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Radiographic analysis of the growth rate of long bones in bustards

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SUMMARY

A serial radiographic study was conducted on seven houbara bustard (*Chlamydotis undulata macqueenii*), 10 rufous-crested bustard (*Eupodotis ruficrista*), four white-bellied bustard (*Eupodotis senegalensis*) and eight kori bustard (*Ardeotis kori*) chicks to determine the growth rate of long bones and to establish radiographic standards for assessing skeletal maturity. The growth rates of the tarsometatarsus and tibiotarsus in the bustard species investigated were similar to those in domestic fowl (*Gallus domesticus*) and some long-legged avian species. Maturation of long bones occurred earlier in houbara bustards compared with rufous-crested, white-bellied and kori bustards. © 2000 Harcourt Publishers Ltd

MUSCULOSKELETAL disorders of the limb bones are significant factors in the health and development of bustards (Bailey et al 1996, Naldo et al 1998a). In a review of clinical and pathological findings in juvenile bustards reared at the National Avian Research Center (NARC), Abu Dhabi, United Arab Emirates during the 1993 to 1995 breeding seasons, musculoskeletal disorders were an important cause of morbidity (49%) and mortality (16%) over the first 180 days after hatching (Bailey et al 1997, Naldo et al 1998a). Angel wings, rotational and angular limb deformities, spraddle legs, rolled toes and fractures are some of the common limb abnormalities that affect bustards (Naldo et al 1998a).

An important factor in the diagnosis of skeletal abnormalities is an understanding of the normal anatomy and development of the long bones. Radiography is one tool that can be used to document bone development and bone abnormalities (Church and Johnson 1964, Duff 1986).

Previous radiographic studies by Naldo et al (1997, 1998b) on long bone ossification in houbara (*Chlamydotis undulata macqueenii*), rufous-crested (*Eupodotis ruficrista*), white-bellied (*Eupodotis senegalensis*) and kori (*Ardeotis kori*) bustards have shown that secondary centres of ossification were present at the proximal and distal tibiotarsus, proximal tarsometatarsus, and proximal metacarpal III. The ossification pattern, appearance of secondary ossification centres, and epiphyseal fusion of the long bones in the bustard species investigated were similar to those in domestic fowl (*Gallus domesticus*) (Church and Johnson 1964) and domestic pigeons (*Columba livia*) (Kirchner 1992). As part of this long bone development study, measurements of the length and midshaft diameter of the tarsometatarsus, tibiotarsus, humerus, radius and ulna were taken to determine the growth rate of these bones. This paper describes the growth rate of the long bones in houbara, rufous-crested, white-bellied and kori bustards. The aims of the study were two-fold: (1) to establish the nature of long bone development and (2) to determine whether there are species differences in long bone development, between the bustard species investigated.

MATERIALS AND METHODS

Growth rates of the length and midshaft diameter of the humerus, radius, ulna, tibiotarsus and tarsometatarsus were obtained by serial individual X ray measurements on 29 hand-raised bustard chicks. Seven were houbara bustards (three females, four males), 10 were rufous-crested bustards (five females, five males), eight were kori bustards (four females, four males), and four were white-bellied bustards (one female, three males). These birds were hatched and reared at NARC as part of its captive breeding programme. The diet and management were as described by Bailey et al (1997). This study was approved by the Animal Welfare Committee of NARC.

Anaesthesia and radiography methods have been described (Naldo et al 1997, 1998b). All birds were weighed each time they were radiographed. Mean body weights of each species were calculated according to sex. The mean body weight of white-bellied bustards was not calculated because of the small sample size.

Measurements of the lengths and midshaft diameter of long bones were taken directly from the radiographs using a vernier calliper to 0·1 mm. To be able to compare the daily growth rate of the length of long bones (whole bone) in bustards with other avian species, measurements taken at 3 weeks of age were subtracted from those at 4 weeks old and divided by seven.

The end point of the study was determined by radiographic evidence of maturation of the long bones and by insignificant additional growth of the long bones.

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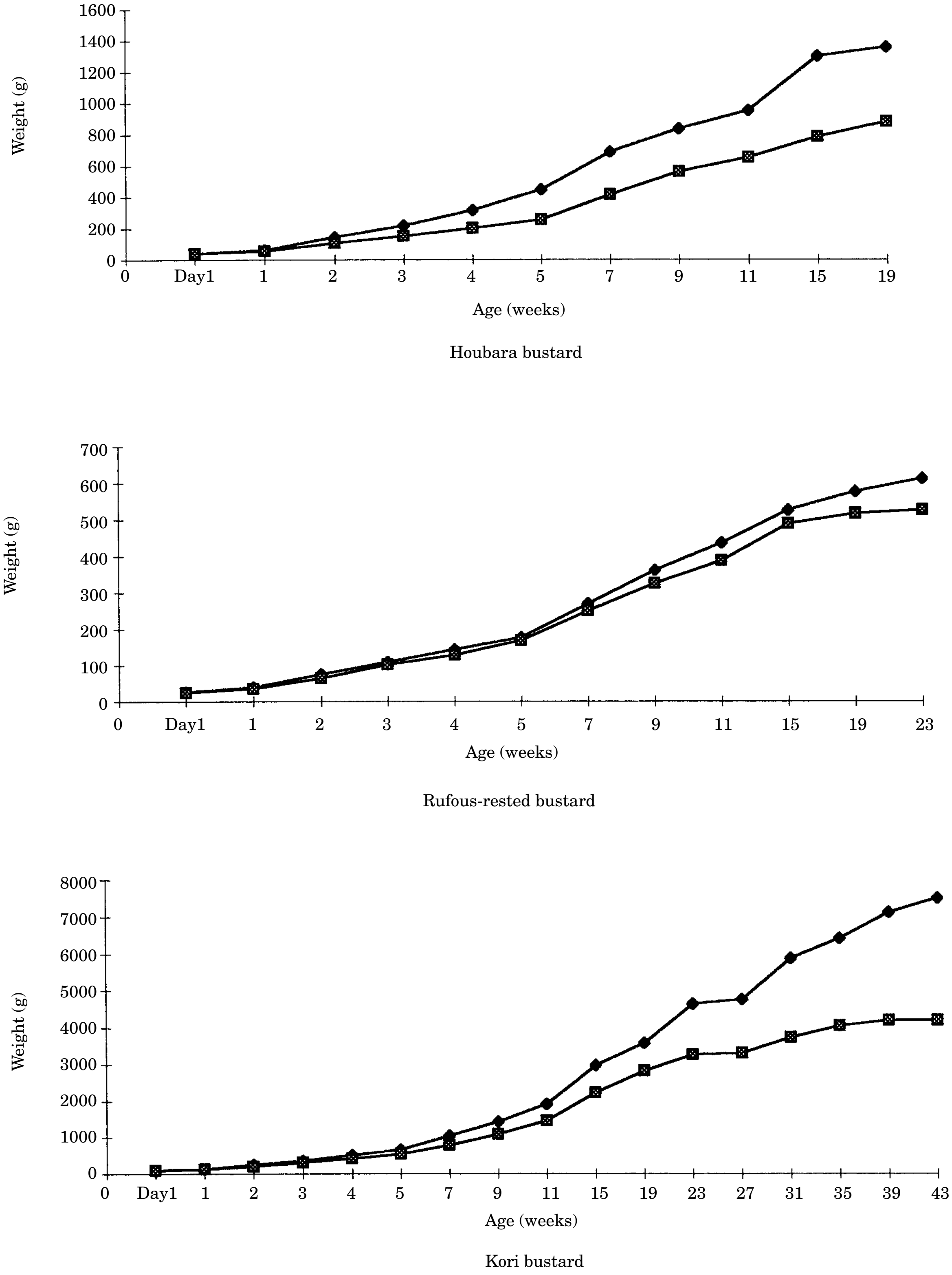

FIG 1: Mean body weights (g) of houbara, rufous-crested and kori bustard chicks. Males, ◆; females, ⊠.

RESULTS

Figures 1 and 2 show the growth rate in weight of the houbara, rufous-crested, kori and white-bellied bustards. Figures 3 to 6 show the mean growth rate in length of the tarsometatarsus, tibiotarsus, humerus, radius and ulna. Figures 7 to 10 show the mean growth rate in midshaft diameter of the same bones.

Evaluation of Figures 3 to 6 revealed that the growth of long bones varied between the four bustard species. The two

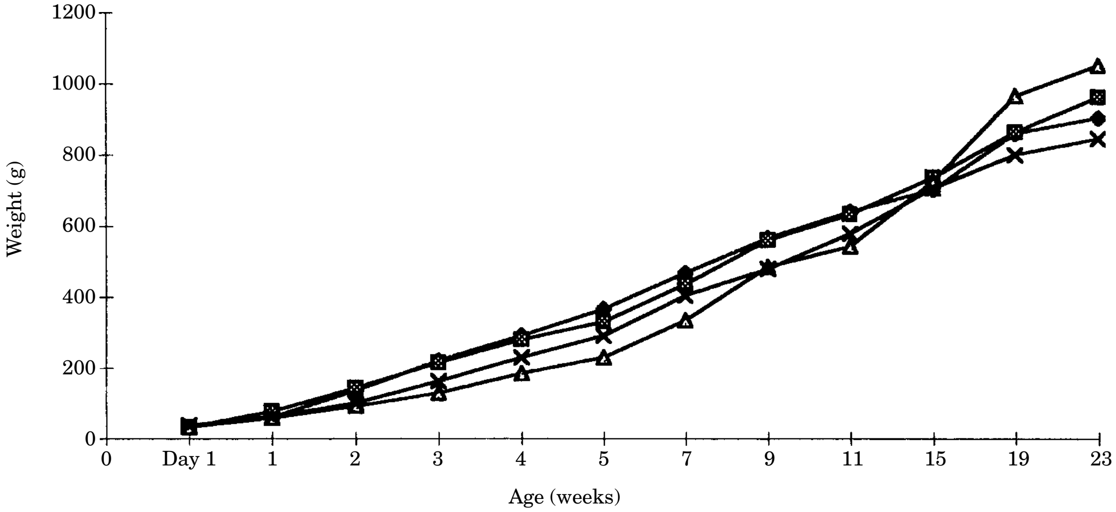

FIG 2: Body weights (g) of four white-bellied bustard chicks. Male 1, ◆; male 2, ⊡; male 3, △; female 1, x.

longest bones are the tibiotarsus and tarsometatarsus in rufous-crested at 19 weeks and white-bellied bustards at 23 weeks, tibiotarsus and ulna in kori bustards at 43 weeks and ulna and radius in houbara bustards at 15 weeks. The tarsometatarsus is the shortest long bone in both kori and houbara bustards.

The mean growth rate of the tarsometatarsus measured at 3–4 weeks in the houbara, rufous-crested, white-bellied and kori bustards were 1·47, 0·85, 1·35 and 1·84 mm day^{-1}, respectively. The mean growth rates of the tibiotarsus were 1·44, 0·95, 1·47 and 1·8 mm day^{-1}, respectively.

The mean growth rate of the humerus measured at 3–4 weeks in the houbara, rufous-crested, white-bellied and kori bustards were 2·12, 1·22, 1·67 and 2·68 mm day^{-1}, respectively; of the radius 2·34, 1·08, 1·3 and 2·70 mm day^{-1}, respectively; and of the ulna 2·52, 1·15, 1·32 and 2·22 mm day^{-1}, respectively.

Houbara bustard

In houbara bustards from 2 to 15 weeks the mean length of tarsometatarsus, tibiotarsus, humerus, radius and ulna increased from 41·6 to 93·9 mm, 52·3 to 126·7 mm, 38·5 to 121·6 mm, 41·1 to 128·9 mm and 42·1 to 136·4 mm, respectively (Fig 3). The mean midshaft diameter increased from 3·9 to 4·5 mm, 3·0 to 5·6 mm, 2·8 to 6·6 mm, 1·7 to 3·9 mm and 2·2 to 5·2 mm, respectively (Fig 7).

The highest growth rate in length of long bones was achieved between 3 to 4 weeks for the tarsometatarsus (1·47 mm day^{-1}) and ulna (2·52 mm day^{-1}), 4 to 5 weeks for the tibiotarsus (1·55 mm day^{-1}) and 2 to 3 weeks for the humerus (2·37 mm day^{-1}) and radius (2·38 mm day^{-1}). The growth rate of all long bones slowed to 0·04 to 0·4 mm day^{-1} by 9 to 11 weeks.

Mean body weights increased steadily until 9 weeks. Maximum percentage weight gains of 101 per cent and 137 per cent per week were observed between weeks 1 and 2 for female and male houbara bustards. By 19 weeks the weight gains slowed to 1 per cent and 3 per cent per week for female and male houbara bustards with mean body weights of 882 and 1355 g, respectively.

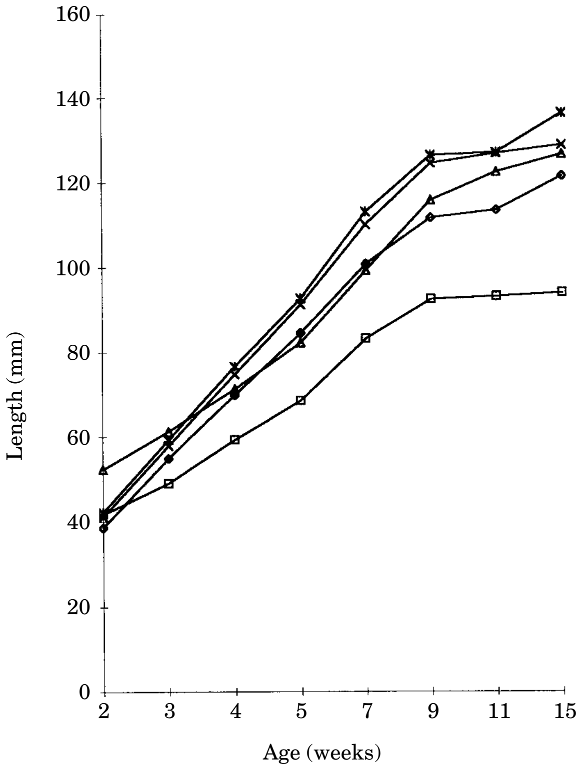

FIG 3: Growth in length of long bones in houbara bustard evaluated from 2 to 15 weeks of age. Humerus, ◇; metatarsus, □; tibiotarsus, △; radius, x; ulna, ⁎.

Rufous-crested bustard

In rufous-crested bustards from 2 to 19 weeks the mean lengths of the tarsometatarsus, tibiotarsus, humerus, radius and ulna increased from 29·8 to 87·9 mm, 36·9 to 109·9 mm, 23·5 to 79·5 mm, 26·9 to 79·7 mm and 27·4 to 83·4 mm, respectively (Fig 4). The mean midshaft diameter increased from 3·1 to 3·9 mm, 2·1 to 4·2 mm, 2·4 to 5·3 mm, 1·3 to 3·1 mm and 1·8 to 4·4 mm, respectively (Fig 8).

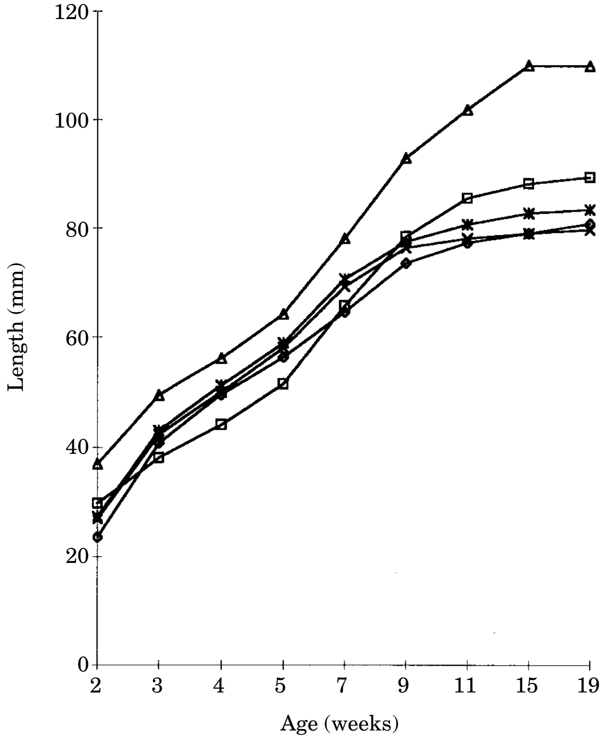

FIG 4: Growth in length of long bones in rufous-crested bustard evaluated from 2 to 19 weeks of age. Humerus, ◇; metatarsus, □; tibiotarsus, △; radius, x; ulna, ⁎.

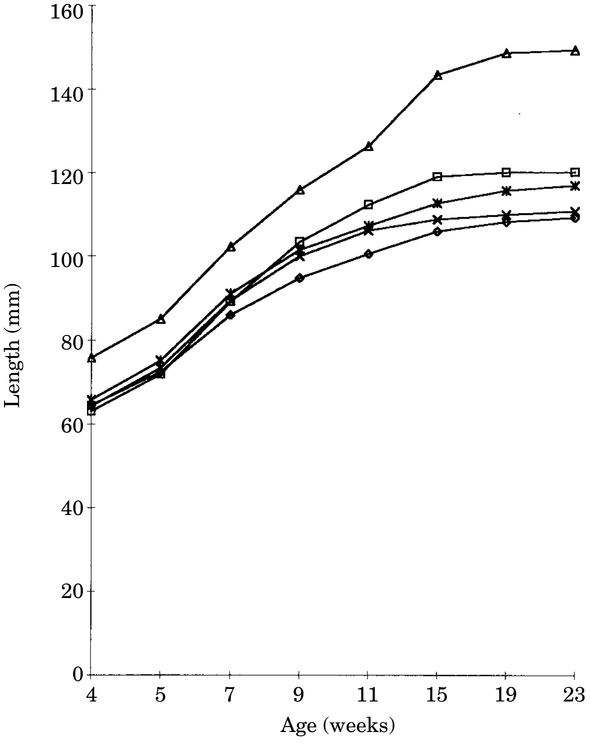

FIG 5: Growth in length of long bones in white-bellied bustard evaluated from 4 to 23 weeks of age. Humerus, ◇; metatarsus, □; tibiotarsus, △; radius, x; ulna, ⁎.

The highest growth rate in length of all long bones was achieved between 2 to 3 weeks. At this age, the growth rate was 1·18, 1·78, 2·47, 2·2 and 2·24 mm day^{-1} for the tarsometatarsus, tibiotarsus, humerus, radius and ulna, respectively. The growth rate of all long bones slowed to 0·03 to 0·28 mm day^{-1} by 11 to 15 weeks.

Mean body weights increased steadily until 11 weeks. Maximum percentage weight gains of 88 per cent and 97 per cent per week were observed between weeks 2 and 3 for female and male rufous-crested bustards. By 23 weeks the weight gains slowed to 0·5 per cent and 1·5 per cent per week for female and male rufous-crested bustards with mean body weights of 526 and 613 g, respectively.

White-bellied bustard

In white-bellied bustards from 2 to 23 weeks the mean lengths of the tarsometatarsus, tibiotarsus, humerus, radius and ulna increased from 42·8 to 120·3 mm, 47·2 to 149·4 mm, 34·8 to 109·3 mm, 35 to 110·8 mm and 34·7 to 116·9 mm, respectively (Fig 5). The mean midshaft diameter increased from 4·3 to 5·4 mm, 3·1 to 5·7 mm, 3 to 6·5 mm, 1·6 to 3·5 mm and 1·9 to 5·2 mm, respectively (Fig 9).

The highest growth rate of long bones in the white-bellied bustard was achieved between 3 to 4 weeks for the tarsometatarsus (1·35 mm day^{-1}) and 2 to 3 weeks for the tibiotarsus (2·02 mm day^{-1}), humerus (2·38 mm day^{-1}), radius (2·2 mm day^{-1}) and ulna (2·44 mm day^{-1}). The growth rate of all long bones slowed to 0·03 to 0·18 mm day^{-1} by 15 to 19 weeks.

Body weights increased steadily until 11 weeks. Maximum percentage weight gains of 68·8 per cent and 138 per cent per week were observed between day 1 and day 7 for female and male white-bellied bustards. By 23 weeks of age the weight gains slowed to 1·2 per cent and 2·8 per cent per week for female and male white-bellied bustards with body weights of 845 and 1050 g, respectively.

Kori bustard

In kori bustards from 2 to 43 weeks the mean lengths of the tarsometatarsus, tibiotarsus, humerus, radius and ulna increased from 53·6 to 236·3 mm, 61·8 to 296·8 mm, 38·5 to 245·2 mm, 40·6 to 276·3 mm and 41·4 to 286·8 mm, respectively (Fig 6). The mean midshaft diameter increased from 5·4 to 10·8 mm, 4·1 to 11·6 mm, 3·3 to 16·2 mm, 1·6 to 6·8 mm and 2·0 to 10·2 mm, respectively (Fig 10).

The highest growth rate in length of all long bones was achieved between 2 to 3 weeks. At this age, the growth rate was 1·98, 2·12, 3·6, 2·71 and 3·27 mm day^{-1} for the tarsometatarsus, tibiotarsus, humerus, radius and ulna, respectively. The growth rate of all long bones slowed to 0·07 to 0·35 mm day^{-1} by 27 to 31 weeks.

Mean body weights increased steadily until 15 weeks. Maximum percentage weight gains of 59 per cent and 90 per cent per week were observed between weeks 3 and 4 for female and male kori bustards. By 35 weeks the weight gains slowed to 0·01 per cent and 2·7 per cent per week for female and male kori bustards with mean body weights of 4197 and 7486 g, respectively.

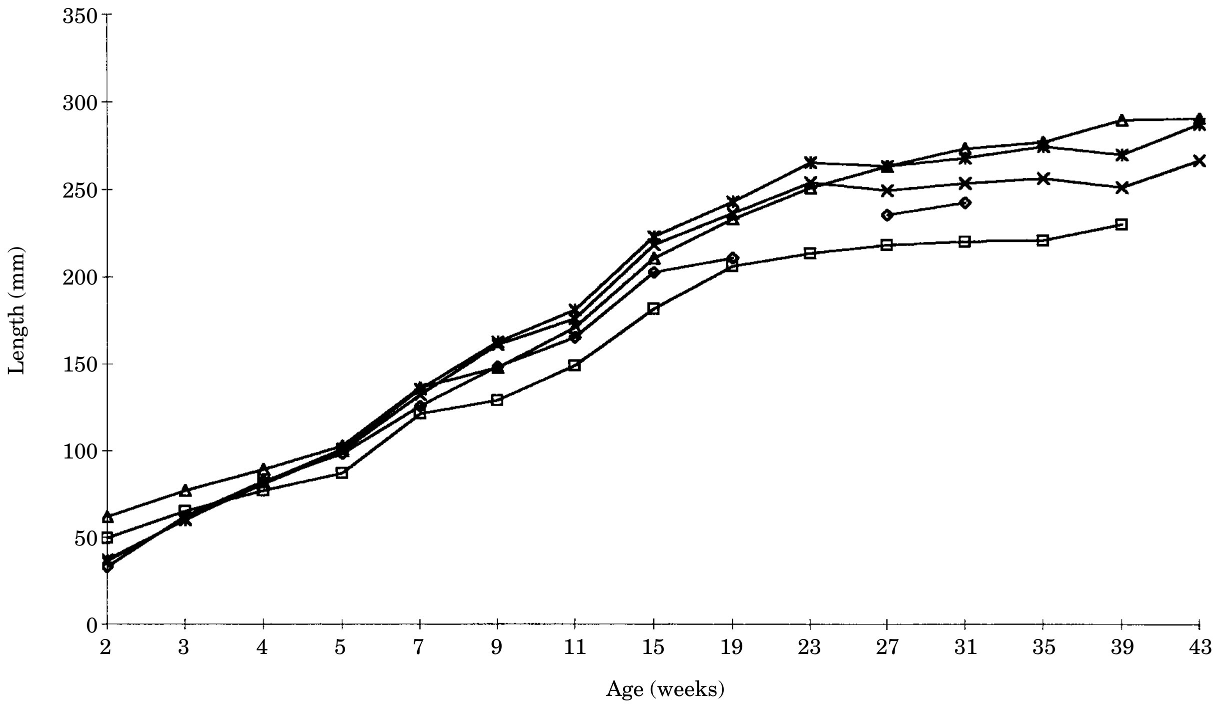

FIG 6: Growth in length of long bones in kori bustard evaluated from 2 to 43 weeks of age. Humerus, ◇; metatarsus, □; tibiotarsus, △; radius, x; ulna, ⁎.

DISCUSSION

Musculoskeletal abnormalities are important problems of long-legged birds reared in captivity (Carpenter 1986, Perelman 1991, Deeming et al 1993, Rowland et al 1996). Similar to many avian species, angular limb deformities, spraddle legs, bowing and folding fractures of the long bones are common findings in bustards with metabolic bone disease (Bailey et al 1996, Ostrowski et al 1996, Naldo et al 1998a). Evaluation of radiographs of young birds with metabolic bone disease is often difficult; therefore, knowledge of normal skeletal development is essential to an understanding of developmental skeletal abnormalities.

This study demonstrates the changes in bone size and bone maturation that occur during the developmental period of bustards. It should be noted that the study utilised captive, hand-reared bustard chicks.

A high incidence of musculoskeletal disorders in captive-bred houbara, rufous-crested and white-bellied bustards at NARC occurred between day 1 and 13 weeks of age (Naldo et al 1998a) at the time when the growth rates in length of long bones are at their peak and the bones are probably more susceptible to pathological disturbances. The growth rate in length of long bones diminishes between 9 and 11 weeks in houbara, 11 and 15 weeks in rufous-crested and 15 and 19 weeks in white-bellied bustards. In kori bustards, on the other hand, a high incidence of musculoskeletal disorders occurred until 26 weeks (Naldo et al 1998a). The long bones of the kori bustards increase in growth rate until 27 to 31 weeks.

The tarsometatarsal mean growth rates of the four bustard species studied are within the range of 0·35 to 6·0 mm day^{-1} reported by Kirkwood et al (1989a) for a wide range of avian species. The tarsometatarsus of the houbara, white-bellied and kori bustards have higher growth rates than the domestic fowl but lower growth rates than the ostrich (*Struthio camelus*) (2·4 mm day^{-1}), greater sandhill crane (*Grus canadensis*) (4·2 mm day^{-1}) and stone curlew (*Burhinus oedicnemus*) (2·1 mm day^{-1}) (Kirkwood et al 1989a). The tarsometatarsal mean growth rate of the houbara, white-bellied and kori bustards are similar to the tarsometatarsal growth rate of the moorhen (*Gallinula chloropus*) (1·5 mm day^{-1}), reed cormorant (*Phalacrocorax africanus*) (1·36 mm day^{-1}) and cape gannet (*Sula capensis*) (1·8 mm day^{-1}), respectively (Kirkwood et al 1989a). On the other hand, the tarsometatarsal mean growth rate of the rufous-crested bustards (0·85 mm day^{-1}) is close to the 0·99 mm day^{-1} reported in 3- to 4-week-old Rhode Island red domestic fowl cockerels (Kirkwood et al 1989b), 0·9 mm day^{-1} in New Hampshire cross barred rock crosses (Church and Johnson 1964) and 0·9 mm day^{-1} in rhea (*Rhea americana*) (Kirkwood et al 1989a).

The growth rates of the tibiotarsus of houbara, rufous-crested, white-bellied and kori bustards are similar to the domestic fowl. A tibiotarsus growth rate of 1·34 mm day^{-1} was reported in 3- to 4-week-old Rhode Island red cockerels (Kirkwood et al 1989b), 1·3 mm day^{-1} in New Hampshire cross barred rock crosses (Church and Johnson 1964), 1·0 mm day^{-1} in white leghorns and 2·2 mm day^{-1} in broilers (Reiland et al 1978).

The humerus, radius and ulna of the four bustard species studied have higher growth rates compared with those of the tibiotarsus and tarsometatarsus. Sequential measurements taken from captive-bred great bustard chicks (not radiographed) showed that the wing grows fastest, while the tibia and tarsus are slightly slower (Sukhanova 1992).

Although houbara bustards are larger than rufous-crested and white-bellied bustards, maximum bone growth is

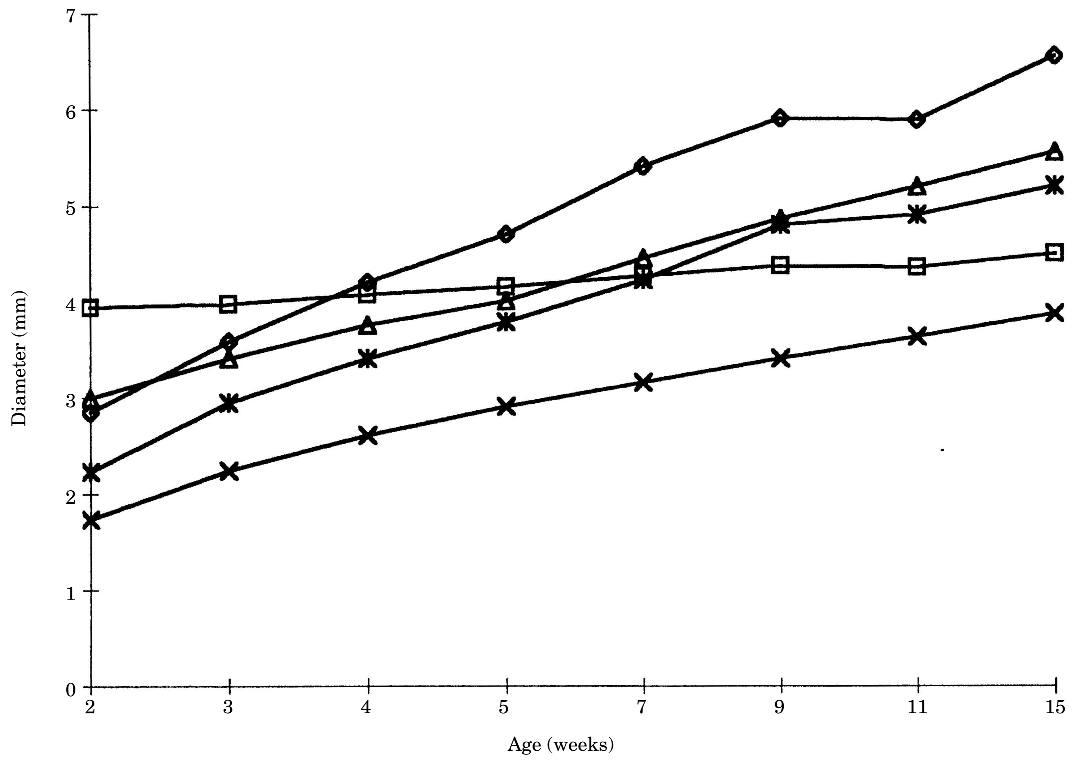

FIG 7: Growth in diameter of midshaft in houbara bustard evaluated from 2 to 15 weeks of age. Humerus, ◇; metatarsus, □; tibiotarsus, △; radius, x; ulna, ⁎.

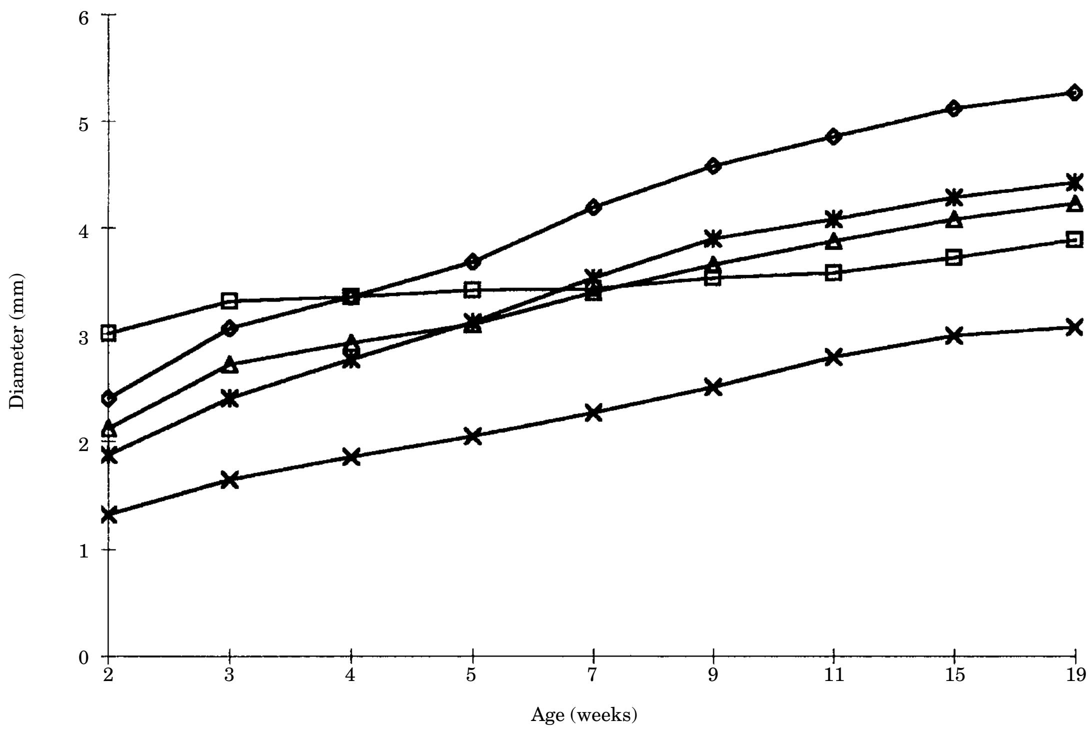

FIG 8: Growth in diameter of midshaft in rufous-crested bustard evaluated from 2 to 19 weeks of age. Humerus, ◇; metatarsus, □; tibiotarsus, △; radius,; ulna, ⁎.

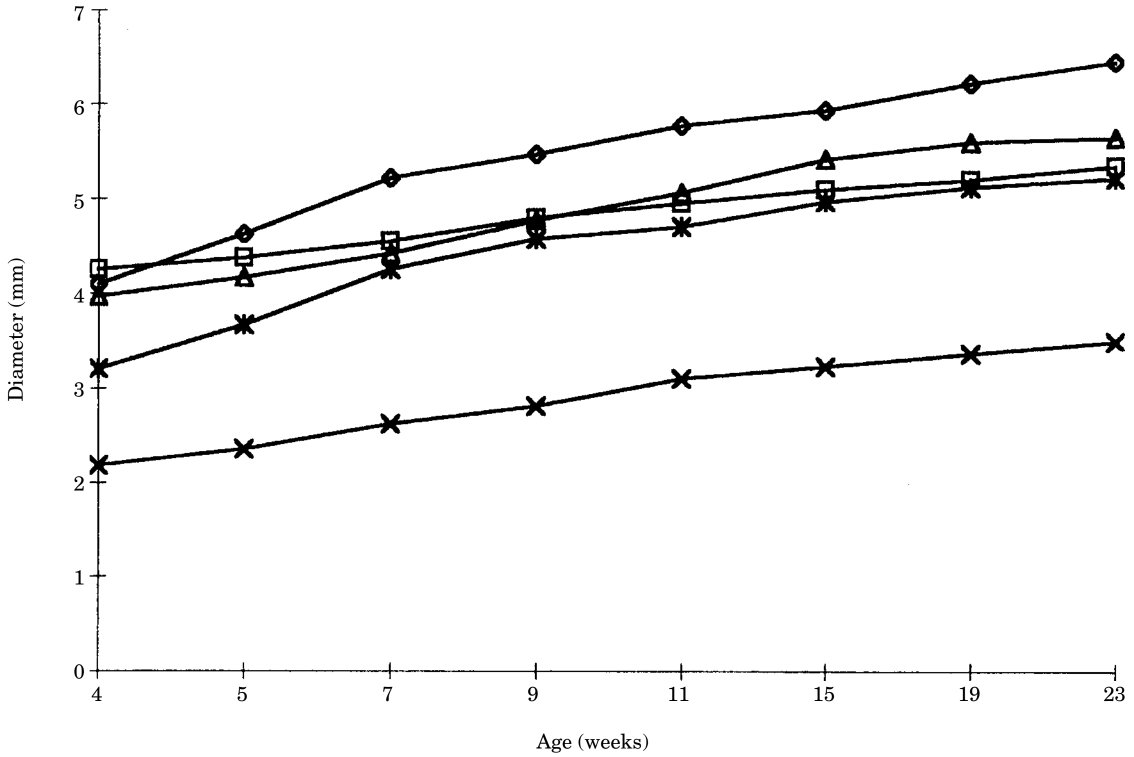

FIG 9: Growth in diameter of midshaft in white-bellied bustard evaluated from 4 to 23 weeks of age. Humerus, ◇; metatarsus, □; tibiotarsus, △; radius, x; ulna, ⁎.

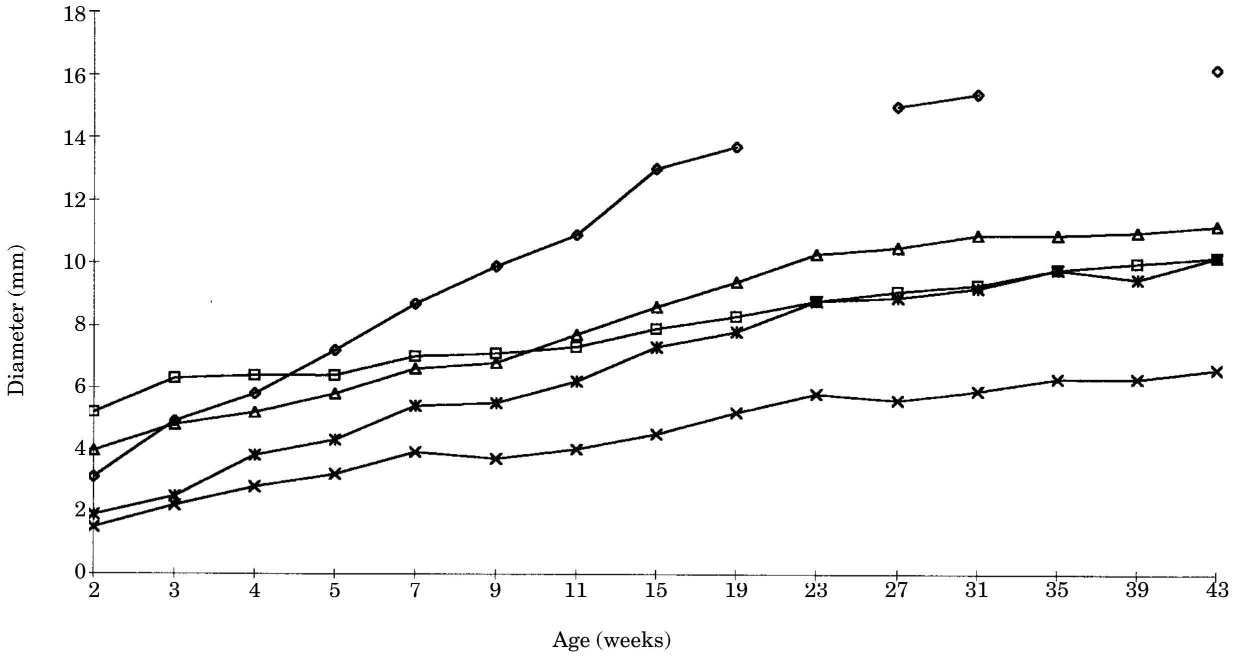

FIG 10: Growth in diameter of midshaft in kori bustard evaluated from 2 to 43 weeks of age. Humerus, ◇; metatarsus, □; tibiotarsus, △; radius, x; ulna, ⁎.

achieved much earlier in houbara bustards. This supports the findings in previous studies that ossification of long bones occurred much earlier in houbara bustards than it does in rufous-crested and white-bellied bustards (Naldo et al 1997, 1998b). In comparison, the maximum bone growth and ossification of long bones of the kori bustards are achieved much later. The early bone development in houbara bustards could be related to their ability to migrate. Of the four bustard species, the houbara bustards are known to leave their breeding ground on their autumn migration in early September to November and to return in March to April (Osborne et al 1984).

In this study, no attempt was made to differentiate the growth rate of long bones between male and female birds. However, in earlier reports on long bone ossification in bustards (Naldo et al 1997, 1998b), although male houbara bustards are heavier than females, the fusion of the secondary ossification centres was not significantly different between the sexes. In rufous-crested bustards the ossification at the proximal tarsometatarsus was completed earlier in females than in males. In kori bustards the fusion at the tibiotarsus and tarsometatarsus was completed earlier in females. No comparison between male and female white-bellied bustards could be made due to the small sample size.

In a survey of 87 avian species, Kirkwood et al (1989a) found that the growth rate of the tarsometatarsus was not correlated with adult body weight. Thus, in this study no attempt was made to correlate body weights with the growth rates of long bones of houbara, rufous-crested, white-bellied and kori bustards.

The average adult weights of captive female and male houbara, rufous-crested, white-bellied and kori bustards are 1050 and 1570 g, 600 and 670 g, 1080 and 1250 g, and 4840 and 10 010 g, respectively. Thus, at the end of the study the female and male houbara bustards reached 84 per cent and 86 per cent of their adult weights at 19 weeks, rufous-crested bustards 87 per cent and 91 per cent of adult weights at 23 weeks, white-bellied bustards 78 per cent of adult weights for both sexes at 23 weeks, and kori bustards 87 per cent and 75 per cent of adult weights at 43 weeks.

Repeated handling, anaesthesia and radiographic exposures did not appear to affect the birds' fertility. Some of the birds laid fertile eggs 2 to 3 years after the study.

CONCLUSIONS

This study demonstrates that the growth rates of long bones of four species of bustards reared under captive conditions are similar to the domestic fowl and some long-legged avian species. Maximum bone growth is achieved much earlier in houbara bustards compared with rufous-crested, white-bellied and kori bustards. A high prevalence of musculoskeletal disorders in bustards occurred at a time when the growths of long bones are at their peak. Careful monitoring of growing bustard chicks at this stage, including regular physical examination and measurement of body weight and food intake, is important because early detection is crucial to success in correcting these abnormalities.

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