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Abstract: Tusk fractures in Asian (*Elephas maximus*) and African elephants (*Loxodonta africana*) can result in damage to the distal end or to longitudinal cracks, potentially progressing to pulpitis. With pulp exposure, endodontic therapy is the treatment of choice, but conservative therapy has sufficed for some elephants. This manuscript describes the use of composite materials as a component of tusk fracture management. A 7-yr-old male Asian elephant fractured the distal end of both tusks with pulp exposure in one. Capping of each tusk with a Kevlar/fiberglass composite prevented further damage, and a modification allowed care of the exposed pulp tissue. A 34-yr-old male African elephant with a longitudinal crack received a carbon fiber/fiberglass composite circumferential wrap to potentially stabilize the crack. Compression of the crack was achieved, but follow-up was truncated due to bacterial pulpitis. Both cases show that composite material allows for lightweight, durable management of tusk fractures with continued radiographic monitoring.

Key words: Composite, elephant, *Elephas maximus*, *Loxodonta africana*, tusk fracture.

BRIEF COMMUNICATION

Tusk fractures are common in captive and free-ranging Asian (*Elephas maximus*) and African (*Loxodonta africana*) elephants and can result in pulp exposure.[3–6] The recommended therapies for possible pulpitis include pulpotomy, pulpectomy, or extraction; these therapies require general anesthesia and specialized dental equipment.[4,7] With or without treatment, the pulp has exceptional healing capability, with new dentine produced to close the pulp cavity from the interior.[2,4–6] Some elephants with exposed pulp have done well with conservative therapy consisting of antibiotics and flushing.[1,7] As a component of tusk fracture management, metal caps and circumferential bands can be used to prevent wear and to stabilize fractures; however, they are heavy, unsightly, can be removed by the elephant, and they prevent radiographic evaluation.[1–4] Composite materials are a combination of a matrix and a reinforcement which, when combined, give properties superior to those of the individual components.[4] This report purports that the use of durable, lightweight, composite materials can be a component of tusk fracture management, as these materials adhere well to the tusk and allow continued radiographic evaluation.

A 7-yr-old male Asian elephant presented for a fracture of the distal left tusk. Examination and radiographs confirmed that the pulp was not involved. Staff elected to cap the tusk to prevent further damage using a Kevlar/fiberglass composite. An alginate impression (Alja-Safe®; Smooth-On, Inc., Macungie, Pennsylvania 18062, USA; mixed 1 : 1 ratio of powder to warm water) was made before Plaster of Paris (DAP Products Inc., Baltimore, Maryland 21224, USA; mixed 2 : 1 ratio of powder to cold water) was poured into it. The resulting left tusk replica allowed fabrication of a composite cap using two uncommon fiberglass and Kevlar cloths that were layered on the replica and laminated with epoxy resin sequentially. It was then vacuum-bagged, cured at room temperature, trimmed, and colored to match the ivory. The inside of the cap was scored to create a rough surface for better adhesion to the fractured tusk. This fiberglass/Kevlar cap weighed 220 g, was 15 cm long, and the diameter at the proximal

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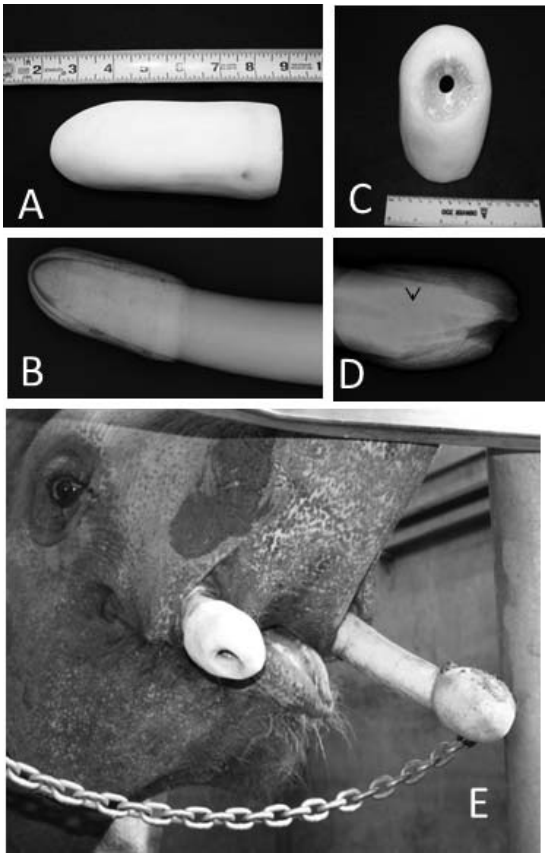

Figure 1. Kevlar/fiberglass composite tusk caps placed as management for distal tusk fractures, and radiographs of a 7-yr-old male Asian elephant (*Elephas maximus*). **A.** Original cap for the left tusk. **B.** Lateral-medial radiograph of the left tusk and original cap immediately following placement. **C.** Right tusk cap with distal hole to align with the open pulp cavity. **D.** Lateral-medial radiograph of the right tusk and cap 8 mo after the tusk was fractured and 4 mo after cap placement. New dentin formation is evident with partial closure of the pulp canal (black arrowhead). **E.** The elephant with right tusk cap and the second left cap.

end was 6 cm (Fig. 1A). It fit excellently with an approximately 1-mm gap between the cap and tusk.

Before application, the tusk and the inside of the cap were cleaned with isopropyl alcohol and allowed to dry. Epoxy (Equilox adhesive; Equilox International Inc., Pine Island, Minnesota 55963, USA) was applied to the proximal two-thirds of the inside of the cap. The cap was applied to the left tusk and held in place for 3 min. As the fit was tight, this short period of manual pressure resulted in a well-adhered cap. The set time for the chosen epoxy is 6–8 min with a final cure in 10–13 min at room temperature. A thin layer of epoxy was applied to the proximal edge of the cap and smoothed to prevent this edge from catching on items in the enclosure. Radiographs showed a small area of air/epoxy between the distal end of the tusk and the cap (Fig. 1B). The cap remained well adhered based on daily visual monitoring and palpation for wear or slippage.

Approximately 4 mo later, the animal wore through the distal layers of the cap from regular digging and playing, resulting in fraying and a 1-cm–diameter hole. As staff felt a shorter tusk would facilitate further management, the tusk was transected 28 cm from the distal tip after radiographic evaluation to avoid pulp exposure. The tusk was immediately recapped to prevent further damage. This second cap was modified from the original design to be reinforced on the distal end with additional layers of Kevlar and fiberglass so that it was rounded and thicker distally. The new left cap weighed 380 g and was 11 cm long and 2 cm thick at the distal end. The cap inner diameter at the proximal end was 6 cm. This cap was applied using the same technique described above. Later, the original left cap/tusk piece was cut through with a reciprocating saw and examined to confirm excellent adhesion. This left cap eventually came off through wear and tear 14.5 mo after application.

Several months after placement of the second left tusk cap, the right tusk fractured. With minor hemorrhage, exposed pulp tissue was 4.5 cm in length and 2.5 cm in diameter; it was treated with lidocaine and epinephrine topically for vasoconstriction and analgesia before continued flushing 4× per day with dilute chlorhexidine solution (Vedco Inc., St. Joseph, Missouri 64507, USA). Complete blood cell counts were monitored monthly. Sulfamethoxazole and trimethoprim (Amneal Pharmaceuticals, Bridgewater, New Jersey 08807, USA; 20 mg/kg po q 12 hr for 21 days) was started but was changed to amoxicillin trihydrate (DAVA Pharmaceuticals Inc., Fort Lee, New Jersey 07024, USA; 11 mg/kg po q 24 hr for 14 days) based on aerobic culture results and a mild white blood cell (WBC) count elevation (13,475 cells/μl) with relative monocytosis (59%). This WBC count was higher than this animal's historic individual values and resolved within 2 wk. The flush was changed to hypertonic saline (7.2%; Nova-Tech Inc., Grand Island, Nebraska 68801, USA) 5 mo later, and frequency was reduced to twice daily due to identification of

partial closure of the pulp cavity with new dentin via visual inspection and radiography.

Due to continued wear on this short tusk, the remainder of the tusk was capped. The cap was molded to fit precisely over the fractured end with a hole aligning with the pulp cavity to allow regular flushing and assessment of the exposed pulp tissue (Fig. 1C). The right cap weighed 505 g and was 12.5 cm long and 2 cm thick at the distal end. The cap inner diameter was 6.5 cm and 1 cm thick proximally. The cap was adhered to the tusk as described above, with the pulp cavity packed with cotton to prevent contamination.

Radiographs were taken every 4 mo, with some obstruction of detail due to the overlying cap, but pulp cavity margins could easily be identified (Fig. 1D). The tusks were measured every few months and grew between 1.67–2.2 cm per month, with an increased growth rate in the right tusk postfracture when compared to the left tusk. The pulp cavity slowly closed, with visible dentin spicules starting at 6 mo postfracture. Dentin was more-rapidly laid down starting at 9 mo postfracture and had completely closed by 12 mo, as confirmed on radiographs. Both caps remained well-adhered with only minor wear at the time of publication (Fig. 1E).

A 33-yr-old male African elephant presented with a longitudinal, linear fracture of the left tusk laterodistal to the sulcus. The crack had been present since the animal moved to Birmingham Zoo, Inc. 4 yr prior and grew over time despite attempts to limit growth. During this 4 yr, the pulp canal could not be probed and conventional radiography was nondiagnostic. At the time of evaluation, the crack was approximately 33 cm long, 0.4 cm wide at its widest superficial point, and extended under the gingival margin (Fig. 2A). Digital radiographs revealed round, focal radiolucencies and one round, focal opacity within the pulp canal (Fig. 2B). Bacterial pulpitis was suspected a few months later because a putrid odor developed but could not be confirmed without opening the fracture further. Sulfadiazine and trimethoprim (Uniprim; Neogen Corp., Lansing, Michigan 48912, USA; 22 mg/kg po q 12 hr) was administered for 14 mo, 30 days on/30 days off. The odor was undetectable during this treatment period, but serial radiographic monitoring revealed slowly progressing pulp lesions. Monthly complete blood counts, serum chemistries, and fibrinogen levels were consistently unremarkable.

While planning for an eventual extraction, staff applied a composite wrap that was created in situ under behavioral restraint (Fig. 3). The goal was to learn if a composite wrap could augment management of a longitudinal crack by stabilizing it and allowing it to be trimmed away once grown out. If successful, the authors envisioned that such a technique could be applied to cracks without pulp exposure, as has historically been done with metal circumferential bands.[3,4] For this

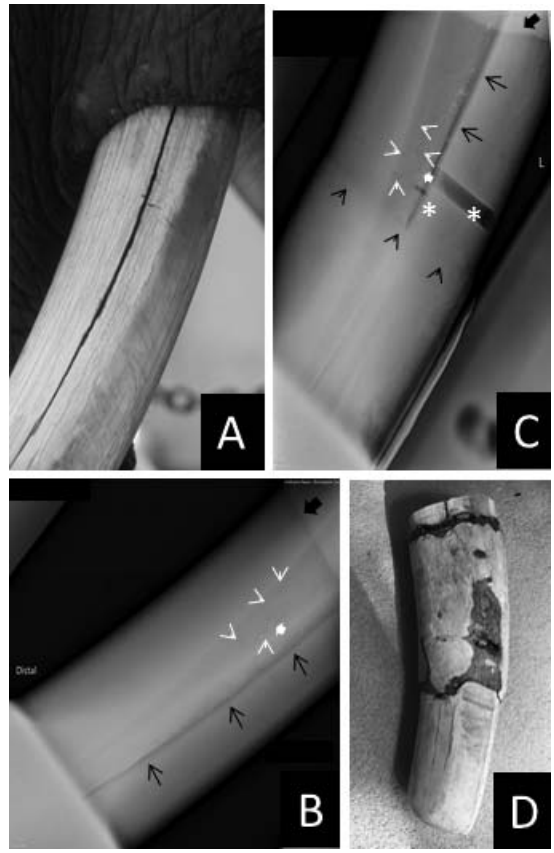

Figure 2. Application of a carbon fiber/fiberglass composite circumferential wrap to the left tusk of a 33-yr-old male African elephant (*Loxodonta africana*). **A.** Left tusk with longitudinal crack. **B.** Dorsolateral-ventromedial oblique radiograph of the tusk 1 yr before wrap application. The lip margin (black, thick arrow), crack (black, thin arrows), focal radiolucencies (white arrowheads), and focal radiopacity (white, thick arrow) are evident. **C.** Lateral-medial radiograph of the wrap 4 mo after application. The wrap margin (black arrowheads), lip margin (black, thick arrow), crack (black, thin arrows), diagnostic drill holes (white asterisks), focal radiolucencies (white arrowheads), and focal radiopacity (white, thick arrow) within the pulp cavity are evident. **D.** The left tusk with wrap after 6 mo in place. This distal portion of the tusk was transected as a component of management for chronic pulpitis.

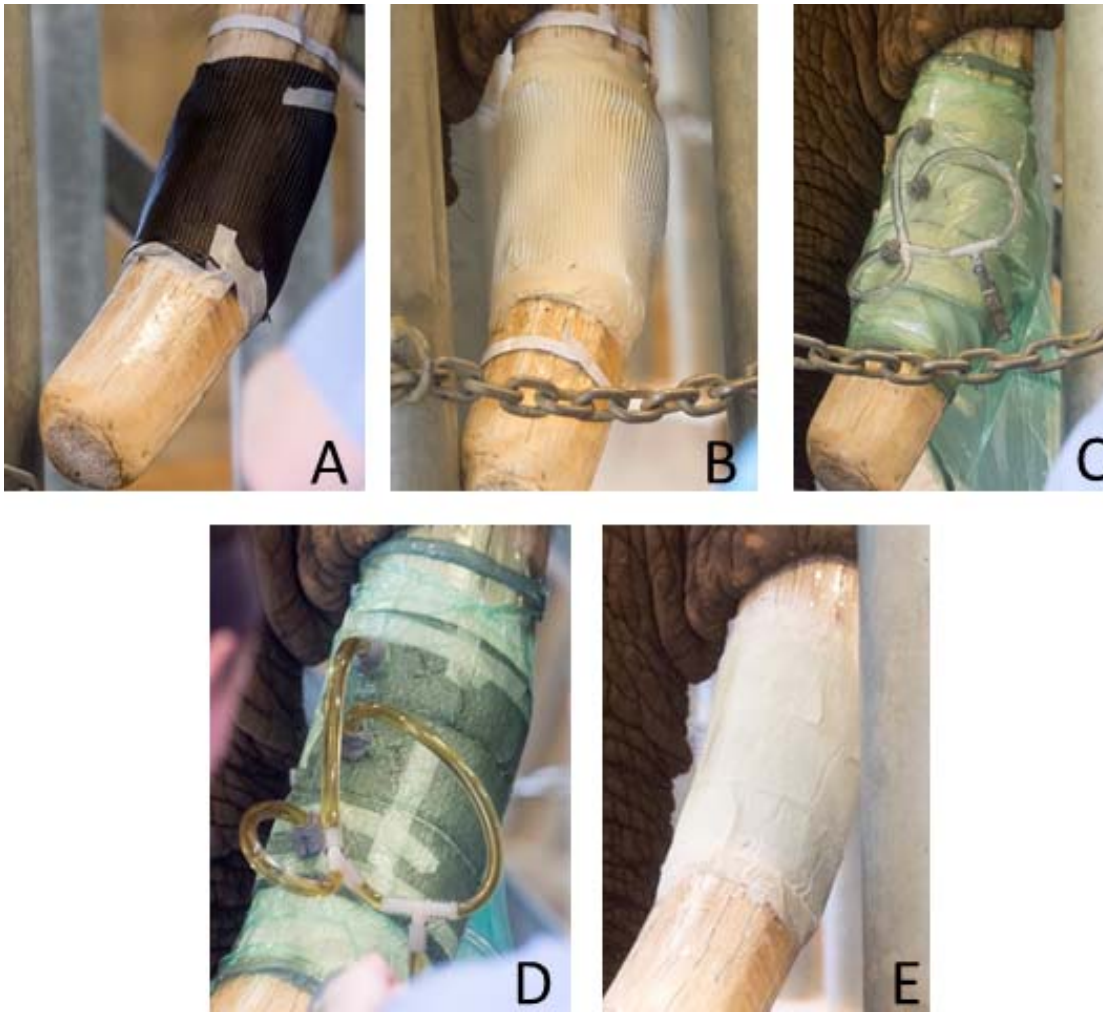

Figure 3. Sequential photographs during the application of a carbon fiber/fiberglass composite wrap to the left tusk as management for a longitudinal crack. **A.** Carbon fiber layers and proximal vacuum sealant tape in place. **B.** Fiberglass layers overlaying carbon fiber layers with vacuum sealant tape proximal and distal to the wrap. **C.** Wrap covered with porous Teflon cloth and a resin distribution layer, bagged, and sealed with a high temperature film and infusion tubing in place. **D.** System under negative pressure using vacuum pump and with catalyzed polyurethane resin impregnating the wrap. **E.** The composite wrap in the left tusk immediately after curing for 23 min under vacuum and removal of the bagging and distributive layers.

case, after being cleaned with a mild detergent, the tusk was rinsed with 70% isopropyl alcohol and the crack was covered with clear, polypropylene-backed adhesive tape. The following materials (A&P Technology, Cincinnati, Ohio 45245, USA) were placed creating a seven-layered, 30-cm tube of material: 1) one layer of unidirectional, transverse carbon fiber wrap material (Zero®); 2) one layer of unidirectional, longitudinal carbon fiber tubing (Unimax™ Carbon Unidirectional Sleevings); 3) two layers of braided carbon fiber tubing (Sharx™ Braided Carbon Biaxial Sleevings); and 4) three layers of braided fiberglass tubing (Sharx™ Braided Fiberglass Biaxial Sleevings). The anticipated loading forces that the tusk would potentially experience directed the material selection and layering sequence. The sequential placement of the initial three layers was challenging due to close contact with chute bollards, so the remaining four layers were layered ex situ and then applied over the three layers. The materials were applied dry, then infused with a catalyzed polyurethane resin (DP-11-90; BCC Products, Franklin, Indiana 46131, USA) by Vacuum-as-

sisted Resin Transfer Molding as previously described.[4] The resin was selected because it had a 3-min working time (adequate for full fiber impregnation), high impact strength, no odor, and turns an ivory color once cured. The resin cured in 23 min under vacuum and had a peak exothermic reaction temperature of 65°C. The whole process took 135 min, which included multiple breaks. The authors estimate that the wrap could be completed in 40–70 min if all materials were prepared beforehand and the fiber tubing materials were layered ex situ.

Nineteen days after application, a malodorous exudate developed with degenerative heterophils, and no intracellular bacteria was identified cytologically. Radiographs revealed that the pulp cavity could still be visualized through the wrap with some detail obstruction (Fig. 2C). Regular cleaning of the crack with dilute chlorhexidine solution was instituted and antibiotics were continued. The odor and amount of exudate decreased, but the elephant showed signs of sensitivity with increased trunk-touching of the left face/tusk 2 mo after wrap application. Under behavioral restraint, a 1.25-cm diameter hole was drilled into the pulp canal proximoventral to the wrap, releasing a large quantity of purulent exudate which was culture positive for *Pseudomonas aeruginosa*. Based on a susceptibility profile, enrofloxacin (Wedgewood Pharmacy, Swedesboro, New Jersey 08085, USA; 2.6 mg/kg po q 24 hr, 30 days on/30 days off) and twice a week flushing of the pulp cavity were initiated. Necrotic pulp tissue drained out with flushing, initially, but soon ceased and the exudate was minimal.

For the 6 mo following the application, the wrap remained well adhered, with no slippage, and the crack width was static in width. Marked wear of the lateral and ventral aspects of the wrap were evident with the fiberglass worn through, revealing carbon fiber (Fig. 2D). At 6 mo, the left tusk extraction was attempted under general anesthesia but failed. Failure was surmised to be either due to inadequate periodontal ligament release (periotomes were 61 cm in length) or ankyloses. The tusk was transected at the drainage hole to facilitate conservative therapy in the future. Endoscopy of the empty pulp cavity revealed that the internal length was 87 cm from the cut edge (58 cm from the gingival margin) and the fracture line extended 62 cm from the cut edge (33 cm from the gingival margin). The total external length of the tusk is unknown.

For the 10 mo since transection, to date the animal has done very well with twice a day flushing of the empty pulp cavity. There is no discharge and the animal is comfortable. Endoscopic biopsies of the internal terminal tissue reveals moderate diffuse neutrophilic and plasmacytic subepithelial gingivitis and rare intracellular Gram-positive cocci and Gram-negative coccobacilli. Per the pathologists, inflammation is slightly above what would be expected in this anatomic location, but these sparse numbers of bacteria do not indicate a significant infection.

In summary, the use of composite materials for the management of elephant tusk fractures has utility as both a cap and circumferential wrap. Composites are versatile media that can be custom fit, are easy to apply through operant conditioning, and are lightweight. The composite materials were fairly durable, although both elephants did wear through aspects over time. The addition of a superficial, wear-resistant layer composed of a tough polymeric fiber layer such as polytetrafluoroethylene (Teflon) or ultrahigh molecular weight polyethylene (Innegra) to future composites may, based on experience with industrial applications, mitigate the forces exerted by the elephants.

In the Asian elephant case, the caps were effective at protecting the tusks, preventing further damage, and allowing normal growth with closure of the pulp cavity. In the African elephant case, compression of the crack likely aided in stabilization. In theory, when stabilized a tusk could grow out long enough without the crack continuing to lengthen proximally, so the wrapped/fractured portion could eventually be trimmed away; however, whether this strategy would work is unknown from this case. Use of a composite wrap for management of a longitudinal fracture warrants further investigation and should be applied early in the disease process when the crack is shallow and there is no pulp exposure. Application of a circumferential composite wrap is contraindicated for pulpitis. The composite cap and wrap both allowed radiographic evaluation of the pulp canal after placement. Radiographic detail was obscured slightly by the composite material, but images remained diagnostic.

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LITERATURE CITED

1. Dumonceaux G. Digestive system. In: Fowler ME, Mikota SK (eds.). Biology, medicine, and surgery of elephants. Ames (IA): Blackwell; 2006. p. 303.

2. Fowler ME. Surgery and surgical conditions. In: Fowler ME, Mikota SK (eds.). Biology, medicine, and surgery of elephants. Ames (IA): Blackwell; 2006. p. 127–128.

3. Kuntze A. Oral and nasal diseases of elephants. In: Calle P, Morris P, Fowler ME, Miller RE (eds.). Zoo and wild animal medicine, current therapy 4. Philadelphia (PA): W. B. Saunders; 1999. Pp. 544–546.

4. Steenkamp G. Oral biology and disorders of tusked mammals. Vet Clin North Am Exot Anim Pract. 2003;6(3):689–725.

5. Uddin N, Vaidya UK, Shohel M, Serrano-Perez JC. Vacuum-assisted resin transfer molding. Concrete Int. 2006;28:53–56.

6. Weissengruber GE, Egerbacher M, Forstenpointner G. Structure and innervation of the tusk pulp in the African elephant (*Loxodonta africana*). J Anat. 2005; 206:387–393.

7. Wiedner E. Proboscidea. In: Miller RE, Fowler ME (eds.). Fowler's zoo and wild animal medicine, Volume 8. St. Louis (MO): Elsevier; 2015. Pp. 517–532.

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