WORKING WITH SUBCHONDRAL BONE TO MINIMISE INJURY IN RACEHORSES : A REVIEW

R.C. Whitton

Equine Centre, Faculty of Veterinary and Agricultural Sciences,
University of Melbourne, 250 Princes Hwy, Werribee,
Victoria, 3030, Australia

ABSTRACT

This paper covers recent published research, by the author, investigating bone remodelling in horses.

Subchondral bone fatigue is an important cause of poor performance, morbidity and mortality in racehorses resulting in fractures and subchondral bone injury. Fatigued bone is repaired by remodelling; a process that is attenuated under high cyclical loads, yet the effects of training on remodelling activity in Thoroughbred racehorses is unknown. In order to test the hypothesis that remodelling rates are lower in training horses, than those that are resting from training, histomorphological measures of bone remodelling were compared.

Sections of the palmar metacarpal condyles from Thoroughbred horses that were in race training (n=24) or resting from training (n=24) at the time of death were examined with light microscopy and back scattered electron microscopy (BSEM). Bone area fraction (B.Ar/T.Ar), and eroded (E.Pm/T.Ar) bone surface were measured with 2 areas of interest; (1) the lateral parasagittal groove (PS); and (2) the lateral condylar subchondral bone (LC). BSEM variables were analysed for the effect of group (independent samples *t*-test), region (paired *t*-test) and interaction with time since change in training status (general linear model). Mean ± SE are reported.

For both regions of interest, E.Pm/T.Ar was lower in the training horses (PS: 0.39±0.06mm^{-1}, LC: 0.24±0.04mm^{-1}) than in the resting group (PS: 0.65±0.07mm^{-1}, P= 0.010, LC: 0.85±0.10mm^{-1}, P<0.001). Lower subchondral bone porosity was observed, reflected by higher B.Ar/T.Ar in the LC of training horses (90.8±0.6%) than resting horses (85.3±1.4%, P= 0.0010). E.Pm/T.Ar was higher, with increased duration of a training period, in the lateral condyle (r^2=0.26, P=0.011).

Race training inhibits remodelling in the subchondral bone of highly loaded areas of the distal metacarpus. Therefore periods of less intense loading are important for allowing repair of subchondral bone fatigue in Thoroughbred racehorses.

INTRODUCTION

Subchondral bone injury is highly prevalent in Thoroughbred racehorses (Pinchbeck et al., 2013b). In the fetlock joint subchondral bone injury is associated with poor performance (Trope et al., 2011), lameness resulting in enforced rest or early retirement (Pinchbeck et al., 2013b), and fracture which may, in some instances, be fatal (Whitton et al., 2010).

There is substantial evidence that these injuries are due to bone material fatigue: the injuries only occur in horses in race training, fractures occur spontaneously; pre-existing pathology and microcracks are often observed at fracture predilection sites; and the epidemiology of injury is consistent with accumulated galloping distance being an important contributor (Parkin et al., 2005; Pinchbeck et al., 2013a; Verheyen et al., 2006).

Because of the high prevalence of subchondral bone fatigue in racehorses, an understanding of bone fatigue is fundamental to dealing with musculoskeletal injury in athletic horses.

SUBCHONDRAL BONE FATIGUE

Subchondral bone fatigue is the gradual degrading of mechanical properties caused by cyclic loading of the joint surface. This repeated loading results in a gradual loss of bone stiffness, which begins with molecular debonding, followed by the development of microcracks and ultimately complete failure. The number of cycles of load that bone can sustain prior to failure is dependent on the magnitude of the load (Martig et al., 2013). And because horses subject their fetlocks and carpi to extreme loads subchondral bone injury due to fatigue failure is common in these joints (Harrison et al., 2010) .

BONE RESPONSE TO FATIGUE LOADING

Bone is a dynamic tissue and is able to adapt to increased loading by modelling. Cortical bone models by increasing cortical thickness, with small increases in cortical bone thickness resulting in large increases in fatigue life (Warden et al., 2005). Subchondral bone models by increasing subchondral bone plate and trabecular bone thickness. Evidence for the importance of this in horses includes the observation that metacarpal condylar fractures occur early in a training period in two-year-old race horses with less adapted bone, whereas they occur later in a training period in mature horses with better adapted bone (Whitton et al., 2010).

The potential for injury is high when subchondral bone is poorly adapted to galloping. For example higher fracture rates are observed in young horses, and in those that do no gallop training prior to racing (Parkin et al., 2004).

BONE REPAIR

Fatigued bone is repaired by remodelling. Osteoclasts remove fatigued bone which is then replaced with new bone by osteoblasts. It is generally accepted in bone biology that remodelling activity is inhibited in a high load environment due to reduced recruitment of osteoclasts (Jee and Li, 1990). There is some evidence that subchondral bone remodelling is reduced in racehorses in training. Less bone eroded surface has been demonstrated in the carpus of horses undergoing treadmill training compared to horses that have never been in training (Murray et al., 2001) and using high resolution peripheral quantitative CT we have observed less porosity in the distal metacarpal subchondral bone in horses in race training compared with those resting from training (Whitton et al., 2010). Detailed examination of remodelling activity in the distal metacarpal subchondral bone in horses in race training has not been performed.

EFFECT OF TRAINING AND REST ON SUBCHONDRAL BONE REMODELLING

A cross sectional study using metacarpal bones collected at post-mortem from Thoroughbred racehorses that died or were euthanased was performed (Holmes et al., 2014). Horses with metacarpal bone fractures were excluded. Twenty four horses were in race training and 24 were resting from previous race training for various periods. The sex distribution was the same for both groups but horses in training were, on average, older than the resting horses.

Oblique frontal sections of the palmar aspect of the distal metacarpus were examined with back scattered electron microscopy. Two regions of interest were examined in detail, the lateral condylar subchondral bone, an area that sustains some of the highest loads, and the lateral parasagittal groove which is less highly loaded but still subjected to fatigue damage. Larger areas of the lateral and medial condyles were also examined.

Images were automatically thresholded to create a binary image and porosity was measured as the percentage area of void over the total area using image analysis software. Surface analysis was performed where eroded surface (seen here as scalloped surfaces as evidence of previous osteoclast activity) was measured and expressed per unit area. A power analysis found that 26 horses per group were required in order to detect a 20% difference in remodelling variables with a power of 80%. The effect of group was determined with a general linear model which allowed testing for confounding for variables such as age which was shown not to be a confounder.

Porosity was measured in all regions of interest and only in the lateral condylar subchondral bone was it significantly lower in training than resting horses (P=0.001).

Eroded bone surface was lower in horses in training in both regions of interest (PS: 0.39±0.06 vs. 0.65±0.07 per mm, P= 0.010; LC: 0.24±0.04 vs. 0.85±0.10 per mm, P<0.001), the lateral condylar subchondral bone and the lateral parasaggital groove but the difference was most marked in the lateral condylar subchondral bone

In the lateral condylar subchondral bone eroded surface increased in association with greater duration of training (parasagittal groove E.Pm/B.Pm: R^2=0.20, P=0.027; lateral condyle E.Pm/T.Ar: R^2=0.26, P=0.011). There was no association with duration of rest period partly because there was a large variation in eroded surface measures in the resting horses.

This study demonstrated that the repeated high magnitude loads applied to subchondral bone by horses in race training causes bone fatigue and is associated with reduced repair. This combination results in the inevitable accumulation of subchondral bone fatigue damage and explains the high prevalence of subchondral bone injury identified in post mortem studies.

These findings also highlight the importance of periods of less intense exercise to allow bone replacement to avoid fatigue injury. Although more work is required to determine how much rest time is required to maintain fatigue damage at safe levels, based on the burden of fatigue damage in race horses at present it is likely that most horses need more rest time.

CONCLUSION

Subchondral bone injuries occur with a high prevalence in race horses. Bone is a dynamic tissue and the response of subchondral bone to race training needs to be understood in order to reduce the prevalence of subchondral bone injury. Trainers need to allow appropriate adaptation of bone to race training and to increase the duration of periods of less intense training in order to facilitate bone repair.

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References ....

Harrison, S.M., Whitton, R.C., Kawcak, C.E., Stover, S.M. and Pandy, M.G. (2010) Relationship between muscle forces, joint loading and utilization of elastic strain energy in equine locomotion. *J Exp Biol.* **213**, 3998-4009.

Holmes, J.M., Mirams, M., Mackie, E.J. and Whitton, R.C. (2014) Thoroughbred horses in race training have lower levels of subchondral bone remodelling in highly loaded regions of the distal metacarpus compared to horses resting from training. *Vet J.* **202**, 443-447.

Jee, W.S. and Li, X.J. (1990) Adaptation of cancellous bone to overloading in the adult rat: a single photon absorptiometry and histomorphometry study. *Anat Rec.* **227,** 418-426.

Martig, S., Lee, P.V., Anderson, G.A. and Whitton, R.C. (2013) Compressive fatigue life of subchondral bone of the metacarpal condyle in thoroughbred racehorses. *Bone.* **57**, 392-398.

Murray, R.C., Vedi, S., Birch, H.L., Lakhani, K.H. and Goodship, A.E. (2001) Subchondral bone thickness, hardness and remodelling are influenced by short-term exercise in a site-specific manner. *J Orthop Res.* **19**, 1035-1042.

Parkin, T.D., Clegg, P.D., French, N.P., Proudman, C.J., Riggs, C.M., Singer, E.R., Webbon, P.M. and Morgan, K.L. (2004) Risk of fatal distal limb fractures among Thoroughbreds involved in the five types of racing in the United Kingdom. *Vet Rec.* **154**, 493-497.

Parkin, T.D., Clegg, P.D., French, N.P., Proudman, C.J., Riggs, C.M., Singer, E.R., Webbon, P.M. and Morgan, K.L. (2005) Risk factors for fatal lateral condylar fracture of the third metacarpus/metatarsus in UK racing. *Equine Vet J.* **37,** 192-199.

Pinchbeck, G.L., Clegg, P.D., Boyde, A., Barr, E.D. and Riggs, C.M. (2013a) Horse-, training- and race-level risk factors for palmar/plantar osteochondral disease in the racing Thoroughbred. *Equine Vet J.* **45,** 582-586.

Pinchbeck, G.L., Clegg, P.D., Boyde, A. and Riggs, C.M. (2013b) Pathological and clinical features associated with palmar/plantar osteochondral disease of the metacarpo/metatarsophalangeal joint in Thoroughbred racehorses. *Equine Vet J.* **45,** 587-592.

Trope, G.D., Anderson, G.A., Whitton, R.C. (2011) Patterns of scintigraphic uptake in the fetlock joint of Thoroughbred racehorses and the effect of increased radiopharmaceutical uptake in the distal metacarpal/tarsal condyle on performance. *Equine Vet J.* **43**, 509-515.

Verheyen, K., Price, J., Lanyon, L. and Wood, J. (2006) Exercise distance and speed affect the risk of fracture in racehorses. *Bone.* **39,** 1322-1330.

Warden, S.J., Hurst, J.A., Sanders, M.S., Turner, C.H., Burr, D.B. and Li, J. (2005) Bone adaptation to a mechanical loading program significantly increases skeletal fatigue resistance. *J Bone Miner Res.* **20,** 809-816.

Whitton, R.C., Trope, G.D., Ghasem-Zadeh, A., Anderson, G.A., Parkin, T.D., Mackie, E.J. and Seeman, E. (2010) Third metacarpal condylar fatigue fractures in equine athletes occur within previously modelled subchondral bone. *Bone.* **47,** 826-831.