

## Estimating exposed pulp lengths of tusks in the African elephant (*Loxodonta africana africana*)

G Steenkamp<sup>a</sup>, W H Ferguson<sup>a</sup>, S C Boy<sup>b</sup>, S M Ferreira<sup>c</sup> and M N Bester<sup>a</sup>

### ABSTRACT

Captive and wild African elephants frequently suffer tusk fractures. Several institutions shorten the tusks of captive elephants to reduce fractures and injury as a result of behaviour within enclosures. Fracturing or coronal amputations that expose pulp lead to pain for the elephant. Estimating coronal pulp lengths may thus help to minimise the risk of pulp exposure during amputations. We aimed to determine the length of the pulp beyond the lip margin from an external tusk characteristic. Tusks collected from elephants in Namibia and the Kruger National Park had similar morphological relationships. This statistical property allowed us to correct for missing data in our data sets. Pulp volume and pulp length correlated with tusk circumference at the lip. Even so, the circumference at the lip could not predict the length of the pulp in the crown external to the lip. Our findings suggest that tusks, irrespective of sex or age, amputated further than 300 mm from the lip should not expose pulp.

**Key words:** African elephant, captive populations, free-ranging populations, tusk amputation, tusk fractures, tusk pulp, tusk pulp treatment.

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### INTRODUCTION

Tusks are the only maxillary incisors present in African elephants (*Loxodonta africana*). These incisors are continuously growing teeth (elodont teeth) with an open apex<sup>6</sup>. The growth rate of tusks varies between the sexes with males having large tusks that increases in size, while females have smaller tusks of which the growth rate decreases at the time of puberty<sup>12</sup>. The outer mineralised layer of a tusk is ivory, which comprises dentin not covered by enamel. Ivory has a unique pattern on a cut section. Enamel is only present for a short period when the permanent tusk erupts<sup>14</sup>. The ivory protects the pulp of the tusk which consists of numerous blood vessels, lymphatic and neural tissue, bound in a loosely arranged connective tissue stroma<sup>2,23</sup>.

The tusk anatomy and biology create several potential clinical and management conundrums. Although captive and wild elephants suffer tusk fractures<sup>6,9,19,20</sup>, the

incidence in captive elephants is higher than that in free-ranging ones<sup>20</sup>. Tusk fractures in captivity result from trauma during the transport and offloading of elephants as well as individuals falling into moats or damaging their tusks against enclosure barriers<sup>19</sup>. In many cases, institutions shorten or blunt the tusks<sup>25</sup> to reduce fractures and injury. Pulp exposure through fracturing or coronal amputation leads to pain for the elephant<sup>2,3,10</sup>, for which various techniques are available as treatment<sup>19</sup>. Even so, tusk amputation is a regularly used option that aims to shorten a tusk without exposing the pulp. Assessment of coronal pulp length (exposed pulp length) relies on measuring the distance from the lip (labio-dental fold) surrounding the tusk to the eye<sup>15</sup>. It assumes a 1:1 ratio between this measure and exposed pulp length. This method is at best a crude guide, since it does not consider variation associated with age or sex.

The aim of this study was to find a complementary and alternative way of estimating the coronal pulp length in African elephants. This will allow veterinarians to evaluate if a tusk fracture has exposed the pulp, and to assess the need for general anesthesia to treat a fracture. In the case of institutions housing captive African

elephants, estimating coronal pulp length from external tusk features may guide veterinarians when amputating long tusks without causing pulp exposure.

### MATERIALS AND METHODS

#### Study populations

Our samples included tusks collected from elephants in two regions. Firstly, the Namibian sample comprised stockpiled tusks originating mainly from the Etosha National Park, but also included individuals from the Caprivi and Khaudum Game Reserves. The elephants in the Etosha National Park in Namibia (22 270 km<sup>2</sup>, 19°S, 16°E), live in a dry savanna<sup>16</sup> (annual rainfall: 316–442 mm)<sup>8</sup>. This population is stable and comprised 1754–3080 elephants in 2002<sup>1</sup>. The population has a high incidence of tusk fractures but low incidence of tusklessness<sup>20</sup>. Authorities removed 316 female elephants from 1983 to 1985, water is provided artificially and the park is partially fenced<sup>8</sup>.

The Khaudum Game Reserve (3841 km<sup>2</sup>, 19°S, 20°E) is partially fenced and has several boreholes that provide water year-round (D. Alberts, Namibian Ministry of Environment and Tourism, pers. comm., 2005). The Reserve had 993–2939 elephants in 2000<sup>1</sup> and comprises dry savanna<sup>16</sup> (annual rainfall 487 ± 221 mm, data provided by the Ministry of Environment and Tourism, Tsumkwe, Namibia). Nearly 25 % of tusks in Khaudum are fractured, lower than recorded for Etosha<sup>20</sup>.

The 3353–5799 elephants living in the Caprivi Game Reserve (5715 km<sup>2</sup>, 18°S 22°E) during 1998<sup>1</sup> are part of a large regional population that spans several countries. It has no management and elephants are free to move in and out of the reserve. The vegetation is typically that of a dry savanna<sup>16</sup>. Tusklessness is not common in the regional population, but the incidence of fractures is about the same as that noted in the Khaudum Game Reserve<sup>20</sup>.

The second population consisted entirely of individuals from the Kruger National Park, SA (Kruger) (19 442 km<sup>2</sup>, 24°S, 31.5°E). The elephants in Kruger live in a transition savanna<sup>16</sup> (annual rainfall 500–

<sup>a</sup>Mammal Research Institute, University of Pretoria, Pretoria, 0002 South Africa.

<sup>b</sup>Department of Oral Pathology and Oral Biology, School of Dentistry, Faculty of Health Sciences, University of Pretoria, 0002 South Africa.

<sup>c</sup>Conservation Ecology Research Unit, University of Pretoria, Pretoria, 0002 South Africa.

\*Author for correspondence.

E-mail: gerhard.steenkamp@up.ac.za

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700 mm)<sup>22</sup>. Here the population comprised 10 459 elephants in 2002<sup>1</sup>. The population has a low incidence of tusk fractures and tusklessness<sup>20</sup>. Authorities removed 17 219 elephants between 1967 and 1996<sup>21</sup>, water is provided artificially<sup>13</sup> and the park is mostly fenced<sup>24</sup>.

#### Data collection

Several measurements were made (Table 1) on 242 tusks (all natural deaths) from Namibia and collated data for 448 tusks collected during the culling programme in Kruger from 1991 to 1996 (A. Hall-Martin, African Parks, pers. comm., 2004). All tusk length measurements were measured along the outside curvature of the tusk. Total tusk length ( $l_t$ ) was the length from the base of the tusk to the incisal edge of the tusk (Fig. 1). Tusk circumference was measured at the base of each tusk ( $c_b$ ), as well as at the lip margin visible as a brown ring on each tusk ( $c_l$ ). Tusk diameter was also measured using calipers at the same sites as described for circumference (diameter at the base –  $d_b$ , diameter at the lip –  $d_l$ ). Pulp length ( $l_p$ ) was measured on the inside of the outer curvature of the tusks, using a wire that would follow the shape of the tusk. Pulp volume ( $v_p$ ) was determined using fine river sand and filling the pulp until the sand was level with the rim of the tusk. All lengths and heights are in millimetre, volume in millilitre and weight in kilogram.

Only 217 of the Namibian tusks were included since it was not possible to

Table 1: Data recorded for stockpiled tusks from the Etosha National Park, Khaudum Game Reserve and Caprivi Game Reserve in Namibia, and collated for tusks measured from culled specimens in the Kruger National Park in South Africa.

Data collected	Measurement description	Unit	Namibia	Kruger
Date	–	–	X	
Age	Estimated from molar teeth	–		X
Sex	Male, female, unknown	–		X
Tusk weight	–	kg	X	X
Total tusk length	Outer curvature	mm	X	X
Length of tusk to lip	Outer curvature	mm	X	X
Exposed (coronal) tusk length	Outer curvature	mm	X	X
Tusk circumference at lip	–	mm	X	X
Tusk circumference at base	–	mm	X	X
Base measurements	Height and width	mm	X	
Pulp length	Inside of outer curvature	mm	X	
Pulp volume	–	ml	X	X
Number of tusks included			217	447

measure all defined parameters on broken or split tusks. For the Kruger group, 447 tusks were included in the study (Table 1). At the time of sampling, the Kruger observers sexed individuals and assigned ages to them using tooth eruption criteria<sup>7</sup>. The collated data for this sample did not include pulp length and tusks were no longer available for further measurements.

#### Data analysis

To accommodate the missing pulp lengths for the Kruger sample we first tested whether the two samples is one statistical population. We thus tested whether the relationships between the circumference at the base of the tusk ( $c_b$ )

and at the lip ( $c_l$ ) and the circumference at the base of the lip ( $c_i$ ) and pulp volume ( $v_p$ ) is the same for Namibia and Kruger. Least square regression analyses was used to find the linear relationships and tested whether the slopes differed using *t*-tests<sup>18</sup>. Intercepts were set at zero. Proving statistical unity would enable prediction of the pulp length ( $l_p$ ) for the Kruger tusks. For this purpose, the relationship between pulp length ( $l_p$ ) and circumference at the lip ( $c_l$ ) for the Namibian population through least square linear regression analyses. This relationship was used to predict the expected pulp lengths ( $l_p$ ) for tusks that had circumference at lip ( $c_l$ ) noted in the Kruger data set.

From measured and predicted vari-

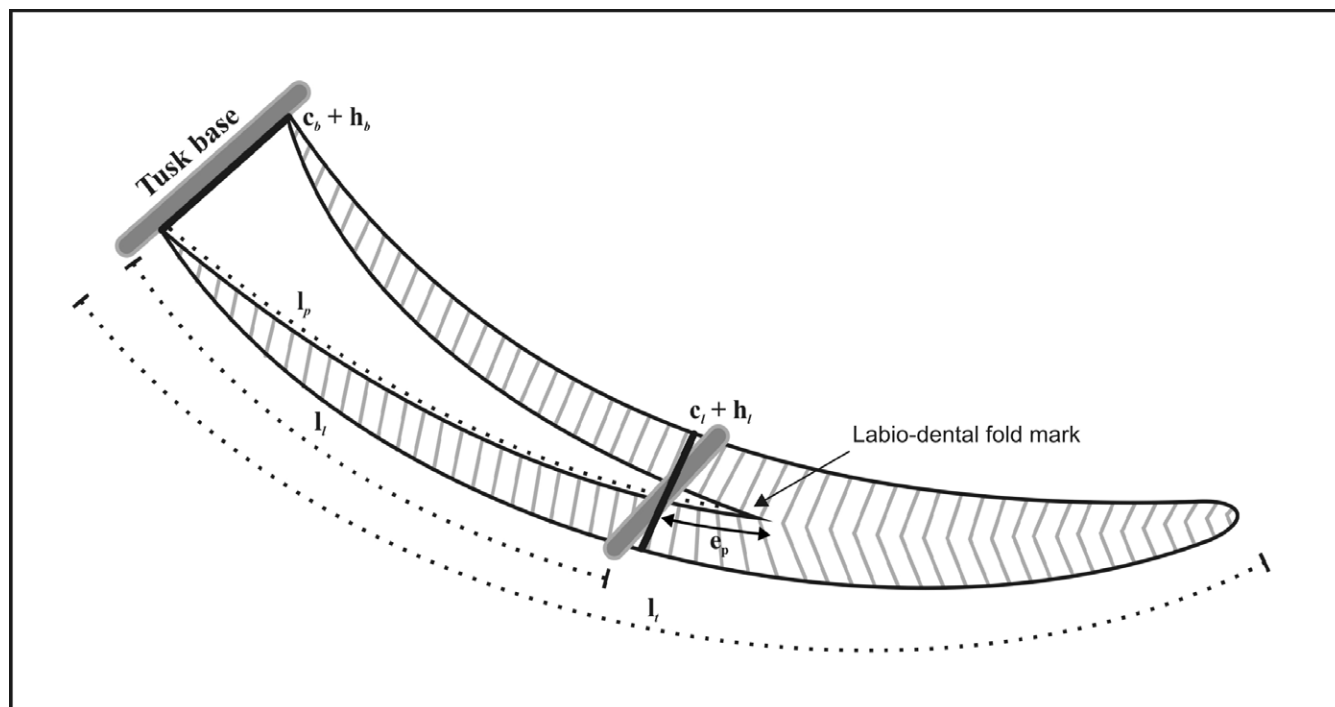


Fig. 1: Diagrammatic illustration of a tusk sectioned longitudinally showing all the length, height and circumference measurements taken on the tusks. A, Total tusk length; B, length of tusk to lip. C, pulp length; D, height and circumference at base; E, height and circumference at lip;  $c_b$  = circumference at tusk base;  $c_l$  = circumference at lip margin;  $d_b$  = diameter at tusk base;  $d_l$  = diameter at lip margin;  $e_p$  = exposed pulp length;  $l_t$  = length base of tusk to labial fold;  $l_p$  = total pulp length;  $l_i$  = total tusk length;  $v_p$  = pulp volume;

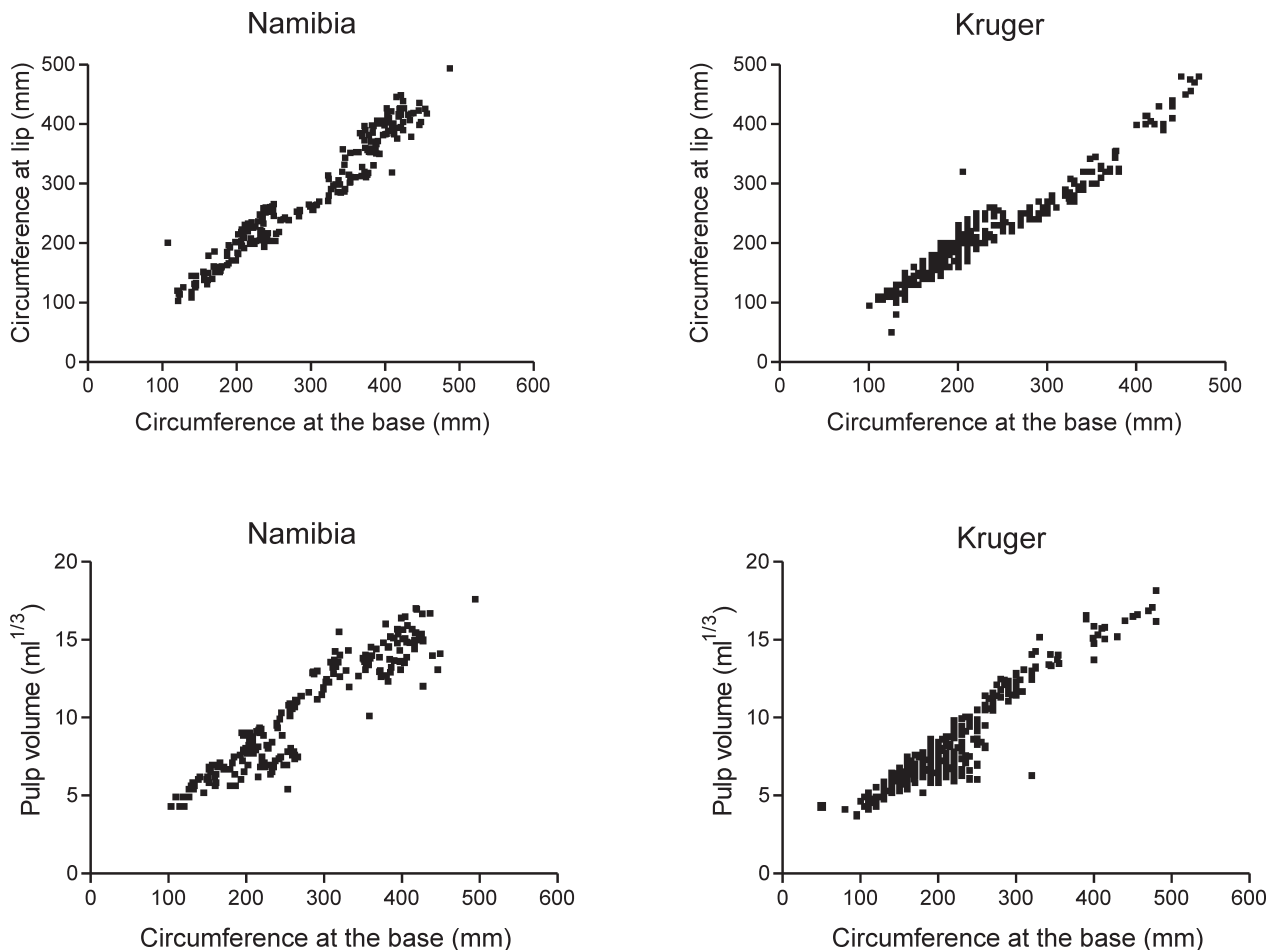


Fig. 2: Relationships between measures of the tusk circumference at base ( $c_b$ ) and values of tusk circumference at the lip ( $c_l$ ) as well as the third root of pulp volume ( $v_p$ ) recorded for samples from Namibia and Kruger. We found no difference between Namibia and Kruger in the respective relationships (see text) and thus pooled the data.

ables, coronal pulp length was calculated *i.e.* the pulp that extends into the tusk crown beyond the labio-dental fold also termed the exposed pulp length ( $e_p$ ) (Fig. 1). To determine the exposed pulp length ( $e_p$ ) the length of the tusk was subtracted from its base to the labio-dental fold ( $l_i$ ) from the total pulp length ( $l_p$ ) ( $e_p = l_p - l_i$ ) using both measured and predicted data. With linear least square regression analysis, the relationship between the exposed pulp length ( $e_p$ ) and the circumferences at the lip ( $c_l$ ) in both data sets was determined. The predicted pulp lengths together with the known sex and age data of the Kruger set also allowed a study of the influence of sex and age on exposed pulp length ( $e_p$ ).

## RESULTS

The Namibian and Kruger relationships between circumference at the lip ( $c_l$ ) and circumference at the base ( $c_b$ ) was the same (Etosha:  $c_b = 0.948c_l$ ,  $t_{217} = 189.9$ ,  $P < 0.01$ ; Kruger:  $c_b = 0.934c_l$ ,  $t_{447} = 250.2$ ,  $P < 0.01$ ) (Fig. 2). Confidence intervals of the slope (95 % CI: 0.939–0.958) for the data measured at Etosha overlapped that for the data collated from Kruger (95 % CI: 0.936–0.951).

Similarly, there was no difference in the relationship between the circumference at the lip ( $c_l$ ) and the third root of pulp volume ( $v_p^{1/3}$ ) (Namibia: ( $v_p^{1/3}$ ) =  $0.038c_l$ ,  $t_{217} = 128.2$ ,  $P < 0.01$ ; Kruger: ( $v_p^{1/3}$ ) =  $0.038c_l$ ,  $t_{447} = 187.6$ ,  $P < 0.01$ ) (Fig. 2). The 95 % confidence interval for the slope estimated from the Namibian data (0.037–0.039) overlapped that of Kruger (0.037–0.038). Given that these results suggest one statistical population, the pulp length was predicted from data collected for tusks at Kruger from the relationship between the circumference at the lip ( $c_l$ ) and pulp length ( $l_p$ ) noted in the Namibian population ( $l_p = 1.584c_l + 72.671$ ,  $t_{216} = 430.9$ ,  $P < 0.01$ ) (Fig. 3).

No relationship was found between exposed pulp length ( $e_p$ ) and circumference at the lip ( $c_l$ ) ( $F_{1,216} = 1.352$ ,  $P = 0.246$ ) for the Namibian data set. However, a wide spread was noted of this derived variable ranging from 300 mm coronal of the labio-dental fold to 300 mm apical of it (Fig. 4). Some of this variation could in exposed pulp length could be explained when we the derived Kruger data were separated into age and sex categories (Fig. 5). For the observed Namibian data, the maximum exposed pulp length was

300 mm and the upper 95 % confidence interval for this group was 255.5 mm (Fig. 4).

## DISCUSSION

Elephants fracture their tusks and do more so in captivity<sup>20</sup>. When fractures expose pulp, clinicians may need general anesthesia to treat the tusk. However, general anesthesia in elephants carries the risk of animals having adverse reactions to drugs<sup>4</sup>, falling into moats surrounding their enclosures<sup>19</sup> or damaging the enclosures from falling on anesthetic induction and/or recovery<sup>5</sup>. Clinicians can minimise these risks by estimating the length of exposed pulp and applying general anaesthesia only to those individuals that need treatment. This study thus focused on finding an externally visible tusk measure from which to estimate the coronal pulp length and complement the existing guidelines<sup>15</sup>.

Application of these findings extends further to inform clinical decisions regarding tusk amputations that can prevent complications associated with pulp exposure. Some challenges were encountered though since the majority of environment-independent measurements of

elephant tusks are within the bony alveolus of the maxilla and obscured when observing a live animal. However, several techniques (e.g. digital photogrammetry)<sup>17</sup> easily allow measures of tusk circumference ( $c_l$ ) and diameter ( $d_l$ ) at the lip. We therefore focused on such variables and in particular on circumference at the lip ( $c_l$ ).

Initially we encountered some analytical constraints due to partially available information for some data sets. Namibia had all the tusk measurements, but little data on the sex and age of the individuals from which the tusks came. Kruger had the sex and age data, but missed some of the morphological tusk measurements required. It was thus first necessary to evaluate whether these samples could be pooled into one statistical population – that allowed prediction of the missing data for Kruger. Two morphological relationships were found that did not differ between the geographically separated Namibian and Kruger samples irrespective of sex or age. These two samples were therefore treated as one statistical population for the purpose of this study.

To find a stable, clinically visible measure for exposed pulp length, focus was placed on the total pulp length ( $l_p$ ), a crucial variable that was not recorded for Kruger. However, accepting the samples from Kruger and Namibia as a single statistical population allowed prediction of the total pulp length ( $l_p$ ) for the Kruger samples. The relationship between total pulp length ( $l_p$ ) was used and the circumference at the lip ( $c_l$ ) constructed from the Namibian samples to estimate total pulp lengths ( $l_p$ ) for the Kruger samples from their circumference at the lip ( $c_l$ ) measurements. That allowed calculation of a measure of exposed pulp length for both Kruger and Namibia.

It was expected that older and thus larger elephants would have larger tusks and presumably more exposed pulp beyond the lip margin. However, no relationship was found between exposed pulp ( $e_p$ ) and the circumference at the lip ( $c_l$ ) of a tusk. Several reasons for this finding were considered. The surrounding soft tissue and associated alveolar bone enlarge with the growing tooth that may result in constant exposed pulp lengths – when elephants increase in size the exposed pulp lengths do not increase at the same rate. As elephants age, they become larger and the surrounding tissue increases owing to growth-enhancing factors while bone mass increases to accommodate the heavier tooth. Rates of increase in pulp length, tissue and bone volume need to be the same to keep exposed pulp constant when elephant

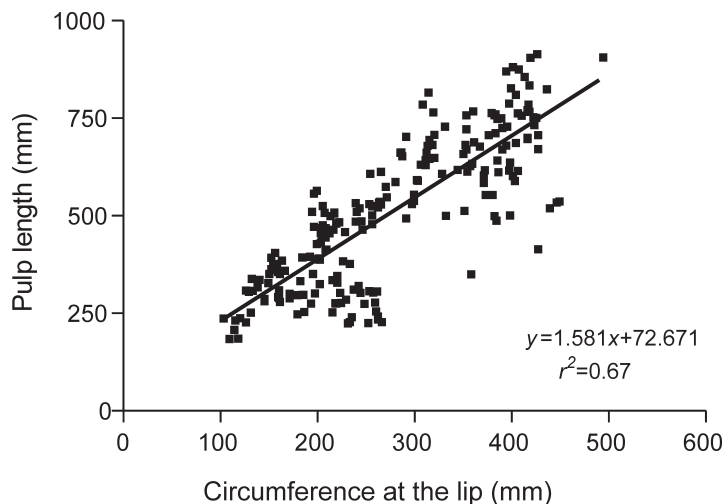


Fig. 3: Relationship between pulp length ( $l_p$ ) and the circumference at the lip ( $c_l$ ) established for tusk collected in Namibia. We did not know the sexes from which these tusks came. The relationship allowed us to predict pulp length for tusks collected in Kruger since the tusks from Namibia and Kruger come from the same statistical population (see text and Fig. 2).

size increases. No measures of how tissue and bone volume change with age were available. However, the large variation in exposed pulp length that we have noted suggest that age related rates of change in pulp length, tissue and bone volume are not the same. Other factors thus most

likely influence allometric relationships of exposed pulp length.

Alternatively, the analytical approach to accommodate the shortcomings of the data sets may have masked the results, particularly in the case of Kruger. It is conceded that the pooling of sex and age

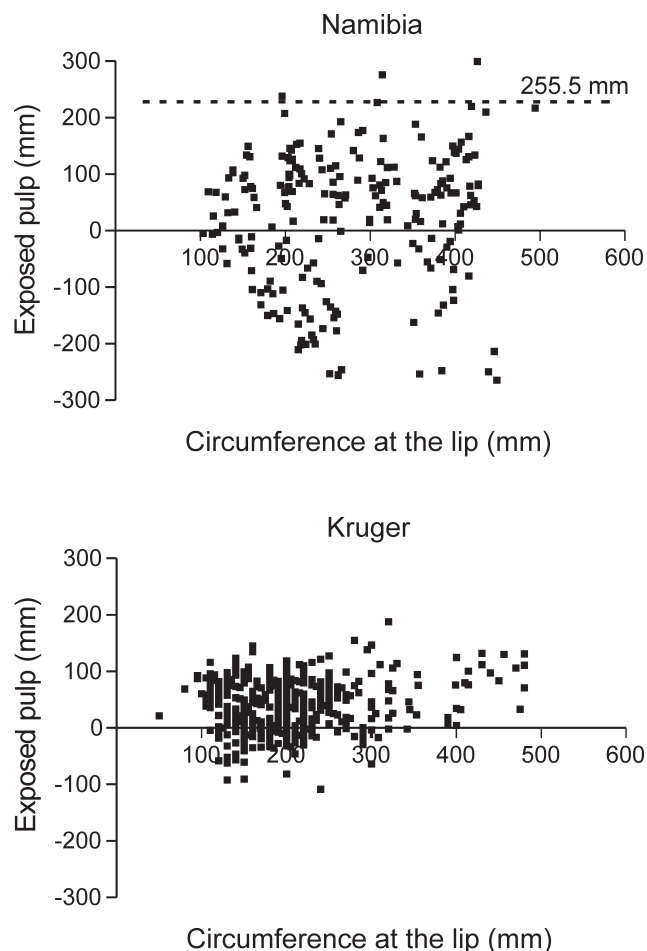


Fig. 4: Length of the exposed pulp ( $e_p$ ) recorded for Namibia and predicted for Kruger in relation to the circumference at the lip. We did not record any relationship between these variables. The broken line gives the upper 95% confidence interval for exposed pulp in the Namibian data recorded at 255.5 mm.

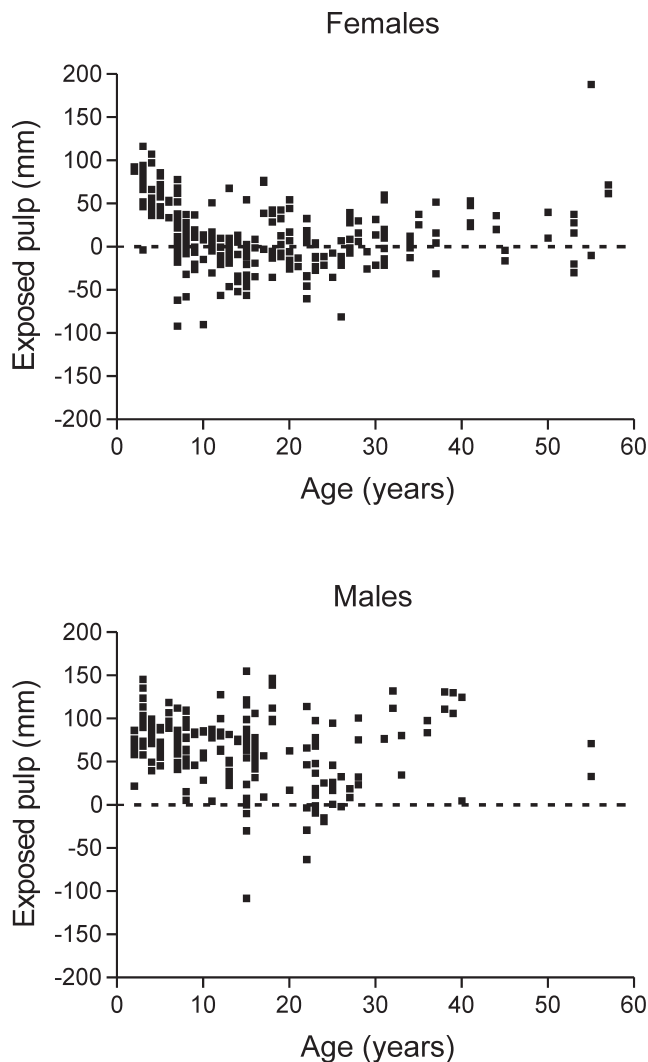


Fig. 5: Sex differences in estimated exposed pulp ( $e_p$ ) are apparent, while age differences are not well defined for the values we predicted for tusks from Kruger. Males usually have a longer exposed pulp than females, while the variability in females decreases with age.

may also influence our results. Sex and age differences in exposed pulp length, ( $e_p$ ) as evident for the values predicted for Kruger, explained some of the variations noted. Males tended to have a larger variance in exposed pulp length ( $e_p$ ) irrespective of age than that of females. However, interpretation of these sex- and age-specific patterns are cautious, as much of the variation will be removed by the statistical relationship used to predict total pulp length ( $l_p$ ) from which exposed pulp length ( $e_p$ ) is calculated.

Furthermore, geographical differences may skew the conclusions. The relationships for Namibia, from which the exposed pulp lengths for Kruger were predicted, came from tusks collected from three widely separated areas spanning a large rainfall gradient. It was not possible to separate these tusks. Since the incidence of tusk fractures seems to decrease with rainfall<sup>20</sup>, it is not inconceivable that tusk growth and development may differ across a rainfall gradient.

Finally, unknown biological processes

may be a more compelling reason for the lack of a relationship between exposed pulp ( $e_p$ ) and the circumference at the lip ( $c_l$ ). The maximum exposed pulp ( $e_p$ ) calculated for tusks from Namibia were 300 mm (Fig. 4), a relatively small value compared with the total tusk lengths measured in this sample. This was surprising as it was expected that the total pulp length and therefore exposed pulp length to elongates as the tusk elongates. Given that the volume of the pulp is conical, both the diameter at the base of the tusk ( $d_b$ ) and the total pulp length ( $l_p$ ) can influence pulp volume ( $v_p$ ). Tusks do not only increase in length with age, but the circumference of the tusk also increases. It is likely that the increased pulp volume of older male elephants, for instance, may be a result of an increase in circumference more than an increase in length. This conceivably influenced our results.

In addition, secondary dentin formation is a well-recognised entity<sup>11</sup>. It is a life-long continuous, physiological deposition of dentin that eventually results in

reduced pulp volume. Tertiary dentin, by contrast, is deposited specifically in response to injury of the tooth<sup>11</sup>. It was therefore also postulated that continuous deposition of dentin, either as a normal physiological process or as a result of trauma/injury or a combination thereof to be responsible for this reduction in pulp volume that affects both the diameter at the base of the tusk ( $d_b$ ) and the total pulp length ( $l_p$ ). For instance, the process could result in reduction of pulp length even while tusk length and circumference increases. This may explain why a tendency was noted for the range of exposed pulp ( $e_p$ ) values to reduce, as females get older.

The biological and statistical reasons highlighted above may explain why a linear correlation between exposed pulp length ( $e_p$ ) and the circumference at the lip ( $c_l$ ) was not found. What does this mean clinically? The variance noted in exposed pulp defined an upper 95 % confidence level of 255.5 mm that served as a guideline. It is therefore proposed that no tusk should be amputated less than 300 mm from the labio-dental fold, regardless of sex or age of the individual animal. It is suggested that this guideline is a complement to the existing index<sup>15</sup>.

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