MECHANICAL AND ELECTRICAL STUDIES ON THE HORSE

A thesis presented in partial fulfilment
of the requirements for the degree of
Doctor of Philosophy at Massey University

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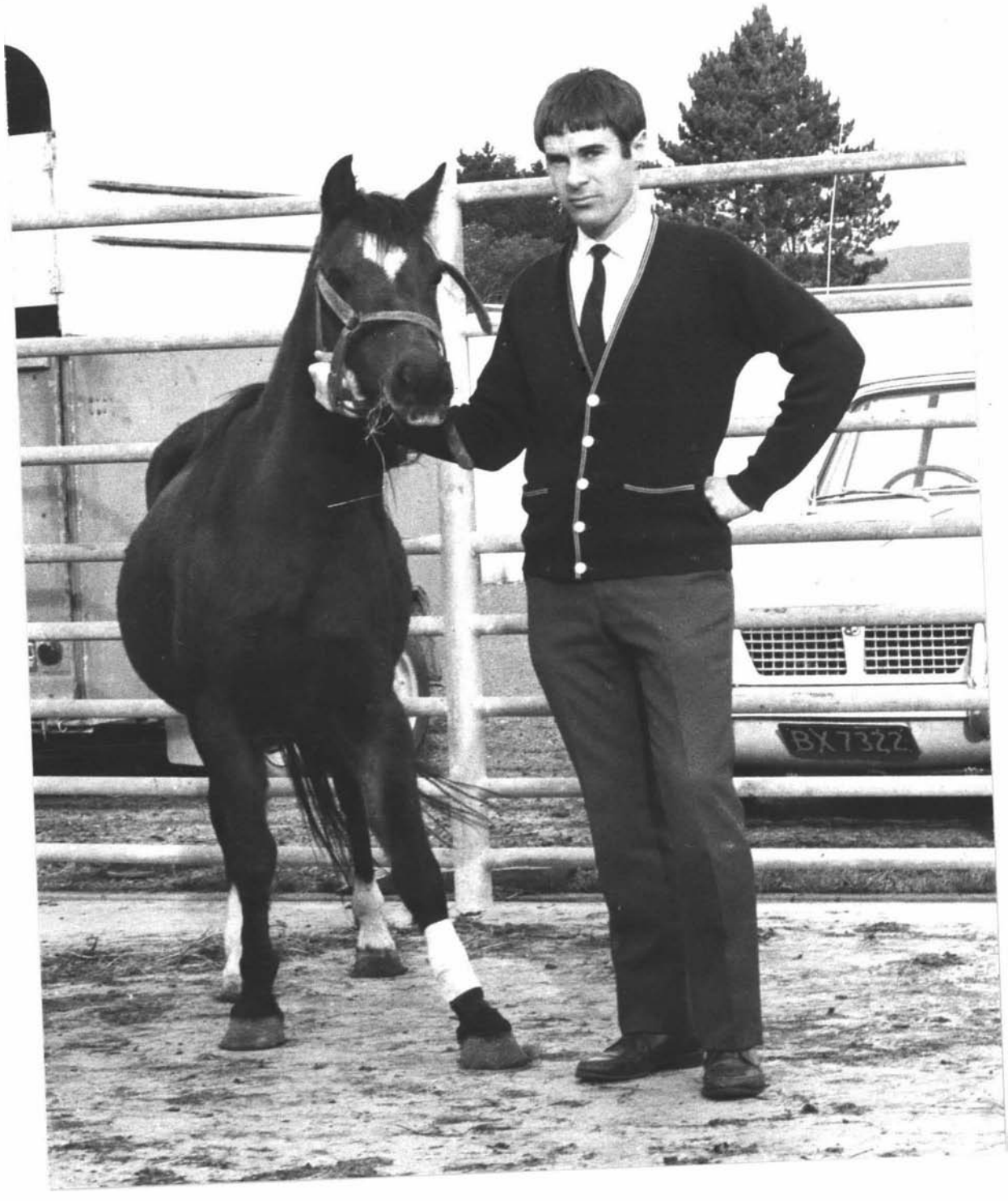
FRONTISPIECE

Great Expectations - the author and horse 001.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Figures 2.2-3 and 2.2-5 were adapted from Scientific American 202/5 (1960) and Figure 3.8-1 from R.A.R. and B.J.K. Trickers' The Science of Movement, American Elsevier, New York, (1967).

ABSTRACT

Muscle forces may have profound influences on stress and strain within the muscle - skeletal system of an animal. These forces have previously been measured by indirect methods often with severe restrictions on the type of movement (if any) that the skeleton was allowed to undergo. A direct method of muscle force (or tendon tension) measurement in the conscious animal was sought which did not necessitate restriction of skeletal movement.

This project reports the manufacture and successful *in vivo* functioning of a tendon tension 'buckle' transducer. The use of the device was demonstrated by correlating tension in the common digital extensor tendon with strain on the lateral and medial aspects of the bone of the walking horse. Strain was monitored by bonding foil electrical resistance strain gauges to the bone surface using a contact cement.

The swing and support phases of the forelegs were monitored by switches attached to each forefoot and occasionally monitored by cinematography. Thus it was possible to make a detailed analysis of the lateral bone strain recording in terms of body weight bearing and of muscle action via the monitored tendon. Also considered were the influences of tension in other tendons of the limb and the action of the head and neck during walking.

A further application of the tendon tension transducer was its use in monitoring tendon tension during recordings of the electrical activity generated by the corresponding muscle. This activity, which was recorded from intramuscular wire electrodes, was later rectified, integrated and compared with the directly measured force.

Experience in electromyography was gained through extensive studies of the equine larynx during which the instrumentation was improved.

The early attempts at bonding strain gauges and flanges to living equine bone failed because the epoxy resin flanges which held the lead wires became detached from the bone. The epoxy resin mouldings were consequently screwed in place but this caused slight lameness immediately following surgery.

Experiments with a tendon tension transducer proved fruitless until the 'buckle' configuration was adopted. This device, when suitably constructed, did not significantly affect the gait of the animal.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

GLOSSARY

Generally, a term is defined only in the context in which it is used in the script.

abduct:	to draw away from a centre or median line.
adduct:	to draw toward a centre or median line.
aspect:	that part of a surface viewed from a particular direction.
autoclave:	a self-locking apparatus for the sterilization of materials by steam under pressure.
bolus:	a rounded mass, e.g., a quantity of food entering the oesophagus at one swallow.
caudal:	the tail end of the body.
contralateral:	pertaining to or situated on the opposite side.
cranial:	the head end of the body.
distal:	away from the long axis of the body.
dorsal surface:	that directed away from the plane of support (the ground), OR (of the manus) opposite to palmar surface.
dowel:	a peg or pin for fastening.
electrogoniometer:	an electrical instrument for measuring angles.
electromyography:	the recording of the changes in electric potential of a muscle.
EMG:	electromyography or electromyogram.
endotracheal:	within the trachea.
fascia:	a band or sheet of tissue enclosing and connecting muscles.
fire:	discharge.
gauge factor:	ratio of the fractional change in resistance and the strain sensed by an electric resistance strain gauge.
insertion:	attachement, as the site of attachement of a skeletal muscle on the bone that is moved when the muscle contracts.

interosseus:	between two bones.
intratracheal:	endotracheal.
in vitro:	in glass; referring to studies performed on tissues removed from the living organism under arteficial conditions in the laboratory.
in vivo:	in life; referring to studies performed on tissues not removed from the living organism.
ischaemia:	local diminution in the blood supply.
isometric:	maintaining the same length (e.g. of muscle).
isotonic:	of the same strength.
kineplasty:	utilization of the stump of an amputated extremity for producing motion in a prosthesis.
kinesiology:	scientific study of movement of body parts.
laparotomy:	incision of the abdominal wall.
lateral:	pertaining to or situated at the side.
medial:	pertaining to or situated toward the midline.
motor unit:	the motor fibre of a cranial nerve, together with the striated muscle fibres innervated by its terminal branches.
motor unit threshold:	muscle force beyond which motor unit is activated.
movement artefact:	the signal resulting from a disturbance of the steady state potential of an EMG electrode.
MPa:	Megapascal.
muscle head:	a segment of a muscle.
myofibril:	a muscle fibril running parallel with the long axis of the fibre and representing the contractile elements.
neutral surface:	the locus of points in an object at which there is no longitudinal extension.
origin:	the end of a skeletal muscle that remains relatively fixed when the muscle contracts.
palmar:	pertaining to the palm.
percutaneous:	performed through the skin.

periosteum: a specialized connective tissue covering all bones and having bone - forming potentialities.

phalanges: pl. of phalanx.

phalanx: any bone of a finger or toe.

phrenic: pertaining to the diaphragm.

piezoelectric effect: electric polarization produced by compression or extension of a material.

plasticity: the retention of deformation after removal of stress.

p.p.m. parts per million.

prosthesis: an artificial substitute for a missing body part.

proximal: near the long axis of the body.

recovery (of strain): tendency of deformed body to resume original shape after removal of applied forces.

recumbent: lying down.

reflection: a turning or bending back.

relaxation (of stress): decreasing stress required to maintain a given deformation.

resection: surgical removal of a considerable portion of an organ or body part.

rheology: the study of deformation and flow of materials.

sarcomere: the unit of length of a myofibril.

settling time: the time taken by the step response of a filter to remain within 5% of its final value.

Steinmann bone pin: a surgical nail inserted in distal portions of bones for skeletal tractions.

subcutaneous: beneath the layers of the skin.

suture: a stitch, series of stitches, or the application of such.

systolic: pertaining to the contraction, or period of contraction, of the heart, especially of the ventricles.

tensile strength: the tensile stress at which a body will fracture, or will continue to deform with decreasing load.

tetanus:	sustained contraction of a muscle.
time constant:	the time taken for current, voltage or charge to reach (1 - 1/e) of its final value.
tonic:	characterized by continuous tension.
trace:	graph with time as abscissa.
ultimate strength:	tensile strength.
ventral surface:	that directed toward the plane of support (the ground).
viscoelastic substance:	a solid or liquid which can both store and dissipate energy.

PREFACE

Many horses during races or while training have injured themselves beyond recovery by the overstrain of a bone or tendon in a leg. It seemed appropriate to begin a study of this biophysical topic, since at Massey University the experimenter (a physicist) could count on the advice and help of people from the Veterinary Faculty. Experiments began in 1972.

The money available was small, and we feel much indebted to the owner of the local knackery, Mr J.C. Clement, for his willingness to make horses available for limited periods, between the time when he received them and the time when he needed to destroy them and prepare the meat for the big-cat cage at Wellington Zoo. The University fed and stabled the horses. The period varied between seven and thirty days. On one occasion a horse seemed to have dislocated its shoulder while recovering from the anaesthetic. Mr Clement's advice by telephone was for us to destroy the horse, and at once to bleed the carcass, gut it, and chill it in a particular way. With good help this was achieved and we did not incur the cost of a spoiled carcass.

The biophysical study involved the progressive development and evaluation of a comprehensive monitoring system for recording biomechanical and bioelectrical information from the horse foreleg. We wished to demonstrate that it was possible to monitor various phenomena simultaneously and then to interpret these measurements in terms of the walking gait of the animal. We developed systems for monitoring bone strain, then developed techniques for monitoring those gait and tendon tension phenomena thought likely to influence bone strain. Lastly we extended the study to include electromyography of horse limb muscles.

The first operations on legs were attempts to fix resistance strain - gauges to a bone of the lower forelimb. Work on hind legs was avoided as needlessly risky.

The next operations demonstrated (for the first time) that one could fit transducers to indicate tension in an uncut tendon. Recordings were made as the animal stood, walked or trotted.

In the third stage, intramuscular wire electrodes were inserted to detect electrical signals activating the muscles. This proved easy, and it was done in the hope that a suitably smoothed EMG signal might give an imitation of tendon tension good enough for some purposes. This sequence of tests involved nine operations, using eight horses in all. The horse's gait was originally recorded on cine film, but it proved simpler to record the contact of foot switches to show whether each forefoot was on the ground or off it.

The complete system, making simultaneous records of bone strain, tendon tension, myoelectric activity and foot position, was then fitted in succession to two horses. Chapters 3 and 4 show some records and attempt some comparisons.

The use of knacker's horses had the advantage of low cost. It also allowed the forelimb to be retrieved from the knackery, so that the transducers and their sites could be inspected for damage.

The arrangement with the knackery, however, had two disadvantages which are reflected in the work we were able to do. Firstly we had little control over the availability of horses or over the length of time that we could work with any one particular horse. This meant that in general we were restricted to only one operation per horse. It was not practicable to perform a whole series of separate operations on one particular horse even if the horse could have withstood the consequent limb damage.

The second disadvantage of our horse supply was that we had little or no control over the type of horse supplied, many were old, some were hacks, one was a thoroughbred, some were used

to being handled, some were semi-wild and bit or fought. There was no possibility of training these animals to walk in a preferred gait in the available time so the variability in recordings taken from different horses was expected to be large. Also, recordings were taken over a period of four years as the transducers were developed. Consequently no effort was expended to calculate mean values and standard errors for the monitored parameters as data collected under such different conditions could not be meaningfully combined.

The data was often recorded at night to avoid interference with and interference from the more usual activities of the large animal hospital of the University Veterinary Faculty, however, the late hour caused drowsiness and hence variability of horse gait. This, coupled to the fact that the horses were not trained in a particular walking gait meant that even for one particular horse the variation in gait from stride to stride caused decreased repeatability in the monitored parameters. Consequently a statistical analysis of results would reflect the variability of stride rather than the uncertainty of the measurements.

Extensive myoelectric laryngeal studies were made on anaesthetised horses, partly as a means of developing expertise in electromyography for studies on the equine limb. Fourteen normal and more than forty abnormal larynges have been electromyographically probed in a programme to elucidate the function of laryngeal muscles in both 'normal' and 'roaring' horses, but it was thought best not to attempt an analysis of these results in this thesis.