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Editorial Open Access

The Next Decade for Sport Horses Will Be the Time of Wearable Technology

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Ensuring a high level of horse welfare is a critical factor in contemporary equine breeding. In specific disciplines, horses in equestrian sports start their careers at a young age while still developing and being physically and mentally immature. The exercise session activates both behavioral and physiological responses, which serve as stimuli for adaptation. Scientific understanding of the stressful stimuli and training load associated with equestrian sports can greatly enhance the development of well-balanced training programs, promoting better sports results and overall well-being. Improving the quality and safety of sports competitions is a relevant scientific topic, both in humans, but especially in other animal species that do not have free will, such as horses. Trainers, owners, and veterinaries need to improve the functional capacity in conjunction with the well-being of the athlete's horse. In recent years, there has been a significant advancement in obtaining real-time data from athletic horses during training and equestrian competitions, leading to improved performance and injury prevention. The development of equipment attached to the horse's body, also known as wearable devices, is rapidly evolving. Wearable technology is a relatively new phenomenon related to equestrian sports, supporting biomechanics, cardiovascular, respiratory, and thermometry biometrics studies [1]. As a line of research, this trend can contribute to the generation of health indicators, which could help prevent heat stress, musculoskeletal injuries, and catastrophic events during the athletic life of horses. These devices can aid the lameness diagnosis by detecting movement asymmetries and assessing fitness levels. Some researchers seek alternative methods to improve performance and preserve the equine athlete's health and safety. The areas of exercise physiology and biomechanics, when approached jointly, could be an interesting interface between sport science and equine culture. Some breeds of horses are used almost exclusively for sport, requiring technical and rational training programs. In the last two decades, there has been considerable progress in research in both areas.

The use of wearable sensors in athletic horses is extensive, encompassing all physiological and biomechanical information-gathering systems that a horse may carry during training and competitions. Wearables should accurately assess biometrics such as locomotion, plasma lactate, heart rate, heart rate variability, respiration rate, and impact forces.

In articles that address human training protocols, the authors often use the concept of external or internal load to prescribe and evaluate conditioning programs to optimize training adaptation. The load concept considers volume and intensity for training prescription. External load is represented by duration, frequency, distance covered, average and maximum speed, treadmill or track inclination, duration and number of steps, duration and number of strides, and support time; in other words, external stimuli induce internal physiological responses. Internal load indicates systemic physiological adjustments of athletes that occur due to stimuli caused by an external load. Both heart rate and blood lactate levels can

serve as classic indicators to measure internal load during running exercise. In this way, the physical conditioning of athletic horses should employ a training load to induce specific physiological responses, such as angiogenesis and muscle hypertrophy, as well as an increase in cardiac output, among others. In this scenario, monitoring external and internal load during acute training sessions and, even in official competitions, from wearables devices become crucial to improve prescription accuracy and post-exercise recovery. These affordable measurements have been obtaining more and more support of recent validation and accuracy studies performed by research groups worldwide.

Conflicts of Interest

The author declares that there are no conflicts of interest.

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Case Report Open Access

Case Series Presenting a Modified Approach for Permanent Perineal Urethrostomy in Horses

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Abstract

Permanent perineal urethrostomy (PPU) may be performed in horses with severe preputial or penile trauma, in which surgical repair of extensive urethral damage is too complex or even impossible. We hypothesized that a modified PPU approach would abolish the use of postoperative indwelling urinary catheters (PIUC) and that the complication rate would be low. Therefore, the main objective of this report is to share our experience performing a modified approach for PPU in horses. Four geldings were referred after a history of severe urogenital laceration, and PPU was performed by removing a skin flap incision forming an inverted triangle (2.5 cm base and 5 cm sides) on the perineal raphe. None of the horses were submitted to the placement of PIUC. Short-term complications were restricted to partial PPU wound dehiscence in one horse, but this did not impede complete healing. Complications encountered after hospital discharge comprised urine staining of the hind legs in two (50%) horses. Urethral stoma retraction was a common sequel in all horses, but it did not impair urinary patency. The main limitations of this study were the small sample size and reliance on owner recall for outcome information. Overall, the complication rate was considered low, and owner satisfaction with the post-operative result was high. In conclusion, the modified approach for PPU using the inverted triangle-shaped incision adapted from the Williams technique of partial phallectomy proved to be a suitable alternative in the described horses, abolishing the use of PIUC. Furthermore, the urethral stoma remained patent in all horses even 75 months after surgery.

Keywords

Inverted triangle incision; gelding; urine staining; urethral trauma; urinary system; Williams technique

1. Introduction

Disorders of the male equine urinary tract that may require surgery of the urethra include congenital anomalies (rectourethral fistulas), and acquired disorders. Urolithiasis, soft tissue obstructions (neoplasms or strictures), hematomas, and lacerations are the most common acquired disorders [1]. Trauma-induced injuries to the stallion's distal penis and urethra have been related to direct injury during copulation and fights with other horses [2]. Nevertheless, colts and geldings are also at risk of traumatic lacerations of the urogenital tract [3]. These lesions are accompanied by severe blood loss, especially when the *corpus spongiosum* is compromised [4]. Urination may exacerbate blood loss and might not be confused with hematuria. The most common causes of hematuria include renal, ureteral, vesicular, or urethral calculi; renal, and vesicular neoplasia; and pyelonephritis [1]. Therefore, detailed clinical evaluation and ancillary diagnostic methods, such as ultrasonography, may play an important role in achieving a correct diagnosis [3].

Severe preputial or penile trauma in horses is most commonly treated with amputation due to concerns about postoperative urethral stricture and occlusion [5]. Among the treatment options, permanent perineal urethrostomy (PPU) may be

performed in horses with extensive urethral damage, in which surgical repair is too complex or even impossible [1,6].

We hypothesized that the modified PPU approach would abolish the use of postoperative indwelling urinary catheters (PIUC) and that the complication rate would be low. Therefore, the main objective of the present report is to share our experiences performing a modified approach for PPU in four horses. This case series presents clinical and laboratory features of horses with severe urethral laceration, as well as the outcomes following surgical intervention, including short and long-term follow-up. Data were collected retrospectively over 7 years without randomization or a control group.

2. Cases Details

2.1. History and Clinical Evaluation

Four geldings were referred after a history of severe urogenital laceration. Epidemiological and long-term follow-up data are summarized in **Table 1**. Upon physical examination, all horses were apparently calm, tachycardic (48-53 beats per minute), and dehydrated (capillary refill time equal to/ greater than 3 seconds). Pale mucous membranes were present in two (50%) horses. Rectal temperature was within reference values for horses. Intestinal motility was assessed by auscultation and considered within normal parameters in all horses [7]. In Horse 3, the owner sutured the skin laceration causing subcutaneous urine accumulation **(Figure 1A)**. Three (75%) horses (Horses 1-3) presented deep lacerations located on the inner thighs reaching the urethra. Penile urethral catheterization revealed the lacerations located at the subischial arch in these horses. One (25%) horse was a wandering animal and no clinical history was available. This horse presented an extensive scar on the ventral abdomen, and the preputial skin fold and glans penis were not detected. There was a fistula on the right side draining urine and fibrin clots **(Figure 1B)**.

2.2. Laboratory Findings

Laboratory data at hospital admission are presented in **Table 2**. Hematology revealed low hematocrit, red blood cells, and hemoglobin values in all horses, probably due to acute blood loss from the muscular and urethral lacerations or due to chronic inflammatory processes (Horse 4). Horse 1 presented discrete leukopenia. No hemoparasites were visualized on the blood smears [8]. Serum biochemistry assay presented hypoalbuminemia in all horses and hypoproteinemia in Horse 3. Urea and creatinine levels were within reference values in all horses [9], since there was no urinary obstruction and the horses could urinate through the lacerations sites. Fecal egg count using McMaster's technique [10] was negative in all horses.

Urinalysis was performed on one horse (Horse 4) revealing abnormalities in physical (yellowish coloration, fetid odor, and cloudy aspect) and chemical evaluation (proteinuria and occult blood). Examination of urinary sediments presents countless leukocytes, bacteria (cocci and bacilli), and few red blood cells.

2.3. Surgery

After clinical evaluation, PPU was chosen due to the extensive urethral laceration. Two horses (Horses 1 and 3) were submitted to standing PPU after sedation (intravenous continuous infusion rate of detomidine [0.01 mg/kg] and butorphanol [0.02 mg/kg]), epidural anesthesia and pudendal local blockade (bupivacaine: 0.06 mg/kg). Two horses (Horse 2 and 4) underwent general anesthesia for proper surgical debridement on the laceration sites and fistula, respectively. After pre-medication with 10% xylazine hydrochloride (1 mg/kg, intravenously [IV]) and morphine (0.05 mg/kg, intramuscularly [IM]), induction was obtained with ketamine (2 mg/kg, IV) and midazolam (0.05 mg/kg, IV). Orotracheal intubation was performed, and general anesthesia was maintained using isoflurane and oxygen flow in a closed circuit. Horse 4 was initially submitted to fistula exploration by an elliptical incision, and the glans penis was detected on the subcutaneous tissue on the right inguinal region, along with fibrin clots and purulent material **(Figure 1C)**.

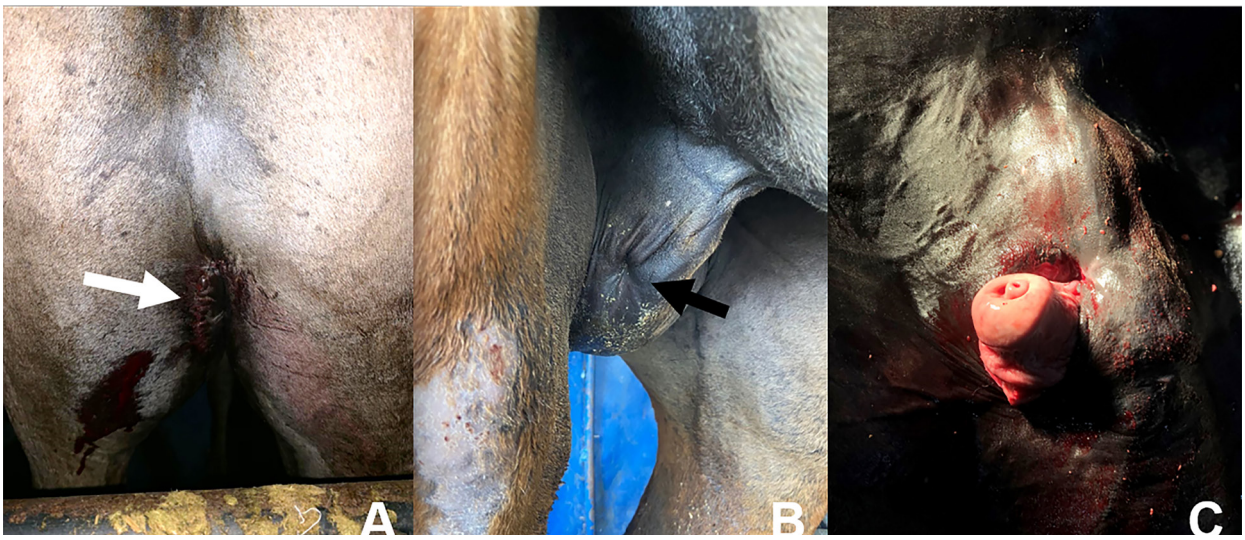

Figure 1: (A) Horse 3. Skin laceration sutured by the owner (white arrow). Note drainage of urine from the suture causing urine staining. (B) Horse 4. Urine and fibrin clots accumulate in the subcutaneous tissue and drain from a fistula (black arrow). (C) Horse 4. After fistula exploration, the glans penis was within the subcutaneous tissue on the right inguinal region.

Table 1: Epidemiological and long-term follow-up data of four horses submitted to permanent perineal urethrostomy.

Horse	Breed	Age (years)	Weight (kg)	Clinical evolution (days)	Anesthesia	Month/year of surgery	Hospital discharge (days)	Complications	Follow-up period (months)
1	MM	10	360	15	Sedation + epidural	July/2016	28	None	75
2	Crossbred	1½	120	3	General	September/2019	39	Urine staining	37
3	Crossbred	4	320	1	Sedation + epidural	December/2019	17	Urine staining	34
4	Crossbred	6	230	NAD	General	February/2022	44	None	8

MM: Mangalarga Machador; NAD: No available data.

All horses were submitted to urethral catheterization through the urethral laceration (Horse 1-3) or penile urethra (Horse 4), reaching the urinary bladder. After surgical preparation, PPU was performed by removing a skin flap incision forming an inverted triangle (2.5 cm base and 5 cm sides) 6-15 cm ventral to the anus on the perineal raphe **(Figure 2A)**. Then, divulsion was propagated through the subcutaneous tissues, bulbospongiosus muscles, and *corpus spongiosum*, using a Metzenbaum scissor and/or scalpel, taking care not to enter the urethral lumen. The bulbospongiosus and the retractor penis muscles were sutured along their cut edges with simple interrupted sutures using 2-0 polyglactin or 2-0 polyglecaprone sutures. The urethra was identified and stabilized by palpation of the urinary catheter. To create the urethral stoma, the exposed urethra was incised on its midline from the base to the apex of the triangle, and the incised edges of the urethra and the triangle's epithelial border were apposed with simple interrupted 2-0 polyglactin or 2-0 polyglecaprone sutures **(Figure 2B-D)**. None of the horses were submitted to the placement of PIUC. Postoperatively, drug therapy consisted of anti-inflammatory drugs (flunixin meglumine: 1.1 mg/kg, IV, q24h, three days), antibiotics (potassium penicillin: 30,000 UI/kg, IV, q6h, three days), and antitetanic serum (5,000 IU; IM). Both surgical wounds were dressed twice daily with diluted (1:100) iodopovidone solution, followed by healing ointment. PPU surgical site completely healed in 12 to 17 days after surgery **(Figure 3A-B)**. The wounds from the lacerations and surgical debridement sites varied from 17 to 44 days for complete secondary intention healing.

2.4. Short and Long-Term Complications

Short-term complications (defined as the time from surgery until hospital discharge) included partial dehiscence of the PPU (three suture stitches) on Horse 3 but did not impede complete healing. Horse 4 was adopted at the end of the treatment. At the time of manuscript preparation, long-term follow-up (defined as ≥ 8 months) was conducted by telephone contact with the owners **(Table 1)**. Owners were asked about complications at the PPU and adaptation of posturing to urinate, and they were asked to send a photograph of the surgical site. All owners reported that the horses adapted their posture to urinate by lifting the tail in approximately 2-6 months. Urethral stoma retraction was a common sequel in all horses, but urinary patency remained unaltered **(Figures 3C-F)**, and urination occurred only through the PPU. Even after adaptation, Horses 2 and 3 presented persistent urine staining of the hind limbs (**Figures 3C** and **F**). The owners were advised to manage the staining by regularly washing the area and protecting the skin with baby oil.

Table 2: Hematological and biochemical findings at hospital admission in four horses with a urethral laceration.

Parameter	Horse 1	Horse 2	Horse 3	Horse 4	X ± SD	Reference values*
Hematocrit (%)	16	21	19	23	19.75 ± 2.98	24-44
Red blood cells (x 106/µL)	3.16	4.13	4.57	4.37	4.05 ± 0.62	5.5-9.5
Hemoglobin (g/dL)	5.5	7.3	6.6	8	6.85 ± 1.06	8-14
TPP (g/dL)	6.7	5.4	5	6.6	5.92 ± 0.85	5.2-7.9
Albumin (g/dL)	1.9	1.53	2.1	1.14	1.66 ± 0.42	2.6-3.7
Fibrinogen (mg/dL)	200	400	600	400	400 ± 163.29	100-400
Total leukocytes(/µL)	5,100	10,500	10,400	7,300	8,320 ± 2,610	6,000-12,000
AST (U/L)	150	354	288	183	243.75 ± 94.15	226-366
GGT (U/L)	4	12	6	7	7.25 ± 3.04	6.1-17.4
Creatinine (mg/dL)	1.5	1.8	1.3	1.2	1.45 ± 0.26	1.2-1.9
Urea (mg/dL)	34	48	26	45	38.25 ± 10.14	21.4-51.3

TPP: total plasma protein; AST: aspartate aminotransferase; GGT: gamma-glutamyltransferase. *Kaneko *et al.* [9], Freeman *et al.* [8].

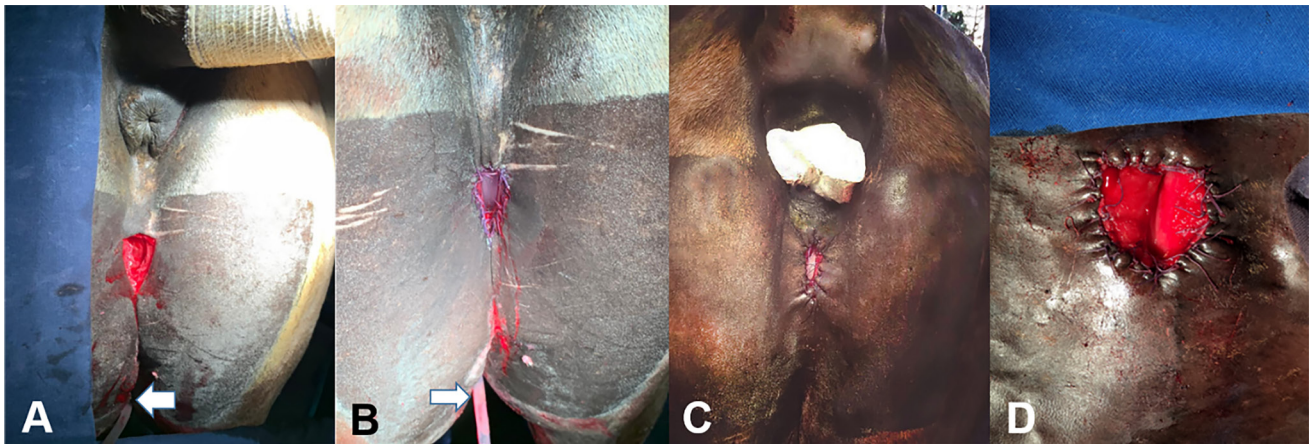

Figure 2: Surgical procedure. (A) A triangular skin flap forming an inverted triangle (2.5 cm base and 5 cm sides) 6-15 cm ventral to the anus on the perineal raphe is removed. Note that urethral catheterization was performed through the laceration site (white arrows). (B-D) The appearance of the permanent perineal urethrostomy immediately after surgery on Horse 3 (B), Horse 1 (C), and Horse 4 (D – closer view).

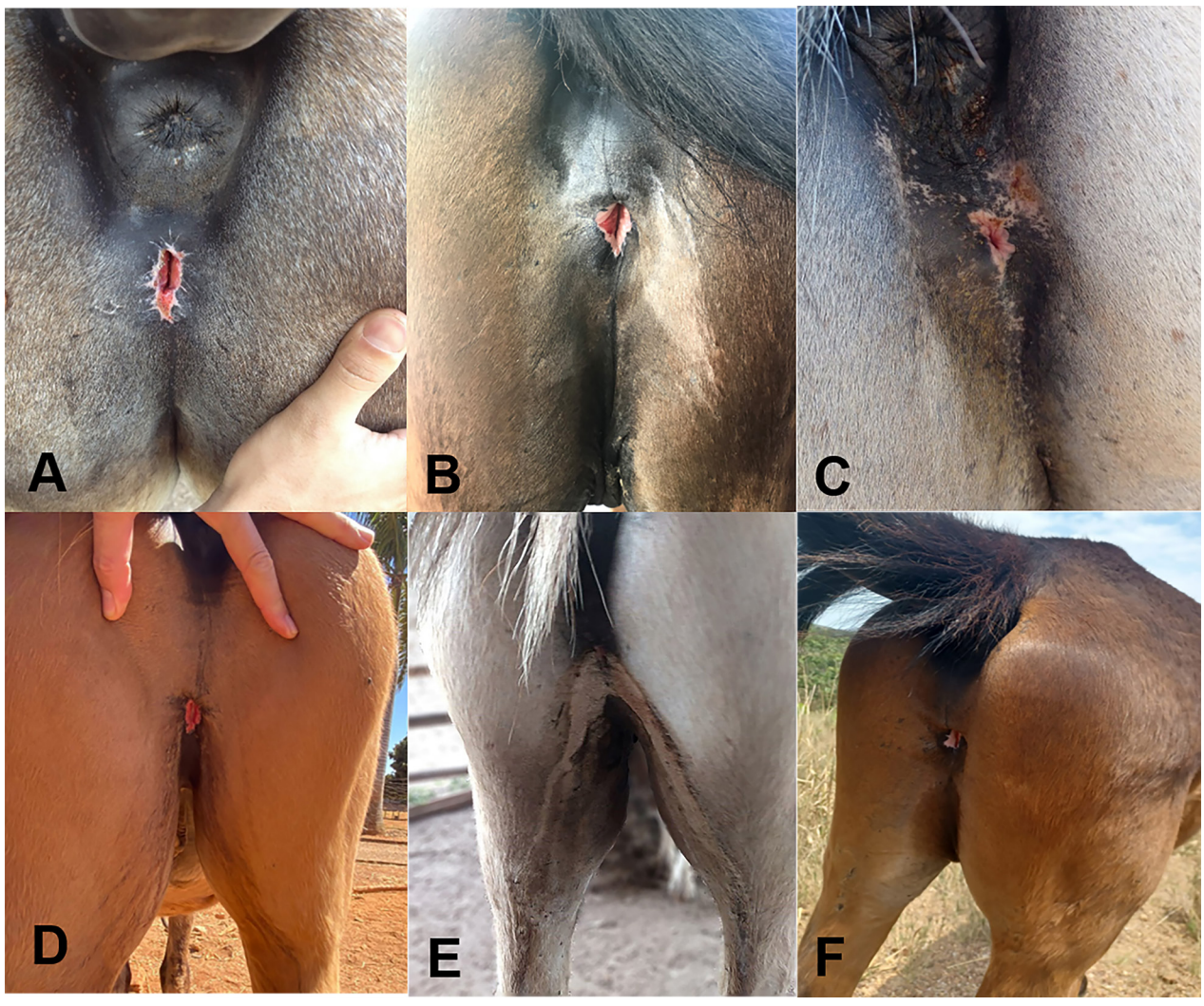

Figure 3: Short and long-term follow-up. (A-B) The appearance of the permanent perineal urethrostomy (PPU) of Horse 1 (A), and Horse 4 (B) at hospital discharge at 28 and 44 days' post-surgery. (C-F) The appearance of the PPU of Horse 1 (C), Horse 2 (D), Horse 3 (E), and Horse 4 (F) at 75, 37, 34, and 8 months' post-surgery, respectively. Note the urine staining on the inner thighs of Horse 2 (D) and Horse 3 (E).

3. Discussion

Perineal urethrotomy at the ischial arch is most commonly performed to provide access to small cystic calculi, to treat hemospermia or hematuria, and to divert the flow of urine from the penile urethra for such conditions as urethral laceration or urethrolithiasis in horses [1]. This technique is often associated with the placement of PIUC aiming to prevent urethral stricture, and associated short-term complications may achieve 75% [11]. Placement of PIUC is also performed in horses submitted to PPU [5,12,13], and seemed to be related to the development of postoperative complications [11].

Herein, we adapted the Williams technique of partial phallectomy [14] to be performed as a PPU. The intention of the inverted triangle incision with a 2.5 cm base was to assure urethral patency, eliminating the use of PIUC and decreasing the chance for urethral stoma stricture. None of the horses demonstrated short-term complications reported in horses with PIUC, that includes colic, stranguria, severe cystitis, urethral stricture, and ruptured bladder [11]. Long-term follow-up was performed at 8 to 75 months post-surgery proving maintenance of urethral patency, even in cases where some urethral stoma retraction occurred (Horse 1).

Caution must be taken when performing a PPU in order to make the incision on the perineal raphe and that multiple planes of dissection are not made through the tissues, preventing excessive edema and increasing suture tension [1]. Suturing of the bulbospongiosus and the retractor penis muscles along their cut edges is important to ensure accurate and tensionless apposition, facilitating the subsequent apposition of the perineal skin and urethral mucosa. These preventive measures also decrease the occurrence of hemorrhage from the surgical site at the end of urination, that may occur up to two weeks, since the bulbospongiousus muscle contracts at the end of urination, and this increases the pressure in the *corpus spongiosum* [6,11]. Additionally, prior urethral catheterization is crucial to prevent midline incision deviation and cranial urethral wall penetration [1,6,12]. All these cares were taken on the horses submitted to PPU in this case series, reducing the incidence of short-term complications, which was restricted to partial surgical wound dehiscence in one case (Horse 3).

Severe preputial or penile trauma in horses is most commonly treated with amputation [5]. Although, PPU may be an interesting surgical option in geldings with extensive urethral laceration since it can be performed in a standing position in sedated subjects, which mitigates against additional costs and risks associated with general anesthesia [4,6]. Recently, a temporary perineal urethrostomy was performed to divert urine from the urethral reconstruction site in a stallion submitted to fistulectomy and urethral resection and anastomosis, that caused distortion of the urethral lumen at the fistulectomy site. This complication was managed by urethral dilatation for 5 minutes every 12 hours for 3 days [5]. In our cases, PPU seemed the best approach regarding the acute nature of the injury in three horses (Horse 1-3) associated with the owner's financial constraints.

Long-term complications in this study were restricted to urine staining of the hind legs in 50% of the horses (in 2/4 cases) following PPU. In these cases, persistent urine staining of variable degrees made regular cleaning of the hind legs necessary on a long-term basis. This complication is frequently reported and may vary from 11% [15] to 71% [4] of the cases. In more severe cases, urine staining may evolve into scalding and/or urine-induced dermatitis [4]. Herein, probably the variation in the distance from the PPU incision to the anus (6-15 cm) may have influenced the occurrence of urine staining since some authors advocate the subischial approach [1,13]. A recent study on 14 horses submitted to PPU reports that some horses never adapt the posture to urinate or learn to lift the tail while urinating, and others horses present urine staining despite lifting their tail and adapting the posture to urinate [4]. Owners must be made aware of this possible complication prior to surgery and that this may demand a more involved long-term post-operative management, such as daily cleaning of the affected area [4,11,15]. Other complications include ascending cystitis, urethral stricture [11], and myiasis [12].

The limitations of the present study included its retrospective nature; the small sample size, and reliance on owner recall for long-term complications and outcome information. However, the overall complication rate was considered low, and owner satisfaction with the post-operative result was high, including cases with persistent urine staining.

4. Conclusion

In conclusion, the modified approach for PPU using the inverted triangle-shaped incision adapted from the Williams technique of partial phallectomy proved to be a suitable alternative in the described horses, abolishing the use of PIUC. Furthermore, the urethral stoma remained patent in all horses even 75 months after PPU.

Authors' Contributions

A.C.L.C, H.A.L.A., F.H.B.X. and R.C.C. conducted the clinical examination, laboratorial analysis. and surgical procedures. A.C.L.C and H.A.L.A. wrote the manuscript, and F.H.B.X. and R.C.C. revised it. All authors read and approved the manuscript.

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Conflicts of Interest

The authors declare that there are no conflicts of interest.

Ethical Approval

The horses presented herein were attended as patients at the Large Animal Veterinary Teaching Hospital, Universidade de Brasília, Brasília-DF, Brazil. The owners signed a consent form to permit hospitalization, surgery, and treatment. Additional consent was obtained for using the images for research purposes. The authors also confirm that the study has followed the guidelines of the Declaration of Helsinki.

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Original Article Open Access

A Study Investigating Prevalence of Pain in UK Horse Riders over Thirty-Five Years Old

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Abstract

Horse riding is considered one of the most dangerous sports, more so than skiing, motor racing, and rugby. On average, a rider falls once every two years, and during their career, one in five are seriously injured. Previous research has examined pain in elite dressage, show jumping, and event riders, as well as how overuse injuries and lifestyle can exacerbate pain and affect performance. Persistent pain can be debilitating and determine the end of a career. This study aims to investigate the prevalence of pain in riders over 35 years old, the location and management of pain, and the self-perception of whether pain affected riding. Due to the exploratory nature of the survey undertaken, a primarily quantitative approach was used. 2185 participants completed a questionnaire containing 46 open and closed questions. Pain was experienced by 85.4% (n = 1866) of participants, making riders over 35 years old 5.85 times (O.R.) more likely to experience pain than pain-free. Females were 1.28 times (O.R.) more likely to experience pain than male riders. Participants attributed their pain to old age, arthritis, performing stable duties, and previous injuries, with 42% (n = 784) of participants having to stop riding due to pain. The most common method to treat pain was over-the-counter medication, with female participants being 2.2 times more likely to take medication than males. Participants who had been riding for 20 years or more were 6.54 times (O.R.) more likely to have pain than not, and riders who did not take part in any other physical exercise were 1.4 times (O.R.) more likely to suffer pain. The high frequency of pain in riders over 35 years, particularly lower back pain, could be due to the length of their riding career. While this study reports individual perception of pain and pain management, it is individual perception that is likely to determine the impact of the pain on that individual. Further research is required regarding the perception of pain to better establish the causes of pain and determine appropriate management strategies.

Keywords

Horse riding; equestrian; injury; pain; asymmetry

1. Introduction

In the United Kingdom, 3 million people ride horses regularly [1]. Compared to many other sports, equestrian career longevity can span for decades and it is classed as an early start, late specialization sport [2]. Within the sporting disciplines competition ages range from under 10 to seniors. Some riders regularly compete into their 60's and 70's, even at the Olympics level, suggesting age is not necessarily a limiting factor in equestrian sport. Leisure riding has become increasingly popular with many older riders coming back into the sport later in life [1]. Riding is considered moderately physically demanding and can be highly challenging. It presents a degree of risk as the horse is often an unpredictable creature, capable of moving at 35 mph, and the rider being approximately 3 meters off the ground. During their career, one in five equestrians are seriously injured [3]. On average, a rider will fall from a horse once every two years [4]. This indicates that older athletes who have ridden for many years are likely to have been injured at some point during their riding career. Thirty-seven percent of riders with equestrian-

related injuries requiring hospitalization were over the age of 35 years [5].

In addition to traumatic injury, repetitive movements over a long period of time can cause overuse musculoskeletal injuries and are a common cause of early retirement from sports [6]. Long-term consequences of injury and pain may affect the quality of life and general health [7–10] and may continue to be problematic long after the rider ends their riding career, potentially affecting their everyday lifestyle [11,12].

Injury and pain may also reduce physical performance and sport participation, impacting the success of teams and organizations, as well as individual athletes [7]. Previous injury may lead to asymmetry affecting balance and performance [13–15]. Poor posture and an inactive core may cause pain at some point in the rider's life, and if not actively trained and rehabilitated, repetitive injuries can cause back pain to be more common earlier in life [16].

Previous studies have shown there to be a large proportion of elite competition riders suffering from pain [17,18], with over 35-year-olds reporting the highest levels. There is little research on the prevalence of pain in older non-elite and leisure riders. Further research is needed to establish how pain affects riders as they get older to establish common injuries seen in riding, prevention, treatment, and pain management strategies.

The study aims to investigate the prevalence, location, and severity of pain in riders over the age of 35 years. It also aims to discover factors that affect the pain that riders experience and the pain management techniques used by riders over the age of 35 years.

2. Methods

A survey methodology was selected to answer the aims. The survey tool was a six-part online questionnaire (SurveyMonkey®) that was made available to riders thirty-five years old or over, following full institutional ethical approval. The online questionnaire was accessible for one month, and no incentive was offered to participants. The questionnaire was delivered online to access a geographically diverse population and allow them to respond at their convenience. Volunteer participants were recruited from personal contacts via email, and a number of specialist equestrian social media sites (such as the Horse & Hound forum) were identified, and a link to the questionnaire was posted on these sites. A snowball sampling technique was employed where those receiving an email regarding the questionnaire were asked to send the email to other horse riders that they knew. Due to the anonymity of the questionnaire, completion of the form was considered consent to take part in the study (as explained to them in the participant information sheet preceding the survey).

2.1. Measure

A questionnaire was constructed using the principles put forward by Diem [19] and was adapted from the questionnaire used to investigate pain in elite competitive horse riders [17,18,20]. The questionnaire, containing forty-six questions, was developed containing a mixture of closed-response (e.g. Yes/No and Likert scale) and open-response items [21] and was designed to take no longer than 15 minutes to complete. Section 1 asked respondents to state their riding and competition level. Section 2 asked questions related to a previous injury and self-reported level, location, and cause of pain (adapted from validated questions taken from the short-form McGill Pain Questionnaire [22]). Section 3 was specific to the perceived impact this pain had on their performance. Section 4 asked what factors contributed to increased levels of pain when riding (e.g. saddle, movement of the horse, cold weather, yard work). Information related to the participant's management strategies for dealing with this pain (e.g. over-the-counter pain medication, prescription pain medication, manual therapy such as physical therapy, chiropractic treatment, and other strategies) was also gathered. The final section (5) was modified for equestrian athletes from the Oswestry pain questionnaire [23] to assess the impact their pain has on their general life and wellbeing. Validity evidence for the instrument was provided by reviewing the questionnaire for (1) clarity of wording, (2) use of standard English and spelling, (3) reliance of items, (4) absence of biased words and phrases, (5) formatting of items, and (6) clarity of instructions [24]. Two faculty senior academics experienced in survey design were asked to use these guidelines to review the instrument. Based on the reviewers' comments the instrument was revised and as a pilot study, the questionnaire was distributed to 10 riders before further revisions were made prior to final administration.

2.2. Data Analysis

In total, there were 2803 respondents with 618 discounted due to non-completion of the questionnaire, leaving 2185 to be analyzed. Data from the SurveyMonkey® package were downloaded into a Microsoft Excel® (2010) spreadsheet. Descriptive statistics were used to report frequencies and percentages within the data. The Chi-squared test and odds ratios were utilized to assess the prevalence of pain experienced by riders over the age of 35 years. To analyze relationships between variables, Spearman's test, Kendall's Tua test, and odds ratios were performed. An alpha value was set at $p < 0.05$ (confidence interval 95%) throughout unless otherwise stated. Data were analyzed using SPSS for Windows version 24.

3. Results

3.1. Sex and Age

Of the participants that completed the survey, 98% were female and 2% were male. Female participants were 1.28 times (O.R.) more likely to have experienced pain in the last two years than male participants.

Total participants per age group ranged from 31% of the riders in the 35–40 category to under 1% in the over 70 years category **(Table 1)**. Eighty-three percent of participants reported suffering from chronic pain, with the 61 to 65 years category experiencing the most pain (90%) and the 35 to 40-year-old group, reporting the least pain (79%). Most pain reported was mild or moderate **(Table 2)**.

3.2. Location and Severity of Pain

The most common location of pain experienced was the lower back (51.9% of participants), and the least common location to experience pain was the head (12.7%). Other areas of pain are reported in **Figure 1**. A total of 54% suffered from pain for over 6 years, 16% for four-five years, 21% for two-three years, and 8% for 1 year or less. 7.8% of those reporting pain had experienced severe pain (**Table 2** and **4**), with the most

common location being the hip. 41.2% of those reporting pain had experienced moderate pain, with the most common location being the lower back. 7.8% of those reporting pain had experienced mild pain, with the most common location being the lower back.

3.3. Pain Management Techniques

A total of 51.1% of participants took over-the-counter pain medication, 23.9% of participants were prescribed pain medication, 47.7% had therapy such as physiotherapy, massage, or chiropractic treatment, and 34.2% were on an exercise program to help manage their pain. Female participants were 2.2 times (O.R.) more likely to take over-the-counter medication than males. Half of the participants stated that their pain was medically diagnosed.

A total of 1596 participants managed their pain with medication, 51% (n = 1088) self-medicated taking over-the-counter pain medication, and 47.7% (n = 1016) used therapeutic treatment **(Table 3)**.

3.4. Equestrian Activities and Pain

Only 103 participants reported that no particular activity increased the level of pain they experienced. Participants reported that the weather (including the temperature, n = 903) and sitting for long periods (n = 816) increased the pain they experienced. They also reported some equestrian activities increased pain levels **(Figure 2)**. The most common individual reason was doing stable duties, but collectively ridden activities were reported by 72.8% (1549 of 2128) of participants who reported experiencing pain, as increasing pain levels.

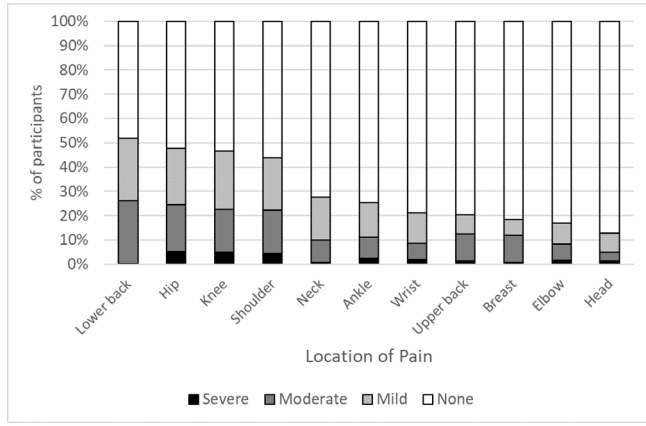

Figure 1: Location and level of pain reported by participants.

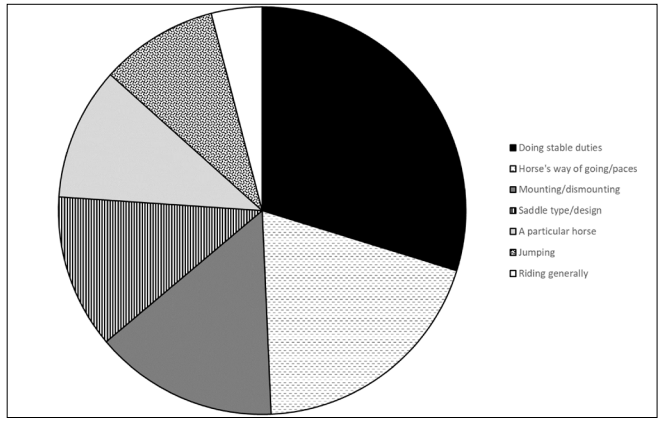

Figure 2: The equestrian activities that increase the pain experienced.

Table 1: Participant demographics and pain reported.

Group	Total number of participants	Participants experiencing pain	Participants experiencing no pain	Odds ratio Pain: No Pain
All respondents	2185	85.4% (1866)	14.6% (319)	5.85
Sex				
Females	2137	85.5% (1828)	14.5% (309)	5.92
Males	43	79.1% (34)	20.9% (9)	3.78
Age (years)				
35-40	688	82.8% (570)	17.2% (118)	4.83
41-45	377	86.7% (327)	13.3% (50)	6.54
46-50	374	89.0% (333)	11.0% (41)	8.12
51-55	363	83.5% (303)	16.5% (60)	5.05
56-60	216	85.2% (184)	14.8% (32)	5.75
61-65	115	92.2% (106)	7.8% (9)	11.78
66-70	36	80.6% (29)	19.4% (7)	4.14
70 and over	16	87.5% (14)	12.5% (2)	7.00

Table 2: Level of pain experienced.

Group	Least pain level experienced	Lower quartile pain level experienced	Median pain level experienced	Upper quartile pain level experienced	Most pain level experienced
All respondents	No pain	Mild	Mild	Moderate	Worst imaginable
Sex					
Females	No pain				Worst imaginable
Males	No pain				
Age (years)					
35-40	No pain	Mild	Mild	Moderate	Worst imaginable
41-45	No pain	Mild	Mild	Moderate	Worst imaginable
46-50	No pain	Mild	Mild	Moderate	Worst imaginable
51-55	No pain	Mild	Mild	Moderate	Severe
56-60	No pain	Mild	Moderate	Moderate	Severe
61-65	No pain	Mild	Mild	Moderate	Severe
66-70	No pain	Mild	Moderate	Moderate	Severe
70 and over	No pain	Mild	Mild	Moderate	Worst imaginable

Table 3: The techniques the 2128 participants who experienced pain reported using to manage the pain.

	Total	Over counter medication	Therapeutic treatment	Exercise	Prescription medication	Nothing
Over counter medication	51.1% (1088)	-	29.2% (621)	20.3% (431)	8.3% (177)	15.7% (334)
Therapeutic treatment	47.7% (1016)	29.2% (621)	-	24.3% (517)	14.6% (310)	4.1% (88)
Exercise	34.2% (728)	20.6% (439)	24.3% (517)	-	9.4% (199)	2.3% (50)
Prescription medication	23.9% (508)	8.3% (177)	14.6% (310)	9.4% (199)	-	5.4% (115)
Nothing	5.6% (120)	-	-	-	-	-

Table 4: A comparison of how pain and pain levels change before, during, and after riding.

		No pain	Pain	Mild	Moderate	Severe
Before riding		188	1289	812	450	27
Before riding compared to during riding	Decreased	-	30.5% (393)	26.5% (215)	36.7% (165)	48.1% (13)
	Stayed the Same	67.0% (126)	56.7% (731)	56.7% (460)	57.1% (257)	51.9% (14)
	Increased	33.0% (62)	12.7% (164)	16.7% (136)	6.2% (28)	-
During riding vs. after riding	Decreased	4.3% (8)	4.5% (58)	3.9% (32)	5.8% (26)	0
	Stayed the same	55.9% (105)	51.8% (668)	47.2% (383)	59.1% (266)	70.4% (19)
	Increased	38.8% (73)	42.7% (550)	48.6% (395)	34.9% (157)	29.6% (8)
Before riding vs. after riding	Decreased	-	14.3% (184)	10.1% (82)	20.9% (94)	29.6% (8)
	Stayed the same	37.8% (71)	48.8% (629)	43.0% (349)	58.0% (261)	70.4% (19)
	Increased	62.2% (117)	36.7% (473)	46.7% (379)	20.9% (94)	-

3.5. Riding History and Pain

Of the participants, 83% stated that they have been riding for over 20 years, 10% had ridden for 10 to 20 years, 3% had ridden for 6 to 10 years, 3% had ridden for 1 to 5 years, and less than 1% had ridden for 1 year or less. The data showed that pain had been experienced by 86.7% of participants who had ridden for over 20 years, 81.5% of those with 11 to 20 years of riding experience, 73.3% of those with 6 to 10 years of riding experience, 76.2% of those with 1 to 5 years of riding experience, and 75% of those with less than 1 year of riding experience **(Table 5)**.

3.6. Level of Riding and Riding Discipline

Nearly half of the participants (49%) considered themselves as amateur competitive riders, 43% stated that they were leisure or recreational riders, and 8% stated that they were professional riders. The results indicated that the proportion of participants reporting pain was similarly high across levels of competitive participation **(Table 6)**, although those competing for leisure purposes reported slightly less pain.

3.7. Pain Affecting Equestrian Activities

Factors of pain that affected performance included the following: 30% of participants stated that pain causes fatigue, 41% said that it limits movement, and 46% stated that it decreases the range of movement. Additionally, 41% of participants stated that pain causes asymmetry, with 17% stating that it causes asymmetry in the horse **(Figure 3)**. A total of 42% of participants reported that pain or injury had stopped them from riding at some point. Time off riding due to pain ranged from a few days to 15 years and even prevented some from returning to riding permanently.

3.8. Other Sporting Activities

About 36% of participants stated that they exercised or participated in a sport other than riding for two to three hours per week, while 22% reported doing so for less than one hour per week, 12% for four to five hours per week, 9% for six or more hours per week, and 21% did not participate in any other sports or exercise. The odds ratio for participants who did not participate in any exercise other than riding was 1.4 times (O.R.) more likely to suffer from pain than participants that did.

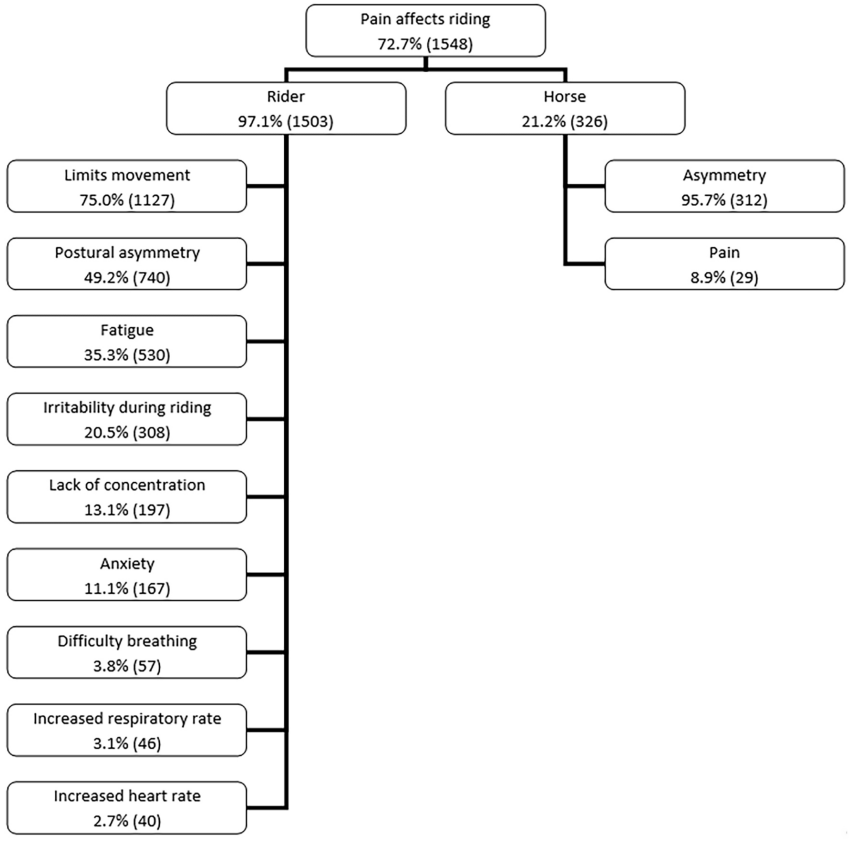

Figure 3: How the participants (2128) who reported pain believed it affected their riding.

Table 5: Comparison between the length of time riding and pain experienced.

Years horse riding	Total number of participants	Participants experiencing pain	Participants experiencing no pain	Odds ratio Pain: No Pain
Less than 1	8	75.0% (6)	25.0% (2)	3.00
1–5	63	76.2% (48)	23.8% (15)	3.20
6–10	75	73.3% (55)	26.7% (20)	2.75
11–20	222	81.5% (181)	18.5% (41)	4.41
More than 20	1817	86.7% (1576)	13.3% (241)	6.54

Table 6: The pain experienced across participants in different equestrian sporting disciplines (with at least 100 participants) and across different levels of competitive participation.

		All	Leisure	Amateur	Professional
All disciplines	Pain	3222	1087	1809	325
	No Pain	525	199	287	45
	Odds ratio (Pain: No Pain)	6.14	5.46	6.30	7.22
Dressage	Pain	1266	371	782	112
	No Pain	196	69	109	17
	Odds ratio (Pain: No Pain)	6.46	5.38	7.17	6.59
Showjumping	Pain	738	207	450	81
	No Pain	130	41	76	12
	Odds ratio (Pain: No Pain)	5.68	5.05	5.92	6.75
Eventing	Pain	429	70	296	63
	No Pain	78	20	50	7
	Odds ratio (Pain: No Pain)	5.50	3.50	5.92	9.00
Hunting	Pain	317	107	162	48
	No Pain	48	12	39	6
	Odds ratio (Pain: No Pain)	6.60	8.92	4.15	8.00
Showing	Pain	151	35	105	11
	No Pain	17	6	10	1
	Odds ratio (Pain: No Pain)	8.88	5.83	10.50	11.00
Non-competitive	Pain	295	277	8	10
	No Pain	54	50	2	2
	Odds ratio (Pain: No Pain)	5.46	5.54	4.00	5.00

*Please note that only those reporting levels were included in this table, however, a participant may take part in more than one discipline.

4. Discussion

Pain is a private and personal experience that each person responds to in a unique way. The feeling of pain alerts the body that something biologically harmful is happening. Pain is subjective and can be substantially influenced by individual susceptibility as well as personality [25]. It is the most common symptomatic reason why medical consultation is sought out [26].

In this study, 83% of riders reported that they experience some level of chronic pain. Results showed that most riders rated their pain between mild and moderate, with over half of all participants having experienced pain for over 6 years. Results also showed a positive correlation between pain and age, as aging is associated with an increased amount of chronic pain [26]. Expectations and perceptions of pain continue to develop from an early age throughout life [27]. Previous experiences and how they are perceived can lead to a pre-empted feeling of pain and a disparity between the severity of pain and the individual appraisal of the pain [28]. Individual perceptions of pain could have affected data and further research is required to determine more accurate results.

Although most pains were considered to be mild to moderate in nature, 72.8% of participants stated that equine activities (riding, grooming, and stable duties) made their pain worse. This could be a result of repetitive asymmetric movements performed over many years when riding or working with horses. These activities have been reported as common causes of chronic long-term pain [3,4]. Indeed, an increase in years of riding increased the levels of pain reported. Participants who had been riding for less than 3 years were 3 times more likely to have no pain than pain. Those who had been riding for over twenty years were 6.54 times more likely to have pain,

suggesting that riding and working with horses is a causal effect of pain.

Females were 1.28 times more likely to experience pain than males as females are more prone to experience pain [29], or at least more prone to reporting pain or injury [30]. One theory seen in American Football is that women players are more honest than men when it comes to self-diagnosis and reporting [31]. Only a third of males stated that their pain was medically diagnosed. This could be due to men in society being conditioned to conceal their pain [32]. In a study by Young [33], male athletes discussed why they hid pain and the normality of not revealing pain to their team. Masculinity is associated with strength and bravery possibly leading men to take greater gambles, to prove their courage in such a way that they become willing to subject their bodies to pain and injury [33].

4.1. Pain and Age

Pain was experienced in 85.4% of riders, with lower back pain (LBP) being the most common location and seen to be higher in riders over 35 compared to other rider populations : elite dressage 76% [17]; general horse riders 72% [13]; and elite eventers 52% [20]. Within the general population, Jordan *et al.* [34], identified that the age group that presented the highest numbers of GP with LBP was the 45-64 year age group, 536 per 10,000 of GP consultations.

Qualitative data from open questions showed that a small number of riders attributed the cause of their pain to aging factors. Open-ended questions gave an insight into what caused rider pain. Common answers were old age and arthritis. Research supports the relationship found between age and pain being caused by age-related degenerative changes [35]. Aging can cause deterioration of the spine, intervertebral discs, and muscles, leading to pain and stiffness [36]. Lumbar disc degeneration (LDD) in particular could be a possible risk factor for back pain in adults, with odds ratios varying from 1.3 to 3.2 [37]. Radiography and magnetic resonance imaging (MRI) can diagnose such problems [36,38]. Over half of the population in this study had received a diagnosis for their pain. However, Kraft, *et al.*, [13] found no conclusive MRI evidence to suggest that riders' LBP was caused by disk degeneration, spondylolysis, spondylolisthesis, or pathologic changes to the paraspinal muscles of the lumbar spine. This suggests that the back pain in some riders may be functional, attributed to muscular dis-balance [13,39,40].

Hip and knee pain was reported by those over 35 years at higher rates than in younger rider populations [18]. Severe pain was reported in the hips. The relationship between hip rotation and low back pain (LBP) is well documented [41,42]. Based on these studies, it appears that people with LBP may have (1) less hip rotation range of motion, either active or passive, and (2) more asymmetry in hip rotation mobility. The relationship between hip rotation motion and LBP is important because external forces can be sequentially transmitted from distal body segments to more proximal ones during movement. Movement at the hip could, therefore, influence movement and loading at the lumbar spine. When performed repeatedly, such hip movement as seen when riding could result in excessive loading on tissues in the low back region [43], and eventually LBP. Gender differences in the pattern of hip and lumbopelvic rotation in people with low back pain [44] might also explain the higher levels reported in female riders and require further research.

4.2. Treatments and Management of Pain

Despite half of the female participants and a third of males having their pain medically diagnosed, the most common method of pain management was the use of over-the-counter medication (61%), although this is slightly lower than what was seen in elite riders (elite event riders 93% self-medication [20], 74% of elite dressage riders [18]). Keogh and Herdenfeldt, [45] suggested that females use emotion-focused coping to manage their pain, whereas men are more likely to use sensory-focused coping strategies. Using drugs to treat oneself without the help of a doctor, known as self-medication, is a fast-developing phenomenon [46]. Riders use painkillers to alleviate pain, allowing them to resume normal activities [47,48]. However, painkillers may restrict the ability to know when the body has reached its limit, increasing the likelihood of injury. Painkillers can be harmful and cause long-term damage to skeletal mechanisms [49]. It is well documented that regular consumption of Non-steroidal anti-inflammatory drugs (NSAIDs) can cause damage to the gastrointestinal tract. When consumed in quantity, Riordan *et al.* [50] found that these drugs can cause headaches, dizziness, and visual disturbances. This could affect the proprioceptive process required to make split-second decisions when riding, potentially resulting in injury due to the high-risk nature of the sport [51]. Continual overuse of NSAIDs can also cause depression, electrolyte disturbance, and even respiratory issues [50]. However, stopping long-term usage of some NSAIDs can increase the risk of a heart attack [52]. Research in 2015 by Bennin and Rother stated that 43% of pharmacists considered the information provided on over-the-counter painkillers to be insufficient, suggesting that some riders may not be fully aware of the health implications of using NSAIDs [53].

Physical therapy was used by 57% of participants to treat or manage pain. Physical therapy is commonly used on athletes in a range of sports, effectively reducing pain and helping to restore the full range of movement [54]. Physical therapy loosens muscles and joints to aid movement and decrease pain [55]. Loosening muscles effectively reduces pain, stress hormones, and symptoms associated with low back pain [56]. Physical therapy can increase serotonin and dopamine levels, and improve trunk flexion and performance [56]. Pilates was used by 40% of participants to manage pain. Mind-body programs using imagery and progressive muscle relaxation improve severe pain and short-term function in people suffering from lower back pain [57–59]. Pilates has been shown to enhance muscular endurance and can improve flexibility and balance [60]. Training programs including Pilates have been shown to improve function and reduce lower back pain, more effectively than core strengthening programs [61]. Pilates reduces the risk of injury by improving balance and trunk stability [62]. Seventy-four percent of participants who took part in other sports or physical activity were 1.4 times (Odds Ratio) less likely to have pain, suggesting that riding

is the possible cause of the pain or other activities reduce the pain. More research is needed to understand this further.

4.3. Causes: Decrease/Limited Movement, Fatigue, Asymmetry

Consequences of reported pain on rider performance are consistent with findings reported in other rider pain studies [17,18] such as decreased or limited range of movement, fatigue, and asymmetrical riding position. These reduced functions are not only problematic for the riders' control and communication with the horse but could impact the welfare of the horse involved. According to the ISES 10 principles of training, the rider must only apply one signal or aid at a time, and each signal has one clear meaning to the horse [63]. These cues should be applied in timing with equine limb biomechanics. Riders must be able to maintain a symmetrical riding position and be able to coordinate movements of the body segments in order that the application of aids is not unclear, ambiguous, or simultaneous [64,65], which can lead to confusion, stress, and conflict behavior that ultimately impact equine welfare [66].

5. Limitations

A quarter of the participants who started the questionnaire did not answer all the questions or did not complete it, limiting the potential of an accurate representation of the overall population. While this study reports individual perception of pain and pain management, it is the individual perception that is likely to determine the impact of the pain on that individual. This self-reported perception of pain limits the reliability of the results.

6. Conclusion

This study demonstrates the prevalence of pain in riders over 35 years of age. Many participants attributed their pain to old age. The high frequency of pain in older riders could be due to the length of their riding career. The most common sites for pain were the lower back and hips, possibly due to the physical demands of riding. Stable duties and riding put strain on the musculoskeletal system by twisting and lifting, which many of the riders felt to be responsible for their source of pain. Riders stated that the weather, sitting, and the horse's way of going made their pain worse. Most riders had been suffering from pain for over 6 years and said that pain affected performance in terms of causing fatigue, limiting movement, decreasing the range of movement, and causing postural asymmetry. These were common symptoms of lower back pain caused by the demands of riding and performing stable duties. Physical limitations can be detrimental to human welfare due to riding being a high-risk sport. Riders used multiple treatments to prevent and manage pain. Self-medicating was the most common pain management technique. However, the effectiveness of the pain prevention and management techniques is debatable due to the high number of participants that still experienced pain.

This exploratory study achieved its aims. Results show that the attitude of riders to their personal health and welfare should be of concern to the equestrian industry. Future studies should contain both quantitative and qualitative methods to get more in-depth knowledge on the chosen subject. Further research on causes of pain, injury diagnosis, treatment of injury, and prevention of pain is needed to improve awareness of rider welfare. Research on pain in male riders and their perception of pain is required to increase understanding of the topic and establish causes of pain and effective management strategies.

Authors' Contributions

V.L. and Z.N. planned and designed the study. Z.N. collected the data and carried out the study. L.D. conducted the statistical analysis. V.L. wrote the manuscript and L.C. reviewed it. All authors read and approved the manuscript.

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Data Availability

The data supporting the findings of this study are available upon request from the corresponding author.

Funding

No funding was received for this research project.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

Ethical Approval

This study received ethical approval from Hartpury University Ethics Committee. The study complied with the guidelines of the Declaration of Helsinki.

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Evaluating the Feeding Management and Housing Conditions of Horses in Lesotho

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Abstract

Lesotho is proud of its horses, and there are many skilled riders in rural areas. A cross-sectional study was conducted from September to December 2020, involving 321 horse owners. The objective of the study was to assess the housing and feeding management of horses in Lesotho. The evaluation of feeding management focused on production systems, types of commercial feeds, and access to water. The housing conditions assessment was based on the horses' environment. The majority of horses were kept under a semi-enclosed framework. In rural, semi-urban, and urban areas, grazing alone failed to meet the nutritional needs of horses by 70.1%, 89.4%, and 85.1%, respectively. Regarding housing, the majority of horses were tied, while only a few were kept in clean stalls (8.2%, 3.1%, and 4.1%) with proper bedding. Based on the data obtained in this study, it can be concluded that the feeding and housing conditions for horses in Lesotho are inadequate. Therefore, horse owners should receive training on how to improve the feeding and housing practices for their horses.

Keywords

Horse; evaluation; feeding; housing

1. Introduction

Horses serve as the sole mode of transportation in certain regions of Lesotho due to the rugged terrain [1]. In some parts of the country, horses are used as draft animals for tasks such as plowing, planting, carding, and cultivating fields [2]. Their significance extends to being life-saving couriers, as Lesotho has few paved roads and 80% of the country is more than a mile high. Horses play a crucial role in delivering vital medical supplies, antiretroviral medicine (ARVs), mother-to-baby pregnancy kits, and laboratory samples to remote clinics that are inaccessible by cars [3].

The quality and quantity of an animal's food, along with the feeding practices employed, significantly impact its well-being. Thus, the type of feed and feeding methods represent relevant risk factors [4]. According to Davidson [5], a feeding system is considered satisfactory when it is tailored to meet horse's specific nutritional requirements, enables horses to maintain a body condition score of three on a scale of one to five, and does not lead to behavioral issues associated with feeding frustration. Horses in extensive confinement typically fulfill their nutrient needs by selectively grazing on various forages for up to sixteen hours per day, with very rare voluntary fasting periods of no more than four hours [6].

The social conditions experienced by a horse can jeopardize its behavior, physiology, and overall well-being [7]. Inappropriate social environments, often associated with intensive horse management, have the potential to alter a horse's behavior and compromise its health and welfare [8]. Housing systems that restrict free movement, exploration, and social interaction, such as individual box stalls indoors, may make horses more susceptible to poor air quality [9]. Providing horses with social housing is generally not a feasible choice due to the risk of contamination, unwanted social interactions, or the cost of maintaining additional horses [10]. In light of these considerations, the aim of this study was

to evaluate the feeding management and housing conditions of horses in Lesotho.

2. Materials and Methods

2.1. Study Area

The study was conducted in the Mafeteng and Maseru districts, covering three regions: urban, semi-urban, and rural. Each region was represented by four resource centers. The urban region consisted of Masianokeng, Morija, Semonkong, and Ramokoatsi. The semi-urban region included Ramabanta, Ntsi, Tsákholo, and Thabana Morena, while Matelile, Mosala, Ribaneng, and Marakabei represented the rural region. Data collection took place between September and December 2020.

2.2. Study Design

A cross-sectional survey was conducted using a simple random sampling method. Horse owners were identified in their respective resource centers with the assistance of Ministry of Agriculture and Food Security extension personnel. Owners who owned at least one horse and were willing to participate were included in the study.

2.3. Data Collection Method

Data was collected using individual questionnaires. A total of 321 horse owners were interviewed at their homes in the local language, Sesotho. The distribution of interviews was as follows: 101 in the urban region, 113 in the semi-urban region, and 107 in the rural region. The number of horse owners interviewed in each resource center ranged from a minimum of 12 to a maximum of 36, depending on the number of households owning horses. The questionnaire consisted of six sections: location (district, region, resource center, sub-center, and village), general information about the horse owner (name, gender, and age), socio-economic factors (highest educational qualification, training sessions, horse associations, purpose of rearing horses, years in horse production, and sources of household income). The feeding section included information on production systems, grazing satisfaction, commercial feeds, water sources, and frequency of water provision. The housing section included questions about housing type, bedding, ventilation, housing surface quality, and the risk of injury in housing. The data were then entered into the individual questionnaire forms in English.

2.4. Data Analysis

The data from the 321 surveys were analyzed using Statistical Package for Social Sciences version 20. Descriptive statistics, such as percentages and frequency distributions, were used to describe the data. Chi-square tests were employed to determine whether the differences in the data were due to chance or a connection between the variables being studied. Statistical significance was considered at a level of $p < 0.05$. Standard errors were used to calculate confidence intervals, and a 95% confidence level was set.

3. Results and Discussions

3.1. Feeding Management of Horses

Horse owners in rural (70.1%), semi-urban (89.4%), and urban (81.6%) regions indicated that the production system mostly used is semi-intensive. Chi-square tests showed a significant association ($p < 0.05$) between the production system and the region where the animals are reared. In contrast to the present findings, Buckley [11] reported that the majority of horses were kept on pasture and fed additional roughage, grains, or concentrates. However, Mellor *et al.* [12] found that only 10% of horses were permanently kept out at pasture. On the other hand, Fraser and Broom [6] indicated that horses kept under extensive conditions meet their nutritive requirements through selective grazing on a variety of forages for up to sixteen hours per day. Conversely, Thorne *et al.* [13] stated that horses maintained under intensive conditions such as stables have limited access to forage, which influences both their foraging behavior and welfare.

The results of this study, as reflected in **Table 1**, showed that the majority of horses did not derive satisfaction from grazing. The Chi-square tests revealed a significant relationship ($p < 0.05$) between horses being satisfied from grazing and the region where they graze. Furthermore, most farmers reported that they are unable to fulfill all the needs of horses due to their slim household income. Consequently, this puts horses at risk of malnutrition since their nutritional needs cannot be fully met, compromising their welfare.

In support of the present results, Bonde [4] emphasized that horses dependent on grazing alone are deficient in important nutrients. Kompi *et al.* [14] also reported that most horses were not nutritionally satisfied because they mainly depended on grazing as a source of feeding. However, Upjohn *et al.* [15] found that Lesotho owners are less dependent on communal grazing. The difference in results could be attributed to the fact that Upjohn *et al.*'s [15] study was conducted during a drought period, which is associated with low grazing availability.

Bonde [4] further stated that the welfare of an animal could be affected by the quality and quantity of feed it receives, as well as the feeding procedures themselves. Additionally, Davidson [5] noted that a feeding system could be considered satisfactory if it is adjusted to the nutritional needs of a horse.

Based on the findings of the current study, the majority of horse owners are unable to purchase commercial feeds for horses. This is supported by the fact that 60.7%, 54.95%, and 57.4% in rural, semi-urban, and urban regions, respectively, reported their inability to afford commercial feeds. In contrast to the findings of this study, Murray *et al.* [16] found that the majority of owners fed commercial premixed feeds to horses, despite having less knowledge about managing nutrition-related disorders. The reason for horse owners being unable to buy commercial feeds could be attributed to their inability to cover all the needs of horses based on their income. However, equine nutrition is increasingly significant in ensuring good health and welfare [16].

Bran (wheat or maize) is the most commonly fed commercial feed to horses, followed by lucerne, and lastly, barley, as illustrated in **Table 1**. In contrast to the results of the current study, Murray *et al.* [16] found that the majority (87%) of horse owners fed concentrates. Harris [17,18] further reported that barley was generally fed rolled or cooked to increase small intestinal digestibility. The preference for bran as the most common commercial feed might be due to its cheaper cost compared to other feeds such as barley and lucerne. Additionally, bran is easily found, with almost every village having a local grinding mill.

Table 1: Feeding management of horses in different regions.

Category	Rural (%)	Semi-urban (%)	Urban (%)	SE	X^2	Sig
Production systems						
Intensive	29.9	10.6	14.9	0.111	14.851[a]	0.001
Semi-intensive	70.1	89.4	85.1	0.048		
Satisfaction from grazing						
No	70.1	89.4	85.1	0.048	14.851[a]	0.001
None	29.9	10.6	14.9	0.111		
Commercial feeds						
Yes	60.7	54.9	57.4	0.060	0.781[a]	0.677
No	39.3	45.1	42.6	0.068		
Kinds of commercial feeds						
Lucerne	19.6	10.6	6.9	0.122	9.180[a]	0.164
Bran	39.3	43.4	48.5	0.068		
Barley	1.9	0.9	2.0	0.447		
None	39.3	45.1	46.2	0.068		
Water access						
Dam	11.2	20.4	34.7	0.090	22.970[a]	0.000
River	60.7	66.4	47.5	0.056		
Tap water	28.0	13.3	17.8	0.108		
Drinking times per day						
1-3	100.0	100.0	100.0	0.045		

SE: Standard Error
X^2: Pearson Chi-Square Value
Sig: Significant Value

The majority of horses have access to water from rivers, with 60.7%, 66.4%, and 47.5% in rural, semi-urban, and urban regions, respectively. A significant percentage of horses in urban regions access water from dams. This can pose a problem for horses as water from dams can accumulate impurities since it does not flow out. However, some horse owners provide tap water to the horses. Adequate water supply and quality are important for an animal's well-being, and water quantity and quality appear to be appropriate risk factors. Nonetheless, requirements differ based on the animal's age and physiological condition [4].

All horses in the current study were reported to drink water 1 to 3 times per day, as indicated in **Table 1**. Novak *et al.* [19] indicated that the body of a horse is mainly composed of water, which is essential for maintaining health. On average, a horse consumes approximately 25 to 55 liters of water per day, depending on the weather conditions, level of activity, and diet.

3.2. Health Management of Horses

As shown in **Table 2**, the findings of this study indicate that a minority of horse owners in rural (8.2%), semi-urban (3.1%), and urban (4.1%) regions keep their horses in stalls. The majority of horse owners reported that they tie up their horses. However, the Chi-square tests revealed no significant association ($p > 0.05$) between housing type and the region in which the horse is reared.

In support of the present study, Macleay [20] reported that only 2.1% of horses were permanently stabled. These results are consistent with those of Thompson *et al.* [21], who also found that 2.0% of horses were permanently stabled, although slightly lower than the findings of McGowan *et al.* [22], who reported a stabling rate of 5% for horses. Mezgebu *et al.* [23] also reported that the majority of horse owners keep their horses in deprived stables without roofs.

Contrary to the findings of this study, Leme *et al.* [24] found that 90% of horses reared in cities were permanently stabled. Connysson *et al.* [9] also indicated that many horses are currently kept in individual box stalls indoors. However, Søndergaard and Ladewig [25] stated that horses are less likely to develop abnormal behavior if they spend more time outside the stable and are easier to break in.

As shown in **Table 2**, the housing of the majority of assessed horses had no bedding in rural (99.3%), semi-urban (99.4%), and urban (98.6%) regions. However, no horses were sweating because of proper ventilation. The housing floor surface was mostly non-slippery, indicating that only 11.6%, 15.6%, and 18.9% of horses in the rural, semi-urban, and urban regions, respectively, were at risk of injury.

The results of the present do not tally with the report of AWIN [26] which emphasized that the comfort around the resting place of a horse relies on suitable bedding material that is non-toxic, free of mold and excessive dust, and absorbent enough to maintain a dry bed. Stable air quality and the choice of bedding material are crucial for the health and well-being of both horses and people working or visiting horse stables [27].

Table 2: Housing conditions of horses in different regions.

Category	Rural (%)	Semi-urban (%)	Urban (%)	SE	X^2	Sig
Housing type						
Kraal	7.5	6.2	8.1	0.180	5.008[a]	0.286
Tie-up	84.4	90.6	87.8	0.147		
Stall	8.2	3.1	4.1	0.040		
Bedding						
Presence of clean bedding	0.7	0.6	1.4	0.479	0.564	0.754
No bedding	99.3	99.4	98.6	0.038		
Ventilation						
No sweating or shivering	100.0	100.0	100.0	0.038		
Housing surface quality						
Anti-slip	100.0	98.8	100.0	0.038	3.704[a]	0.157
Slippery	0.0	1.2	0.0	0.000		
Risk of injury in housing						
No risk of injuries	88.4	84.4	81.1	0.041	3.075[a]	0.125
Risk of injuries	11.6	15.6	18.9	0.095		

SE: Standard Error
X^2: Pearson Chi-Square Value
Sig: Significant Value

4. Conclusion

Based on the results of this study, it can be concluded that horses in Lesotho were reared under a semi-intensive production system. The primary source of nutrition for the horses was grazing on rangelands, which proved to be insufficient to meet their nutritional needs. Additionally, the horses relied on drinking water from rivers. The housing conditions did not meet the standards set by the World Organization for Animal Health, as the horses were either tied up or kept in stalls without bedding. Therefore, there is a need to change the behavior of horse owners through targeted educational sessions, with a focus on improving the management practices related to housing and feeding of horses in Lesotho.

Authors' Contributions

Moleboheng Bolibe: study design, data collection, analysis, and interpretation of data. Setsumi Molapo: study design, data analysis, and interpretation of data.

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Data Availability

The data supporting this study will be made available by the authors upon request.

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Conflicts of Interest

The authors declare that there are no conflicts of interest related to the work presented in this manuscript.

Ethical Approval

The study was approved by the Scientific and Ethics Committee of the Department of Animal Science, National University of Lesotho.

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The Psychological Responses of Elite Equestrian Athletes to Their Horses' Injuries

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Abstract

Equestrian sport requires optimal performance from horse and rider for a successful partnership, and the high-risk nature increases the injury risk for both parties. Negative psychological responses have been reported following equine injury in amateur and youth riders, but little is known about elite athletes, for whom the horse-rider relationship may be more transactional than familial. The aim was to investigate the psychological responses of elite riders to their horses' injuries. Twelve international riders (8 women, 4 men, $\bar{x}$ = 30.8 ± 10.8 years (range 20–51 years), who had competed from CCI-2* to the Olympics and World Equestrian Games (WEG), were interviewed about their experiences of equine injury. Interview questions explored athletes' careers, initial reactions, coping mechanisms, and return to elite competition. Thematic analysis revealed three themes: cognitive appraisal, emotional responses, and coping strategies. Riders reported a sense of loss, and several felt this impacted their athletic identity. All riders reported a sense of duty towards their horse. Elite athletes experienced negative emotional responses, including devastation, frustration, denial, and guilt, at the onset of equine injury. Several coping strategies were utilized, including avoidance and reliance on social support, and some riders also reported personal growth. Elite riders reported wider psychological impacts on support networks and responses were shaped by the normalization of injury within the equestrian community. Further research should explore the benefits of intervention programs on equestrian athletes' coping strategies, as well as the impact of equine injury on the mental health of grooms.

Keywords

Cognitive appraisal; emotion; partnership; coping; horse rider; Olympian

1. Introduction

In Olympic equestrian disciplines (dressage, eventing, and show jumping), both the horse and rider must work as a team to achieve a final combined performance result [1,2], therefore riders need to build a strong working relationship with their horses based on mutual trust and respect [3]. Equestrianism differs from other sports as riders must depend on their horses' wellbeing to perform [4–6], and there is a heightened risk of injury within competitive equestrian disciplines to both parties. Elite equestrian sport requires perseverance, dedication, personal effort, considerable time, and financial investment to be competitive [1,7]. Many riders sacrifice their social life and family to their horses whom they consider as 'partners' [8], however at elite level, the pressures of professional sport and commercialization could negatively impact individual partnerships between horses and riders, creating a more transactional relationship [3]. Elite young riders and amateurs have both been found to experience negative cognitive and emotional responses when their horses are injured [9,10], but the sense of loss experienced by a rider following equine euthanasia has been shown to be influenced by the strength of the relationship [11,12]. Horse-rider relationships are unique, and range in intensity and type of interactions between levels [12]. For elite equestrian athletes, coping with adversity, such as loss of a horse, was identified as an important trait [1], thus it is imperative to

explore the psychological implications of equine injury on elite equestrian athletes.

Injury is common for equine athletes and can be caused by both competition and training [13–16]. In all equestrian disciplines, musculoskeletal injuries are the most common reason for the loss of horses [17]. Injury types vary between discipline and the level of performance [16,18] with up to 50% of elite Grand Prix Dressage combinations reporting lameness in the preceding two years [16]. Singer *et al.* [19] found that 21% of horses intending to compete in long-format international eventing competitions did not start due to injury whilst 32.5% of horse falls during the cross-country phase incurred one or more injuries, and 7.2% of these were classified as serious, such as fractures or tendon injury [20]. Injuries can also lead to withdrawal prior to competition, with 21–45% of horses per year withdrawing due to musculoskeletal injury [14,15]. A setback, such as equine injury, could leave elite riders vulnerable to additional psychological stressors, such as financial stress from veterinary costs or lost income [1], feelings of guilt regarding commitments to owners or sponsors, or emotional loss linked to the horse rider partnership [9,10].

Injury is also considered a common source of stress in elite sports [21], with financial pressure, emotional responses, and feelings of loss all previously reported in elite athletes who have experienced an injury during their career [22]. Following an injury, athletes undergo a cognitive re-appraisal, considering several personal and situational factors, including their perception of the cause of injury, recovery status, available social support, and their ability to cope [23]. This appraisal influences an athlete's emotional responses and can be viewed either positively, promoting optimal physical and psychological recovery, or negatively, resulting in depression, guilt, isolation, anxiety, and frustration [24,25]. Some studies suggest that athletes experiencing an injury could exhibit grief-like reactions such as those described by Kübler-Ross [26] with a 5-stage grief reaction response: denial, anger, bargaining, depression, and acceptance [27]. These reactions could be explained by the sensation of loss that athletes experience after an injury [22]. Emotional responses are not just reported in injured athletes however, with sporting partners, teammates, and coaches all reporting horror, fear, helplessness, and depression following a teammate's injury, suggesting that injury can psychologically affect others beyond just the injured party [28,29]. More recently, the notion that the psychological implications of injury extend beyond the injured individual has been extended to non-human animal partners within equestrian sport, with riders reporting a sense of loss and grief, guilt, and denial when their horse was injured [9,10]. Partnerships between elite riders and their horses have been perceived as more transactional, which may influence the emotional responses seen in elite riders [3]. When an injury occurs, athletes who are intensively involved with their sport may suffer more significant negative psychological and emotional reactions than those who are less involved, due to challenges to their athletic identity [30,31]. Individuals with stronger athletic identities often experience increased stress during transitions, such as during injury or retirement [32]. For elite equestrian athletes, who invest significant time and resources into their career [7], and whose identity as an athlete is linked to the performance capabilities of their horse [1], injury may negatively challenge athletic identity and intensify psychological stress.

In wider sporting literature, changes to behavior following injury have been reported to affect an athlete's adherence to their rehabilitation program, as well as their engagement with medical provision, use of effective coping mechanisms, and the likelihood of engaging in risk-taking behaviors, both within and outside of the sporting environment [23], influencing successful return to play [33]. Employing effective psychological coping strategies aids injured athletes in avoiding undue psychological harm from difficult experiences [21]. Early interventions can enhance emotional regulation, self-motivation, and resilience, as well as access to, and perceived benefits of social support [33]. Social support has also been shown to help overcome stressful events such as sports injuries and is important for maintaining adherence to rehabilitation [34,35]. Social support was previously identified by both elite young riders and amateur equestrians as critical to their psychological wellbeing when their horses were injured, with riders suggesting that non-horsey people were less supportive due to a lack of understanding about the unique relationship between horse and rider [9,10,36]. An individual's satisfaction with their social support is related to mood, with more positive perceptions of social support leading to a decrease in mood disturbance [37]. This could suggest that equine communities need to better understand the significance of social support for riders experiencing equine injury to ensure that human wellbeing is managed alongside equine recovery. The aim of this study was therefore to investigate the psychological responses of elite riders to their horses' injuries.

2. Materials and Methods

2.1. Participants

Twelve elite equestrian athletes (8 women and 4 men, $\bar{x}$ = 30.8 ± 10.8 years (range 20–51 years old) participated in the study. The athletes were over 18 and must have competed in elite international competitions run by the Fédération Equestre Internationale (FEI) in one or multiple Olympic disciplines (dressage, eventing, and/or show jumping) to be classified as 'elite' [38]. Athletes were selected based on their competition level and their horse's injury status. The participants must have been riding an elite horse which had sustained either a serious injury (requiring more than three months' rehabilitation) or a career-ending injury, which impacted the rider's goals and career in the sport [9]. This study used purposive recruitment [39] and participants were contacted through the primary researcher's personal contacts, and supplemented by snowball sampling methods, and social media posts [40]. The method was dependent on the researcher's personal connection with possible participants, and the most appropriate way to contact them was deduced. Participants were sampled in a deliberate and flexible way, to select a diverse range of participants to provide a variety of experiences. The final sample size (n=12) was deemed sufficient to evaluate the in-depth understanding of the riders' experiences.

2.2. Procedure

Following institutional ethics approval by the Hartpury University Human Research Ethics Committee, informed consent was obtained from each participant during the recruitment process, whereby participants were given an

information sheet and consent form, detailing the intentions of the study, the risks and benefits and their rights as a participant to withdraw from the study at any time with no consequences to them. Following this, semi-structured interviews were used to collect data from 12 participants who met the inclusion/exclusion criteria. Semi-structured interviews were chosen to allow sufficient depth and exploration of the complex issue of sports injury, whilst still maintaining flexibility. Guided questions, probes, and non-verbal cues were used to facilitate the discussion and ensure the researcher's understanding of the participants' experiences [41]. The interview guide was used previously by Davies *et al.* [9] and was developed based on the psychology of sports injury literature and the authors' experiences with severe equine injuries. The same interview guide was utilized to allow comparison within the discussion of how the level of combination influenced the psychological responses following equine injury. The interview guide was designed to address pre-injury career, the rehabilitation phase, pre-return to competition phase issues, and coping strategies used by riders [9,42]. All names given in this study are pseudonyms to protect the anonymity of the participants, and any identifying information e.g. career highlights, horse name, and competition venue have been removed during analysis. Each interview, conducted by VL, lasted between 18–51 minutes and was recorded using an iPhone 6 Memo Recorder. Considering the international aspect of this study and language differences, the discussions were held in the rider's first language and the interviewer (VL - bilingual) subsequently created verbatim transcripts in the original language which were then translated into English for analysis.

Athletes and trainers can be difficult to contact due to busy schedules [43], so the researcher adapted interview methods and times to suit the participants. Building a positive rapport with the riders was important due to the sensitive nature of the topic being discussed. The researcher invited participants to tell stories, give personal accounts, and relate their behavior in relation to the study [44]. In addition, the researcher personally knew most of the participants, and that facilitated openness during the interviews [1]. Face-to-face and online interviews with the use of applications (WhatsApp, Skype, and Facebook Messenger) were undertaken and were implemented depending on the most convenient method for the participant and increasing COVID-19 restrictions (Spring 2020). A total of six participants were interviewed face-to-face, one was interviewed via Skype, one was interviewed via WhatsApp and four via Facebook Messenger.

2.3. Data Analysis

The interviews were transcribed verbatim, and an eight-step thematic analysis process was employed to allow new information to be extracted from the data [45]. The data were analysed using an eight-stage approach adapted from Lamperd *et al.* [1], consisting of the following: (1) verbatim transcription, and translation from French to English for four interviews (VL), (2) all transcripts were reviewed, read and re-read to facilitate analysis (ED, VL), (3) direct quotes were divided into the categories of the questioning framework (ED, VL), (4) inductive grounded theory analysis was undertaken using line-by-line open coding using tags to create themes (ED, VL), (5) focused coding was used to formulate themes (ED), (6) themes were organised relative to the study aims (ED), (7) validation consensus was conducted by both researchers (VL, ED), (8) followed by discussion to determine whether the research aims had been appropriately met (ED, VL).

During the course of data collection and analysis, the interviewer (VL) continuously reflected on her personal experience as an international rider and her own thoughts about her personal experiences when her horse was injured. Her background allowed her to connect and be sympathetic with participants. Furthermore, the supervisor's (ED) epistemological perspective is a social constructivist lens, which framed how the thematic analysis was undertaken. It should be acknowledged that the interpretation of the findings and emergent themes may have been influenced by the research team's experiences with personal injury within the equestrian and racing sectors. Both researchers independently conducted the thematic analysis, and then discussed their positioning to ensure this had not influenced their coding or subsequent themes. The shared experiences of the research team however are considered a strength, as it can aid in building rapport, and demonstrating empathy which may allow for increased honesty regarding complex subjects during the interview process.

3. Results

A total of 12 participants were interviewed for this study (8 women and 4 men, $\bar{x} = 30.8 \pm 10.8$ years (range 20–51 years old)). All participants were international athletes in their respective disciplines, with six eventers, one dressage, and para dressage rider, and the remaining five reported competing in more than one discipline (three riders competed in both eventing and show jumping, and two riders in eventing and dressage). All riders were competing internationally at the time of their horse's injury which impacted their competitive career in the sport. At the time of the interviews, five horses had fully recovered, three were still undergoing recovery and four were euthanized (**Table 1**).

The themes identified by the primary researcher were independently confirmed by the remaining author. Ultimately, the analysis resulted in three higher-order themes: cognitive appraisal, emotional responses, and coping strategies (**Figure 1**).

4. Discussion

4.1. Cognitive Appraisal

The first higher-order theme was cognitive appraisal undertaken by the riders at the onset of their horses' injuries. All riders reported feeling a sense of loss when their horses were injured, and this led to some of them re-evaluating their athletic identity. Riders also reported a duty of care to their horses and felt responsible for the horse's health and wellbeing during recovery. Furthermore, several riders discussed the impact of the injury on their wider support team.

Table 1: Participant details including rider age, nationality, competition level, equine injury status, and impact.

Participant	Age	Gender	Nationality	Discipline	Level	MI	Recovery	NbH	Owned Horse?	Main Impact
Aphy	25	Female	Canadian	Dr/Para-Dr	Junior and Young Rider FEI WEG Para-dressage	SL	PTS (colic)	1	Yes	Olympic Selection Trials
Camille	20	Female	British	Ev/Dr	FEI Pony Trials PSG	DDFT	R	2	Yes	1st Inter I
Sophie	28	Female	Dutch	Ev/SJ	European Championships CCI4*-L	T	R	+	No	European Championship & Olympic Selection Trials
Mandy	42	Female	British	Ev	European Championships CCI-5*	F	Y	+	No	Olympic Games
Anne	-	Female	Swiss	Ev	European Championships CCI4*-L	Frac	Y	2	Yes	Performance Swiss Championships
Claire	20	Female	Swiss/ French	Ev	FEI Pony Trials CCI3*-L	T	Y	2	Yes	None
Margaux	40	Female	French	Ev/SJ	CCI-2*	T	PTS (colic)	2	Yes	End of International career
Serena	22	Female	French/ English	Ev/Dr	FEI Pony Trials	Frac	PTS (injury)	1	Yes	Stopped riding
Tom	42	Male	Irish	Ev/ SJ	Olympic Games CCI5*	T	R	+	No	CCI5*L Participation
Christian	51	Male	Australian	Ev	CCI5*	T	PTS (colic)	1	Yes	Time out of Elite level
Guillaume	26	Male	French	Ev	CCI3*-L	F	Y	1	Yes	Time out of Elite level
Augustin	23	Male	Irish	Ev	CCI3*-L	T	Y	2	Yes	Loss of competition horse

MI- Main injury / NbH- Number of horses

Dr- Dressage / SJ- Show jumping / Ev- Eventing / WEG – World Equestrian Games

SL- Suspensory ligament / DDFT – Deep Digital Flexor Tendon/ T – other Tendon injury / F– Foot injury / Frac – Fracture

PTS – Put to sleep / R- in recovery during data collection / Y – Recovered

+ - Multiple horses but senior or elite horse was injured

4.1.1. Sense of Loss

Most riders discussed a sense of loss, linked to their routine, dreams, purpose, and career aspirations.

> *I just didn't know what, didn't have anything to do, at all. It's just hard when you done it every day all day for like years and years, and you have nothing. (Camille)*

> *And that day I was very disappointed because, you know, it was a competition I really wanted to finish and do well at, and yeah, it didn't happen so that was, at that moment very disappointing. (Tom)*

A sense of loss is considered part of the cognitive appraisal process in athletes, which occurs at the onset of injury and can influence negative emotional responses such as grief or devastation, as seen here [23]. A sense of loss is often attributed to an impact on competition goals, or long-term career aspirations, with an inability to perform or compete reported as the major source of disappointment for injured athletes [46,47]. For elite athletes, loss can be a more prominent response to injury, as they often experience a sense of purpose in competition and training, which is disrupted, and they are emotionally invested in their sport [46]. Previous research in equestrian sport suggests that young riders also experienced loss at the onset of their horse's injury [9], and that riders who have invested more time into their horses may be at increased risk of devastation following injury [10]. Peretz's [48] model proposes that loss occurs across four dimensions: loss of a significant person, loss of some aspect of self, loss of external objects, and developmental loss [49]. Elite riders whose horses are injured could experience all four dimensions of loss, thus riders' psychological state should be closely monitored by coaches and performance teams following an equine injury to maximize athlete wellbeing [50].

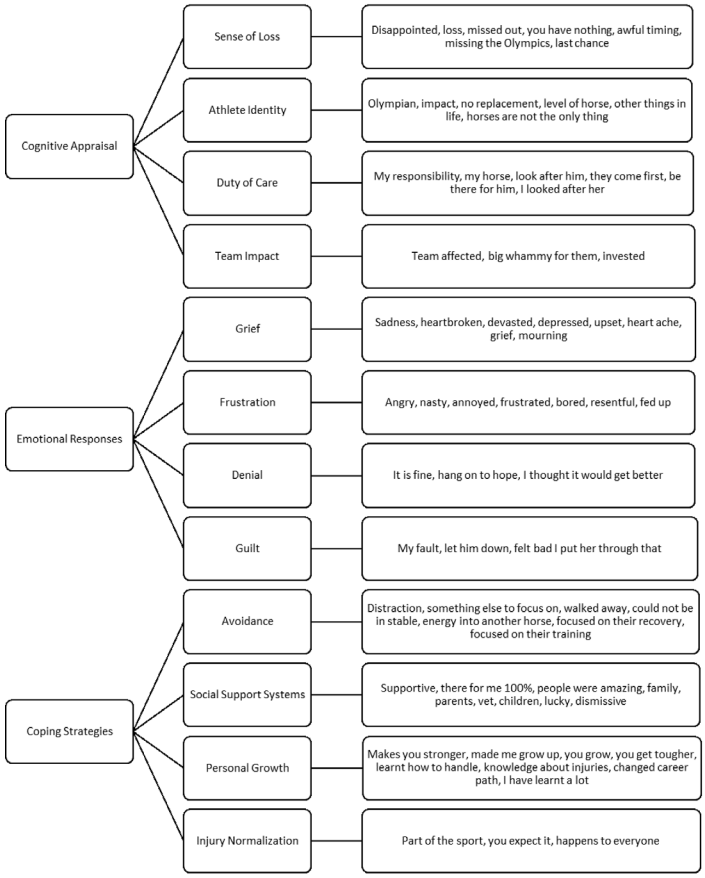

Figure 1: Higher and lower-order themes.

4.1.2. Athlete Identity

All participants mentioned the importance of horses in their life at the time of the injury. Dashper **[36]** proposed that horses were an integral part of a rider's life and thus are an important part of an individual identity, which may be impacted by equine injury.

> *…were given all the new team stuff and it had all of the Olympic logos on and everything…. But actually, I haven't worn that at all. I feel like I don't really want to, because I am not going to the Olympics, and I have no chance anymore (Sophie)*

> *That was hard as well, cause I was I have nothing else now, like I was afraid … worried, am I going to forget how to ride at that level? (Augustin)*

It has been suggested that riders question their own personal identity after their horse is injured, as they develop a strong athlete identity surrounding their role as a rider **[9]**. Moreover, it seems that professional elite riders do not just identify themselves around the fact that they are elite riders, but also around their accomplishments in the sport, such as being an Olympian or a World Champion. Wylleman *et al.* **[51]** suggested that the athletes perceived a strengthened identity with their role as elite athletes after the Olympic Games. Challenges to athletic identity have previously been related to a decrease in mental wellbeing **[35]**, suggesting that coaches and governing bodies should be cognizant of elite riders' wellbeing following equine injury.

Interestingly, riders with access to only one horse, or only one elite-level horse, seemed to experience increased negative psychological responses following their horse's injury, possibly as they were unable to continue competing at the same level. Previous research has found that elite riders struggled with their athletic identity when they lost their ride at the elite level **[52]**, and elite youth athletes also reported that lack of a horse at elite level made them feel like they were not elite riders anymore **[9]**. Equestrian sport incorporates both horse and rider under the umbrella of 'athlete' at elite level, and this increases the risk of injury-related psychological issues compared to other elite athletes. This can be seen in Anne's response:

> *I don't have a big string so for me an injured horse has a big impact because I don't have a replacement (Anne)*

Two riders did not feel their athletic identity was impacted by the equine injury. Individuals who formulate a significant part of their identity around an activity, but have other life pursuits, and do not rely on continued involvement for self-esteem, social approval, or validation, are defined as having harmonious passion **[53,54]**. Whilst Tom's only elite-level horse had experienced a serious injury, resulting in losing the opportunity to compete at a CCI5*L competition, he reflected on those external elements of his life that allowed him to gain perspective on the situation, such as college or

children. Margaux also reflected on family and children, and ultimately decided to end her international career in favor of other pursuits.

> *There is more to life than this. I mean I already had that experience that because I went back to college, and I already had the awakening that there is more to life that horses. (Tom)*

> *…you have a family life, you have children, there are other things that make you realize that it's not the only thing in life. Horses are not the only thing. (Margaux)*

4.1.3. Duty of Care

Participants discussed feeling a sense of responsibility towards the care of their injured horse. They expressed gratitude towards their horses, who did a lot for them, and wanted them to have a happy life, which involved making decisions about what was best for them.

> *So, he was my horse, he's my responsibility, you can't just send him away, so I have to make sure he is all right, … I didn't have a lot of resources at that time. And so, you just sort of, you take responsibility for it. And it's personal because it's your horse (Christian)*

> *..you are responsible for that horse, so they are counting on you, and you know at the end of the day, that's what matters. I think just get up do it for the horse, like you know this is not about me. I'm not the one that is hurt, I don't need to be taken care of right now. (Aphy)*

Horses require daily care and attention to maintain their health and wellbeing **[5,36]**, and typically those responsibilities belong to the rider **[38]**. In the occurrence of an injury, these responsibilities are even greater. Not all riders are directly responsible for daily horse care, due to the presence of grooms in some commercial yard structures, which may be more likely in elite riders compared to amateurs or youth athletes. However, for doping and prohibited substances, the FEI states that the athlete is still classified as the 'person responsible' thus ensuring that the rider is responsible for oversight of their horses' care.

4.1.4. Team Impact

Along with discussing their own responses, several elite athletes also reported the impact of the horse's injury on wider members of their teams, including family, owners, grooms, and coaches.

> *I mean the team, obviously, you know, they live everything, feel everything just as much as you do…that was really a big whammy for them too. (Mandy)*

> *Everybody shares your disappointment because it is a team effort…it's not only my disappointment but the grooms, they also, for them going to a big competition is every bit as important that it is for me. And so, I think the whole team share the disappointment. (Tom)*

Research has yet to identify the wider implications of sports injury on an athlete's support network **[55]**, although some limited research exists considering the impact of athlete injury on coaches **[28,56,57]**. Coaches experienced high levels of guilt when their athletes were injured **[57]**, and some coaches reported experiencing intrusive flashbacks, and subsequently avoided sports practice following an injury incident at the gym **[28]**, demonstrating that there are wider impacts of injury than just to the athlete themselves. The impact of equine injury on the human athlete is already identified as a form of vicarious trauma **[9,10]**, whereby the athlete is experiencing significant psychological responses to witnessing a partner or teammates injury **[28,29]**. However, the human athlete is not the only individual to develop a significant partnership or bond with the horse. At elite level, grooms are common practice, and hold an integral position with the equine support team, often acting as a primary caregiver and working closely with the rider to achieve optimal equine health and performance **[58]**. As such, it could be argued that the psychological impact of injury in elite horses is likely to produce a significant emotional reaction in the grooms, which may be different than what is seen in the rider and should be investigated in further research.

4.2. Emotional Responses

A range of emotions were identified in riders at the onset of their horse's injury, including depression, denial, anger, frustration, blame, disappointment, and guilt. In response to equine injury, four lower-order themes were identified: grief, frustration, denial, and guilt.

4.2.1. Grief

Several riders reported experiencing devastation and grief when their horses were injured, akin to losing a family member or a best friend.

> *So that was pretty traumatic cause he was like my best friend, cause it was basically me and him together coming up here from Australia, …, he shared the whole experience. (Christian)*

> *Even if he was only an animal, for me at the time he represented much more than that…It was a rather as if I had lost someone close. People who aren't riders, would find that, would I say mad, but that's the way it was…(Margaux)*

Grief-like responses have been previously reported in injured athletes, typically resulting from a sense of loss of sporting performance **[59]**, and grief responses are often heightened if the injury occurs prior to a critical event, such as the Olympic Games **[46]**. However, the grief experienced by several riders in this study focuses on the implications of injury on the horse-human bond, which may be more akin to an owner and pet relationship, rather than the proposed transactional athlete and 'tool' relationship which has been previously reported as a concern for elite equestrian athletes **[3]**. Research in companion animals suggests that the strength of attachment between owner and pet is considered a predictor of grief when an animal dies **[11]**. Whilst death was not the outcome for most horses discussed as part of this study (four were euthanized, remaining eight were recovering or returned to work), research has suggested that owners with higher levels of empathy are more likely to recognize pain in animals **[60,61]**, and consequently experience heightened emotional reactions and a sense of devastation during periods of equine injury **[10]**. Empathy, defined as a 'vicariously induced emotional reaction … that is similar to the other's emotional state or consistent with the other's situation' **[62]**, has been shown to increase when viewing others in pain or

distress, particularly if there is a strong emotional attachment [63]. It may be suggested that for some riders in this study, a stronger horse-human bond, and increased feelings of empathy may have resulted in increased emotional responses to their horses' injuries than other riders.

4.2.2. Frustration

Some riders reported feeling angry or frustrated at their situation, and this was often linked to missed opportunities, such as team selection or career goals.

> *…then I got really angry. I got very jealous as well and bitter towards people that did make the team [removed] I thought, well that could have been me. You know, it's not fair that should have been me. (Aphy)*

> *…looking back on it has been frustrating because I don't think I've quite achieved all the things that I was possibly able to do… (Mandy)*

Frustration has been identified as a common emotional response to injuries in athletes [23,64], whereby injury is seen as a setback in their career trajectory [21]. Frustration is typically seen in athletes who are highly invested in their sporting career [21], and elite riders are known to invest considerable time and finances into their sport to be competitive [1,7,30]. Frustration can also be a secondary emotional response to feelings of uncertainty, possibly in relation to injury prognosis, career opportunities, or changes to routine, as seen in some of the riders in this study [46,65]. It is also proposed that frustration is related to the level of blame an athlete puts upon themselves [64], and for riders, blame may be significantly higher due to having direct control over their horses' daily routine, training, and care [9]. This could predispose riders to increased levels of frustration following equine injury. Furthermore, as riders are still physically capable but unable to compete due to equine injury, this could increase the frustration experienced by these riders.

4.2.3. Denial

Several riders reported experiencing denial when their horses were injured. Riders typically acknowledged the injury occurrence but were more likely to be in denial about the severity or long-term prognosis.

> *I told myself that if I used more clay, more cold water, he would recover quicker. (Margaux)*

> *To start with, I was kind of like, it's fine, it's an abscess, she is going to be fine. And then 3 weeks in, I was like it's fine, it is going to be an abscess, like it's going to be fine and then I was like this isn't going to be fine. And it just kind of got work. In my head, I was like, kind of crossing my fingers it's all going to be ok, and then I was trying like to hang on to hope and then I was like no this isn't going to be ok. (Camille)*

Denial is considered a temporary defense mechanism, employed in a negative situation, whereby an individual will consciously or unconsciously refuse to accept a given reality [26,66]. Elite riders reported denying the severity of their horse's injury, or long-term prognosis, which are common portrayals of denial in other athletes [26,33]. Decisions to deny or ignore the injury may lead to heightened emotional reactions, and increased difficulty in coping [67], resulting in delayed access to medical treatment or rehabilitation [68]. Denial of equine injury severity and prognosis was also reported in elite youth equestrian athletes [9], however, for both youth and elite equestrians, denial states did not impact the use of veterinary medical provision, with Margaux even highlighting additional measures taken to facilitate recovery. The vicarious nature of the injury may suggest that whilst the protective mechanism of injury denial is still prevalent in horse riders with injured horses, the consequences of engagement with treatment and rehabilitation for their horses may be different and warrant further research.

4.2.4. Guilt

Some of the elite riders questioned their personal responsibility for the injury, with some attributing causality to their own actions, or questioning their lack of anticipation of the injury incident.

> *It's happened, there's nothing you can do about it… what is more of an issue is it happened because you had done something stupid (Christian)*

> *But when the vet is like: I don't know what (caused it), it kind of makes it harder because you think like: what did I do? (Camille)*

> *What I remember today is that I should have anticipated this. (Guillaume)*

Guilt is considered one of the more threatening emotions reported in injured athletes and increases the risk of social isolation during recovery [68,69]. Indicative of an individual's perceived responsibility for the injury, due to their tactical decisions, training, or management strategies [69,70], athletes also attribute guilt to 'letting the team/coach down' [71]. For riders, the role of teammate also extends to the horse, and this has been seen by riders in this study, as well as in previous research [9]. Furthermore, riders reported feeling guilty for actions or decisions that may have caused the injury incident; Guillaume reported feeling guilty for not previously anticipating the risk of injury when training and competing, which could suggest prioritizing career progression over equine welfare in training [3], or could suggest a lack of prior knowledge on specific injury risk factors at the time of the incident. Riders displaying high levels of guilt, self-blame, or frustration should be monitored closely by coaches, and peer-to-peer support interventions considered, to reduce the risk of social isolation and disengagement from the sport.

4.3. Coping Strategies

All riders discussed various coping resources and strategies they employed when their horse was injured. Lower-order themes included avoidance, social support systems, growth, and injury normalization.

4.3.1. Avoidance

Several examples of avoidance coping were seen in elite riders, including behavioral and cognitive avoidance coping [72]. Athletes reported physically removing themselves from the stables or barn, or disengaging from equestrian sport, which are examples of behavioral avoidance.

> *I just walked away from the stable…I couldn't really be in the stable because I knew what it was…I just left; I didn't go*

into the yard for the rest of the day… I did nothing, didn't go near the yard, didn't want to look at a horse. I just wanted to be on my own … (Sophie)

I stopped going to the yard. I decided I was not going to ride horses for the moment because it was too difficult, too hard. I didn't put a foot at the yard for 6 months, not to see his stable, not see the stuff that was here and stuff. (Serena)

Behavioral avoidance is a common coping technique for situations involving vicarious trauma and has been suggested to be advantageous when an individual has little to no control over their circumstances, resulting in high-stress levels [28,73]. Whilst avoidance coping as a temporary method of coping is designed to protect athlete wellbeing, the long-term implications of avoidance coping are predominantly debilitative for successful return to competition [74,75]. This could result in elite equestrian athletes disengaging from equestrian sport following equine injury, as seen in Serena's case, and previously reported in youth equestrian athletes as well [9].

Previous equestrian research found that elite young riders also utilized cognitive avoidance coping, employing thought-stopping techniques to distract and divert from their situation [9,72]. After a setback, athletes try to focus and direct their energy on what they can do and control [21,64]. Whilst youth athletes previously avoided thinking about the injury at all, and often withdrew from competitive careers due to a lack of horses, elite athletes in this study redirected their focus towards productive means, often investing more time into other horses. Lamperd *et al.* [1] suggested that the characteristics of elite equestrian athletes include coping with adversity, and motivation to succeed, which may explain why some athletes chose to redirect their loss into more productive career routes. Horses, whether seen as commodities or as loved ones, or both [3,8] may help riders to overcome negative responses due to the loss/injury of another horse. Having access to other high-level horses could help a professional continue their career trajectory. This can be seen in Augustin's quote below:

*Probably the fact that I had the other horse **** [name], I probably the way to cope was I put more time and effort into him rather than thinking about what happened (Augustin)*

4.3.2. Social Support Systems

All elite riders discussed social support systems used during their horse's injury period, however, not all of these were viewed positively. It was generally agreed upon that the equestrian community was more understanding of equine injury than non-horsey individuals, due to shared social norms and experiences, however, Claire also reported a lack of empathy from her trainer when her horse was injured.

But I think the community, the equestrian community, particularly the eventing community are very very supportive, because we are all in together and everybody, nobody gets away with not having an injured horse. So you know, not that it ever fixes anything, at least you know people understand where you are…(Tom)

But maybe at the time my trainer was a bit, a bit dismissive about it, and he was more, he wanted to forget about it more easily…he kind of just brushed it off. And was like it doesn't matter. (Claire)

Social support is one of the most important psychosocial factors for athlete recovery [76,77] and seeking social support is a common behavioral response [78]. Social support provides a buffer to psychological distress [79] and isolation [80] and enhances perceptions of psychological readiness during recovery [81]. Freeman [82] suggests that social support may encompass several key relationships, including family, friends, physiotherapists, or coaches, although perceptions of their support differ within the literature [76]. Athletes with similar injury experiences are often seen as the best source of social support [83]. These individuals, often teammates or peers, act as role models, and are more relatable to injured athletes, reinforcing the belief that recovery is achievable [76]. The support of the equestrian community has been previously reported in injury literature, with riders identifying the best sources of support being those who 'understood' [9] and can be seen here in the experiences of elite riders as well.

The role of the coach during athlete injury is to aid in the athlete's successful return to sport [84], and should encompass a holistic approach, considering the psychological, emotional, and social needs of the athlete, alongside their physical recovery [85]. However, whilst coaches believe they are providing adequate support for athletes during injury [86], athletes are reporting dissatisfaction with that support [87]. Athletes cited coaches' resistance to acknowledge injuries, lack of communication, doubt of injury severity, or increased focus on competition and training rather than recovery as barriers [84,87]. Claire highlights a lack of emotional support from her coach, which can increase psychological distress during injury recovery [37], and impact subsequent engagement in the sport [76]. However, Maurice *et al.* [84] identify that coaches receive little training on supporting athletes with injury, beyond the physiological training adaptations required, thus may be ill-prepared to offer emotional support. Additional training to support equestrian coaches in communicating with riders during human or equine injury periods would be beneficial to optimize psychological readiness for return to sport [81].

4.3.3. Personal Growth

Recent research has determined that not all responses to injury are negative, with many individuals reporting positive changes, in lifestyle, health, or mentality following injury [88]. Whilst many conceptual definitions exist, personal growth is deemed as broadly encompassing all growth experienced by individuals who have sustained a sporting injury [89]. Positivity and personal growth can be seen in several participants following equine injury:

I think positively. I think it kind of made me grow as a person, as in making more mature to injuries, and kind of just accepting the fact that horses do get injured…made me more patient, more careful on how I work my horses… (Claire)

I think from all of it, it's you grow, and you get tougher and whatever. But at the same time, I don't think it never gets

any easier, if you got a horse that level that becomes injured. (Sophie)

Recent research suggests that growth has five dimensions: personal strength, improved social life, health benefits, sporting benefits, and social support [90]. Elite equestrian athletes in this study were more likely to identify personal strength and psychological benefits from the injury incident, highlighting increased mental toughness, resilience, and changes in attitude. Elite athletes are unique compared to non-elite as they typically emphasize positivity, and this may explain why personal growth was not previously identified in amateur riders following equine injury [10]. Whilst growth following a stressful event is not exclusive to athlete injury, physical growth linked to increased knowledge around injury physiology, training, and recovery is considered bespoke to athletes [88] and that can be seen in Claire's response, where she notes a change in her training practices, suggesting an implication towards sporting benefits as well. This could suggest that for some elite equestrian athletes, the experience of equine injury may help to shape future training practices.

4.3.4. Injury Normalization

There seems to be a normative culture of injury in equestrian sports, where both equine and rider injuries are accepted and even expected as part of engagement within the sport. This viewpoint seems to have been used as a coping strategy by many riders to regulate their emotional reactions to the injury.

I do think it's part of the sport and arguably it's part of life, you do need to learn how to deal with it because it is going to happen (Christian)

To be honest, …, I think if you are in the sport, unless you're a complete naïve and young and inexperienced, you know that those (things) happen (Tom)

By choosing to engage in physically demanding or high-risk sports, athletes assume a certain level of injury risk, and an expectation of injury is often seen in athletic populations, although many athletes are unprepared for the consequences [91]. Within these sports, injury, risk-taking behavior, and tolerance of pain are normalized, and seen as 'part of the sport' and this can influence the mentality and actions of injured athletes, coaches, rehabilitation teams, and teammates [92,93]. Whilst normalization of injury can result in negative recovery behaviors, such as continuing to train or compete whilst injured or social isolation, the culture of injury within sport has also been found to positively influence personal growth [89]. Roy-Davis *et al.* [94] suggest that athletes who acknowledge that injuries are an acceptable risk of competing in sports are more likely to experience stress-related growth. Both Tom and Christian highlight a level of acceptance that has aided their cognitive appraisal and psychological recovery following their horses' injuries. Unlike research on human equestrian athletes [95,96], the injury normalization culture seen in response to equine injuries seems to facilitate a positive response in riders during periods of injury stress.

In this study, riders mentioned the wider impact of equine injury, highlighting several key members of their team: coaches, grooms, and owners. Examining the team's appraisal and responses to equine injury would be interesting as equestrian sports, although considered an individual sport, do require a substantial team investment to develop an elite horse. Future research in this area should explore the wellbeing of all those working around the horse and the impact of equine injuries on grooms, coaches, and wider sports science support teams [97]. Furthermore, other sports have investigated the success of both pre- and post-injury interventions to enhance coping strategies in athletic populations [33]. Future research could evaluate the efficacy of pre- and post-injury intervention programs in elite equestrian populations, through the World Class Programme structure.

There are limitations to consider within the study. All riders discussed their story when one of their horses was injured and their responses to this injury. There were no objective measures or monitoring during the study and therefore it is based on rider self-awareness [9]. Indeed, any story will be influenced by the teller, the audience, and the relationship between the two [28]. There was some limitation in the sample and differences in injury type and timeline. Riders talked about the injuries that affected them most during their careers, but these ranged from relatively insignificant injuries to injuries that resulted in the euthanization of the horse, and this could have impacted the responses of the riders. In addition, some riders talked about injuries which happened some years ago, and others about injuries to horses which are still in the recovery process. They were at different stages of acceptance from the disruption of their horse's injury. However, that allowed the examination of the responses of riders to the injury of their horses as a collective [35].

5. Conclusion

The impact of an equine injury on elite equestrian athletes is complex, as equestrian sports are dependent upon the unique partnership between horse and rider. This study found that regardless of elite status, and concerns over the transactional nature of equestrian sports at elite level, elite equestrian athletes still experience psychological stress when their equine partner is injured. All elite riders experienced a feeling of loss and grief, although the source of this loss was different for individual riders. Riders highlighted a loss of routine, career opportunities, and athletic identity, through loss of participation at elite level. Similar negative emotions were seen in elite riders as in other athletic populations, including devastation, frustration, denial, and guilt, and riders employed a variety of coping mechanisms, including avoidance, and reliance on social support. Supplementary coach education to facilitate the recognition of these emotions and behaviors in riders following equine injury, and further training on effective communication and signposting would be beneficial. Equestrian communities are still viewed as most helpful during equine injury and equestrian governing bodies and performance programs should consider the development of targeted social support systems for injured combinations (horse and rider). Further research should consider the impact of equine injury on members of the support team, including grooms who, for elite level combinations, are often the primary caregiver.

Authors' Contributions

Conceptualization, ED & VL; methodology, ED; validation, ED & VL; formal analysis, ED & VL; resources, ED; writing-original draft preparation, ED & VL; writing- review and editing, ED & VL; visualization, ED; supervision, ED; project

administration, ED. All authors have read and agreed to the published version of the manuscript.

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Data Availability

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Conflicts of Interest

The authors declare that there are no conflicts of interest.

Ethical Approval

This study received ethical from Hartpury University Ethics Committee. The study complied with the guidelines of the Declaration of Helsinki.

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Review Article Open Access

Prebiotics and Synbiotics in Equine Health and Disease

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Abstract

Prebiotics are non-digestible food ingredients that promote the growth of probiotic microorganisms in the intestines. They are marketed as feed supplements to support equine digestion, metabolism, growth, and immunity. Synbiotics are supplements that contain combinations of prebiotics and probiotic bacteria and/or yeasts. Both prebiotics and synbiotics are commercially available and are promoted for use in supporting equine digestion, enhancing athletic performance, as well as reducing stress and morbidity associated with intestinal disease. This narrative review aimed to summarize the literature on the use of prebiotics and synbiotic supplementation in equine nutritional practice. Sixteen papers were identified that reported on the use of prebiotic or synbiotic supplementation in horses. The literature presented here suggests that prebiotics may play a role in equine health and disease prevention. Prebiotics have been studied for their effects on athletic performance; increasing production of volatile fatty acids (VFA's) associated with hindgut fibre fermentation; insulin resistance and carbohydrate metabolism associated with reduction in the development of gastric mucositis, and hindgut acidosis and laminitis. Prebiotic compounds are thought to have an entero-protective effect by improving the composition and diversity of the intestinal microbiota, that in turn impacts immune function via metabolomic effects. Prebiotics derived from yeasts, including mannan-oligosaccharides (MOS), have been shown to reduce colonies of intestinal pathobionts and accelerate healing in acute enterocolitis. Overall, the current evidence to support the use of prebiotics and synbiotics in equine health and disease is not extensive but promising.

Keywords

Equine; prebiotics; fiber; synbiotics; microbiome; digestion

1. Introduction

Equine veterinarians play an important role in advising on interventions that prevent and treat gastrointestinal disorders in horses. Equine gastrointestinal disorders include scouring in neonates [1], colitis and fatal colic events [2], parasitic gastrointestinal infections [3], gastric ulceration [4], salmonellosis associated inflammatory bowel disease [5], coronavirus infection with necrotizing enteritis and eosinophilic enterocolitis [5], sand-accumulation enteropathy [6] and caecal disorders [7]. Dysbiosis of the intestinal microbiome defined as "a loss of diversity, a bloom of potential pathobionts, and a loss of commensals" [8] may predispose horses to many of these gastrointestinal disorders [9]. Interestingly, there is evidence to suggest that equid type (size, breed, or conformation) may influence predisposition to the development of various gastrointestinal lesions; for example, larger breeds such as Clydesdales experience more caecal disorders, whereas smaller breeds and miniature horses are less likely to be affected by colon displacements [10]. Furthermore, extraintestinal conditions such as exacerbations in asthma [11], obesity [12], and impaired athletic performance [13] have all been associated with alterations to the composition and diversity of the equine gastrointestinal

microbiome. Therefore, the equine microbiome has gained increasing attention in veterinary research [14] as reflected by the initiation of the Equine Gut Microbiome Project in 2015 [15].

Hindgut fermentation, which fundamentally influences intestinal microbiome composition [16,17], is a digestive process seen in animals with a simple, single-chambered stomach. These animals include equids, rhinoceros, koalas, rodents, and rabbits; in these mono-gastric herbivores, cellulose from plant foods is digested with the support of intestinal bacteria [18]. Popular interventions thought to alter the composition and diversity of the gastrointestinal microbiome include supplementation with probiotics and prebiotics. Probiotics are defined as "live microorganisms which, when administered in adequate amounts, confer a health benefit on the host" [19] and prebiotics are defined as "selectively fermented ingredients that result in specific changes in the composition and/or activity of the gastrointestinal microbiota, thus conferring benefit(s) upon host health" [20].

Prebiotics are widely used in equine management regimens to support the intestinal processing of a variety of feedstuffs, based on the belief that they improve the diversity and richness of the species that inhabit the intestinal microbiome [21]. Adding prebiotics containing fructo-oligosaccharides (FOS) or mannan-oligosaccharides (MOS) to high-fiber diets increases feed digestibility, supports energy production, and improves the general fitness and health of the horse [21]. Research conducted with Irish thoroughbreds undergoing a sudden change in feeding regimen found that digestive sensitivity particularly affected individuals carrying a limited abundance of hindgut core bacterial species [22].

When probiotic bacteria and/or yeasts are combined with prebiotics, the formulation is referred to as a 'synbiotic'. These combinations have been used in human studies to promote the growth of beneficial microbes, aiming to increase the diversity and richness of the intestinal milieu [23].

While there are limited studies in the equid, the potential role of pro- and prebiotics in human health and disease has been explored far more extensively, with the current PubMed citations exceeding five thousand. No summary of studies that report on the nutritional and therapeutic role of prebiotic and synbiotic supplementation in equine health and disease has been conducted to date. Therefore, the aim of this review was to provide an overview of the literature reporting on the use of prebiotic and synbiotic supplements, in equine nutritional practice. An online search of Embase and PubMed databases for papers published from inception to 2023, using the search terms 'prebiotics', 'synbiotics', 'horses', and 'equine', was conducted to identify original research evaluating the effects of prebiotics and synbiotics on the composition and/or metabolism of the equine intestinal microbiome, along with associated health outcomes.

Sixteen papers reporting on the effects of prebiotic or synbiotic supplementation in horses were subject to full-text review. The findings of those studies are discussed and evaluated here. This review does not address the use of probiotics in equine populations, which was the topic of a previous review published by the authors of the present manuscript [24].

2. Types of Prebiotics

In the horse, naturally occurring prebiotic compounds can constitute part of the regular feed or supplementation regimen, supporting potential colonization of the intestinal environment with bacteria that are thought to confer a benefit. Prebiotics include fermentable sugars, predominantly oligosaccharides or disaccharides, of which there are several types: oligofructose, inulin, isomalto-oligosaccharides (IMOS), lacto-sucrose, fructo-oligosaccharides (FOS), galacto-oligosaccharides (GOS), lactulose, pyrodextrins and xylo-oligosaccharides (XOS), and mannan-oligosaccharides (MOS) [25]. Certain prebiotic types are compounded dietary sugars, for example, FOS is composed of short chains of fructose molecules and GOS is composed of a chain of galactose molecules; IMOS is derived from the disaccharide maltose (sourced from honey, for example) following enzymatic activity, which produces a mixture of short-chain carbohydrates; XOS, a natural prebiotic fiber extracted from sugar cane fiber, and inulin belong to a class of polysaccharides known as "fructans" and are found in vegetables such as Jerusalem artichoke, plantains, and chicory root. MOS are complex carbohydrate molecules, derived from the outer cell wall of the yeast *Saccharomyces cerevisiae* - mainly β-glucans (mannoproteins). Soluble arabinogalactans are classified as non-carbohydrate sources of prebiotic fiber derived from larch trees (*Larix sp.*) [26]. From the literature, equine prebiotics most studied are inulin, FOS, GOS, and MOS.

Different prebiotic classes supply fuel to resident microbes in various regions of the equine gut. The caecum and colon comprise 66% of the digestive tract volume and contain large populations of anaerobic bacteria; these probiotic species process pectin, cellulose, hemicellulose, and starch, producing volatile fatty acids (VFA's) through the process of fermentation, to be utilized as a metabolic energy source [27]. The hindgut (colon and caecum) houses a complex microbiome, composed of mostly bacteria but also viruses, fungi, protozoa, archaebacteria, and phages; these microorganisms ferment the residual indigestible cellulose which has not been processed proximally, to produce VFA's that serve as a fuel source for the host [28]. Nutrients including protein and B-group vitamins are also rendered more digestible by microbial fermentation in the hindgut [21]. Equids digest a very limited amount of the lignin present in plants, and it is mostly excreted in feces, as they lack the necessary enzymes, relying on microbially-generated enzymes to aid digestion [29].

3. Prebiotics in Forage and Carbohydrate Digestion

Forage of various types supplies energy, nutrients, and prebiotics to equids; by definition, the prebiotic constituents of regular feed assist in promoting the growth of intestinal microbiota that confer a health benefit [30]. Naturally occurring fructans are long-chain sugar molecules found in a variety of pasture grasses, with nutrient-dense verdant grasses being higher in fructan content and ranging to low-fructan native grass species, the latter being prevalent in Australia [31]. While fructans are considered to act as prebiotics, grass varieties such as Timothy and some types of Perennial Rye

are either processed rapidly in the equine intestine or have a significant proportion of their carbohydrate pass undigested into the hindgut for fermentation by resident microbiota, generating lactic acid as a by-product [31]. Contrary to the definition of a prebiotic, high fructan intake is thought to contribute to the development of hindgut acidosis, increasing the risk of laminitis [32], however, this effect may be ameliorated by the addition of different prebiotic fibers to the feed which degrade more slowly [33]. Mature grasses are composed of more indigestible fiber [34] and fewer fructans than young fresh grasses, hence presumably would pose less risk of hindgut acidosis to horses grazing on these pastures. From a management perspective, grazing horses on native grasses is preferable to administering prebiotic extracts, as native grasses are more fully processed and do not contribute to increased intestinal gas production which might arise from unfermented fructans reaching the hindgut [31].

The starch component of an ideal equine prebiotic feed should predominantly degrade in the intestine, proximal to the hindgut. Jerusalem artichoke is a source of the prebiotic FOS and inulin, which can influence the metabolism of hindgut microbiota by modulating the fermentation of ingesta [21]. Additionally, according to one study in which carbohydrate processing from the stomach to the transverse colon was evaluated, Jerusalem artichoke can also contribute to increased gas production in the hindgut due to the fermentation of undigested fructans [33]. Importantly, inulin derived from Jerusalem artichoke is fermented differently than that present in grasses and may not support the development of beneficial *Lactobacillus* colonies as effectively as the inulin from forage does. The rapid fermentation of high fructan grasses favors hindgut cultivation of lactate-producing bacterial species, such as *Streptococcus bovis* and *S. equinus*, overwhelming colonies of predominantly lactate-utilizing species, such as *Veillonella sp.* and *Megapshera sp.*, the latter which metabolize lactate to propionate [32,35,36]. If carbohydrates ferment early in their passage through the equine foregut (esophagus, stomach, and small intestine), rather than having this process slowed by the presence of indigestible prebiotic fiber, the resultant production of organic acids may accumulate and produce mucosal injury (ulceration) [33]. An *in vivo* experiment conducted on postmortem equine gastric mucosa tissue samples, applying various concentrations of butyrate to replicate those achieved by natural Jerusalem artichoke bacterial fermentation in the hindgut, showed evidence of injury to the gastric mucosa, postulating that this FOS-rich prebiotic supplement could increase the risk of developing equine gastric ulcer syndrome (EGUS) [37].

4. Prebiotic Supplementation in Hindgut Fermenters

Given the limited literature relating to the use of prebiotic supplementation in horses, it is of interest to consider what is known about other species that are hindgut fermenters. Researchers have explored the effects of supplementing the diets of other hindgut fermenting animals with prebiotics, specifically rodents and rabbits. These studies found associated improvements in lipid metabolism, the composition of the intestinal microbiome, and nutrient absorption, particularly minerals [18]. Hindgut fermentation, cell-mediated immunity, and various blood parameters improved in rats supplemented with pulverized Jerusalem artichoke, rich in prebiotic inulin and FOS for twelve weeks [38]. Further, in these rats, skin indurations induced by a mitogen reduced, while CD4 lymphocyte populations increased, and blood levels of glucose, urea, and hemoglobin in these rats adjusted favorably [38]. Yeast-derived MOS supplementation enhanced VFA concentrations and lowered pH in the cecal region of rabbit intestines and was associated with longer intestinal villi when compared to controls. In addition, the weight gain observed with the addition of MOS to the diets of the study animals was similar to that which could be expected from antibiotic treatment for promoting growth [39]. By further comparison, koalas possess a proportionally large hindgut for processing their exclusive diet of Eucalyptus leaves and, while their core intestinal microbiome has been explored [40], no study has been published involving prebiotic supplementation of this marsupial species nor the other remaining hindgut fermenter, the rhinoceros. Although evidence supporting the use of prebiotics in the dietary management of horses is limited, there are many commercial prebiotics and synbiotic supplementary feed formulations, currently available in several countries, which are purported to enhance the intestinal microbiome, digestion, energy production, and immunity.

5. The Effects of Prebiotics on the Equine Microbiome

There is a paucity of studies evaluating how the addition of prebiotic compounds to commercial horse feeds impacts the intestinal microbiome. Most attention has been given to the modulation of intestinal carbohydrate processing by specific prebiotics to reduce the incidence of laminitis, which can be experimentally induced by administering large doses (10g/kg bwt) of fructans to horses [41,42]. Such carbohydrate loading causes acidification of the intestinal milieu, producing a shift from eubiotic Gram-positive bacteria to lactate-producing species, such as *Streptococcus bovis/equinus* in the gut microbiome [32]. It is believed that these bacterial species, via the generation of vasoactive amines and endotoxins which can permeate into the systemic circulation and cause ischemia/reperfusion injury to the equine digit, contribute to the development of laminitis in horses [42]. A balance needs to be maintained between the number of commensal bacterial species which are lactate-producers (e.g. *Lactobacillus salivarius*, *L.delbreukii*, *L. mucosae*) and those which are lactate-utilisers (e.g. *Veillonella sp.*, *Megasphera sp.*) [36]; the latter metabolize lactate to propionate to support energy production, with propionate being a key precursor molecule for gluconeogenesis [43].

Prebiotic sugars and fibers provide energy and nutrients to intestinal microbiota to fuel their metabolic activity. Berg *et al.* evaluated supplementing the diet of yearling quarter horses with FOS, finding that this intervention led to alterations in the microbiome and metabolome, with respect to fecal pH and concentrations of VFA's [44]. These researchers reported a quadratic effect on fecal *Eschericia coli* populations following FOS supplementation without any apparent alteration in the numbers of *Lactobacillus sp.*; fecal propionate, butyrate, acetate, and lactate concentrations increased linearly with total VFAs in this study [44]. Such VFA's generated by intestinal microbiota can provide an additional energy source to carbohydrates for athletic performance in trotting horses.

Hence, providing such prebiotics to generate fuel could be considered performance-enhancing supplementation.

In Warmblood horses fed FOS and inulin supplements daily for 3 weeks, the abundance of *Lactobacillus sp.* increased in relation to that of *Streptococcus sp.*, which decreased in the gastric microbiome, while higher alpha diversity of the intestinal microbiome was observed [45]. Alpha diversity refers to the number of species (species richness) within that region. Fructo-oligosaccharides are thought to support the colonization of the equine intestine with *Bifidobacteria*, although the effect of this increased colonization is not fully understood [30]. There is limited evidence for the function of *Bifidobacteria* in the equine gut microbiome, which contains a much larger proportion of *Lactobacilli*, even in relation to that found in humans, however, these indigenous probiotic bacteria do not typically utilize FOS as consistently as do *Bifidobacteria* [30].

The core intestinal equine microbiome is considered to be healthy if it contains a relative abundance of *Firmicutes* with respect to *Bacteroidetes* phyla [9] and specifically it is the metabolic function of the intestinal microbes which determines equine health. The fecal microbiome composition of ten healthy horses following supplementation with prebiotic cellobiose for 14 days was profiled by Paßlack *et al.*; the relative abundance of *Firmicutes*, *Coriobacteriales*, and *Clostridium* increased in a dose-dependent way, with a dose-dependent decrease in the relative abundance of *Bacteroidetes* [46]. By association, these findings suggest an improvement in the composition of the fecal microbiome of the study horses following the administration of prebiotics.

Yeast-derived prebiotic and postbiotic compounds, derived from the fermentation of *S.cerevisiae* and administered as feed topdressing to a cohort of Quarter horses in a recent study, have been shown to stabilize the composition of the intestinal microbiome following a stress event [47]. These entero-protective supplements were also found to modulate the early immune response favorably in 11 English Thoroughbreds following vaccination against equine influenza [48].

By promoting a healthy balance between species in both the major and minor phyla of the intestinal microbiome, prebiotics support the condition of the gut mucosa, enhance nutrient absorption and athletic performance and overall equine health [49]. Antibiotic use can be significantly reduced by supplementing livestock and companion animals with synbiotics [49], however, such benefits have not yet been shown in equine management [30].

6. The Effects of Prebiotics on Equine Health and Disease

Table 1 shows the selected publications for review concerning the effects of prebiotic or synbiotic supplementation in horses.

6.1. Equine Performance

Exercising horses are often fed high carbohydrate, grain-dominant diets to deliver immediate energy for enhanced performance. This practice reduces natural forage intake, placing these athletes at risk of developing hindgut acidosis and possibly intestinal dysbiosis, a condition which may also be stress-induced [50], and which has been observed in cattle fed high carbohydrates [51]. The prebiotic fiber found in sugar beet is thought to offer a glycogen-sparing effect when added to such feed, due to enhanced propionate production by intestinal microbiota, thereby assisting energy production for performance [52]. During intense exercise in standardbred geldings, increased concentrations of muscle glycogen, lower muscle lactate levels, and lower peak plasma lactate concentrations were found following supplementation of their standard diet with sugar beet pulp. This effect was attributed to additional VFAs being utilized for aerobic energy production instead of glycogen [52]. High prebiotic fibre-containing diets supply equivalent amounts of energy via glycogen and propionate production compared to lower prebiotic, high-carbohydrate, grain-based diets, also delivering a beneficial alkalizing effect to protect against lactic acidosis generated by intense exercise [44]. These findings could inform equine athlete management for protection against dietary complications and consequent illness, whilst improving performance in these horses.

6.2. The Effects of Prebiotics on Equine Glucose Regulation and Insulin Resistance

Polyphenols and fibers with prebiotic properties have been proposed to reduce inflammation in senior horses possibly via improvements in insulin resistance [53]. Improved glucose metabolism is thought to occur via metabolomic effects including an increase in butyrate [54]. In humans, a lower abundance of butyrate-producing intestinal bacteria has been associated clinically with a higher incidence of Type 2 diabetes, in comparison to healthy controls unaffected by intestinal dysbiosis [55].

Supplementing the standard crushed oat and meadow hay diet of six healthy Warmblood mares for 21 days with Jerusalem artichoke meal, providing prebiotic FOS and inulin, produced a rapid serum insulin peak, followed by a faster decline of both glucose and insulin when compared to controls; this effect was associated with the relative abundances of *Lactobacillus* increasing and *Streptococcus* decreasing in the stomach of the prebiotic-fed group [56].

These findings also suggest a potential protective effect of this prebiotic (FOS and inulin) against insulin resistance/metabolic syndrome and obesity in these animals. High soluble carbohydrate in equine feed (grains and spring grass) increases the prevalence of insulin resistance and obesity, reducing the bacterial diversity of the intestinal microbiome and shifting its composition unfavorably towards potential pathogens such as *Streptococcus lutetiensis*, a species linked to the development of laminitis [42]. Supplementing the daily diet of eight obese mature Arab geldings with short-chain FOS over a period of six weeks optimized fiber processing which increased insulin sensitivity, while reducing acute insulin response to glucose and resting serum insulin, without altering body weight or body condition score [57]. Further, senior horses experience a decline in digestive capacity and the risk of developing insulin resistance increases with advancing age; supplementing the diet of older horses with FOS may improve the composition of the intestinal microbiome of these animals, resulting in better metabolic condition [58].

Table 1: Selected publications on the effects of prebiotic or synbiotic supplementation in horses.

Author, Date, Country	Horses studied – sex, age, breed, health status	Intervention	Duration of study	Results
Berg *et al*., 2005, USA [44]	9 Quarter horses	Diets supplemented with 8 g of FOS/d (low), or 24 g of FOS/d (high)	Three 10-day feeding periods	Fecal pH decreased and total VFA's increased linearly from control to low-FOS, then high-FOS diets. FOS supplementation altered fecal microbiomes, with a quadratic effect observed for *Escherichia coli* populations ($P < 0.01$)
Respondek, 2011, France [57]	8 obese mature Arab geldings (BCS = 8)	4 horses received maltodextrin 45 g/day/horse (control) and 4 horses received the same amount of short-chain fructo-oligosaccharides (scFOS)	Six weeks	Supplementation with scFOS increased insulin sensitivity and reduced acute insulin response to glucose and resting serum insulin in comparison with maltodextrin ($P < 0.05$), without affecting body weight or body condition score. No changes were observed in plasma glucose, serum leptin, or triglyceride levels ($P > 0.05$)
Adams, 2015, USA [59]	40 mixed breed and sex horses, age range 20–33	Four treatment groups: 1. Traditional grain mix; n=10 2. Control; n=10 3. Control + DHA; n=10 4. Control + ActivAge®prebiotic; n=10	Twice daily for 161 days All horses vaccinated on day 56 with equine influenza vaccine and a novel antigen (OVA) Vaccination was boosted on day 70	Serum cytokines TNF-α, IL-6, and IFN-γ were measured prior to and 2 weeks post-vaccination. All inflammatory markers reduced significantly in prebiotic supplemented group compared to horses receiving traditional grain mix, control diet only and DHA
Czech, 2006, Poland [60]	20 Thoroughbred mares	10g/d mannan oligosaccharides (Bio-Mos®)	20 days prepartum	Bio-Mos® improved blood antioxidant status but did not significantly alter the nutritional composition of mare's milk other than a slight protein increase. Treated mares had 20% higher RBC; 30% higher alkaline phosphatase and lactate dehydrogenase; 24% higher plasma superoxide dismutase than controls
Vendrig, 2014, The Netherlands [61]	10 Warmblood pony foals	6 foals supplemented orally with 15g Vivinal® syrup (GOS 45%, lactose 16%, glucose 14%, and 25% water), 4 foals were controls	Twice daily for 28 days from birth	No differences were observed between Vivinal® treated foals and the control group for the range of hematological parameters (hematocrit, white blood cell types, protein, albumin, and various immunoglobulins). *Ex vivo* LPS-induced mRNA expression levels of IFN-γ and IL-6 were significantly lower in PBMCs derived from treated foals compared to the control group
Vendrig, 2013, The Netherlands [62]	Peripheral blood mononuclear cells (PBMC) from 12 healthy Dutch Warmbloods	*In Vitro*	N/A	TNF-α production by PBMCs increased significantly at all oligosaccharide concentrations, compared to controls, with dose-dependent effects seen for all three fractions. Production of IL-10 in unchallenged PBMCs was not significantly influenced by GOS/FOS/AOS compared with blank controls. Several oligosaccharide fractions produced distinct direct immunomodulatory effects
Hassel, 2020, USA [63]	10 horses with radiographic presence of large quantities of sand	Assure® 15g/d or Assure Plus® 226g/d containing a custom blend of psyllium, prebiotics, probiotics, yeast, and digestive enzymes	35 days	Reduction in sand accumulation was observed in all horses, however, there were no significant differences between the treatment and control groups
Niinistö, 2020, Finland [64]	34 hospitalized horses	12 horses given psyllium 1 g/kg bwt only; 10 horses given $MgSO_4$ 1 g/kg bwt only; 12 horses given combined	Via nasogastric intubation daily for 4 days	A combination of psyllium and $MgSO_4$ cleared areas of sand accumulation significantly more ($P < 0.001$) than control horses

Author, Date, Country	Horses studied – sex, age, breed, health status	Intervention	Duration of study	Results
Landes, 2008, USA [65]	8 clinically healthy equids (5 horses, 3 mules, and 1 pony)	60g prebiotic/ probiotic, containing minimum 40 x 10^9 cells *Saccharomyces cerevisiae*, 2.25 x 10^9 CFUs *Lactobacillus acidophilus* and 1.55 x 10^9 CFUs *Enterococcus faecium* plus 0.5 g/ kg psyllium	Daily for 35 days	Average fecal sand output for each horse was at least 2.5 times greater during treatment than in the pre-treatment period for all equids. Fecal sand output on days 1–3 was same as pre-treatment, then significantly increased and remained higher day 4–31
Glatter, 2019, Germany [45]	12 adult healthy warmblood horses	FOS + inulin from Jerusalem artichoke meal (JAM) 0.2 g/kg bwt/d	Daily for 3 weeks, then euthanized 1 hour after final meal	The relative abundance of *Lactobacillus* increased and *Streptococcus* decreased predominantly in the stomach of the prebiotic-fed group. Higher alpha diversity and richness of microbiota were seen in all regions of the GIT, particularly the large intestine, for subjects fed JAM compared to controls ($P < 0.05$). Similar beta diversity was seen in treated subjects and controls. More evenness of species was seen in small and large intestines of JAM-supplemented subjects
Bachmann, 2020, Germany [33]	12 adult healthy warmblood horses	FOS + inulin from Jerusalem artichoke meal (JAM) 0.2 g/kg bwt/d *In vitro*: Fresh digesta removed from selected regions of the GIT, and incubated anaerobically to measure gas production	Daily for 3 weeks, then euthanized 1 hour after final meal	FOS and inulin were mostly fermented in the stomach, not reaching the hindgut in significant quantities, indicated by increased gastric gas production. Stomach pH was lower and VFA concentrations higher in JAM-treated compared to control subjects, but similar in hindguts of both groups. Oxidation-reduction potential increased twofold from pre- to post-incubation with JAM
Cehak, 2019, Germany [37]	Gastric mucosa samples obtained from 3 healthy horses, euthanized	*In vitro*: Mucosal tissue samples treated with four butyric acid concentrations of 10, 18, 24 and 32 mmol/l	N/A	Tissue samples *in vitro* produced histopathological changes consistent with those observed in horses fed prebiotic JAM. The severity of mucosal injury increased with higher concentrations of butyric acid
Glatter, 2017, Germany [56]	Six healthy, warm-blooded mares (age: 6–13 years)	Standard diet (crushed oat grains, 1g starch/kg bwt/d with meadow hay 2kg/100kg bwt/d plus either 0.15g FOS and inulin /kg bwt/d via JAM or control (equal amount of maize cob meal)	2 × 21-day treatment periods	Feeding of JAM versus control resulted in a particularly rapid and definite peak of serum insulin, followed by a faster decline in both plasma glucose and serum insulin post-prandial. Plasma glucose returned to baseline most completely with JAM but not control
Bachmann, 2021, Germany [66]	12 Warmblood horses (10 females, 2 males)	6 horses received 0.15g FOS plus inulin/kg bwt/d via JAM 6 horses fed corncob meal without grains (placebo)	20 days, then euthanized	Simple sugars and fructans rapidly disappeared from gastric digesta at the postprandial state in prebiotic-supplemented horses; elevated degradation to lactic acid and SCFA, especially n-butyric acid, may have gastric and metabolic health impacts
Paßlack, 2020, Germany [46]	8 healthy adult horses, 2 ponies	10g cellobiose /d or 20g cellobiose /d	14 days	A dose-dependent increase in the relative abundance of *Firmicutes* ($P = 0.04$), *Coriobacteriales* ($P < 0.00$), and *Clostridium* ($P = 0.03$) detected. A dose-dependent decrease in the relative abundance of *Bacteroidetes* ($P = 0.03$)

FOS – Fructo-oligosaccharides; GOS – Galacto-oligosaccharides; AOS - Acidic-oligosaccharides; VFA – Volatile fatty acid; CFUs - Colony forming units.

6.3. The Effects of Prebiotics on Equine Intestinal Inflammation

The discovery that prebiotic supplements may modulate intestinal inflammatory and immune responses has potential applications for veterinary medicine. Anti-inflammatory and immunomodulatory activity have been demonstrated in two equine studies [59,62] and one human study [67] using prebiotics. Specific actions of microbial metabolites, such as butyrate, are believed to include reduced cytokine production by the mucosal cells lining the intestine [67]. Anti-inflammatory and immunomodulatory activity of prebiotics were demonstrated in one *in vitro* study, in which equine peripheral blood mononuclear cells (PBMCs) were challenged with lipopolysaccharide (LPS) to induce an inflammatory response [62]. A protective effect was

observed when PBMCs were pre-incubated with GOS/FOS/AOS (acidic oligosaccharides) prior to being challenged with LPS, producing a dose-dependent reduction in both tumor necrosis factor alpha (TNF-α) and interleukin (IL-10) production. However, if PBMCs were pre-treated with GOS or GOS/FOS fractions alone, TNF-α production by the immune cells rose substantially [62]. These oligosaccharide fractions demonstrated a dampening effect on the allergic response while enhancing immune defenses in PBMCs; pre-treatment incubation with glucose/lactose concentrations similar to 1% GOS, as a comparison control, significantly increased cell viability by 14%, while GOS/FOS/AOS pre-treatment increased cell viability by a range of 38-61% [62]. The authors suggested that this protective effect on PBMCs was due to lower mitogenic potential [62].

7. Prebiotic Yeast Extracts in Equine Health and Disease

Mannan-oligosaccharides, derived from proteins in *S. cerevisiae* cell walls, protect against bacterial infection by competitively inhibiting the binding of bacterial lectins to intestinal enterocytes [68] and a dried yeast extract from mechanically ruptured *S. cerevisiae* cells containing beta-glucan acts as a prebiotic substance, effectively absorbing mycotoxins from contaminated feed and thereby offering immune protection [69]. In terms of the impact of prebiotic yeast extracts such as MOS on inflammation, horses exhibiting exercise-induced stress demonstrated more rapid recovery of cortisol and cytokine levels following eight weeks' supplementation with a fermented *S. cerevisiae* product as compared to controls [70].

Twenty thoroughbred mares supplemented with MOS, for 20 days prepartum, exhibited improved blood antioxidant parameters, namely 24% higher plasma superoxide dismutase levels than controls, without alteration to the nutritional composition of their milk [60]. Furthermore, there is evidence to suggest that mares' plasma and colostrum IgG levels may be boosted by adding MOS to their feed, protecting both mare and foal for 24 hours post-partum from serious infectious complications, such as diarrhea, sepsis, and possibly death [71].

7.1. Prebiotic Safety

It is generally considered that prebiotics may be safely administered to horses, although this assumed safety has not yet been scientifically evaluated. Any alteration in feed or supplementation which might adversely impact microbial diversity and species richness could disturb intestinal homeostasis [72]. Intestinal dysbiosis often results from the administration of antibiotics to horses and may render the animal susceptible to the proliferation of pathogenic species such as *Clostridium difficile* and *Salmonella sp.* in the gut, causing antimicrobial-induced colitis [73], and diarrhea [72]. Prebiotics have been shown to protect horses against intestinal dysbiosis, by supporting the colonization of favorable probiotic species and dispelling enteric pathobionts [36]. Soluble arabinogalactans, the prebiotic fiber derived from larch (*Larix sp.*) was administered to foals to treat scouring with some benefit and, although its specific mode of action is yet to be determined, its administration has proven to be safe in young horses [30]. Another study supplemented seven mares and their foals with a soluble arabinogalactan preparation (LaraFeed AC9) for 2 weeks pre-foaling and until 14 days post-foaling, using five mares and their foals as controls. The results were a lower frequency of diarrhoea episodes with more normal feces amongst the treated foals, requiring less veterinary intervention in comparison to controls. No treatment effects were found in the foals with respect to weight, blood parameters (complete blood count (CBC), immunoglobin A (IgA), and immunoglobulin G (IgG)), or fecal *Salmonella* or *Rotavirus* cultures, demonstrating tolerance for the larch extract [74].

8. Synbiotics in Equine Health and Disease

A combination of a probiotic and a prebiotic, referred to as a synbiotic, can increase the survival time and colonization potential of the probiotic bacteria or yeast in the intestinal milieu [30]. There is also some evidence that synbiotics may be beneficial for assisting intestinal sand clearance in horses, thereby playing a preventive role against the development of sand colic and enteropathy [65]. The accidental ingestion of sand commonly occurs in horses as a result of daily feeding on pasture grasses [65], which may result in sand accumulation and lead to colic. Synbiotic treatments containing probiotics (*Lactobacillus acidophilus*, *Enterococcus faecium*), prebiotics (derived from *S. cerevisiae*), and up to 90% psyllium seed husks have been effectively utilized to reduce and treat sand enteropathy and sand colic [65]. While sand accumulation was significantly reduced with this treatment, radiographic evidence of clearance was not observed [63]. It is uncertain, however, whether pre- and probiotics play a significant role in correcting this painful condition, or whether favorable results are achieved by dosing with high-fiber pulverized psyllium seeds alone. A synbiotic-only effect on this condition cannot be confirmed with this study, as the treatment contained predominantly psyllium seed husks, however, there may have been a therapeutic synergism delivered by the compound treatment formulation. Another report has been published on the more effective removal of accumulated intestinal sand with psyllium seed husk therapy supported by the addition of cathartic magnesium sulfate via nasogastric delivery [64].

The addition of probiotics to prebiotic supplementation has also been shown to assist in improving the composition of the equine microbiome [21] and provide protection against excess colonization of microbial pathogens, thereby reducing the requirement for antibiotic use [71]. A recent review reported on the safety, tolerability, and efficacy of probiotic bacteria currently in equine veterinary use, revealing conflicting evidence for the overall health benefits of probiotic bacterial treatments for horses, although some specific benefits for managing scouring in foals and improving athletic performance were reported [24]. In general, recent publications are supporting the use of prebiotics plus probiotics to improve animal health by manipulating the microbiome of many different domestic, livestock, and wild species, without the need for antibiotic use, thus providing societal and economic benefits [75].

9. Conclusion

Current evidence for the use of prebiotics and synbiotics in the management of equine health and disease is not extensive, although it could be considered promising and practical in many cases. Prebiotics and synbiotics, when added to the equine diet, have been shown to influence insulin sensitivity for obesity prevention, to reduce markers of systemic inflammation and allergy, and intestinal dysbiosis. Reduction of hindgut acidosis and correcting intestinal dysbiosis by the administration of prebiotics containing fiber to the equine diet may also confer protection against inflammatory conditions such as colitis and laminitis. Finally, the thoroughbred racing industry might consider adopting the safe and legal practice of administering prebiotics to their athletes, to assist energy production from volatile fatty acids resulting from microbial fermentation.

Authors' Contributions

CGC conducted the review of the literature, compiled the table of publications, and drafted the manuscript; JEH, ZG, and CGG reviewed the findings, revised the manuscript, and approved the final draft.

Data Availability

All data presented are published by the authors listed in this review.

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Conflicts of Interest

The authors declare no conflicts of interest.

Ethical Approval

Ethical approval was not required to conduct this review.

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