HORSE METACARPAL BONE: AGE, ASH CONTENT, CORTICAL AREA AND FAILURE STRESS INTERRELATIONSHIPS1,2

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Summary

In a study of interrelationships among the parameters of ash content, failure stress and cortical area of the horse metacarpal bone, bones from 41 horses aged 1 day to 33 years were analyzed. Calcium, phosphorus and magnesium in bone ash at all ages ranged from 35 to 39, 14 to 17 and .32 to .85%, respectively; range of calcium to phosphorus ratios was 2.1 to 2.6. There was no correlation between age and either percentage calcium or phosphorus in the ash or calcium to phosphorus ratio. Ash content of the bone reached a maximum at 4 years of age which was maintained through age 7 years, then declined. Area of the cortical portion of the bone increased sharply between 1 day and 1 year, from 4.6 ± 1.2 to 6.7 ± 2.4 cm²; highest values, averaging 8.8 ± 1.5 cm², were found at 4 to 7 years of age. Failure stress values of the fresh bones increased sharply between 8 months and 1 year of age, with a maximum of 2328 kg/cm² reached at 4 to 7 years of age. A positive correlation was found between age and: ash content (r² = .57, P<.01); cortical area (r² = .63, P<.01); failure stress (r² = .51, P<.01). A lower positive correlation was found between failure stress and cortical area (r² = .40, P<.05), and a linear regression analysis of failure stress relative to ash content showed a positive correlation (r² = .58, P<.01). Findings indicate that the metacarpal bone reaches maximum ash content, cortex area and failure stress resistance at age 4 to 7 years.

(Key Words: Bone, Failure Stress, Age, Ash, Horse.)

Introduction

Lameness is a problem that causes high losses in the horse industry, especially with racing horses. It often occurs in the young horse during training, customarily initiated at age 18 to 24 months, before the bones of the foreleg have attained sufficient size and degree of mineralization to bear the weight of the horse under the stress of running. Arnold et al. (1966) noted progressive increases in the ash content of human bones for the first 20 years of life. Vos and Kubala (1959) found a positive correlation between ash content and failure stress in the human femur. In studies of cortical area or thickness in humans, Garnet al. (1963) found an increase with age through the third decade, at the expense of the marrow area. Hendricks et al. (1973) found no consistent relationship between the area of the cortical portion of bones of cattle and their failure stress values. Haugh et al. (1971) studied the effect of an anabolic agent on failure stress in bones of Shetland ponies. Bynum et al. (1971) performed flexural tests on metacarpal bones from 37 horses aged 3 months to 37 years, and noted that the module of elasticity, rupture and failure increased then decreased with increasing age.

The present study was carried out to determine the interrelationships among the parameters of failure stress, cortical area and mineral content in the metacarpal bones of horses of various ages.

Materials and Methods

Metacarpal bones from both forelegs of 19 female and 22 male horses 1 day to 33 years of age were studied. Most of the horses had been put down at horse farms and birth records were available; most were of the Thoroughbred or Quarter Horse breed. Records of the nutritional backgrounds were not obtained, but the horses were generally from well-managed Ocala area horse farms and appeared to have been maintained on an adequate plane of nutrition.

The bones were cleaned and one bone of

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each pair, in the fresh state, was tested for load required to cause failure using a Riehle testing apparatus, load cell capacity 3,636 kilograms. The bone rested across two metal rods laid on the bench, with one rod 15% of the bone length from the proximal end, the other 10% of the length from the distal end. Pressure was applied from above at the longitudinal center by downward movement of a metal block 2.5 cm in width, attached to the under surface of a metal plate (three-point flexural loading). This plate was driven downward at a rate of 2.5 cm/min. The maximum force attained before the sudden decrease which accompanied failure was indicated on a dial, and this value (F) was applied in the calculation of failure stress (S) by the equation employed by Haugh et al. (1971), 

\[ S = \frac{F \times L \times C}{4 \times I} \]

where \( S \) = failure stress (kg/cm²), \( F \) = load at failure (kg), \( L \) = length between support points, \( C \) = bone radius at the point where the force was applied and \( I \) = moment of inertia. Moment of inertia is equal to \( \pi \times (D^4 - d^4)/64 \), where \( D \) = total diameter and \( d \) = marrow diameter, in circumference.

The entire broken bone was dried at 100°C, freed of fat by ether extraction, and ashed at 550°C for determination of calcium, magnesium and phosphorus. The second bone of each pair was cut transversely at the longitudinal center and the cross-section and marrow cavity areas measured by tracing outlines of the outside and marrow cavity circumferences on a sheet of paper laid on the end, then scribing with a planimeter the circles drawn. The difference between total and marrow cavity areas represented the cortical area.

Calcium and magnesium content of the bone ash were determined by absorption spectrophotometry following dissolving in hydrochloric acid. Phosphorus was determined colorimetrically by the method of Fiske and Subbarow (1925).

**Results**

Percentages of calcium, phosphorus and magnesium ranged from 35 to 39, 14 to 17 and .32 to .85 respectively in the ash of bone from horses aged 1 day to 33 years. Values did not indicate a relationship between age and percentage of these elements in the ash and the value of the sum of the three cations was fairly constant. Ratio of calcium to phosphorus ranged from 2.1 to 2.6 with no relationship to age observed.

A positive correlation was found between bone ash (table 1) expressed as percentage of the dry, fat-free bone and age of the horses, up to 7 years. The statistical analysis for the combined male and female values showed a correlation coefficient, \( r^2 = .57 \) (P<.01), between ash content and age. The quadratic regression equation for age (X) and ash (Y) was \( y = 56.4 + 2.9X - .25X^2 \). Ash content increased sharply from 55.2 ± 3 to 61.7 ± 2 between age 1 day to 8 months and 1 year. During the period between 1 and 4 to 7 years, ash increased to 64.0 ± .8, then decreased to approximately 62.7 ± 2 at age 8 to 10 years and to 58.9 ± 5 at advanced ages (up to 33 years). Values for males were generally slightly higher than for females of the same age.

Cortical area of the metacarpal bone (table 1) ranged from 4.6 ± 1.2 cm² in horses age 1 day to 8 months to a high of 8.8 ± 1.5 cm² in those aged 4 to 7 years. Values increased sharply at age 1 year over those for horses age 1 day to 8 months. There was an increase of 18% in cortical area between horses age 1 year and those 1.5 to 3 years of age, and of 20% between ages 4 to 7 and 8 to 10 years. Thereafter, values remained fairly constant up to 17 years, with a decrease between 11 to 17 and 33 years. For horses through 7 years of age, a high positive correlation coefficient between age and cortical area was found (\( r^2 = .63 \), P<.01). The quadratic regression equation for cortical area (Y) relative to age (X) was \( Y = 4.43 + 1.56 X - .126 X^2 \).

Table 1 shows values for breaking load (kg) and failure stress (kg/cm²) for bones of horses of various ages. There was a sharp increase in failure stress as the horses' age increased from 8 months to 1 year. The increase from age 1 year to 1.5 to 3 years was slight, with similar increases in the next two age intervals. Failure stress decreased after 10 years of age. An analysis of the values showed a correlation coefficient (\( r^2 = .51 \), P<.01) between failure stress and age. A lower positive correlation was found between failure stress and cortical area (\( r^2 = .40 \)).

A linear regression analysis of failure stress relative to ash content for values for horses through 9 years of age showed an \( r^2 \) value of .58 (P<.01). This observation indicates a high correlation between failure stress and ash content.

**Discussion**

The bone ash values found in this study,
ranging from 50 to 65% for horses of all ages, are in agreement with values reported by others (Armstrong and Singer, 1964; Robinson and Elliot, 1957). The finding of a positive correlation \( r^2 = 57.6, P<.01 \) between ash content and age agrees with results obtained by Hammet (1925) with rats and Trotter and Peterson (1955) with humans.

The method used in this study for determining cortical area is felt to have advantages over that used by Exton-Smith et al. (1969). It is simple and direct and the planimeter used is inexpensive. The values obtained for cortical area gave a clear indication of the formation and resorption of osseous tissue during growth and aging. The finding of a positive correlation between cortical area and age is in agreement with findings reported by other investigators with humans (Garn et al., 1967; Takahashi and Frost, 1964; Sedlin, 1964). The correlation coefficient found with the horse metacarpal bone \( r^2 = .63, P<.01 \) might have been even higher had the nutritional background been identical for all horses.

The measurement of failure stress in the present study involved three-point bending. This approach allows comparison among the bones assayed in the study, and with findings of other studies in which stress was determined similarly (Haugh et al., 1971; Bynum et al., 1971), but does introduce uncertainties in the estimation (Curry, 1970) and may provide a low estimate of the strength of equine bone. The failure stress values reported here are similar to those reported by Haugh et al. (1971) for normal ponies. In the present study the positive correlation between failure stress and age \( (r^2 = .51, P<.01) \) bears out the observation of Bell et al. (1967) for humans. A slightly higher correlation was noted between breaking strength and ash content \( (r^2 = .58, P<.01) \). Rockoff et al. (1969), Bartley (1966) and Weaver and Chalmers (1966) in studies with humans, also noted a positive correlation between these factors. The correlation between failure stress and cortical area found in the present study was \( r^2 = .40, P<.05 \). The reason that this coefficient was not as high as that for failure stress and ash may lie in the fact that some bones with large cortical area showed relatively low ash content, indicating poor deposition of mineral in the matrix. Rockoff et al. (1969) noted that in humans, bones having the highest percentage ash along with a large cortical area showed the greatest strength.
Literature Cited


