used for defining swelling as a complication, as was used in the current study. However, in the study by Rosanowski et al. (2018), many of the horses with post-operative swelling required an extended administration of antimicrobial drugs and/or local management through re-opening of the
surgical incisions, suggesting that severity of swelling may vary between studies and possibly with patient positioning (standing versus recumbent). In support of this supposition is the finding in a prospective study where a ‘standing non-sutured’ technique of castration in a field setting was associated with a nearly 4-fold greater occurrence of post-operative swelling (20%) in comparison with a ‘recumbent sutured’ technique performed in a surgical theatre (6%). While these studies\(^7,\^{14}\) suggest that technique may influence development of post-operative swelling, there was no difference in rate of swelling between the Henderson and emasculator techniques, and castration of standing sedated horses was not examined, in the current study.

Similar to the findings of a recent large retrospective study of the Henderson castrating instrument\(^47\), our study found that the likelihood of overall complications, and, when analysed alone, swelling, increased as the horse increased in age and weight. Unlike the study of Hinto et al (2018), which specifically assessed Henderson instrument castrations, our study found that this influence of age and body weight was true for both emasculator and Henderson instrument castrated horses. As a result, these findings may suggest that castration of horses at an early age may be advantageous, since the likelihood of post-operative complications is less.

Another important finding in the study described in Chapter 4 was that use of a ligation of the common vaginal tunic in the emasculator castrations was not associated with development of infection of the scrotum or spermatic cord remnants. In the current study, the rate of infection was only 1%, which is similar to rates described in some previous studies\(^20,\^{47}\). Previous authors have suggested that ligation is associated with increased infection\(^5,\^{6}\), likely as a consequence of the presence of foreign material in a contaminated surgical site. However, a number of more recent studies have not reported a link between complications and use of a trans-fixation ligature around the vaginal tunic\(^8,\^{20}\). In the current study, horses that had conventional castration using an emasculator and placement of a trans-fixation ligature had an infection rate of 1.1%, which is lower than rates in horses that did not have placement of a suture, including those had open standing castration (20-36.7%)\(^7,\^{14}\). Ligation of the vaginal tunic is used to reduce the risk of post-operative haemorrhage and evisceration. Haemorrhage can still occur after placement of the
ligature, due to either insufficient tightening of the suture or bleeding arising from scrotal vessels, rather than the spermatic cord\textsuperscript{8}. Importantly, appropriate ligation of the common vaginal tunic appears to markedly reduce the risk of evisceration and omental herniation, as assessed in Draught-horse colts\textsuperscript{8}, a breed predisposed to these complications after castration\textsuperscript{2}. In a recent retrospective study\textsuperscript{20}, horses that underwent castration without ligation of the tunic did not have an increased rate of evisceration or omental herniation in comparison to those horses that did have a ligature placed; however this conflicting result to that of the study by Carmalt and co-workers\textsuperscript{16} may reflect important breed differences as Draught-horses and Standardbreds, breeds considered predisposed to these complications, comprised of only 3% of the study population.

At the multivariate level, only age and weight were retained as factors associated with increased odds of developing complications. However, an important finding from the univariate analysis was that castration with the Henderson castrating instrument was associated with tissue hanging from the incision site (P = 0.05) and tissue hanging from the wound including evisceration (P = 0.023) when compared with castrations performed with surgical emasculators. A motivation for performing the study in Chapter 4 were anecdotal reports that use of the Henderson instrument may be associated with increased evisceration if the twisted cord and vaginal tunic were to untwist following surgery. While these impressions were unfounded by robust scientific investigation and reliant on personal opinion/anecdote, they are logical and the findings at the univariate level of our data analysis could be considered a stimulus for further investigation via surgical studies with a different population of horses. Conversely, an important consideration when assessing such studies is the comparability of the data. The recent study by Hinton and coworkers\textsuperscript{9} recorded outcomes from a larger number of horses, all castrated with the Henderson castrating instrument, and of a different population to that of the current study. Although the retrospective nature of their data collection may predispose to some observation bias in comparison to a prospective study, it is unlikely that this would affect the recording of such devastating and severe outcomes as evisceration. That study only recorded 1 evisceration out of 252 horses\textsuperscript{9}. That being said, due to the severity of the outcome if a horse were to eviscerate,
the information this paper has provided may provide informed consideration for clinicians using or considering using the Henderson castrating instrument.

Due to logistical constraints, it was impractical to keep horses in the controlled environment of the hospital for the entire 3 month observation period. As such, reporting of post operative outcomes was reliant on the observations of owners and trainers. Aside from the obvious limitations of collecting information second hand, via telephone interview, important questions that came out of the study in Chapter 4 were the effects of post-operative protocols including timing of return to exercise, level of exercise, confinement, utilization of cold hosing hydrotherapy, and use of pharmacological treatments could not be controlled or sufficiently measured. Previously\textsuperscript{6}, and in the study described in Chapter 3\textsuperscript{83}, wide variation in post castration preferences among veterinarians has been reported; however the potential impact of post-operative management has received little attention. In a retrospective study of 324 castrations\textsuperscript{20}, administration of antimicrobial drugs and non-steroid anti-inflammatory drugs were not associated with development of complications, while other aspects of post-operative management, including exercise protocols, level of confinement and hydrotherapy were not assessed. As such, a prospective study assessing the effects of post-operative protocols on outcomes in horses castrated using a standardised procedure is warranted to further develop the capacity for evidence-based decision-making for the management of horses in the post-operative period.

6.3.2 Study Limitations

Notwithstanding the contributions made by this study to the knowledge of equine castration and associated complications, there are possible limitations of the study. Follow-up bias (a form of information bias) may have occurred as post-discharge information not available for some horses, which may have influenced conclusions drawn on outcomes. Information on outcomes following discharge from the hospital was obtained by phone interviews with owners/trainers with risk of recall bias. This form of bias was considered during the planning of the study and effort was made to minimise this impact on internal validity of the study by use of a standardised
telephone survey which was validated to ensure clarity and repeatability of questions. Additional possible sources of bias were information bias from the possibility of errors in classification of the post-operative or post-discharge complications and confounding bias, where mixing of the effects of two or more factors may have occurred, resulting in observed observations of associations between an exposure factor and an outcome includes the effects of one or more extraneous factors. In our study, the likelihood of confounding was minimised through careful consideration of possible confounders and exposures for the outcomes of interest. While our study was undertaken prospectively and with randomisation of surgical technique, external validity cannot be assumed. Our results reflect the Australian context, however, differences in population type (e.g. breed, use and age of horses) in other countries may preclude direct application of our findings. This limitation is inevitable in many clinical studies, given the absence of homogenous horse populations, worldwide. Nevertheless, our results provide important information that can be considered in other geographical contexts and serve as a basis for further investigative studies of complications associated with castration.

6.4 Direct observations of a novel method of equine castration

Despite the numerous options in castration technique (including spermatic cord ligation, surgical approach, patient positioning and peri-operative protocol) and a number of iterations of the emasculator (White’s improved, Sand’s, Serra and Reimer), the industry wide standard for castration has been emasulators, which clamp and crush the tissues of the spermatic cord to achieve haemostasis and occlusion of the vaginal tunic. With the introduction of the Henderson castrating instrument, a new variation of castration surgery became available that achieved the surgical goals of castration in a novel way. Rather than crushing of the tissues, the Henderson instrument achieves haemostasis and security of the contents of the vaginal tunic via torsion. While previous studies and reports have been valuable in generating impressions and limited epidemiological data regarding the use, efficacy and safety of the Henderson instrument for castration, the study contained in Chapter 5 makes a valuable contribution to the understanding of the immediate effects of both the Henderson and emasculator methods of castration in horses. The study has generated further information for consideration during
selection of castration methods in equine clinical practice. The findings in Chapter 5 extend and compliment the outcomes of the study in Chapter 4: collectively these studies have provided the profession with the most comprehensive prospective assessment of the outcomes of the Henderson castrating technique, advancing the knowledge of castration in horses.

6.4.1 Contribution of the research to the scientific literature: Chapter 5

Direct observation of the inguinal ring and remnants of the vaginal tunic and spermatic cord was undertaken in the study in Chapter 5 and we observed potentially important differences between the two methods of castration. In all cases, when horses were castrated using the Henderson technique, the twisted spermatic cord and tunic retracted into the abdomen as soon as the testis was separated from the body. The important clinical implication of this observation is that there is no way to retrieve the cord remnants from the abdomen after use of the Henderson instrument and it is therefore not possible to assess the spermatic cord stump during surgery to confirm adequate haemostasis and closure of the vaginal tunic. Marked haemorrhage did not occur in any of the cases in our study, however, a small amount of intra-abdominal haemorrhage occurred immediately after castration using the Henderson instrument. Furthermore, when subjected to post-mortem examination, the twisted cremaster muscle and vaginal tunic were easily unravelled which exposed the interior of the vaginal tunic which communicates directly with the abdominal cavity and could predispose horses to evisceration or possibly peritonitis. These findings are important as they indicate that the potential for haemorrhage or evisceration by the nature of the mechanism of the torsion of tissue by the Henderson instrument.

The most important observation from the study in Chapter 5 was that in two of the 4 horses castrated using the Henderson instrument, tearing of the internal inguinal ring occurred. It appears that in the horses observed in this study, when the spermatic cord is twisted, it changes from a wide flat structure running through the ring, to a thick narrow structure as it twists around itself. In some cases the expansion of the ring may be enough to exceed tension limits and result in tearing of the vaginal ring and internal inguinal ring. An alternate suggestion for the mechanism of this tearing may also be that connective tissue in the inguinal ring becomes inadvertently wrapped and incorporated into the torsion of the spermatic cord and exert tension on the
structure of the internal inguinal ring eventually causing tearing. Regardless of the mechanism of tearing, the implication of this finding is that damage to the internal inguinal ring could predispose the horse to evisceration.

While the small sample size in the current study precludes conclusive assessment of the association of the Henderson instrument with evisceration or haemorrhage, the presence of these observations warrants further investigation and consideration by equine practitioners. Future assessment of the technique should include the repeatability and possible mechanisms of the tearing of the vaginal and internal inguinal rings, the security of the occlusion of the testicular arteries and the security of the closure of the vaginal tunic. The possible influence of breed on the tissue effects at the vaginal and inguinal rings by the Henderson instrument is worthy of exploration, given that certain breeds (Standardbreds, Draught-horse breeds) are considered to have larger inguinal rings in comparison to other breeds and may be at risk of post-castration herniation or evisceration\textsuperscript{2,6}. Currently, the potential influence of animal signalment on the outcomes of Henderson castration are incompletely understood, although in a recent retrospective study\textsuperscript{47}, when compared to Thoroughbred horses, ‘other breeds’ which included Clydesdales and Standardbreds were associated with increased odds of complication after castration with the Henderson instrument. In the study of Chapter 4, breed was not found to be associated with development of complications in the final multivariable logistic regression models. However, there were only 8 Clydesdale horses in the study population which may have precluded determination of any influence of Draught-horse breeds on development of complications. The study population of Chapter 4 included 56 Standardbred horses, and despite previous descriptions of predisposition to herniation and evisceration after castration\textsuperscript{6}, we found no association of this breed with development of complications in the prospective study. As such, the lack of consistency in the findings of the current studies (Chapters 4 and 5) and previous studies\textsuperscript{22,47} indicate that further assessment of breed predisposition to complications after use of the Henderson technique is warranted to provide best evidence for selection of castration type in individual patients. This study was undertaken as a proof of concept study, to determine the feasibility of the methods used to investigate the effects of castration techniques on soft
tissues that may be associated with risk of complications. This study involved the use of client owned entire male horses that were to be subjected to euthanasia for a non-reproductive disease process associated with a grave prognosis and recruitment of horses relied on horses fulfilling the inclusion criteria and informed owner consent. As such, the number of horses used was small and precluded any statistical exploration of differences between techniques robust conclusions of the risk of evisceration associated with damage from castration techniques. However, this study does provide evidence that structural change occurs with the Henderson technique and it is plausible that this could increase risk of complications.

6.5 Overall recommendations
Based on the investigations carried out in this thesis, a number of recommendations can be made. Chapter 3 highlighted how varied the approach to castration methods are among our veterinarians, and showed that our rates and types of complications are comparable to past studies from overseas. Chapter 4 suggested that there was no significant differences in the clinically-important complications associated with two differed methods of castration, and Chapter 5 demonstrated that the Henderson instrument remains incompletely understood, as the method was found to cause internal damage. However, the importance of this damage is uncertain as the results of Chapters 3 and 4 indicate that this damage is not associated with an increased likelihood or severity of complications. While it was not a major focus of our studies, the finding that ligation of the spermatic cord which some clinicians choose to add security against evisceration was not associated with increased rates of infection, we recommend a ligature. We recommend that veterinarians consider the size of the hose when planning the castration regimen, as heavier horses experienced more complications. Practically speaking, choosing the method with the least tissue trauma, adding peri-operative antimicrobials, use of anti-inflammatory and close monitoring of the patient following the surgery may be warranted based on the individual situation.

The most important recommendation from this research highlights the complimentary nature of the three experiments: it appears that no one factor in castration seems to dictate the outcome.
Presumably this is due to the many and varied surgical and treatment options and possible complications. This is especially evident, as there was no significant different in mortality and serious complications between the two fundamentally different surgical methods which this project set out to compare and contrast. The shorter surgical times found with the Henderson technique makes it both financially appealing to the clinician in practice (and theoretically superior when following Halstead’s principle to minimise surgical time). Yet the impression from the laparoscopic study that there was potential for the Henderson instrument to tear the inguinal ring raised important concerns that should be answered before the Henderson instrument can be fully endorsed. On balance, based on the evidence we have of clinical outcomes at this time, the deciding factor would be the clinician’s comfort with a procedure. This was further evident when the veterinarians of Australia were surveyed: responses were highly varied and often reflected passionate promotion of their approaches to castration, and yet there were similarities between reported rates and types of complications. One important exception is that we would recommend that horses predisposed to inguinal herniation such as Draft breeds be castrated using surgical emasculators until further research be done to clarify our finding of inguinal ring tearing when using the Henderson technique.

6.6 Conclusion

This thesis has provided a profile of the preferences and experiences of Australian equine clinicians when performing castration and reveals attitudes toward pain associated with castration and patterns of use of antimicrobial drugs among Australian equine veterinarians and has further highlighted the lack of consensus regarding best practice for castration. The differences in the attitudes of the veterinarians who responded to the survey (Chapter 3) suggests that the wide range of choices available for performing castration surgery, and the large number of variables involved in the assessment and measurement of surgical outcomes will make comprehensive comparisons between all method options challenging. As such, the ideal combination of patient positioning, surgical technique (including use of ligation, open/semi-closed/closed, instrument type) and post-operative management remains unknown. The findings of Chapters 4 and 5 indicate that surgical instrument type and also possible influences of animal
factors should be considered during the pre-operative planning for castration of individual horses.

This thesis has contributed to an improved understanding of contemporary castration practices in Australia (Chapter 3), outcomes of castration, including prevalence of post-operative complications and identified opportunities to minimise adverse post-castration outcomes through assessment of castration techniques and associated complications (Chapters 4 and 5). While a ‘gold standard’ for the castration of horses may not exist due to a multitude of clinical and animal factors that warrant consideration when undertaking castration, our findings suggest castration of horses using the Henderson castrating instrument was associated with similar rates of complications as a commonly used emasculator technique (Chapter 4). However, the results of Chapter 3 and Chapter 5 suggest that a risk of evisceration is associated with the use of the Henderson instrument for equine castration. Further assessment of this castration method, combining direct observation of the inguinal ring and post-operative follow-up of outcomes would be of benefit. Finally, a meta-analysis of published research findings of equine castration techniques and complications may provide a further contribution to the understanding of factors associated with development of post-operative complications to advance the knowledge in the field of equine surgery.
6.6 References


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7 Appendices

Appendix 1: Introductory paper (Chapter 3) Published in The Australian Equine Veterinarian, as forerunner to launch of clinician castration survey

http://www.sciquest.org.nz/node/110610
Appendix 2: Clinician Castration Survey (Chapter 3)
PARTICIPANT INFORMATION

This is part of a doctorate research project evaluating the rate and type of equine castration complications in Australia.

Doctor of Veterinary Studies (DVStud) candidate:
Mr Christopher Owens BVSc, BBus, MANZCVS Ph: 0428 569329 Email: cowens@csu.edu.au Supervisors:
Mr Gareth Trope BVSc DipVCS, CertES, MVSc, FANZCVS Ph: 0404 377798 Email: gtrope@csu.edu.au Associate Professor Bryan Hilbert BVSc, Dip LAS, MS, FANZCVS, DipACVS Ph: 0434 280660 Email: bhilbert@csu.edu.au Associate Professor Kristopher Hughes BVSc FANZCVS DipECEIM Ph: 0488 111973 Email: krhughes@csu.edu.au

The study is being conducted by the researchers at the School of Animal and Veterinary Sciences, Charles Sturt University. Before you decide whether or not you wish to participate in this study, it is important for you to understand why the research is being done and what it will involve. Please take the time to read the following information carefully and discuss it with the researchers if you wish.

What is the purpose of this study?
A limited number of published studies from the United States and United Kingdom reflect the preferences and experiences of veterinarians in those countries relating to equine castration. We would like to gather information on castration practices and experiences for the benefit of Australian veterinarians. We intend to survey equine veterinarians about their surgical preferences for equine castration, and the types and frequency of any complications they have experienced. We aim to include equine veterinarians from across Australia in an anonymous questionnaire study.

Why have I been invited to participate in this study?
Members of Equine Veterinarians Australia have been selected to participate in this study as we believe they will provide the most relevant information and will benefit most from the findings of the study. Veterinarians who have not performed any equine castrations within the last 12 months need not complete the survey.

What does this study involve?
If you agree to participate, you will be asked to complete an anonymous online survey via ‘Survey Monkey’ consisting of 38 multiple choice and short answer questions that will take up to 15 minutes. The questions will cover demographics (years qualified, amount of equine practice, state), castration preferences in terms of technique and post operative care, and the types and rates of surgical complications experienced.

Are there risks and benefits to me in taking part in this study?
There are no risks to this research as the information collection is anonymous. There will be no personal benefit from your participation in this research.
How is this study being paid for?
This research is funded by the operating funds of the Doctorate of Veterinary Studies.

Will taking part in this study cost me anything, and will I be paid?
There will be no costs or incentives to you for taking part in this survey.

What if I don’t want to take part in this study?
Participation in this research is entirely your choice. Only those people who give their informed consent will be included in the project.
Whether or not you decide to participate is your decision and will not disadvantage you.

What if I participate and want to withdraw later?
As this is an anonymous survey, we are not able to remove participants or their data from the research once the survey has been completed as we are not able to identify individual participants or their responses.

How will my confidentiality be protected?
The questionnaire is anonymous and it will not be possible to identify you from your answers.

What will happen to the information that I give you?
The information will be reported in a research thesis by Chris Owens and may be presented at conferences and published in a peerreviewed scientific journal. All information reported and presented will be anonymous and individual veterinarians and veterinary hospitals will not be identified. The information will be kept for 10 years and may be used in other studies.

What should I do if I want to discuss this study further before I decide?
If you would like further information, please contact Christopher Owens (0428 569329; cowens@csu.edu.au).

Consent for Participation
If you complete the questionnaire, this implies provision of your consent for participation in the project.

Who should I contact if I have concerns about the conduct of this study?
NOTE: Charles Sturt University’s Faculty of Science Human Research Ethics Committee has approved this project. If you have any complaints or reservations about the ethical conduct of this project, you may contact the Committee through the Executive Officer: Ingrid Stuart Faculty of Science Minimal Risk Human Ethics Committee Charles Sturt University 8 Tony McGrane Place, Locked Bag 49 Dubbo NSW 2830 Tel: (02) 68857327 Email: scienceFHEC@csu.edu.au; istuart@csu.edu.au

Thank you for participating. Continuing to the next page will begin the survey.
1. In what Australian state(s) or territory do you practise? If you are practising in another country please list it in 'other'

☐ New South Wales
☐ Victoria
☐ Queensland
☐ Northern Territory
☐ Australian Capital Territory
☐ South Australia
☐ Western Australia
☐ Tasmania

Other (please specify)

2. In what year did you graduate?


3. Approximately what percentage of your caseload is equine?

☐ < 10 %
☐ 10 - 30 %
☐ 31 - 50 %
☐ 51 - 80 %
☐ 81 - 100 %
4. Approximately what percentage of the equine castrations that you performed in the last 12 months were done in the following locations?

<table>
<thead>
<tr>
<th>Location</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>The field</td>
<td></td>
</tr>
<tr>
<td>A practice facility</td>
<td></td>
</tr>
<tr>
<td>A surgical suite/theatre</td>
<td></td>
</tr>
</tbody>
</table>

* 5. Did you perform equine castrations using emasculators in the last 12 months?

- [ ] Yes
- [ ] No
Clinician Castration Survey

Castration Using Emasculators
**The questions on this page relate to castration using emasculators:**

6. Approximately how many castrations did you perform using emasculators in the last 12 months?

7. Approximately what percentage did you perform with the horse in the following positions?
   - Standing
   - Recumbent

8. Approximately what percentage did you perform via the following approaches?
   - Open (parietal tunic is incised)
   - Closed (parietal tunic is not incised)
   - Semi-closed (parietal tunic incised but then sutured closed)

9. When using emasculators, did you ligate the vascular cord with suture material?
   - Yes
   - No
The questions on this page relate to castration using emasculators:

10. In approximately what percentage did you ligate the vascular cord?

11. Please state which suture material you use for ligation of the vascular cord:
<table>
<thead>
<tr>
<th>Clinician Castration Survey</th>
</tr>
</thead>
<tbody>
<tr>
<td>Castration Using Emasculators</td>
</tr>
</tbody>
</table>
The questions on this page relate to castrations using emasculators:

12. Approximately what percentage had the following complications?

<table>
<thead>
<tr>
<th>Complication</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swelling</td>
<td></td>
</tr>
<tr>
<td>Haemorrhage</td>
<td></td>
</tr>
<tr>
<td>Evisceration of intestines</td>
<td></td>
</tr>
<tr>
<td>Eventration of tissue</td>
<td></td>
</tr>
<tr>
<td>Infection of surgical site</td>
<td></td>
</tr>
<tr>
<td>Fever</td>
<td></td>
</tr>
<tr>
<td>Peritonitis</td>
<td></td>
</tr>
<tr>
<td>Colic</td>
<td></td>
</tr>
<tr>
<td>Penile damage</td>
<td></td>
</tr>
<tr>
<td>Hydrocoele</td>
<td></td>
</tr>
<tr>
<td>Death (please state cause)</td>
<td></td>
</tr>
<tr>
<td>Other (please specify)</td>
<td></td>
</tr>
<tr>
<td>Don't know</td>
<td></td>
</tr>
</tbody>
</table>

13. Approximately what percentage of swelling complications fell into the following categories?

<table>
<thead>
<tr>
<th>Category</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild (e.g. swollen incision site)</td>
<td></td>
</tr>
<tr>
<td>Moderate (e.g. swollen scrotum/prepuce)</td>
<td></td>
</tr>
<tr>
<td>Marked (e.g. requiring intervention)</td>
<td></td>
</tr>
<tr>
<td>Don't know</td>
<td></td>
</tr>
</tbody>
</table>
14. Approximately what percentage of haemorrhage complications fell into the following categories?

<table>
<thead>
<tr>
<th>Category</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Mild (e.g. occasional drops)</td>
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</tr>
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<td>Moderate (e.g. frequent drops)</td>
<td></td>
</tr>
<tr>
<td>Marked (e.g. persistent stream)</td>
<td></td>
</tr>
<tr>
<td>Don't know</td>
<td></td>
</tr>
</tbody>
</table>

15. Approximately what percentage of evisceration complications fell into the following categories?

<table>
<thead>
<tr>
<th>Category</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild (e.g. omentum hanging)</td>
<td></td>
</tr>
<tr>
<td>Moderate (e.g. intestine protruding)</td>
<td></td>
</tr>
<tr>
<td>Marked (e.g. large amount of intestine hanging)</td>
<td></td>
</tr>
<tr>
<td>Don't know</td>
<td></td>
</tr>
</tbody>
</table>
At approximately what time post castration did most of the following complications occur?

<table>
<thead>
<tr>
<th>Complication</th>
<th>&lt; 3 days</th>
<th>3 - 7 days</th>
<th>&gt; 14 days</th>
<th>Don't know</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swelling</td>
<td></td>
<td></td>
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<td></td>
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</tr>
</tbody>
</table>

Castration Using the Henderson Instrument
The questions on this page relate to castration using the Henderson instrument:

* 17. Did you perform equine castrations using the Henderson instrument in the last 12 months?

   ○ Yes
   ○ No
Castration Using the Henderson Instrument

The questions on this page relate to castration using the Henderson instrument:

18. Approximately how many castrations using the Henderson instrument did you perform in the last 12 months?

19. Approximately what percentage did you perform with the horse in the following positions?

   Standing

   Recumbent

20. Approximately what percentage had the following complications?

   Swelling

   Haemorrhage

   Evisceration of intestine

   Eventration of tissue

   Infection of surgical site

   Fever

   Peritonitis

   Colic

   Penile damage

   Hydrocoele

   Death (please state cause)

   Other (please specify)
Don't know
21. Approximately what percentage of swelling complications fell into the following categories?

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22. Approximately what percentage of haemorrhage complications fell into the following categories?

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23. Approximately what percentage of evisceration complications fell into the following categories?

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</tr>
</tbody>
</table>
24. At approximately what time did most of the following complications occur?

<table>
<thead>
<tr>
<th>Complication</th>
<th>&lt; 3 days</th>
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<th>7 - 14 days</th>
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<tr>
<td>Death</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>
The following questions relate to anaesthesia of the patient:

25. If you perform equine castrations under GA please describe your anaesthetic (induction and maintenance) protocol:

26. If you perform standing equine castrations please describe your sedation protocol:
Clinician Castration Survey

Peri-operative Management

The following questions relate to peri-operative management:

27. Approximately what percentage of horses in each of the following scenarios received pre or intraoperative local anaesthesia?

- Standing emasculator
- Standing Henderson
- Recumbent Emasculator
- Recumbent Henderson
- Don't know

28. What post-operative management protocols do you recommend? (please tick all that apply)

- Box rest
- Turn out to pasture
- Structured exercise
- Cold water hosing
- No recommendation
- Other (please specify)

29. What is your peri-operative antimicrobial protocol?

- No perioperative antimicrobials
- One dose of penicillin before and/or one dose following surgery
- Penicillin before surgery and for 3-5 days following surgery
- Other (please specify)
30. Please specify the dose of the antimicrobial you administer (If applicable):


31. What is your peri-operative anti-inflammatory protocol?

☐ No anti-inflammatories
☐ One dose of phenylbutazone before surgery
☐ One dose of phenylbutazone before and after surgery
☐ One dose of phenylbutazone before surgery and 3-5 days of penylbutazone following surgery

Other (please specify)


32. Please specify the dose of anti-inflammatories you administer (If applicable):


33. Do you change your peri-operative protocols for anti-inflammatories, antimicrobials or physical therapy depending on which surgical technique you employ?

☐ Yes
☐ No
Clinician Castration Survey
34. Please describe how you adjust your post-operative protocol depending on the surgical technique you use:
Clinician Castration Survey
35. Which castration instrument do you prefer?

☐ Emasculators

☐ Henderson instrument

☐ Other
Clinician Castration Survey
36. For what reason(s) do you prefer the Henderson instrument?

- Habit/comfort with technique
- Employer policy
- Experience of fewer complications
- Heard it has fewer complications
- Experience of less serious complications
- Heard it has less serious complications
- Faster
- Easier to use

Other (please specify)
37. For what reason(s) do you prefer emasculators?

- Habit/ comfort with the technique
- Employer policy
- Experience of fewer complications
- Heard it has fewer complications
- Experience of less serious complications
- Heard it has less serious complications
- Faster
- Easier to use

Other (please specify)
38. If you prefer to use another method than surgical emasculators or the Henderson instrument for equine castration please describe it and why you prefer it:
<table>
<thead>
<tr>
<th>Clinician Castration Survey</th>
<th></th>
</tr>
</thead>
</table>
39. Do you have any other comments or impressions regarding the Henderson instrument, surgical emasculators or castration complications?

This concludes the survey. Thank you for your participation in this research. We greatly appreciate your time and candour and we hope this study will lead to useful information for our fellow Australian equine veterinary surgeons. We look forward to sharing our research with you soon.

Yours Faithfully,

Christopher Owens and the equine team at Charles Sturt University.
Appendix 3: Follow up phone questionnaire (chapter 4)
Owner/animal details

1. What is your horse's name?

2. How old was your horse when he was castrated?

3. How many days has it been since the castration was performed?
   - ☐ 7 days
   - ☐ 14 days
   - ☐ 28 days
   - ☐ 84 days (3 months)

4. Did your horse develop any swelling following castration?
   - ☐ No
   - ☐ Yes

Swelling
5. On a scale of 0-4 (0 = no swelling and 4 = the most severe swelling), how much swelling developed after castration?

- 0 = none
- 1 = mild
- 2 = moderate
- 3 = marked
- 4 = severe

6. When did the swelling appear?

- Days 0-3
- Days 4-7
- Days 8-14
- Days 15-21
- Days 21 or more

7. Where was the predominant swelling?

- Scrotum/wound
- Sheath
- Scrotum and sheath
- Scrotum, sheath and ventral abdomen
- Scrotum, sheath, ventral abdomen and legs
8. Was any treatment required to resolve the swelling?

☐ ☐ No

☐ ☑ Yes

Swelling continued

9. What type of treatment was required?

☐ ☐ Walking and hosing

☐ ☐ Bute + walking and hosing

☐ ☐ Antibiotics + walking and hosing

☐ ☐ Antibiotics, Bute + walking and hosing

☐ ☐ Drainage of incisions under sedation + antibiotics, bute, walking and hosing

☐ ☑ Surgical resection under general anaesthesia to achieve drainage + antibiotics, bute, walking and hosing

Other (please specify)

10. Was the horse treated at the VCC?

☐ ☐ ☐ No

☐ ☐ ☑ Yes

Swelling continued
11. If your horse was not treated at the VCC, do you give us permission to contact the veterinarian who treated your horse?

- [ ] No
- [ ] Yes
- [ ] Not Applicable

Please advise which vet practice/veterinarian treated your horse

Bleeding complications

12. Was there any bleeding from the castration site?

- [ ] No
- [ ] Yes

Bleeding cont'd
13. When did the bleeding occur?

- Days 0-3
- Days 4-7
- Days 8-14
- Days 15-21
- Days 21 or more

14. On a scale of 1-5 (1 = dried blood around incision and 5 = fast flow of blood from the incision), how much bleeding was present?

- 1 = Dried blood around incision
- 2 = Blood clot from incision and occasional drop
- 3 = Slow steady drops from incision (1-2 drops/second)
- 4 = Fast drips of blood from incision (3-4 drops/second)
- 5 = Fast, steady flow from incision

15. Did the bleeding require further treatment?

- No
- Yes
16. If the horse required treatment, what type of treatment was required?

- Sedation and monitoring alone
- Sedate, pack incision with swabs
- General anaesthesia, tie off bleeding vessels
- Blood transfusion, general anaesthesia, tie-off bleeding vessel
- Died/Euthanasia

If died/euthanased - please specify which

17. Was your horse treated at the VCC?

- No
- Yes

18. If your horse was not treated at the VCC, do you give us permission to contact the veterinarian who treated your horse?

- No
- Yes
- Not Applicable

Please advise which vet practice/veterinarian treated your horse
Infection complications

19. Did you observe any pus/infection from the castration sites?

- [ ] No
- [ ] Yes

Discharge/infection cont'd

20. When was the infection first noticed?

- [ ] Days 0-3
- [ ] Days 4-7
- [ ] Days 8-14
- [ ] Days 15-21
- [ ] Days 21 or more

21. On a scale of 1-5, how much pus/discharge was present?

- [ ] 1 = crust around incision
- [ ] 2 = occasional drop of pus, easily wiped away
- [ ] 3 = small amount of pus but always present despite hosing/wiping
- [ ] 4 = Continuous dripping of pus
- [ ] 5 = Other

Other (please specify)

22. Did the infection require further treatment?
Discharge/infection cont'd
23. If infection did occur, what treatment was required?

- Walking and hosing alone
- Antibiotics + walking and hosing
- Bute + walking and hosing
- Antibiotics, Bute + walking and hosing
- Drainage under standing sedation + Antibiotics, Bute, walking and hosing
- General anaesthetic, resection of infected material + Antibiotics, Bute, walking and hosing
- Died/Euthanasia
- Other

If other, please specify

24. Was there a swab taken of the infected fluid/tissue?

- No
- Yes

If yes, what bug was cultured?

25. Was the horse treated at the VCC for the infected castration?

- No
- Yes
26. If your horse was not treated at the VCC, do you give us permission to contact the veterinarian who treated your horse?

- [ ] No
- [ ] Yes
- [ ] Not Applicable

Please advise which vet practice/veterinarian treated your horse

Tissue hanging from castration site

27. Did you notice anything (blood, fat, intestines etc) hanging from the scrotum (wound)?

- [ ] No
- [ ] Yes

Tissue hanging from castration site cont'd
28. When was the tissue hanging from the wound first noticed?

- Days 0-3
- Days 4-7
- Days 8-14
- Days 15-21
- Days 21 or more

29. If tissue was noticed hanging from the wound, what type of tissue was it?

- Blood clot
- Fat
- Omentum
- Small amount of intestine protruding from incision
- Intestine hanging on ground
- Other (please specify)

30. Did this require further treatment?

- No
- Yes

Tissue hanging from castration site cont'd
31. What type of treatment was required to remove the tissue from the wound?

- Gentle walking and hosing
- Trimming of tissue under sedation
- GA and resection of tissue
- GA, exploratory laparotomy, resection of intestine
- Died/Euthanasia
- Other

If died/euthanased - please specify which

32. Was the horse treated at the VCC for the tissue hanging from the wound?

- No
- Yes

Tissue hanging from castration site cont’d

33. If your horse was not treated at the VCC, do you give us permission to contact the veterinarian who treated your horse?

- No
- Yes
- Not Applicable

Please advise which vet practice/veterinarian treated your horse

Poor appetite
34. Did your horse show any signs of poor appetite following castration?

- No
- Yes

**Poor appetite cont'd**

35. When was the poor appetite following castration first noticed?

- Days 0-3
- Days 4-7
- Days 8-14
- Days 15-21
- Days 21 or more

36. Did the poor appetite require further treatment/investigation?

- No
- Yes
37. What, if any, treatment was given to the horse to improve his appetite?

- [ ] NSAIIDs (Bute?)
- [ ] Antibiotics (ABs)
- [ ] Antibiotics and NSAIIDs (Bute)
- [ ] Stomach tube, ABs and NSAIIDs
- [ ] IV fluids, ABs and NSAIIDs
- [ ] Other (please specify)

38. Was the treatment/investigation performed at the VCC?

- [ ] No
- [ ] Yes

**Poor appetite cont’d**

39. If your horse was not treated at the VCC, do you give us permission to contact the veterinarian who treated your horse?

- [ ] No
- [ ] Yes
- [ ] Not Applicable

Please advise which vet practice/veterinarian treated your horse

**High temperature**
40. Did you take your horse's temperature following the castration?
- [ ] No
- [ ] Yes

High temperature cont'd

41. What was your horse's temperature when you measured it?
- [ ] < 37.0 degrees C
- [ ] 37.0 - 38.5 degrees C
- [ ] 38.6 - 39.0 degrees C
- [ ] 39.1 - 40.0 degrees C
- [ ] > 40.0 degrees C
Other (please specify)

42. Did you think your horse had a high temperature following castration?
- [ ] No
- [ ] Yes

High temperature cont'd
43. When was the high temperature first noticed?

- Days 0-3
- Days 4-7
- Days 8-14
- Days 15-21
- Days 21 or more

44. Did the high temperature require further treatment/investigation?

- No
- Yes

High temperature cont'd

45. What, if any, treatment was administered?

- NSAIDs (Bute?)
- Antibiotics (ABs)
- Antibiotics and NSAIDs (Bute)
- Drainage of castration site, ABs and NSAIDs
- GA, surgical resection/drainage of infected material, AB's and NSAIDs

Other (please specify)

46. Was the treatment/investigation performed at the VCC?

- No
- Yes
### High temperature cont'd

47. If your horse was not treated at the VCC, do you give us permission to contact the veterinarian who treated your horse?

- [ ] No
- [ ] Yes
- [ ] Not Applicable

Please advise which vet practice/veterinarian treated your horse

### Colic

48. Did your horse show any signs of colic following castration?

- [ ] No
- [ ] Yes

### Colic cont'd
49. How many episodes of colic were noticed following castration?

- [ ] 1
- [ ] 2
- [ ] 3
- [ ] >3

50. When was the colic first noticed?

- [ ] Days 0-3
- [ ] Days 4-7
- [ ] Days 8-14
- [ ] Days 15-21
- [ ] Days 21 or more

51. If your horse experienced more than one episode of colic following castration, how far apart were the episodes?

- [ ] 1-2 days
- [ ] 2-6 days
- [ ] 1-2 weeks
- [ ] 2-4 weeks
- [ ] > 4 weeks

52. Did the colic require further treatment/investigation?
Colic cont’d

53. What treatment was required to resolve the colic signs?

- Gentle walking
- NSAID (Bute or Flunix)
- Antibiotics
- NSAIDs + antibiotics
- Stomach tube + NSAIDs
- IV fluids + NSAIDs
- Exploratory laparotomy
- Died/Euthanasia

If died/euthanased - please specify which

54. Was the colic treatment performed at the VCC?

- No
<table>
<thead>
<tr>
<th>Colic cont'd</th>
</tr>
</thead>
</table>
55. If your horse was not treated at the VCC, do you give us permission to contact the veterinarian who treated your horse?

- ☐ No
- ☑ Yes
- ☐ Not Applicable

Please advise which vet practice/veterinarian treated your horse

56. Did the horse show stallion like behaviour prior to surgery?

- ☐ No
- ☑ Yes

57. Did your horse show any stallion like behaviour following castration?

- ☐ No
- ☑ Yes

58. If your horse showed stallion like behaviour following castration, was this worse or better than before castration?

<table>
<thead>
<tr>
<th></th>
<th>25%</th>
<th>50%</th>
<th>75%</th>
<th>100%</th>
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<tbody>
<tr>
<td>More colt-like than before castration</td>
<td>☐</td>
<td></td>
<td></td>
<td>☑</td>
</tr>
<tr>
<td>Less colt-like than before castration</td>
<td>☑</td>
<td>☐</td>
<td>☐</td>
<td></td>
</tr>
</tbody>
</table>

59. Did the stallion like behaviour require further treatment?

- ☐ No
- ☑ Yes
60. What, if any, treatment has been administered to reduce this behaviour?

- [ ] None
- [ ] Ensure no access to mares/fillies
- [ ] Sedation
- [ ] Surgical exploration for testicular tissue
- [ ] Euthanasia
- [ ] Other

Other (eg Regumate or Equity vaccine)

61. Was this treatment/investigation performed at the VCC?

- [ ] No
- [ ] Yes
62. If your horse was not treated at the VCC, do you give us permission to contact the veterinarian who treated your horse?

- [ ] No
- [ ] Yes
- [ ] Not Applicable

Please advise which vet practice/veterinarian treated your horse

Other complications?

63. Are there any other complications that you have observed regarding this horse that haven't been covered and you would like to discuss?

Please provide additional details.
Appendix 4: Supplementary tables (Chapter 4)
### Outcome variables of interest

<table>
<thead>
<tr>
<th>Explanatory variables</th>
<th>Any complication post-discharge</th>
<th>Haemorrhage post-discharge</th>
<th>Surgical site swelling post-discharge</th>
<th>Any castration complication*</th>
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<tbody>
<tr>
<td></td>
<td>OR</td>
<td>95% CI</td>
<td>P value</td>
<td>OR</td>
</tr>
<tr>
<td>Technique</td>
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<td></td>
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</tr>
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<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surgeon/surgery</td>
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<tr>
<td>resident/non-surgery</td>
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<td>Surgeon/Resident</td>
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<td>Comorbidities</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<table>
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Table 4.3.2b Results of univariate analysis for associations between clinical factors and development of complications after discharge of horses from hospital after elective castration (extended).
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<th>Explanatory variables</th>
<th>Any post-operative complication</th>
<th>Post-operative haemorrhage</th>
<th>Surgical site swelling</th>
<th>Surgical site tissue eversion</th>
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<td>P value</td>
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<td>Breed 3: draft/horse/pony</td>
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</tr>
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<td>Anaesthetist</td>
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<td>Anaesthetic time (min)</td>
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<td>1.01</td>
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<tr>
<td>Surgery time (min)</td>
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<td>1.01</td>
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<td>Intra/immediate post-operative treatments</td>
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<td>Treatment for post-operative complication</td>
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</tr>
<tr>
<td>Treatment for swelling prior to discharge</td>
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<td></td>
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<tr>
<td>Treatment for haemorrhage prior to discharge</td>
<td>NA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 4.3.23b Results of univariate analysis for associations between clinical factors and post-operative complications in 180 horses that have undergone elective castration (extended).

| Treatment for tissue eversion prior to discharge | NA | NA | NA |
| Treatment for fever prior to discharge | NA |

Table 4.3.23b Results of univariate analysis for associations between clinical factors and post-operative complications in 180 horses that have undergone elective castration (extended).
References

17. Henderson LS and Parks RC iSMaSCI, assignee, Method and application for livestock castration. US patent5591176A November 29, 1994
41. Palmer SE: Castration of the horse using a primary closure technique, Proceedings, Proceedings of the Annual Convention of the American Association of Equine Practitioners 1984 (available from
43. Riemersma D: Complication rate of castration of the horses using an inguinal approach in 554 cases, Proceedings, Proceedings of the European College of Veterinary Surgeons, 2005 (available from