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Original Research

A Comparative Study on the Effects of Copper and Steel Nails on the Health of Horseshoe Nail Holes

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ABSTRACT

Copper-coated steel nails are being increasingly used during shoeing due to their proposed ability to reduce bacterial invasion, despite limited evidence for their effectiveness in this application. The aim of the present study was to determine whether copper-coated horseshoe nails would have a beneficial effect on nail hole health compared to traditional steel nails. All horses were shod by the same farrier at 5- to 6-week intervals. In phase one of the study, a cohort of 11 sport horses was shod for two shoeing cycles using copper-coated nails in the left forefoot (LF) and steel nails in the right forefoot (RF). To eliminate bias related to the use of the same foot in all animals, a second phase of the study was carried out where a subset ($n = 6$) of the horses were then reshod for two shoeing cycles using a cross-over design. In phase two, the copper-coated nails were used in the RF and steel nails in the LF after a washout period. At the completion of each phase, the horseshoes were removed and the feet trimmed for reshoeing. Before reshoeing, a photograph was taken of the solear surface of each foot and a 10-point pathology score scale was used to assess nail hole health. Overall, the mean ± standard error nail hole pathology score was significantly ($P < .01$) higher (less healthy) for the steel nails (6.1 ± 0.31), compared with the copper-coated nails (4.4 ± 0.27). Following the cross-over period, the mean ± standard error nail hole pathology score was found to be similar for the LF and RF for each type of nail. Consistent with phase one of the study, there was a significant difference between the pathology scores when copper-coated nails were used in the RF, compared to the steel nails. It appears that the well-known antimicrobial effects of copper may apply to the application of copper coating of horseshoe nails in reducing the microbial damage to the horses' hoof frequently associated with horseshoe nail insertion.

1. Introduction

Optimal digitigrade locomotion in the mammalian family Equidae relies on the integrity of the tough keratinized hoof of each limb. The hoof wall consists of hard keratin tubules, which affords strength and elasticity during locomotion [1]. These tubules, which are essentially hollow at their distal end where they strike the ground, may permit ascending bacteria to invade the hoof wall. This is particularly likely during hoof wall trauma, in the form of cracks and breaks at the solear surface, and often results in dysfunction and pain [2,3]. Furthermore, chronic bacterial invasion of the hoof wall reduces horn quality and may lead to decay and loss of functional strength [2,4,5].

The white line of the horse's hoof represents the suspension of the distal phalanx to the lamellae of the stratum internum of the hoof capsule. The white line consists of two components; the brittle tubular horn complements the lamellae at the white line originating from the stratum internum. The tubular horn is the weakest and enables bacteria to enter deeper layers of the hoof horn [2]. Defects of the white line are commonly referred to as "white line disease" and if unmanaged can result in lameness, secondary infection, and progressive wall separation [6].

Steel horseshoes are often used to protect the hoof from excessive wear during locomotion and are typically nailed in place to the hoof wall. The nails are inserted from the bearing surface of the hoof through the white line and erupt more proximally through the stratum externum. As the hoof wall continues to grow during a 5–6 weeks of shoeing interval, ground reaction forces and changes

Animal welfare/ethical statement: Ethical approval was not required for this study. The horses were privately owned and the owners consented to the involvement of their horse in the study. All horses were shod by their usual farrier, with their usual shoes and within their usual foot care program.

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in the shape and size of the ground bearing hoof surface may cause the nail holes to enlarge and change shape, during which time the nails may become loose [7]. Studies have suggested that nail holes allow bacterial migration proximally from the ground bearing surface to deeper into the hoof wall [5]. Horseshoe nails also increase shearing stress in the wall surrounding the nail holes [8].

Traditional horseshoe nails are made of steel, and steel offers no antibacterial qualities [9,10]. By comparison, copper and many copper alloys have been registered by the U.S. Environmental Protection Agency as a solid antimicrobial material [8]. Copper ions from copper alloys destroy the bacterial cell wall and penetrate into the bacteria and cause degeneration and death [9–12]. Copper has been used as an antibacterial agent for many centuries and has recently gained mainstream support as a first line of defense against multiresistant bacteria in human health and medicine [9]. A number of recent studies using hospitalized human subjects have shown that on copper surfaces, there is a substantial reduction of the microbial burden on an ongoing basis [11,12]. As such, copper-coated steel nails are being increasingly used during shoeing due to their proposed ability to reduce bacterial invasion, despite limited evidence for their effectiveness in this application. The rationale behind this recent upsurge in the use of copper-coated nails is that the coating of traditional steel nails with copper facilitates the use of copper at the nail-hoof contact surface, while maintaining the original mechanical properties of the steel nail. Thus, the aim of the present study was to determine whether copper-coated horseshoe nails would in fact better maintain the morphology of nail holes and reduce the visual evidence of pathogen invasion of nail holes, compared to traditional steel nails.

2. Material and Methods

2.1. Study Design

Eleven currently active sport horses (jumping and eventing) from two facilities 10 km apart on the Sunshine Coast, Queensland, Australia, were used in the study. Horses were typically housed in 1 hectare paddocks for the duration of the study. Diet was not controlled and horses ate grass supplemented by hay. Climatic conditions during the study could be described as dry. Horses did not stand in wet boggy substrate and were not stabled during the study. Horses were shod by the same farrier using the same nailing pattern (two nails medially and three nails laterally) on a 5- to 6-week shoeing cycle.

In phase one of the study, a cohort of 11 horses was shod for two shoeing cycles using copper-coated nails in the left forefoot (LF) and steel nails in the right forefoot (RF). To ensure that there was no bias related to the use of the same foot in all animals, a second phase of the study was carried out where a subset ($n = 6$) of the horses were then reshod for two shoeing cycles using a cross-over design. In phase two, the copper-coated nails were used in the RF and steel nails in the LF after a 12-week washout period when all horses were shod twice with using steel nails. Before the study, all horses were shod by the same farrier using steel nails. This same farrier performed the shoeing on all horses during the study. During the study period, the fore feet of all horses were shod with the same brand of single toe-clip horseshoe. The copper-coated and steel nails were all the same brand and size.

2.2. Measurements

For each horse at the completion of each phase, the horseshoes were removed and the feet trimmed for reshoeing, removing only flaking sole material and leaving 2–3 mm of hoof wall beyond the solear surface. Before reshoeing, a Nikon D100 digital camera fitted with a 55 mm Micro Nikkor lens and Nikon SB-800 DX Speedlight flash was used to photograph the solear surface of each foot at a perpendicular distance of 300 mm from the solear surface of the lifted foot. This provided photographs of 6 MB file size, dimensions 6000×4000 pixels with 300 dpi resolution. The hoof (left vs. right) and nail type (copper-coated vs. steel) was coded for to enable later blind assessment of the images.

A 10-point scale for the assessment of nail hole health was developed based on representative images and included a short subjective description of pathology (Table 1). A single scorer,

Table 1
Descriptions used to score the health of nail hole morphology and pathology.

Pathology Score	Nail Hole Morphology	Appearance of Pathogens
1	Clearly defined nail hole morphology Straight sides and right-angled corners	No discoloration of tissue surrounding nail hole No decay of the white line or adjacent hoof wall
2	Clearly defined nail hole morphology Straight sides and right-angled corners	Slight discoloration of tissue surrounding nail hole No decay of the white line or adjacent hoof wall
3	Slight loss of definition of nail hole morphology Loss of straight edge on one side and loss of right-angled appearance of one corner	Thin band of discoloration of tissue surrounding nail hole Patchy areas of decay of the white line or adjacent hoof wall
4	Some loss of delineation of the nail hole shape and size Loss of straight edge on two sides and loss of right-angled appearance of two corners	Thin band of discoloration of tissue surrounding nail hole Continuous area of decay of the white line or adjacent hoof wall
5	Marked loss of delineation of the nail hole shape and size Loss of straight edge on three sides and loss of right-angled appearance of three corners	Broad band of discoloration of tissue surrounding nail hole Continuous area of decay of the white line or adjacent hoof wall
6	Marked loss of delineation of the nail hole shape and size Loss of straight edge on at all sides and loss of right-angled appearance of all corners	Broad band of discoloration of tissue surrounding nail hole Continuous area of decay of the white line or adjacent hoof wall
7	Extensive loss of morphology of the nail hole Loss of straight edge on all sides and loss of right-angled appearance of all corners Rectangular shape still apparent	Broad band of discoloration of tissue surrounding nail hole Continuous area of decay of the white line and adjacent hoof wall
8	Almost complete loss of morphology of the nail hole Loss of straight edge on all sides and loss of right-angled appearance of all corners Rectangular shape semiapparent	Broad band of discoloration of tissue surrounding nail hole Continuous area of decay of the white line and adjacent hoof wall
9	Almost complete loss of morphology of the nail hole Rectangular shape barely apparent	Gross decay of the tissue on the perimeter of the nail hole extending into the while line and hoof wall tubes surrounding the nail hole and remote to the nail hole
10	Complete loss of morphology of the nail hole	Gross decay of the tissue on the perimeter of the nail hole extending into the while line and hoof wall surrounding the nail hole and remote to the nail hole

blinded to the nail type and hoof, scored each nail hole pathology against the 10-point scale.

2.3. Ethical Considerations and Statistical Analyses

The horses were privately owned and the owners consented to the involvement of their horse in the study. All horses were shod by their usual farrier, with their usual shoes and within their usual foot care program. The data were normally distributed (Shapiro–Wilk test) and are reported as mean ± standard error (SE). The data for phase one of the study were examined using a two-way analysis of variance (ANOVA), while in phase two of the study, a repeated measures, two-way ANOVA was used. Post hoc pairwise comparisons were analyzed with a Holm-Sidak test. Significance was accepted at <0.05. The analyses were performed using SigmaPlot v 13.

3. Results

The visible effect on the solear surface of the hoof from nailing was variable ranging from minimal effect to gross disturbance of localized hoof wall integrity. Fig. 1 clearly shows areas of discoloration surrounding nail holes with tissue decay and hoof wall disruptions associated with some nail hole locations. Overall, the mean ± SE nail hole pathology score was significantly ($P < .01$) higher (less healthy) for the steel nails (6.1 ± 0.31), compared with the copper-coated nails (4.4 ± 0.27). The typical appearance of the nail hole with a pathology score of 6 (Fig. 2C) was characterized by marked loss of delineation of the nail hole shape and size with a broad band of discoloration of tissue surrounding the nail hole. There was a continuous area of decay of the white line or adjacent hoof wall. Conversely, the typical appearance of the nail hole with a pathology score of 4 (Fig. 2B) was characterized by some loss of delineation of the nail hole shape and size with loss of straight edge appearance on two sides and loss of right-angled appearance of two corners. There was a thin band of discoloration of tissue surrounding the nail hole and a continuous area of decay of the white line or adjacent hoof wall.

Following the cross-over period, the mean ± SE nail hole pathology score was found to be similar for the LF and RF for each type of nail, in the subset of horses examined (Table 2). Consistent with phase one of the study, there was a significant difference between the pathology scores when copper-coated nails were used in the RF, compared to the steel nails (Table 2).

Fig. 1. Photograph of a subject horses' hoof prepared for assessment following a 5-week shoeing cycle. The steel horseshoe has been removed and the hoof cleaned and trimmed in preparation for the next horseshoe application. The left-hand view of the photo is the medial side of the hoof where two horseshoe nails were applied, and the right-hand view is the lateral side of the hoof where three horseshoe nails were applied. There is clear evidence of pathogen presence at each nail hole site with evidence of greater tissue decay associated with the lateral hoof nail holes. This photograph clearly demonstrates an effect of nailing on the health of the solear surface of the hoof.

4. Discussion

The present study is the first to present evidence that the use of copper-coated horseshoe nails assists in the prevention of hoof wall decay associated with nailing on horseshoes. Pathogens associated with hoof wall disease have mostly been identified as bacterial while fewer are fungal [2,3]. Traditionally, topical applications, such as preparations of copper sulfate, have been successfully used to manage pathogen invasion into the hoof wall [13,14]. In this study, the use of copper-coated nails was associated with significantly less nail hole pathology than was seen with the use of traditional steel nails. These data suggest that further studies that directly assess pathogenic contamination and bacterial migration into the hoof wall associated with the use of both steel and copper-coated horseshoe nails are required.

Copper-containing steel does not have antibacterial properties if the copper exists in the steel as a solid solution because copper ions are in an inactive state and find it difficult to penetrate through the steel substrate to exert their antibacterial effect [10]. As such, the technical aspects of combining copper with steel during the construction of the copper-coated horseshoe nails are crucial to the ability of the material to exert its antibacterial properties. It is relevant to note that the use of copper-coated nails gave the hoof wall only partially improved nail hole health in this study. This suggests that pathogen invasion from the ground-bearing surface of the nail hole proximally may have occurred into the hoof wall. Direct contact of bacteria with the copper substrate is required for bacterial lysis. By comparison, the bacteria not in direct contact with the copper will remain unaffected [9,10,15]. This requirement for direct-contact killing may be one of the main limitations of the use of copper-coated nails in the reduction of bacterial penetration of the hoof wall and likely explains the only partial improvement in nail hole health seen in the present study. During the shoeing cycle, the hoof wall grows distally and the bearing border increases in circumference. If the foot is not trimmed and reshod in a timely manner, the bearing border of the hoof wall may overgrow the horseshoe. Horseshoe nail holes often change shape and loosen during this growth and due to the mechanical stress of locomotion [8], causing the nail to lose contact with some of the nail hole surface. If copper ions are unable to flow from the material and infiltrate the surrounding hoof wall, there will be no antibacterial protection remote to the nail surface. This potentiation of antibacterial effect is an area for improvement in the future manufacture and design of copper-coated nails. For example, once it is nailed in place, a copper-leaching nail could potentially exert an ongoing antibacterial effect on the white line and hoof wall immediately surrounding the nail. However, the effect of gross copper ion leaching into the hoof wall has not been studied. Therefore, the investigation of the effects of copper leaching on hoof wall and systemic health may be warranted before the use of copper-leaching products in horses' hooves. Additional caution should be exercised when applying copper-coated horseshoe nails in the presence of other horseshoeing materials. Practical evidence from farriers indicates that copper may react adversely with aluminum horseshoes, resulting in damage to the hoof wall. The use of copper in horseshoeing may not be limited to horseshoe

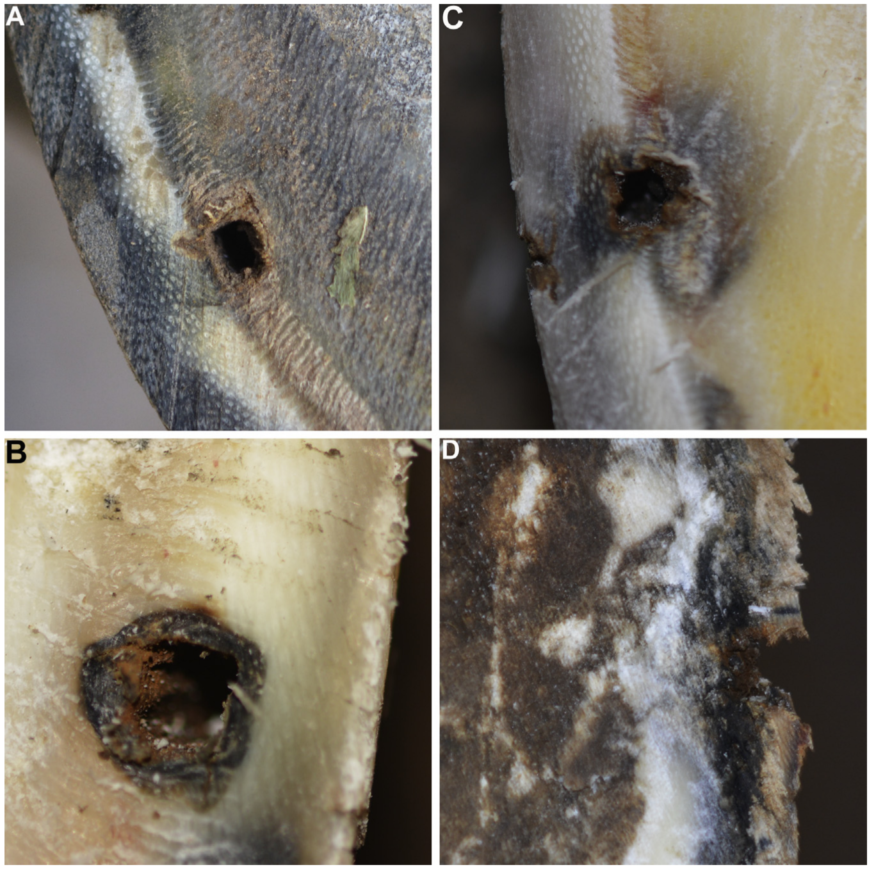

Fig. 2. (A) Photographic representation of nail hole pathology score 1 described as "Clearly defined nail hole morphology. Straight sides and right-angled corners. No discoloration of tissue surrounding nail hole. No decay of the white line or adjacent hoof wall." (B). Photographic representation of nail hole pathology score 4 described as "Some loss of delineation of the nail hole shape and size. Loss of straight edge on two sides and loss of right-angled appearance of two corners. Thin band of discoloration of tissue surrounding nail hole. Continuous area of decay of the white line or adjacent hoof wall." (C). Photographic representation of nail hole pathology score 6 described as "Marked loss of delineation of the nail hole shape and size. Loss of straight edge on at all sides and loss of right-angled appearance of all corners. Broad band of discoloration of tissue surrounding nail hole. Continuous area of decay of the white line or adjacent hoof wall." (D). Photographic representation of nail hole pathology score 10 described as "Complete loss of morphology of the nail hole. Gross decay of the tissue on the perimeter of the nail hole extending into the white line and hoof wall surrounding the nail hole and remote to the nail hole."

nails. If the inclusion of copper in nails can have beneficial effects on hoof wall health, then the application of copper to horseshoes may provide further antibacterial protection to the bearing border of the hoof wall and white line. Farriers currently use various topical preparations to manage bacterial invasion of the solear surface of the foot. However, once a horseshoe is applied, further application of topical preparations to areas covered by the horseshoe is not practical. Slow leaching of copper ions from horseshoes may provide long-term antibacterial protection for the duration of the shoeing cycle.

On the strength of the data presented in the present study, farriers may use the antibacterial effects of copper-coated horseshoe nails with confidence when applying steel shoes to horses' hooves susceptible to bacterial invasion. However, the protection offered by the copper-coated horseshoe nail used in this study is not complete and the design of the nail, particularly in respect to the potential leaching of copper ions into the hoof wall, can be improved to promote a more widespread and thorough protection. The soundness of the hoof wall ultimately depends of many factors such as correct trimming, correct shaping, and fitting of horseshoes and overall horse health.

Table 2
The mean ± standard error nail hole pathology score following the use of steel and copper-coated nails in six horses.

Horses	Copper-Coated	Steel	*P* Value
All 11	4.40 ± 0.27	6.10 ± 0.31	<.01
Cross-over (6)	4.17 ± 0.40	6.33 ± 0.37	.003

5. Conclusion

It appears that the well-known antimicrobial effects of copper may apply to the application of copper coating of horseshoe nails in reducing the microbial damage to the horses' hoof frequently associated with horseshoe nail insertion. The inclusion of copper preparations to horseshoes may also provide further benefit by leaching copper ions to the total ground-bearing border of the hoof wall.

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