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USE OF GLUE-ON SHOES TO IMPROVE CONFORMATIONAL ABNORMALITIES IN TWO ASIAN ELEPHANTS (*ELEPHAS MAXIMUS*)

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Abstract: This report describes the use of custom-made, glue-on shoes for the front feet of two female adult Asian elephants (*Elephas maximus*) with conformational abnormalities. Both elephants had unequal leg lengths. The first elephant also had bilateral fetlock varus causing recurrent nail infections of the fourth digits of the front feet. The second elephant displayed weight shifting. Over several years, multiple shoe prototypes were tested. The current version is made of two types of shoe rubber, glued together and attached to the pad of the shorter leg with a liquid adhesive. The first elephant also has bilateral wedge pads to offload pressure from the fourth nails. The shoes are removed each month for foot care, then replaced. Within several months of wearing shoes, the first elephant's nail infections healed and the second elephant stopped weight shifting. Both elephants' gaits became smoother. This is the first description of corrective shoeing in elephants.

Key words: Asian elephant, conformation, corrective shoeing, *Elephas maximus*, foot health, gait.

BRIEF COMMUNICATION

Therapeutic shoeing of elephants in human care has been limited to short-term use of protective boots or sandals for injuries and infections.[1,9,11] Boots are seldom strong enough to endure an elephant's weight for long periods, and elephants sometimes remove them with their trunks. Boots can also trap moisture and dirt, leading to softened nails and damaged tissue.

However, like domestic horses, elephants often have conformational abnormalities[3] as well as various foot pathologies[7] that suggest that therapeutic farriery could be beneficial to elephants. In horses, therapeutic shoeing promotes a more natural gait, reduces stress on soft tissue structures and joints of the leg and foot, and increases animal comfort.[6] Shoes can also redistribute pressures on the feet and decrease concussion when the foot contacts the ground.[6]

Elephants have thin toenails, not hooves, and a keratinized "slipper" (also known as "foot pad") on the bottom of their feet. Adult elephants also usually weigh upwards of 3,200 kg, and each footstep involves extraordinarily high pressures and stresses.[5] These characteristics preclude use of existing equine shoes.

Elephant A was a 45-yr-old female Asian elephant (*Elephas maximus*) weighing 3,727 kg. Elephant A's early history was unknown, but the animal had a pigeon-toed conformation (fetlock varus) throughout its adult life. Despite the varus conformation, this elephant's walk was smooth and normal, without stiffness or joint abnormalities. Regular foot care and appropriate corrective trimming were performed regularly. The elephant experienced a growth spurt during its late 30s that increased its overall height by 4 cm. However, the left front leg did not grow as much as the right during this growth period, and the elephant's previously smooth gait became short strided with an outward rotational movement of each front leg during the swing phase of the stride. Elephant A then began to develop recurrent nail infections of the fourth digits of both feet that waxed and waned with veterinary treatment. The elephant was noted to extend its right front leg and place most of its weight on the left front foot when at rest (see Fig. 1A). When the elephant was standing squarely and viewed from the front, the scapulae were asymmetric, with the right scapula higher than the left. Radiographs of the feet and fetlocks were normal, as were all other health parameters. To determine the disparity between the heights of the front legs, multiple thin sheets of plywood were inserted under the left front foot until both scapulae became even. The height of the plywood was then measured, and the differ-

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Figure 1. Elephant posture standing, before and after shoes. **A.** Elephant A leaning on the left front foot because of asymmetry in leg length before shoes were applied. **B.** Elephant A wearing shoes and standing square (from 2016). **C.** Close-up of partial wedge pad on right foot (arrowheads) and elevated shoe on left foot.

Table 1. Directions for building and applying a glue-on shoe for an elephant.

Step 1: Trace outline of the foot on construction paper to use as a pattern.
Step 2: Use the pattern to cut out shoeing rubber with a utility knife. Shoeing rubber can be purchased in different diameters and with different textures. For elephants A and B, top and bottom pieces are made of Gum Crinkle 12-iron rubber (SoleTech, Nahant, Massachusetts 01908, USA). Note that Gum Crinkle has a rough side and a smoother side. For elephant A, the middle portion of the shoe is cut from three pieces of Firm Crepe 60 24-iron rubber (SoleTech) to achieve necessary height. For elephant B, the center is a single piece of 24-iron pyramid rubber (Vibram USA, Concord, Massachusetts 01742, USA).
Step 3: Roughen all surfaces of each piece with a grinder, then brush acetone over each surface to remove debris. Grinding decreases the final height of each shoe.
Step 4: Use a grinder with a cutting disk to create a shallow checkerboard tread on the rough side of the Gum Crinkle being used for bottom piece. This surface will have contact with the ground.
Step 5: Brush primer (Primer für PUR, Renia, Cologne, Germany) on all surfaces except for the side on which the checkerboard tread was just cut. Allow to dry.
Step 6: Assemble the sandwich. The smooth side of the Gum Crinkle should be at the top of the sandwich. This will be attached to the bottom of the foot. The rough piece of Gum Crinkle with the checkerboard pattern should be at the bottom, facing the ground.
Step 7: Glue the rubber sandwich together using shoe adhesive (Colle de Cologne, Renia). This particular glue must be applied to both surfaces and allowed to dry prior to contact. After joining the pieces, pound the rubber sandwich together with a mallet. Allow up to 30 min to dry.
Step 8: If the elephant needs a wedge pad (as for elephant A), cut an additional piece of Firm Crepe 60 rubber (3-mm thickness was used here) to the shape desired. For this elephant, the rubber was cut in an oblong to fit only the lateral half of the foot, specifically supporting the fourth and fifth digits, then planed down into a wedge shape with a utility knife. Prepare the surfaces of the wedge for gluing as described above, then glue the wedge to the shoe. Allow to dry.
Step 9: To attach the shoe, the elephant's foot must be entirely clean and dry. The elephant should be trained to keep its foot off the ground for the entire process, or the shoe can be applied with the elephant positioned in lateral recumbency.
Step 10: Lightly roughen the bottom of the foot using a 40-grit sanding pad.
Step 11: Attach a tube of Sole-Guard adhesive (Vettec Hoof Care, Pomona, California 91766, USA) to its applicator gun, and apply adhesive generously to the top surface of the shoe, leaving an adhesive-free area around the edge of the shoe to avoid spillover. Allow Sole-Guard to set briefly until it becomes tacky, then press the shoe to the foot. The elephant should not put weight on the shoe until drying is complete. Drying time depends on ambient temperature, and at 70°F (21°C) takes approximately 5–10 min.

ence between the right and left legs was determined to be 5.4 cm.

Although therapeutic shoeing was considered a potential solution, obstacles included sourcing materials that would not break down under the elephant's weight yet provide support and cushioning. Determining how to attach and remove the shoes was another challenge. Overcoming these issues took 5 yr of development.

Elephant A received its first pair of custom-made glue-on shoes in February 2013, but creation of the final models described here required 2 yr of development and the testing of several prototypes. Table 1 provides directions for shoe construction and details about materials. On the elephant's left front foot is a 5.4-cm-high shoe that makes both legs the same length. The shoe is constructed of two different types of shoe-soling rubber sandwiched together in layers and affixed to the foot with a liquid urethane adhesive designed to protect the feet of unshod horses. An oblong wedge pad is attached to the lateral half of the bottom of this shoe, with its thickest part positioned caudolaterally on the shoe and measuring 0.635 cm. The right shoe consists only of a 0.635-cm oblong wedge pad, made of a single type of shoe rubber and glued to the lateral half of the foot. These wedge pads offload pressure from the fourth digit and prevent inappropriate foot pronation. Elephant A wears shoes 24 hr a day and shows no discomfort with either the application or the wearing of the orthotics. The elephant is also exercised daily and maintained at an appropriate weight. Photographs of the shoes can be found in Figure 2.

The increase in shoe height was done gradually over several months, so as not to cause discomfort in either feet or shoulders. The first shoe ever attached to the left foot was only 0.635 cm high.

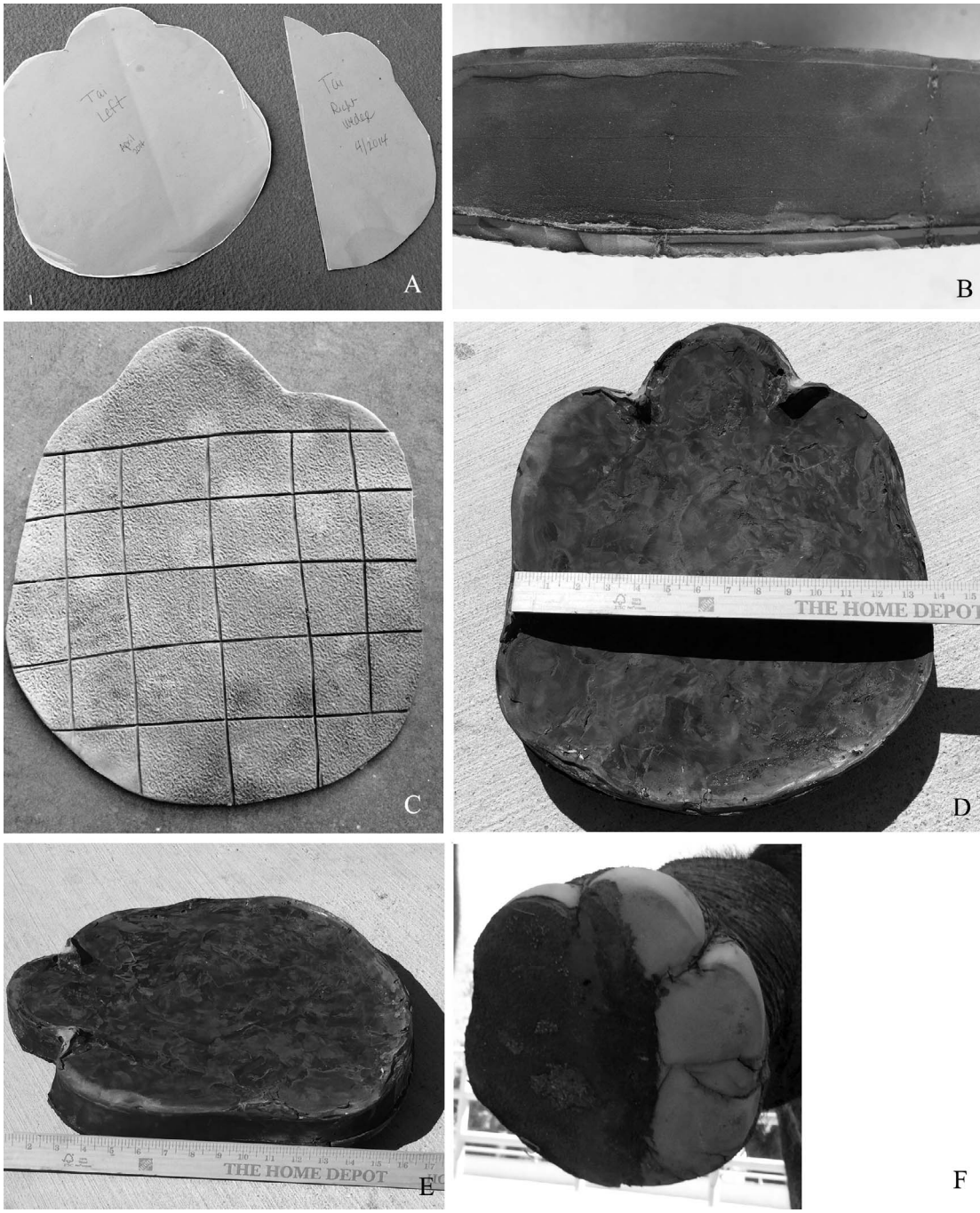

Figure 2. Elephant glue-on shoe construction and materials. **A.** Paper pattern pieces for a whole foot shoe (left), and a partial wedge (right). **B.** A view of the side of the wedge showing the multiple layers of rubber soling material sandwiched together. **C.** Shoe bottom with checkerboard tread. **D.** Top of a used shoe. **E.** Another view of the shoe showing the medial height. **F.** Elephant A wearing the oblong wedge pad on the bottom of the right foot.

Each month, another 0.635–1.27 cm was added to the shoe's height until the total height was the desired 5.4 cm. The shoes are removed monthly with slight prying and a utility knife to facilitate inspection of the foot pads and trimming, after which they are then reattached. New shoes are constructed every few months when the old ones become very worn.

The chronic abscesses associated with the nails of the fourth digit healed fully within several months of shoe application. Reoccurrences have been rare and mild, occurring less than once a year. The fetlock varus conformation has also been improved by the shoes, and the elephant's gait has become more even. Interestingly, between February 2013 and April 2014 the measurements of the left foot increased 6.2% laterally and 7.0% front to back.

Elephant B is a 33-yr-old female elephant weighing 3,773 kg. Elephant B had a 2.54-cm difference between the height of the front legs, with the right leg longer than the left. The elephant was noted to shift its weight frequently between the right and left front feet, although no other medical conditions were associated with either foot and no lameness was present. Radiographs of the feet were normal, and the elephant was otherwise healthy. Since 2013, this elephant has worn a single 2.54-cm-high shoe on its left front foot. The shifting behavior stopped shortly after the shoes were applied and has not recurred. Elephant B wears the shoe 24 hr a day without any complications, and is exercised daily and maintained at an optimal weight.

Glue-on shoes offer a new way to address chronic foot problems and conformational abnormalities in elephants, using the same basic concepts of equine farriery. In these two elephants, evening out the leg lengths and, in elephant A, also using partial wedge pads to alter pronation and redirect pressure from the fourth digit to the third, where the majority of pressure should be in the front foot of an elephant,[5] resulted in improved foot health, conformation, and gait. The remarkably rapid improvement in severity and frequency of the nail abscesses following shoe application indicates that conformation, often ignored in evaluations of elephant lameness, is clearly an important component of chronic foot problems in elephants. Although abnormal foot pressures are a recognized contributor to foot pathology in elephants,[5,7] to date, conformation as it relates to foot problems or lameness has been minimally addressed in the elephant literature and is rarely assessed in live elephants. This is unfortunate, because in horses, evaluating conformation is a fundamental component of using farriery to improve the horse's biomechanics within the constraints of its conformation.[2,6] The increased foot size that occurred in elephant A after a year of wearing shoes may represent increased strength in the foot, because in elephants, the cross-sectional area of the front foot is proportional to body mass, and increased size prevents collapse of the foot pad during walking.[4]

Some Asian elephants have secondary growth spurts later in life.[8,10] Elephant A did not have asymmetry in leg length prior to its growth spurt, but why the growth spurt resulted in asymmetry is unclear. However, the possibility that sudden growth may contribute to foot issues in previously normal older elephants suggests that measuring elephant height annually could provide useful information, as could determining whether the leg lengths are identical.

Additional considerations for using orthopedic devices in elephants include training the elephant to stand still for 15–20 min for shoe application. Additionally, Sole-Guard is affected by environmental conditions, setting slowly in cold conditions and poorly in damp ones. Nevertheless, by itself and without shoes, this adhesive can be a useful tool in elephants because application to the bottom of the foot can provide protection and cushioning to both bruised and thin pads while giving them time to grow out and recover (G. Johnson, pers. comm.).

Staff time and material costs are other aspects of elephant farriery. Because the shoes preclude natural wear of the feet and nails, monthly removal for foot trimming is necessary, followed by replacement. Shoes also should be rinsed off if they become muddy or wet.

A trial-and-error approach was used during the multiyear development of the shoes to see what best improved the elephants' gaits and stances. This included experimenting with different wedge sizes and shapes, as well as with multiple rubber soling materials, which compressed differently in each elephant.

Having a solid understanding of farriery principles and working with an experienced equine or human podiatrist is also strongly recommended. Elephant facilities should expect to spend several months building prototypes and trying different shoes before settling on a final product. The shoes that work best on any given elephant will vary according to the animal's size and orthopedic issues, as well as with availability of materials and environmental constraints. At this point, the full science of shoes is not established in elephants as it is in horses, necessitating an experimental approach.

Glue-on shoes may be novel in elephants but stem from a long and successful history in horses. The remarkable improvements in foot health and comfort that occurred in both elephants after

wearing shoes suggest that orthotics can be a valuable tool for managing elephants in human care.

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