UNIVERSITI PUTRA MALAYSIA

DISTRIBUTION OF COMPLETION AND ELIMINATION OF HORSES PARTICIPATING IN DIFFERENT DISTANCE OF ENDURANCE RACE, AND CAUSES OF ELIMINATION

MOHD AKMAL BIN MOHD NOOR

DISTRIBUTION OF COMPLETION AND ELIMINATION OF HORSES PARTICIPATING IN DIFFERENT DISTANCE OF ENDURANCE RACE, AND CAUSES OF ELIMINATION

MOHD AKMAL BIN MOHD NOOR

A project paper submitted to the
Faculty of Veterinary Medicine, Universiti Putra Malaysia
In partial fulfilment of the requirement for the
DEGREE OF DOCTOR OF VETERINARY MEDICINE
Universiti Putra Malaysia
Serdang, Selangor Darul Ehsan.

MARCH 2015

It is hereby certified that we have read this project paper entitled "Distribution of Completion and Elimination of Horses Participating in Different Distance of Endurance Race, and Causes of Elimination", by Mohd Akmal Bin Mohd Noor and in our opinion it is satisfactory in terms of scope, quality, and presentation as partial fulfilment of the requirement for the course VPD 4999 (Final Year Project).

_____

ASSOCIATE PROFESSOR DATUK DR. BASHIR AHMAD FATEH MOHAMED
DVM (UPM), MVSc (Melbourne), PhD (UPM),
Department of Farm and Exotic Animal Medicine and Surgery
Faculty of Veterinary Medicine
Universiti Putra Malaysia
(Supervisor)

DEDICATION

TO ALL HORSE LOVER

FAMILY

My father, Mohd Noor Bin Mohd Shariff.

My mother, Maziah Binti Mohd Yunus.

My brothers, Mohd Firdaus Bin Mohd Noor and Muhammad Izzat Bin Mohd Noor.

FRIENDS

My Final Year Project's Mate, Wafaa Abdul Washeff.

My best friends, Izdihar Ishak, Faizal Hahlan, Deva Darshini Thinakaran, Nur Diyana Mohd Tahir and Nurul Hafizah Abu Jazid.

ACKNOWLEDGEMENTS

Alhamdulillah, I would like to express my deepest gratitude to my supervisor, Associate Professor Datuk Dr. Bashir Ahmad Fateh Mohamed, for his time, guidance, knowledge and constructive advices, comments and suggestions throughout this project.

I would also like to thank, Dr. Noraniza Mohd Adzahan and Dr. Nurul Hayah Khairuddin, from Department of Farm and Exotic Animal Medicine and Surgery, Universiti Putra Malaysia, for their support and guidance during data collection in Terangganu International Endurance Park (TIEP). Dr. Naguib Mohd Rais, Veterinary Officer from Large Animal Ward, University Veterinary Hospital, Faculty of Veterinary Medicine, Universiti Putra Malaysia for his effort during data collection. Also not to be forgotten, Professor Dr. Mohamed Ariff Omar, for his guidance and revision during data analysis.

I would like also to acknowledge my family for their support and time, and my friends who are involved directly and indirectly in the completion of this study.

TABLE OF CONTENT

LIST OF TABLE **PAGE**

LIST OF FIGURE **PAGE**

LIST OF ABBREVIATIONS

ADP	Adenosine Diphosphate
AMP	Adenosine Monophosphate
AST	Aspartate Transaminase
ATP	Adenosine Triphosphate
BCAA	Branched-Chain Amino Acid
bpm	Beats Per Minute
CK	Creatine Kinase
Cl^-	Chloride
CRI	Cardiac Reflex Index
CRT	Capillary Refill Time
ECF	Extracellular Fluid
FEI	Fédération Equestre Internationale
GS	Gut Sound
GWB	Girth, Withers and Back
HR	Heart Rate
ICF	Intracellular Fluid
K^+	Pottasium

MM	Mucous Membrane
MT	Muscle Tone
Na^+	Sodium
NEFA	Non-Estrified Fatty Acid
ROS	Radical Oxygen Species
RTES	Royal Terangganu Endurance Stable
SR	Skin Recoil
TIEP	Terangganu International Endurance Park
XO	Xanthine Oxidase

ABSTRAK

Abstrak kertas projek yang dikemukakan kepada Fakulti Perubatan Veterinar untuk sebahagian daripada keperluan kursus VPD 4999 (Projek Ilmiah Tahun Akhir)

TABURAN KEBERJAYAAN DAN PEYINGKIRAN KUDA-KUDA YANG MENYERTAI PERLUMBAAN KUDA TAHAN LASAK DI DALAM JARAK YANG BERBEZA SERTA PUNCA-PUNCA PENYINGKIRANNYA

OLEH

Mohd Akmal bin Mohd Noor

2015

Penyelia: Profesor Madya Datuk Dr. Bashir Ahmad Fateh Mohamed

Empat ratus lapan puluh lapan data perlumbaan kuda tahan lasak telah dikumpulkan daripada 61 ekor kuda semasa Piala Sultan Mizan 2014 di dalam jarak yang berlainan; 40 km (171 kuda); 80 km (215 kuda); 120 km (87 kuda) dan 160 km (15 kuda). Daripada 488 kuda, hanya 340 kuda (69.7%) yang berjaya menamatkan perlumbaan dan 148 kuda (30.3%) telah tersingkir daripada perlumbaan. Untuk perlumbaan 40 km, penyingkiran yang disebabkan oleh ketempangan dan peningkatan degupan jantung, masing-masing adalah 46.9%, sementara 6.2% disingkirkan atas sebab ketidaknormalan pergerakan usus. Bagi 80 km, punca penyingkiran yang disebabkan oleh ketempangan adalah 63.9%, diikuti dengan peningkatan denyutan jantung (31.9%) dan pergerakan usus yang abnormal (4.2%). Di dalam 120 km,

penyingkiran yang disebabkan oleh ketempangan adalah 55.6%, peningkatan degupan jantung (38.9%), dan pergerakan usus abnormal (5.5%). Sementara, bagi 160 km; 100% penyingkiran adalah disebabkan oleh ketempangan. Di dalam perlumbaan 40 km, penyingkiran yang disebabkan oleh gangguan metabolik adalah 53.1% dan muskuloskeletal 46.9%. Manakala bagi perlumbaan 80 dan 120 km, majoriti penyingkiran adalah muskuloskeletal dengan peratusan masing-masing adalah 63.9% dan 55.6%, diikuti gangguan metabolik; masing-masing 36.1% dan 44.4%. Akhir sekali, 160 km; 100% penyingkiran disebabkan oleh ketidaknormalan muskuloskeletal.

Kata Kunci: Perlumbaan Kuda Tahan Lasak, Keberjayaan, Penyingkiran, Gangguan Metabolik, Ketidaknormalan Muskuloskeletal, Factor-Faktor Risiko

ABSTRACT

An abstract of the project paper presented to the Faculty of Veterinary Medicine in partial fulfilment of the course VPD 4999 (Final Year Project)

DISTRIBUTION OF COMPLETION AND ELIMINATION OF HORSES PARTICIPATING IN DIFFERENT DISTANCE OF ENDURANCE RACE, AND CAUSES OF ELIMINATION

BY

Mohd Akmal bin Mohd Noor

2015

Supervisor: Associate Professor Datuk Dr. Bashir Ahmad Fateh Mohamed

Four hundred and eighthy eight endurance race data were collected from 61 horses during Sultan Mizan Cup 2014 in different distance; 40 km (171 horses); 80 km (215 horses); 120 km (87 horses); and 160 km (15 horses). Out of 488 horses, only 340 horses (69.7%) were able to complete the endurance race and 148 horses (30.3%) were eliminated. In 40 km race, elimination due to the lameness and elevated heart rate was 46.9% respectively, meanwhile 6.2% were eliminated due to abnormal intestinal motility. For 80 km race , the cause of elimination due to lameness is 63.9%, elevated heart rate; 31.9% and abnormal intestinal motility; 4.2%. In 120 km race, elimination due to lameness is 55.6%, elevated heart rate; 38.9% and abnormal intestinal motility; 5.5%. Meanwhile, for 160 km race; 100% elimination is due to

lameness. In 40 km race, elimination due to metabolic disorder is 53.1% and musculoskeletal; 46.9%. Meanwhile, in 80 and 120 km race, musculoskeletal elimination is 63.9% and 55.6% respectively, followed with metabolic disorder; 36.1% and 44.4% correspondingly. In 160 km race, all elimination is due to musculoskeletal abnormality.

Keywords: Endurance Race, Completion, Elimination, Metabolic Disorder, Musculoskeletal Abnormality, Risk Factors

1.0 Introduction

In recent 15-20 years, equine based sport varies in different part of the world and each country have their own sport related to the horse usage. The popularity of equine sport is not just developed locally in certain country but was established internationally with involvement of several official bodies to regulate and conduct the events (Nagy *et al.*, 2012). The sole international organization governing equine related sport is International Federation for Equestrian Sports or FEI (Fédération Equestre Internationale) based in Lausane, Switzerland since 1921 (FEI, 2015).

Based on the FEI records, there are several officially approved international event in their long-year calendar such as Jumping, Dressage, Eventing, Driving, Vaulting, Reining and Endurance (FEI, 2015). There are specific rules and regulation for every single discipline that was recognized by the FEI as mentioned and the main issue emphasized by the FEI is animal welfare (Nagy *et al.*, 2012).

Therefore, the most common issue of elimination in those event is, whenever the welfare of the horse is compromised before, during or after the event was conducted (Nagy *et al.*, 2012). As a result, the main concern of the horse's welfare was discussed is relation to health aspects. This scope of study is normally focused on the metabolic and musculoskeletal disorder which must be assessed by the authorized veterinarian that were assigned by the governing body. Hence, veterinarian plays a major role in equestrian events (Lawan *et al.*, 2012c).

One of the equestrian sport that is fast gaining popularity worldwide is competitive endurance event (Nagy *et al.*, 2012). Endurance can be define as a sport that aims to test the competitor's ability to safely manage the stamina and fitness of the horse over an endurance course in a competition against the track, the distance, the climate, the terrain, and the clock (FEI, 2015). Another definition for endurance that it is a competition that was established to challenge the ability of the horses to race in particular distance according to the category that was listed by the organizer (Bergero *et al.*, 2005).

Since the endurance international event in Malaysia is governed by the FEI, the presence of veterinarian is mandatory before an endurance event was conducted. Before a horse is allowed to participate in any championship or tournament, the horse will be examined by the authorized veterinarian to ensure the welfare status of the horse is at optimum level without endangering factor as highlighted by the FEI (Lawan *et al.*, 2012b). Failure to complete each examination in every phase will be subjected to elimination and the most common elimination cause is metabolic or musculoskeletal ailment (Lawan *et al.*, 2014).

The objective of this study is to find the overall percentage of horses that are able to complete the competition, identify the elimination cause for each category in the competition and determine the type of elimination for different distance of race in the endurance competition.

2.0 Literature Review

2.1 Endurance Race

Endurance can be described as a sport that aims to test the competitor's ability to safely manage the stamina and fitness of the horse over an endurance course in a competition against the track, the distance, the climate, the terrain, and the timing (FEI, 2015). Endurance can also be defined as the physical and mental capacity to withstand fatigue (Weineck, 1990). In 1982, endurance was recognized by the FEI as one of the equine discipline under regulation and governing of that body (Nagy *et al.*, 2012).

Long-distance horse riding was established many centuries back and military horse have been ridden for a distance of 100-150 km per day. The oldest organized long-distance endurance competition was established in 1892 which is known as Vienna-Berlin ride or Budapest-Vienna ride in 1908. Even though there were several old and earliest endurance race found in different part of the world, the first organized endurance race resembling today's endurance ride was the Tevis Cup with distance of 160 km in one day (100 miles) from Nevada to California that was run in 1955. At present, most of endurance ride ranged between 30 and 160 km, and some races up to 500 km held within 5 days with average race distance per day is 100 km (Nagy *et al.*, 2012).

2.2 Physiology of Endurance Horse

Horse is a unique athletic animal in their kingdom (Art & Lekeux, 2005). They are capable to function and structure adapted to internal and external changes of environment in term of training protocol and regime. They are able to develop high muscle mass fibre proportion, densities of mitochondria, increase oxygen-carrying capacities, buffering and transport capacity for carbon dioxide, intramuscular glycogen energy substrate storage and efficient thermoregulation via evaporation (Schroder *et al.*, 2011). In nature this ability is crucial for the horse to actively survive from the predator. Later, this powerful adaption was observed by human and used as part of transportation purpose and finally evolved to equestrian sport (Bergero *et al.*, 2005).

As the horse starts to move and begins a strenuous activity, muscle contraction that initiate vigorous movement of the horse's body will need an energy source that is normally supplied by the non-structural carbohydrate and fat via adenosine diphosphate (ADP) phosphorylation mechanism (Assenza *et al*,. 2004). However, the utilization level of those source varies according to intensity and duration of exercise (Bergero *et al.*, 2005). Muscle glycogen also play an important role in energy supply to the active movement of the horse, and as the glycogen store is decreasing together with the increment of lactic acid production as result from anaerobic catabolism of glycogen in the muscle concurrently with reduction in glucose level in the blood plasma. This complicated mechanism will lead to peripheral fatigue to the horse (Newsholm *et al.*, 1992). This fatigue mechanism did not occur peripherally but arises

centrally. Instead of carbohydrate and fat served as an energy source, branched-chain amino acid (BCAA) is also capable to supply energy up to 3-15% (Bergero *et al.*, 2005). When the horse is in exercise condition, proportion of BCCA and tryptophan become imbalance due to BCAA utilized as an energy source. As the high metabolism of fat from the muscle triglycerides or freely circulating in the bloodstream in converting energy, production of non-esterified fatty acid (NEFA) will increase. Consequent from this metabolism, NEFA will bind to the albumin as a protein transport due to imbalance ratio between low BCCA and high proportion of tryptophan in the blood plasma. High freely circulating tryptophan level in the blood plasma, resulting in amino acid to cross the blood brain barrier as they are small in molecular size and causing high production of serotonin which is a neurotransmitter that is involved in stimulation of centralized fatigue in an active horse (Assenza *et al,*. 2004). Other factors contributing to exhaustion are heat production incurred during race, water and electrolytes losses including shifting of those substances, lactic acid production, metabolic acidosis, lameness and previously undetected underlying problems (Whiting, 2009).

Once a horse is undergoing exercise, heavy duty or after prolong competition, several physiological adjustment will occur in order to cope with requirement of those activities (Art & Lekeux, 2005). As they are experiencing strenuous activity, the respiratory centre will be activated to stimulate respiratory effector which is respiratory system to ventilate up to 30 times from the normal condition in order to meet requirement of the oxygen demand for active muscle contraction via respiration (Art & Lekeux, 1995). At the same time, the cardiovascular system also work

concurrently together with respiratory system to cope with those changes, normally known as cardiorespiratory response, where the cardiac organ which is heart will pump out blood to the entire body at rate almost ten times from 25-30 heart beats per minute (bpm) at rest to 220-240 bpm (Evans, 1994). When the heart rate is increased, it will lead to low blood reperfusion in the myocardium, resulting in ischemic condition of the cardiac muscle and finally causing production of xanthine oxidase (XO) (Gandhi & Gunjan, 2009). As the muscle intensely contracted, high energy supply is required, and adenosine triphosphate (ATP) will be broken down into ADP and finally adenosine monophosphate (AMP) as an energy supply. This energy utilization is not static until that stage but will be further degraded to the hypoxanthine, and finally to uric acid and xanthine by XO that concurrently produced by the myocardium (Ji, 1999). When exercise constantly continue, uricase activity will decrease due to clogged metabolic pathway and eventually causing high uric acid in the muscle and plasma (Castejon *et al.*, 2006). Uric acid bears oxidant and anti-oxidant properties depending on the cellular environment (Nathalie *et al.*, 2007). When intense horse riding, high leukocytes production and activation will occur (Lawan *et al.*, 2010). These leukocytes activation particularly macrophages will cause oxidative stress via production of radical oxygen species (ROS) that will lead to lipid membrane digestion, and produced high triglyceride and oxidised lipid, which is favourable for uric acid to act as an oxidant, instead of anti-oxidant (Nathalie *et al.*, 2007). When pro-oxidant activity is exceeding anti-oxidant-protection properties, muscle damage constantly occurred resulting in increase in muscle enzyme such as aspartate transaminase (AST) and creatinine kinase (CK) (Fazio *et al.*, 2007). This condition will reduce performance of the horse due to exhaustion resulting from lactic acidosis that is

concurrently enhancing pro-oxidant activity and changes uric acid to oxidant ((Nathalie *et al.*, 2007). Therefore, heart rate is used as a performance indicator (Bashir & Rasedee, 2009) because as the heart rate is increased, more XO is produced to enhance pro-oxidant activity from energy catabolism that finally resulting to muscle damage and reduce horse's performance.

The haematopoietic system will also face hemodynamic adjustment via contraction of the spleen to empty the entire erythrocytes reserve in the red pulp of the spleen via autonomic contraction reflex at the early stage of activity and finally providing double amount of the erythrocytes number to cope with oxygen demand (Art & Lekeux, 2005). In order to maintain optimum body temperature, horse will attempt to regulate body temperature by few mechanism such as evaporation of sweat, vasodilation and thermal polypnea (McConaghy, 1994). However, the sweating evaporation is the most efficient way in order to regulate rising of body temperature without considering environmental temperature and humidity, due to heat production is exceeding heat dissipation (Art & Lekeux, 2005), and estimated about 5 ℓ/hour sweat will be produced in the temperate ambient and 10-15 ℓ/hour in hot humid environment (Schott II, 2010). As the horse is kept sweating while racing, water and electrolytes shifting will occur in the sweat and it is derived from the intracellular fluid (ICF) and extracellular fluid (ECF). These electrolytes including excretion of sodium (Na+), potassium (K+) and chloride (Cl-), and electrolyte depletion will lead to involuntary dehydration systematically, resulting in increase of heart rate as the less water compartment in the blood that sufficiently supply to the vital organs and peripheral cell, as a response to compensate ischemia (Butudom *et al.*, 2003). Thus

heart rate will be affected secondarily due to dehydration and again heart rate is used as a primary physical parameters in veterinary control gate (Schott II, 2010). Simultaneously, besides those multiple physiological adjustment, the horse will also be able to sustain in arterial hypoxia and sometime in hypercapnia to avoid metabolic energy wastage, while maintaining high level of ventilation rate (Lekeux & Art, 1994).

2.3 Physical Parameter Examination

Physical parameter is a very important indicator that is commonly used by the authorized veterinarian at the veterinary control gate. Among the important parameter that normally used is heart rate, mucous membrane colour, capillary refill time (CRT), skin recoil, gut sound and gait (Lawan *et al.*, 2012a).

Heart rate is measured per minute unit and normal acceptable heart rate within 20 minutes of arrival is different for different distance which is 56 bpm for 20-75 km and 64 bpm for 80-160 km endurance race (FEI, 2015). Heart rate will be measured upon the arrival at the veterinary control gate and the horse will be trotted for one minute to check for the gait, before second heart is measured. Difference between first and second reading is called cardiac recovery index (CRI) and this index is used to observe changes of heart rate after trotting (Lawan *et al.*, 2012a). Lower heart rate was used as an indicator for equine fitness in response to strenuous endurance rides (Bashir & Rasedee, 2009).

Mucous membrane colour and CRT is performed concurrently when the mucous membrane is checked, by observing the mucous membrane colour and applying pressure on the gum. Mucous membrane assessment was performed to evaluate the peripheral blood perfusion from the heart contraction, blood vessels capacity and internal health status, meanwhile CRT is used to measure efficiency of the heart pumping the blood to the peripheral blood vessel after slight pressure applied on the gum. Skin recoil is a basic indicator of dehydration by skin pinch at the point of shoulder and this parameter varies with age and pathological status of the horse (Lawan *et al.*, 2014). These three parameters must be incorporated together while appraising to determine the health status of the endurance horse (Schott II, 2010).

During race the horse has been in the critical status. Blood circulation mainly redistributed to the vital organs, and an apparently healthy horse with reduce gut sound is a normal condition, until unless there is sign of colic (Art & Lekeux, 2005). A good athletic performance horse are able to sustain a good gut sound even though in a critical condition (Lawan *et al.*, 2014). As mentioned, gait is evaluated between first and second heart rate measurement and common assessment was performed by trotting the horse along the earthed, flatted, straight track at the veterinary control gate in away and approaching manner of authorized veterinarian (Nagy *et al.*, 2012).

2.4 Metabolic and Musculoskeletal Elimination

Metabolic disorder in endurance horses are considered to be secondary to the dehydration, electrolytes and acid-base abnormalities, heat accumulation, substrate

depletion and previously undetected problem. If the horses are taken past their level of fitness and pushed to continue at that state, it can develop physiological exhaustion (Bergero *et al.*, 2005). It can later be identified during the physical parameter examination at the veterinary control gate. Normally, parameters that are associated with metabolic disorder is heart rate (HR), mucous membrane colour (MM), capillary refill time (CRT), skin recoil and gut sound (GS) (Lawan *et al.*, 2012a). In temperate country, metabolic-related elimination contribute 24% of overall elimination (Nagy *et al.*, 2012) compared to the tropical country such as Malaysia with higher elimination of 53.73% (Lawan *et al.*, 2012c). In Malaysia, there is no data for further diagnosis on the eliminated horses that is caused by metabolic disorder. However, in France about 70% of metabolic eliminated horses is due to fatigue, dehydration and colic, and the rest is due to dysuria, hematuria and haemoglobinuria, anorexia, depression and hyperhidrosis (Langlois & Robert, 2008). However, if colic developed during 48 hours after endurance race, it maybe unrelated to the competition (Alexander & Haines, 2012). Meanwhile in USA, about 30% eliminated horses is due to various metabolic disorders such as colic, oesophageal obstruction, poor cardiovascular recovery, myopathy and synchronous diaphragmatic flutter (Fielding *et al.*, 2009). Heart rate is a good indicator for metabolic disorder (Bashir & Rasedee, 2009).

Common musculoskeletal ailment in endurance race is lameness and the condition can be identified during gait examination in trotting at the veterinary control gate (Lawan *et al.*, 2012c). It contribute to 62.7% of musculoskeletal elimination in temperate country (Nagy *et al.*, 2012) compared to tropical country such as Malaysia only 17.9% (Lawan *et al.*, 2012c). Even though there is a documented data regarding

lameness elimination in endurance horses, but there is no exact percentage of the lameness causes, due to limited time of diagnosis at the veterinary control gate. Competitor are also reluctant to provide information despite reassurances about the confidentiality (Nagy *et al.*, 2012). However, one study based on the personal observations and communications have shown some causes of lameness mainly due to proximal metacarpal pain, foot pain and fetlock pain (Misheff, 2010). Based on the American Endurance Riding Conference's records between 2007 and 2008, the most common cause of lameness resulting in elimination was hindlimb muscle pain, forelimb suspensory ligament pain and foot pain (Halbrook, 2011). Some lameness cases that have been diagnosed at the veterinary control gate often transient in nature and not obviously observed by the treating veterinarian at veterinary hospital as what had been speculated. Usually this cause of lameness is only due to stone in the foot and some muscle spasm or pain that will resolve quickly after removal of the cause (Nagy *et al.*, 2012).

2.5 Risk Factors of Elimination

In certain circumstances, the elimination is not solely due to metabolic and musculoskeletal disorder. There are several risk factors that also contribute to the endurance horse elimination (Nagy *et al.*, 2012). Breed plays an important role in success of endurance horse during competition (Lawan *et al.*, 2014). Most common breed that had been tested and used in endurance race is Arabian or Arabian cross as this breed have good muscle fibre composition. There are also some other breed that are competitive and used in endurance race such as Thoroughbred, Quarter Horses,

Appaloosas, Mustangs, Morgan and Standardbred (Duren, 2000). Based on research, the Arabian horses is more superior in term of oxidative capacity, lower lactic acid concentration at 25 km/h and better adaptation to long distance race (Prince *et al.*, 2001). Therefore, good trait selection of horse breed must be based on the muscle strength and composition, tendon and ligament physiology, muscle metabolism and exercise tolerance, haemodynamic and aerobic metabolism capacity, and mitochondrial biogenesis (Schroder *et al.*, 2011).

Age of horse participating in endurance race also influenced elimination. As the horse is getting older which is more than nine years old, the ability of the horse will be more prominent as their genetic adaptation to the environment, improved health status and greatly enhanced nutritional adaptation (Harrington, 2003). However, some establishment is not using appropriate training protocols and regimes as they were implemented a younger and middle-age horses program in older horse. This explain is why some older horse was not able to exhibit their true genetic capability during endurance race (Lawan *et al.*, 2014). Feeding can also influence the rate of success in the endurance race such as providing high content of branched-chain amino acid (BCAA) as this amino acid is capable to supply 3-15% of energy supply (Bergero *et al.*, 2005). As this nutrient is high in blood plasma, less tryptophan will cross the blood brain barrier to cause centralized fatigue in the horse (Nathalie *et al.*, 2007). High fat-content in feed will also increase the energy source to horse during long-distance race. The horse must be adapted to the high fat-content feed to avoid high heat load in the body, high faecal output and high water requirement in the hot and humid environment (Newsholm *et al.*, 1992). In addition, good nutritional sources

will increase water and electrolytes reserve in the ingesta of the intestinal lumen that can supply up to 12-13% of body mass reserve compartment. From here water and electrolytes can be maintained at the optimum level of hydration status during exercise. Finally reduce risk of heart rate elevation is secondary to involuntary dehydration (Butudom *et al.*, 2003). Administration of antioxidant such as vitamin C is able to reduce oxidative stress due to reactive oxygen species (ROS) that is produced by the macrophages from stress condition during the race (Burke, 2001).

Temperature during the endurance event can also increase the rate of elimination. As the temperature is more than 22 °C, more metabolic cases will occur compared to the cooler environment (Marlin *et al.*, 1996). However, if the environment temperature is less than 20 °C, the horse will be at risk to exercise-induced pulmonary haemorrhage as compared to the warmer condition (Hinchcliff *et al.*, 2010). Hot and humid environment also can lead to exhaustion sooner compared to the temperate climate condition (Nagy *et al.*, 2012). Terrain of the endurance race is also associated with musculoskeletal elimination especially fracture when the race was conducted at the sand-based surface in all kind of weather (Verheyen *et al.*, 2006).

Generally, high speed endurance race will increase the risk of elimination (Whiting, 2009). There is study to show slow speed will also increase rate of elimination as they will reduce in speed and finally eliminated from the race due to exhaustion (Lawan *et al.*, 2012b). Undertraining and over-conditioning of the horses will also increase rate of elimination as the energy store depletion arises.

Inexperienced rider also can increase rate of elimination due to various causes during the endurance race (Nagy *et al.*, 2012).

3.0 Materials and Methods

This study was conducted in Terengganu International Endurance Park (TIEP), Lembah Bidong, Setiu, Terengganu, Malaysia, during Sultan Mizan Cup 2014 between October 10 and 12, 2014. All the endurance data from the participating horses' log book in event between 2010 and 2014 was analysed. 488 endurance race data were collected from 61 horses' log book. Arabian and crossed Arabian horses aged between 6-17 years were involved in this study. There are several different distance in the endurance race that ranged between 20 and 160 km, however only race distance of 40 (171 horses), 80 (215 horses), 120 (87 horses) and 160 km (15 horses) were selected.

Data were collected from horse's log book, which is an important document that must be carried by the rider to allow for the documentation and identification. During competition, at arrival of each race, the metabolic parameters (heart rate, mucous membrane, capillary refill time, skin recoil and gut sound) and musculoskeletal parameters (gait, girth, withers and back, and muscle tone) will be recorded by the veterinarian on duty. Data collection was divided into two main category, which is metabolic and musculoskeletal parameter. All the data including heart rate (HR), mucous membrane colour (MM), capillary refill time (CRT), skin recoil (SR) and gut sound (GS) was group under metabolic parameter. Lameness (Gait), girth, withers and back (GWB), and muscle tone (MT) was grouped under musculoskeletal parameter. Guideline for every single parameter that was described

was parameters outlined by the FEI's recognized event to ensure care and horses welfare.

Endurance is race in 3-6 phases, with distance between 20-30 km each and term as loops. At completion of each loop, the horse will be subjected to veterinary inspection for health status evaluation and among parameters that will be appraised is the metabolic and musculoskeletal parameter. Any abnormality in those parameters, the horse will be subjected to elimination from the event as the health status and condition is compromised and considered not fit to continue the race for the next phase or loop. Usually, the authorized veterinarian will state the cause of elimination in the log book and if necessary the unfit horse will be send to the Royal Terengganu Endurance Stable (RTES) Veterinary Hospital for further treatment according to the ailment.

All the horses that were able to complete the race and all that were eliminated from the race have included in the study. The percentage of horses that are able to complete the competition were analysed. The data were tabulated according to the different distance and presented in bar chart and pie chart. For the second objective of the study; to identify the cause of elimination for each category in competition, all the data of eliminated horses was tabulated. Different cause of elimination was identified and presented in the bar chart according to different distance of race. Consequence from the previous result, to attain the third objective; to determine type of elimination for each different distance of race, and second hypothesis; high elimination rate in long distance race due to metabolic crisis and lameness. The previous result was

divided into two main types of elimination which is metabolic crisis (HR and GS) and musculoskeletal (Gait), and all the data were presented in the bar chart.

All collected data were analysed by using Microsoft Excel 2013 software and the result was presented using the same software in order to enhance the data presentation. All the processed data were analysed by using appropriate statistical test via licensed SPSS version 20 (32-bit). Since most of the data is nominal type of data, non-parametric statistical test was performed to measure the significant different in comparing two groups of data (Mann-Whitney U Test), association of data and hypothesis testing (Chi-Square Test), and correlation of processed data (Spearman's Rank Order Correlation). Scale data type such as heart rate, capillary refill time and skin recoil was assessed normality test via same SPSS software to check for the data distribution pattern. All the statistical test was tested based on the alpha value 0.05.

4.0 Results

Only 340 horses (69.7%) were able to complete the endurance race and 148 horses (30.3%) were eliminated due to various condition. There was significant differences between completed and eliminated horses in relation to different distance race (P<0.0001). The completion percentage of endurance race as following; 40 km (139 horses-81.3%), 80 km (143 horses-66.5%), 120 km (51 horses-58.6%) and 160 km (7 horses-46.7%). Meanwhile, the elimination percentage observed as following; 40 km (32 horses-18.7%), 80 km (72 horses-33.5%), 120 km (36 horses-41.4%) and 160 km (8 horses-53.3%). For first hypothesis, it was statistically proven (P<0.0001) that high elimination was observed throughout the endurance race.

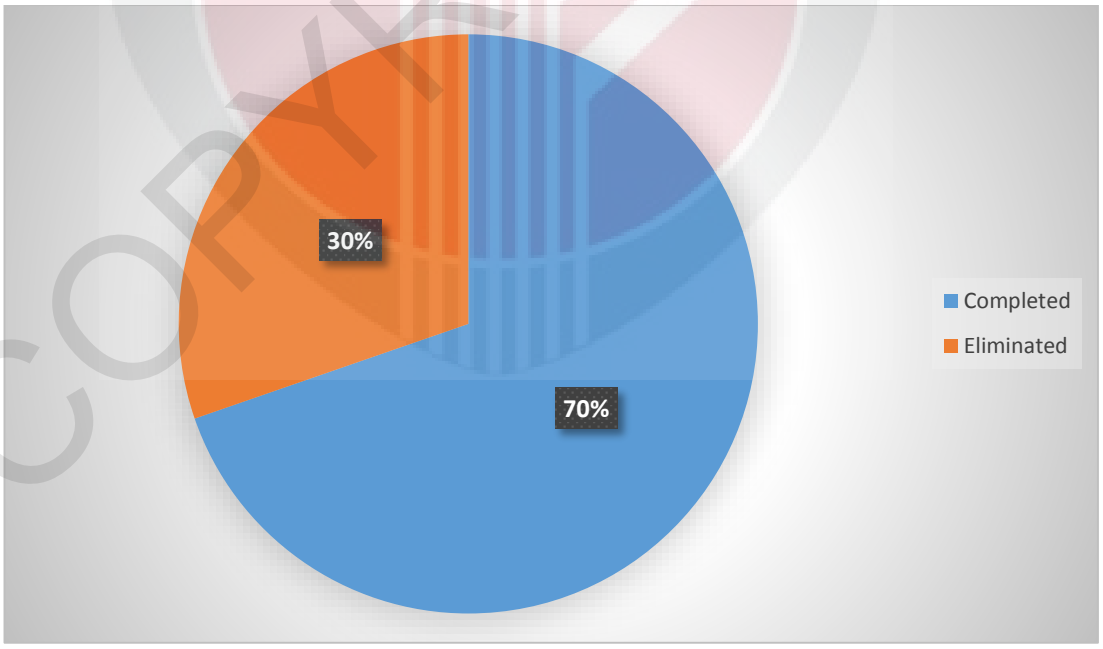

Figure 1 – Percentage of overall result in the endurance races

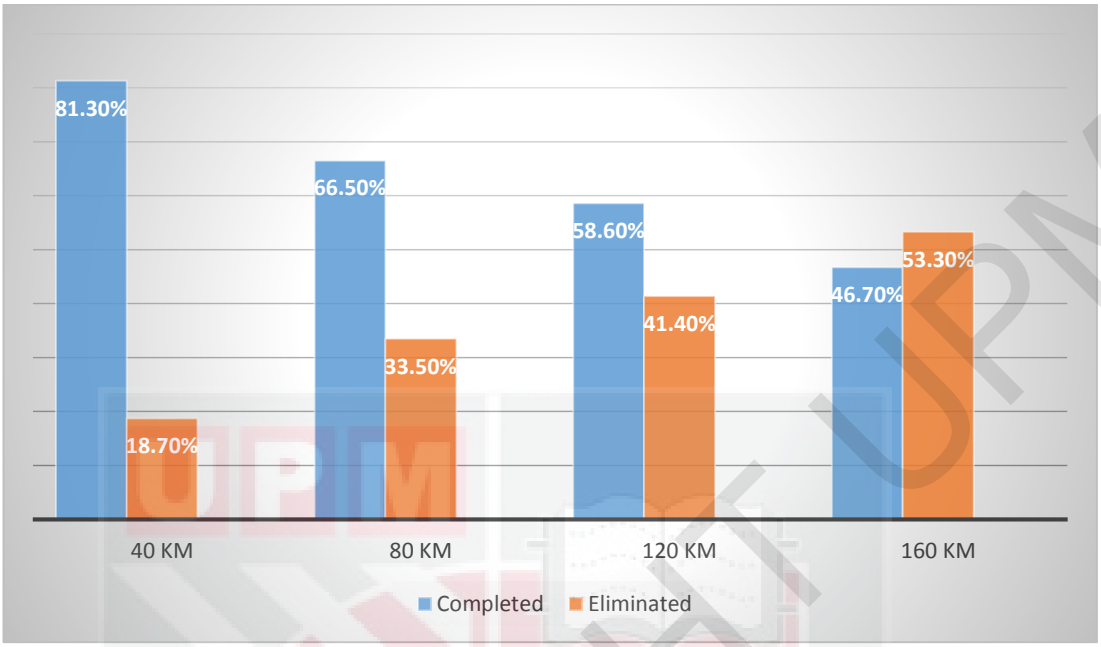

Figure 2 – Percentage of completion and elimination in endurance horse according to distance

The cause of elimination in 40 km race equally due to lameness and elevated heart rate which is both 46.9% (15 horses), and 6.2% (two horses) abnormality in gut sound. For 80 km of race, the cause of elimination due to lameness is 63.9% (46 horses), elevated heart rate 31.9% (23 horses) and abnormal gut sound 4.2% (3 horses). In 120 km race elimination due to lameness is 55.6% (20 horses), elevated heart rate 38.9% (14 horses) and for abnormal gut sound 5.5% (2 horses). Elimination for 160 km is 100% (8 horses) due to lameness. All scale type of data such as heart rate, capillary refill time and skin recoil were not normally distributed with ($P<0.0001$) and same non-parametric statistical test were applied (Mann-Whitney U Test). For 40 km physical parameters, the heart rate, mucous membrane colour, skin recoil and gait were highly significant differences between completed and eliminated horses ($P<0.0001$). Capillary refill time ($P<0.003$) and gut sound ($P<0.0050$) were also significantly

difference, but there was no significant difference for muscle tone (P>0.4620), and girth, withers and back (P>0.3470). Meanwhile in 80 km race, heart rate, mucous membrane and gait were highly significant difference (P<0.0001) followed with gut sound (P<0.0100), but there was no significant difference between completed and eliminated horses in term of muscle tone (P>0.1500), capillary refill time (P>0.4630), skin recoil (P>0.5020), and girth, withers and back (0.7110). In 120 km, only heart rate and gait were highly significant difference (P<0.0001) followed with mucous membrane (P<0.001), capillary refill time (P<0.0200) and gut sound (P<0.0490), but there is no significant difference for muscle tone (P>0.0580), girth, withers and back (P>0.1000) and skin recoil (P>0.2500). There was highly significant difference between completed and eliminated horses in term of gait (0.0001) followed with muscle tone (P<0.0010), girth, withers and back (P<0.0010) and heart rate (P<0.0330), but there was no significant differences for gut sound (P>0.0610), skin recoil (P>0.2960), mucous membrane (P>0.3270) and capillary refill time (P>0.5330).

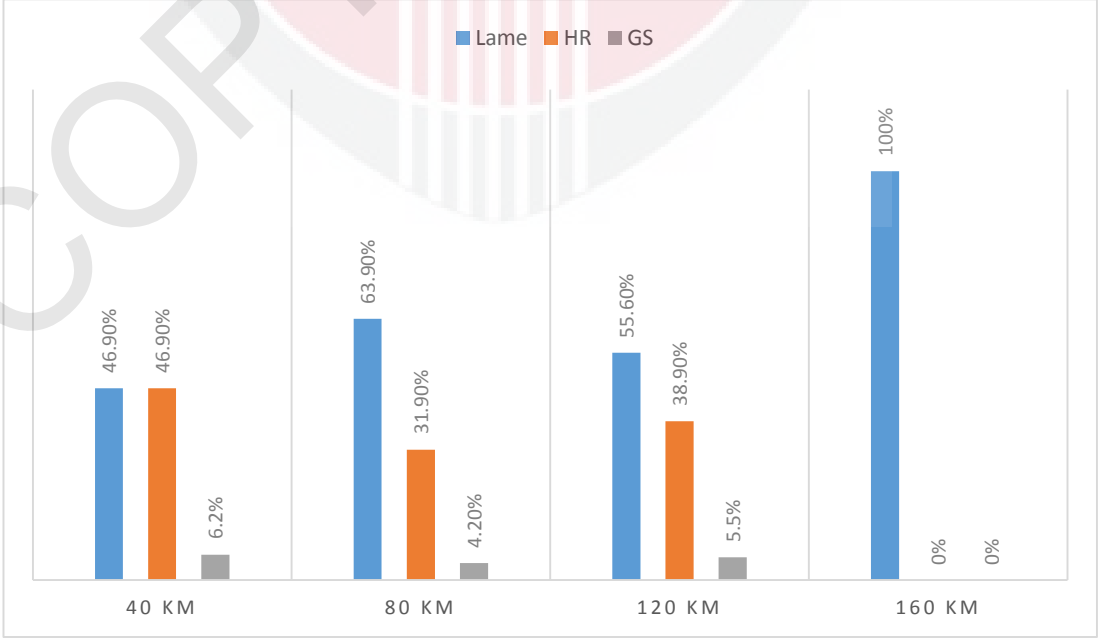

Figure 3 – Distribution of elimination cause in different distance of races

Distance	HR	MM	CRT	SR	GS	MT	GWB	Gait
40 km	0.0001*	0.0001*	0.003*	0.0001*	0.005*	0.462	0.347	0.0001*
80 km	0.0001*	0.0001*	0.463	0.502	0.010*	0.150	0.711	0.0001*
120 km	0.0001*	0.001*	0.020*	0.250	0.049*	0.058	0.100	0.0001*
160 km	0.033*	0.327*	0.533	0.296	0.061	0.001*	0.001*	0.0001*

Table 1 – Significant value between completed and eliminated horses according to different distance for different physical parameters.

"" represents significantly differences; (HR=Heart Rate; MM=Mucous Membrane; CRT=Capillary Refill Time; SR=Skin Recoil; GS=Gut Sound; MT=Muscle Tone & GWB=Girth, Withers and Back)*

In 40 km race, elimination due to metabolic disorder is 53.1% and musculoskeletal is 46.9%. As for 80 and 120 km race, elimination is mainly musculoskeletal with percentage 63.9 and 55.6 respectively, and metabolic disorder is 36.1% and 44.4% respectively. For 160 km race, elimination is all due to musculoskeletal abnormality (100%). From the overall result, 60.1% elimination is caused by the musculoskeletal or lameness and 39.9% is due to metabolic disorder. It was statically proven ($P<0.039$) that high elimination rate in long distance race is due to metabolic crisis and lameness.

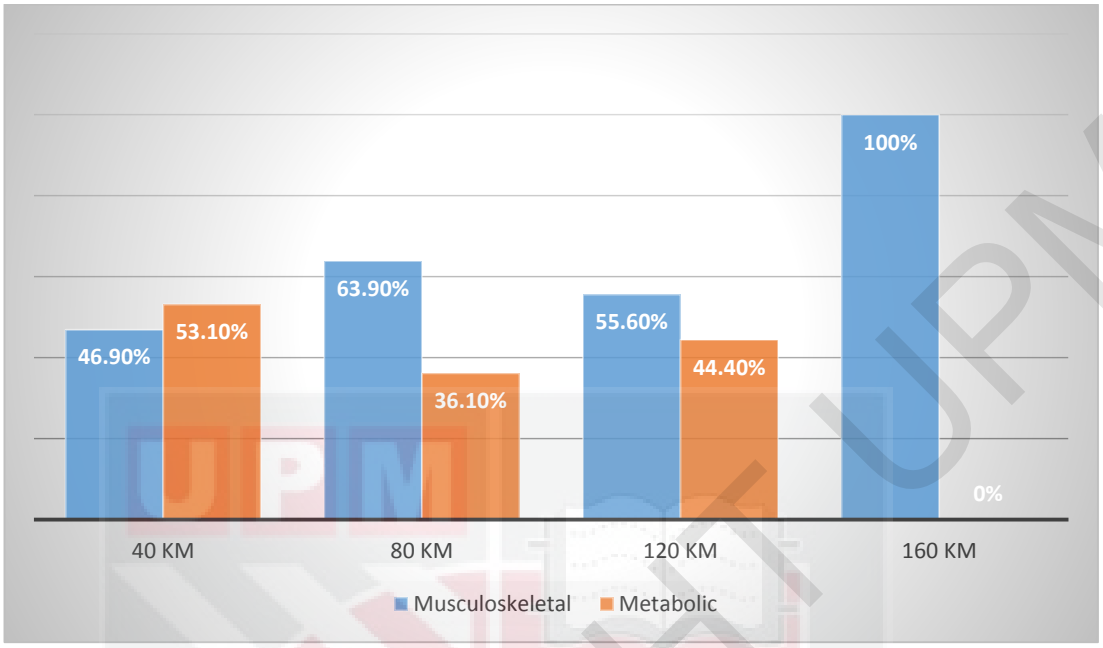

Figure 4 – Distribution of elimination type in different distance of races

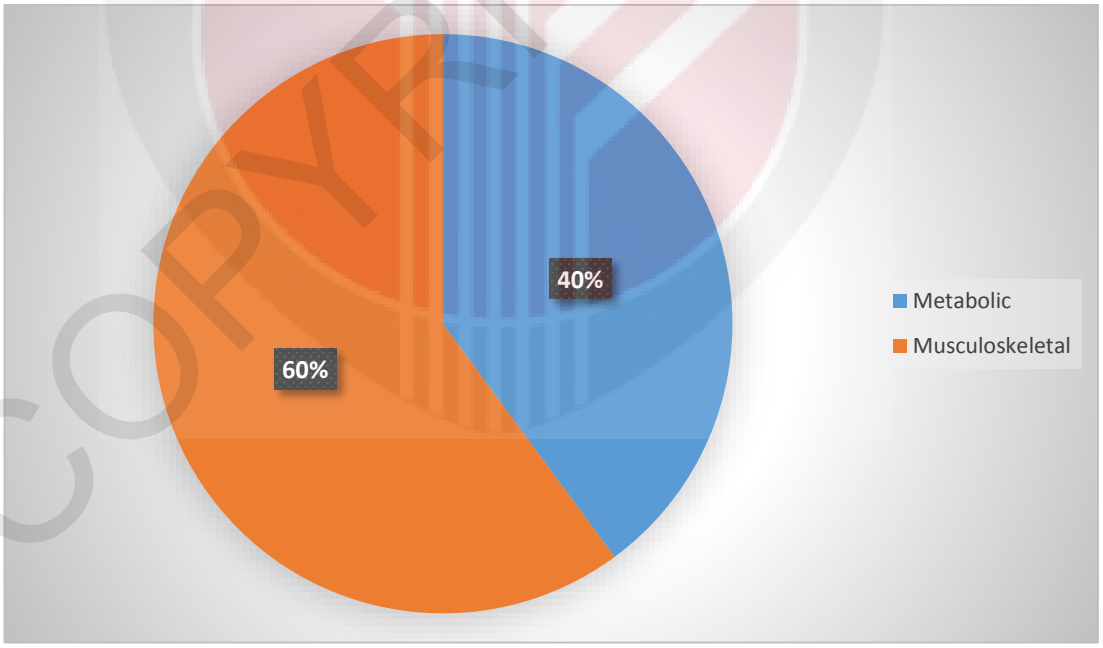

Figure 5 – Percentage of overall elimination according to the type of elimination

Association between elimination rate and different distance of endurance race was calculated, and the significant value (0.0001) is less than alpha value (0.05) which means there is significant association between these two factors. In order to measure the strength of association between these two factors, non-parametric correlation test was done and shown there is positive small correlation (0.203) between different distance of race and elimination rate, which is as the different distance of race increase, the elimination rate also will increase respectively.

5.0 Discussion

Recorded elimination rate ranged between 10-60% depending on the terrain and speed (Bergero *et al.*, 2005). Total elimination in this study is only 30.3% with total completion is almost 70%. This result varies based on the several risk factors such as breed, age, environmental humidity and temperature, terrain, speed, drink and feed, training and riders (Nagy *et al.*, 2012). However, as the distribution of completion and elimination rate narrowed down in different distance, it was observed that there was a dramatic changes, where the completion percentage in this study decreased as the different distance increased and this trend of elimination is increased as the different distance increased. This trend was statistically proved, as there is an association between race distance and rate of elimination ($P<0.0001$) with small positive correlation ($r = 0.203$), which means as the different distance is increased, rate of elimination will increased correspondingly. Elimination can be due to musculoskeletal and/or metabolic disorders depending on the physical parameters abnormality at the veterinary control check (Lawan *et al.*, 2014). This is probably due to higher different distance, the horses were easily exhausted due to several factor such as heat production incurred during race, water and electrolytes losses including shifting of those substances, lactic acid production, metabolic acidosis, lameness and previously undetected underlying problems, which will lead to abnormality in physical parameters which resulting in elimination (Whiting 2009).

As the cause of elimination narrowed down, abnormality in gait that was identified as lameness at the veterinary control check was documented as a highest

percentage in elimination at different distance of endurance race. This corresponds with musculoskeletal injuries that are common in endurance race as this system was intensely moved and contracted to produce good locomotive momentum on the skeletal system during endurance race (Art & Lekeux, 2005). Lameness was the only cause of elimination for 160 km endurance race which could be due to more vigorous musculoskeletal exercise with extra loop and distance compared to the other lower race distance. In addition, gait parameter showed there was highly significant difference ($P<0.0001$) between completed and eliminated horses for the all four different distances and it was proved that successfully completed horses have a fit locomotive adaption during the endurance race (Nagy *et al.*, 2012). Abnormality in heart rate in term of cardiac contraction increment per minute was recorded as among the highest cause of elimination in 40, 80 and 120 km. This could be due to inability of the horses to compensate high metabolic demand during endurance race (Art & Lekeux, 2005). When the horse was in the exercise with profuse hypertonic sweating, high water and electrolytes shifting occurred in the sweat and this will lead to involuntary dehydration causing reduce cardiac output, and the heart had to work more to compensate highly active vital organs and peripheral system requirement in lower blood volume, compared to well-hydrated horse (Butudom *et al.*, 2003). Heart rate parameter also showed significant differences between completed and eliminated horses in all four difference distance because successfully completed horses is well dehydrated and fit enough to experience strenuous activity. Abnormal gut sound was documented as the lowest cause of elimination because it is normal that when a horse is in the race, sympathetic autonomic nervous system will be stimulated and activated to cope with active physiological function, resulting in suppression of parasympathetic

autonomic nervous system that is involved in regulating intestinal motility (Hyyppa, 2005). As a result, gut sound will be reduced in excited horse and only when the gut sound is absent concurrent with other abnormal parameters such as increase in heart rate and changes in mucous membrane colour, the horse will be eliminated (Fielding *et al.*, 2009). However, in 160 km race there was no elimination due to abnormal gut sound because horses are well adapted to the stress condition during training. Statistically there was no significant differences ($P>0.061$) between completed and eliminated horses, which means the gut sound in 160 km's horses are almost similar due to proper training and well adaptation in intestinal motility. Physical parameters such as muscle tone ($P<0.001$) and girt, withers and back ($P<0.001$) were only significantly difference between successfully completed and eliminated horses in 160 km race. This could be due to when in higher distance more loop of race were used and competing horses were subjected to prolong endurance race compared to 40, 80 and 120 km. When this occur the horses will tend to accumulate more lactic acid in the muscle fibres to cause muscle fatigue and abnormality in muscle tone parameter (McGowan, 2008). At the same time in prolong endurance race, riding saddle always exert high pressure on the sensitive anatomical structure of the horse (T6-T10) (Henson *et al.*, 2007) and 90% of rider's weight was concentrated in the withers, which is at those thoracic column vertebrae (Latif *et al.*, 2010). These spinous area is very sensitive and intolerant to pressure, and when prolong pressure applied, withers tend to be in pain causing abnormality in girth, withers and back parameters (Werner *et al.*, 2002). In addition, when a horse is in fatigue during prolong distance race, there was asymmetrical movement while trotting, canter and gallop, and this factor will intense the abnormality of the girth, withers and back parameters (Munoz *et al.*, 2006).

Metabolic disorders type of elimination is only high in the 40 km race compared to other distance race (80, 120 and 160 km) which could be due to new participating horse in 40 km group. This group of horse usually were not or insufficiently trained as compared to other well-trained horses and explained why group of horse was eliminated due to metabolic disorder due to fitness and not well adapted to the race environment (Nagy *et al.*, 2012). Meanwhile, musculoskeletal disorders elimination was dominated in 80, 120 and 160 km. This is probably due to well trained horses that adapted to metabolic changes were pushed beyond the ability limit of the horses particularly in speed because high speed will contribute to musculoskeletal elimination mainly lameness (Nagy *et al.*, 2012). Even though, there is no scientific data regarding common lameness in endurance horse. Some anecdotal data refer to common causes of lameness in endurance concentrated at distal limb such as hindlimb muscle pain, forelimb suspensory ligament pain and foot pain (Halbrook, 2011). In overall, total percentage of elimination due to musculoskeletal and metabolic disorder were 60.1% and 39.9% respectively. This finding were almost similar with previous finding that have shown musculoskeletal and metabolic elimination were 62.7% and 37.3% (Nagy *et al.*, 2012). This is probably due to most system were utilized during race was musculoskeletal (Bergero *et al.*, 2005). Therefore, that system is more prone to demonstrate abnormality.

6.0 Conclusion

Distribution of completion and elimination varies in different part of the world and different event probably contributed by several risk factors that cannot be segregated. However, from this study the common causes of elimination in tropical climate provide and allow knowledge sharing in term of abnormality that subjected to elimination according to FEI rules and regulation. Welfare of the horses were secured in a good manner, and able to produce good athletic horses and riders for further international competition.

7.0 Reference

Alexander, G. R., & Haines, G. R. (2012). Surgical colic in racing endurance horses. *Equine Veterinary Education,* 24, 193-199.

Art, T., & Lekeux, P. (2005). Exercise-induced physiological adjustments to stressful conditions in sport horses. *Livestock Production Science,* 92, 101-111.

Assenza, A., Bergero, D., Tarantola, M., Piccione, G., & Caola, G. (2004). Blood serum branched chain amino acids and tryptophan modifications in horses competing in long distance rides of different length. *Journal Animal Physiology and Animal Nutrition,* 88, 172-177.

Bashir, A., & Rasedee, A. (2009). Plasma catecholamine, sweats electrolytes and physiological responses of exercised normal, partial, anhidrotic and anhidrotic horses. *American Journal of Animal and Veterinary Sciences,* 4, 26-31.

Bergero, D., Assenza, A., & Caola, G. (2005). Contribution to our knowledge of the physiology and metabolism of endurance horses. *Livestock Production Science,* 92, 167-176.

Burke, L. M. (2001). Nutritional needs for exercise in the heat. *Comparative Biochemical Physiology,* 128, 735-748.

Butudom, P., Axiak, S. M., Nielsen, B. D. Eberhart, S. W., & Schott II, H. C. (2003). Effect of varying initial drink volume on rehydration of horses. *Physiology and Behavior*, 79, 135-149.

Castejon, F., Trigo, P., Munoz, A., & Riber, C. (2006). Uric acid responses to endurance racing and relationships with performance, plasma biochemistry and metabolic alterations. *Equine Veterinary Journal*, 36, 70-73.

Duren, S. E. (2000). Feeding the endurance horse. In J. D Pagan (Editor), *Advances in Equine Nutrition* (pp. 351-363). Nottingham, Nottingham University Press.

Evans, D. L. (1994). The cardiovascular system: anatomy, physiology, and adaptations to exercise and training. In D. R. Hodgson & R. J. Rose (Editors), *The athletic horse: principles and practice of equine sports medicine* (pp. 129-144). Philadelphia, W.B. Saunders.

Fazio, F. S., Casella, C., Giannetto, G., Caola, G., & Piccione (2007). Serum homocysteine and oxidative stress evaluation during exercise in horse. *Polish Journal of Veterinary Sciences*, 12, 169-174.

Fédération Equestre Internationale (FEI): http://www.fei.org. Retrieved on 18 January 2015.

Fielding, C. L., Magdesian, K. G., Rhodes, D. M., Meier, & Higgins, J. C. (2009). Clinical and biomechanical abnormalities in endurance horses eliminated from competition for medical complications and requiring emergency medical treatment. *Journal of Veterinary Emergency and Critical Care,* 19, 473-478.

Gandhi, G., & Gunjan, G. (2009). Exercise-induced genetic damage: A review. *International Journal of Human Genetic*, 9, 69-96.

Harrington, M. K. (2003). Aging and how it affects the physiological response to exercise in the horse. *Clinical Technology Equine Practice*, 2, 258-265.

Henson, F. M., Lamas, L., Knezevic, S. & Jeffcott, L. B. (2007). Ultrasonographic evaluation of the supraspinous ligament in a series of ridden and unridden horses and horses with unrelated back pathology. *BMC Veterinary Research,* 3, 3.

Hinchcliff, K. W., Morley, P. S., Jackson, M. A., Brown, J. A., Dredge, A. F., O'Callaghan, P. A., McCaffrey, J. P., Slocombe, R. F. & Clarke, A.F. (2010). Risk factors for exercise-induced pulmonary haemorrhage in Thoroughbred racehorses. *Equine Veterinary Journal,* 38, 228–234.

Hyyppa, S. (2005). Endocrinal responses in exercising horses. *Livestock Production Science,* 92, 113-121.

Ji, L. L. (1999). Antioxidants and oxidative stress in exercise. *Experimental Biology and Medicine*, 222, 283-292.

Langlois, C., & Robert, C. (2008). Épidémiologie des troubles métaboliques chez les chevaux d'endurance. *Pratique Vétérinaire Équine*, 40, 51-60.

Latif, S. N., von Peinen, K., Wiestner, T., Bitschnau, C., Renk, B. & Weishaupt, M. A. (2010). Saddle pressure patterns of three different training saddles (normal tree, flexible tree, treeless) in Thoroughbred racehorses at trot and gallop. *Equine Veterinary Journal,* 42, 630-636.

Lawan, A., Noraniza, M. A., Rasedee, A., & Bashir, A. (2010). Effect of race distance on physical, haematological and biochemical parameters of endurance horses. *American Journal of Animal and Veterinary Science,* 5(4), 244-248.

Lawan, A., Noraniza, M. A., Rasedee, A., & Bashir, A. (2012a). Effect of speed, heart rate, lactate and uric acid on the performance of Arabian horses during a 120 km endurance race. *Journal of Agriculture and Veterinary Science,* 1(4), 1-4.

Lawan, A., Noraniza, M. A., Rasedee, A., & Bashir, A. (2012b). Effect of strenuous sub-maximal race on heart rates of endurance horses. *Malaysian Journal of Veterinary Research,* 3(1), 29-32.

Lawan, A., Noraniza, M. A., Rasedee, A., & Bashir, A. (2012c). Prevalence of lameness and metabolic disorders in endurance horses. *Malaysia Journal of Veterinary Research,* 3(1), 33-37.

Lawan, A., Noraniza, M. A., Rasedee, A., & Bashir, A. (2014). Physical parameters and risk factors associated with the elimination of Arabian and Crossed Arabian endurance horses during a 120 km endurance race. *Journal of Equine Veterinary Science,* 34, 494-499.

Lekeux, P., & Art, T. (1994). The respiratory system: anatomy, physiology, and adaptation to exercise and training. In D. R. Hodgson & R. J. Rose (Editors), *The athletic horse: principles and practice of equine sports medicine* (pp. 79-127). Philadelphia, W.B. Saunders.

Marlin, D. J., Scott, C. M., Schroter, R. C., Mills, P. C., Harris, R. C., Harris, P. A., *et al.*, (1996). Physiological responses in non-heat acclimated horses performing treadmill exercise in cool (20°C/40%RH), hot dry (30°C/40% RH) and hot humid (30°C/80% RH) conditions. *Equine Veterinary Journal,* 22, 70-84.

McConaghy, F. (1994). Thermoregulation. In D. R. Hodgson & R. J. Rose (Editors), *The athletic horse: principles and practice of equine sports medicine* (pp. 181-202). Philadelphia, W.B. Saunders.

McGowan, C. (2008). Clinical pathology in the racing horse: the role of clinical pathology in accessing fitness and performance in the racehorse. *Veterinary Clinics Equine Practice,* 24, 405-421.

Misheff, M. M. (2010). Lameness in endurance horses. In M. W. Ross & S. J. Dyson (Editors), *Diagnosis and management of lameness in the horse; second edition* (pp. 1137-1148). St. Louis. MO, USA, Elsevier Saunders.

Munoz, A., Cuesta, I., Riber, C., Gata, J., Trigo, P., Castejon, F. M., 2006. Trot asymmetry in relation to physical performance and metabolism in equine endurance rides. *Equine Veterinary Journal,* 36, 50-54.

Nagy, A., Dyson, S. J., & Murray, J. K. (2012). A veterinary review of endurance riding as an international competitive sport. *The Veterinary Journal,* 194, 288-293.

Nathalie, K., Brieuc, M., & Pierre, L. (2007). The oxidant or antioxidant equilibrium in horses. *The Veterinary Journal,* 33, 1–14.

Newsholm, E. A., Blomstrad, E., & Ekblom, B. (1992). Physical and mental fatigue metabolic mechanisms and importance of plasma amino acids. *British Medicine Bulletin,* 48, 477-495.

Prince, A., Geor, R., Harris, P., Hoekstra, K., Gardner, S., Hudson, C., & Pagan, J. (2001). Proceedings from Kentucky Equine Research `01: *The 17th Symposium of Equine Nutrition and Physiology Society on Comparison Of The Metabolic Responses Of Trained Arabian And Thoroughbred Horses During High And Low Intensity Exercise.* Lexington, Kentucky.

Schott II, H. C. (2010). Proceedings from Kentucky Equine Research, `10: *The 17th Feeding and Veterinary Management of the Sport Horses Conference on Challenges of Endurance Exercise: Hydration and Electrolyte Depletion.* Lexington, Kentucky.

Schroder, W., Klostermann, A., & Distl, O. (2011). Candidate genes for physical performance in the horse. *The Veterinary Journal,* 190, 39-48.

Verheyen, K. L., Newton, J. R., Price, J. S. & Wood, J. L. N. (2006). A case-control study of factors associated with pelvic and tibial stress fractures in Thoroughbred racehorses in training in the UK. *Equine Veterinary Journal,* 36, 167–173.

Weineck, J. (1990). *Training Manual* (pp. 424). Vigot, Paris.

Werner, D., Nyikos, S., Kalpen, A., Geuder, M., Haas, C., Vontobel, H. D., Auer, J.A., & von Rechenberg, B. (2002). Pressure measurements under the saddle: a

study with an electronic calliper measuring system (Novel GmbH). *Pferdeheilkunde*, 18, 124-140.

Whiting, J. (2009). The exhausted horse. In N. E. Robinson & K. A. Sprayberry (Editors), *Current therapy in equine medicine; sixth edition* (pp. 926-929). St. Louis, MO, Saunders Elsevier