less often in the throats of the tonsillectomized children, the incidence of coryza and sore throats was identical in the two groups.

We wish to acknowledge help from a number of colleagues—W. Brumfit, M. A. Heasman, M. Likar, and R. Mendez—who at some stage assisted with the laboratory or statistical work in this study. Technical help was given by Dawn Allen, Doreen Bobby, Margaret Brown, Barbara M. Hunt, and Vivian Kirkpatrick. Personal research grants from the Medical Research Council were received by F. S. W. Brimblecombe and Dorothy Sanderson during the two years of the study, and financial help for technical assistance and expenses was received from the Board of Governors of St. Mary's Hospital.

REFERENCES

- Andrews, C. H. (1951). *Sci. Amer.*, 184, 39.
Badger, G. F., Dingle, J. H., Feller, A. E., Hodges, R. G., Jordan, W. S., jun., and Rammelkamp, C. H., jun. (1953). *Amer. J. Hyg.*, 58, 31.
Buck, C. (1956). *Ibid.*, 63, 1.
Cralley, L. J. (1942). *Ibid.*, 36, 303.
Dingle, J. H., Badger, G. F., Feller, A. E., Hodges, R. G., Jordan, W. S., jun., and Rammelkamp, C. H., jun. (1953). *Ibid.*, 58, 16.
Gover, M., Reed, L. J., and Collins, S. D. (1934). *Publ. Hlth Rep. Wash.*, 49, 811.
Holmes, Margaret C., and Williams, R. E. O. (1954). *J. Hyg. (Camb.)*, 52, 165.
Lidwell, O. M., and Sommerville, T. (1951). *Ibid.*, 49, 365.
Mudd, S., Goldman, A. S., and Grant, S. B. (1921). *J. exp. Med.*, 34, 11.
Reid, D. D. (1952). *Proc. roy. Soc. Med.*, 45, 897.
Williams, R. E. O., and Hirsch, Ann (1953). *Lancet*, 2, 1303.
Straker, E., Hill, A. B., and Lovell, R. (1939). *Rep. publ. Hlth med. Subj.*, No. 90.
Van Loghem, J. J. (1928). *J. Hyg. (Camb.)*, 28, 33.
Wright, G. Payling, and Wright, Helen Payling (1945). *Ibid.*, 44, 15.
Young, M. (1924). *Ibid.*, 23, 151.

ASSESSMENT OF AGE, SEX, AND HEIGHT FROM IMMATURE HUMAN BONES

BY

J. A. IMRIE, M.D., F.R.C.S.Ed.
Lecturer in Forensic Medicine, Glasgow University

AND

G. M. WYBURN, D.Sc., F.R.F.P.S., F.R.S.Ed.
Regius Professor of Anatomy, University of Glasgow

We have been unable to find any reports of medico-legal identification which, in the absence of all soft parts, had to be based on the estimation of age, sex, and height from portions of immature human bones.

In the present case the material available for examination was a skull, mandible, loose teeth, and 128 separate pieces of bone, many partially destroyed, found scattered over an area of a few hundred square yards of hillside in the West of Scotland. We were able to say that the bones were all part of one human skeleton, and, from the state of dentition and the recognition of separate pieces as bone epiphysis, that the skeleton was not that of an adult. The assessment of age, sex, and, in particular, height, however, was more difficult, presenting special problems, which we thought should be put on record.

Inventory of Bones

Skull: Complete except for the mandible. 76|67 teeth fixed in the maxilla. Mandible with 76|67 fixed in the bone. Loose teeth: 5 321|12345, 5432|12345, plus |DE.

Vertebrae: All the vertebrae recovered as separate bones—incomplete spines and transverse processes (late secondary centres), semilunar ridged areas on upper and lower surface of bodies (for attachment of annular epiphyses). Sacrum:—three separate bones: (1) the first segment, (2) the second segment, and (3) the third, fourth, and fifth segments. Coccyx:—one segment.

Ribs: All ribs except first left, second and twelfth right, all minus heads and tuberosities (late secondary centres).

Sternum:—six separate bones: (1) manubrium, (2) first segment, (3) second segment, (4) half of third segment, (5) half of third segment, and (6) fourth segment.

Clavicles: Right and left—no sternal ends (late secondary centres).

Scapulae: (1) Right and left scapulae, no acromion processes, vertebral borders, or inferior angles (late secondary centres). (2) Right and left coracoid processes.

Humerus: (1) Right and left diaphysis. (2) Right and left complete upper epiphysis. (3) Right lower epiphysis as three separate bones: (a) capitulum—plus lateral half of trochlea and lateral epicondyle, (b) medial half of trochlea, and (c) medial epicondyle.

Ulna: Right and left diaphysis.

Radius: Right and left diaphysis. Right upper epiphysis.

Hand Bones: Right capitate, right hamate, first, second, and fourth right metacarpals, six phalanges.

Innominates: (1) Right and left ileum, no crests or spines (late secondary centres). (2) Right and left ischio-pubic bones, no ischial tuberosities—acetabular separation of ischium and pubis (Figs. 1 and 2).

Femur: (1) Right and left diaphysis, minus distal 2–3 in. (5–7.5 cm.) (Fig. 3). (2) Right and left head epiphysis. (3) Right and left great trochanter epiphysis. (4) Left lower epiphysis.

Tibia: (1) Right and left diaphysis, minus upper 1 in. (2.5 cm.) of right diaphysis. (2) Right and left upper epiphysis. (3) Right and left lower epiphysis.

Fibula: (1) Right and left diaphysis. (2) Left lower epiphysis.

Foot Bones: (1) Right and left os calcis, right and left epiphysis. (2) Right and left talus. (3) Left navicular, cuboid, and three cuneiforms.

Metatarsals: First left with separate epiphysis, second, third, and fourth right and left.

FIG. 1.—Reconstructed right innominate bone, stippled area=reconstructed plasticine triradiate cartilage.

FIG. 2.—Reconstructed pelvis, stippled area=reconstructed parts.

Procedures

The teeth were replaced in the jaws, and upper and lower dental casts were made. The mandible was then articulated with the skull.

Epiphyses were glued on to the appropriate diaphyses, with estimated thickness of plasticine where necessary, to represent the growth cartilage. They were then x-rayed and compared with those of bones of similar "maturation" age.

Two inches (5 cm.) of the shaft of the left femur was reconstructed with dental wax and its alignment with the lower epiphysis checked by x-ray examination and comparison made with femurs of the same maturation age.

FIG. 3.—Reconstructed lower end of left femur. Stippled area represents the defective area replaced by plasticine.

The pelvis was reconstructed from the pieces of sacrum, coccyx, and innominate bones, and the triradiate acetabular cartilage modelled with plasticine to correspond to that of pelves at the same stage of development.

The tarsal and metatarsal bones of the left foot were rearticulated.

Skull.—From the size of the skull, and general build with regard to supraorbital ridges, occipital protuberance, mastoid processes, and facial bones, it was concluded that this was not the skull of an adult male.

Dentition

Maxilla.—The 76|67 were fixed in the maxilla. The loose teeth 5 321|12345 fitted without difficulty into their sockets. In addition to the permanent teeth the |DE of the deciduous dentition fitted naturally into place over the |45. The 4| was missing. There was some overcrowding in the incisor region due to a constriction of the arch between the canines. This overcrowding caused the 2|1 to overlap the 1|. The |2 was overlapped by the |1 and lay a little inside the line of the arch, and the 1| had about $\frac{1}{8}$ in. (1.6 mm.) of the incisal edge broken off, but the pulp had not been exposed. The tooth had erupted further, so that the incisal edges of 1|1 were in line. The incisors were well-formed teeth with large roots, the apices of which were closed. The canines were not fully erupted, and the |3 was not far through the gum. The 5| had erupted and was nearly into its normal position. The |DE were still in place, consequently the |45 were not erupted. The roots of the |D were fully absorbed and it was ready to be shed. The lingual root of the |E was still present,

but the buccal roots had been absorbed so that this tooth would have been shed in about two months. The 6|6 and 7|7 would be showing through the gum.

Mandible.—The 76|67 were fixed in the mandible. The loose teeth 5432|12345 fitted without difficulty into their sockets. The 1| was missing. The three lower incisors were fully erupted. Their roots were well formed and the apices closed. The canines were fully erupted and their apices still open. The four premolars were not yet fully erupted, but the 76|67 were well through the gum.

On articulating the mandible to the skull it was found that the 6|6 were in excellent occlusion. The |2 was lingual to the |12. The other teeth were not in occlusion, but the mandible was obviously the correct one for the skull because: (1) the excellent occlusion of the 6|6; (2) the facets worn on the incisal edge of the |2 fitted into the facets on the incisal edges of the |12.

Dental Age

There are some contradictory data in the dental status. The presence, however, of seven permanent teeth in the two halves of the lower jaw and the right half of the upper jaw indicates a dental maturity, with a minimum chronological age of around 12 years. Spier (1918) gives a mean age of 13.2 ± 2 for the eruption time of 7|7, which he states are present in less than 12% of children under 12. Clements, Davis-Thomas, and Pickett (1953) give the mean eruption time of 7|7 as 12 ± 0.94 for British children. They state, however, that this figure is influenced by the time of the onset of puberty. According to them the eruption times of the teeth are independent of one another, and there is considerable variation in the order in which they appear. In addition, Clements *et al.* found that the frequency of the different patterns of eruption varies not only in upper and lower jaws, but also as between the right and left sides. The eruption pattern of the left upper jaw with a |3, |7, and unerupted |45 has a frequency, they found, of only 4.9%, and this agrees with the figure of 4% (Spier, 1918) of unshed deciduous molars still present at age 13. It can be concluded, therefore, that the eruption pattern in the left upper jaw should not unduly influence the estimate of dental age.

The partial eruption of the permanent upper canines, second molars, and lower pre-molars suggest an upper limit of chronological age of 14. The eruption pattern—apart from the left upper jaw—is a little in advance of the plan for 12 years shown by Simpson (1948).

On the basis of the dental condition, the estimate of chronological age is $12\frac{1}{2}$ – $13\frac{1}{2}$ years. This estimate could be affected, however, by the state of puberty relative to the chronological age.

Skeletal Maturity

While it is realized that there is no steady correlation between skeletal maturity and chronological age (Lancet, 1955), particularly within the puberty period, in this case it has to be assumed that an estimate of age is permissible from the data of dental and skeletal maturity.

Skeletal maturity can normally be assessed by comparison with the standard atlases constructed from sets of x-ray pictures of developing bones of known chronological age groups, or with statistical tables—cumulative incidence curves, based on appearance/absence of secondary centres or union/non-union of epiphyses. The best-known atlases are those of Todd (1937) and Greulich and Pyle (1950)—both, however, with standards for hand and wrist which are not available in the present material, and the reconstructed pelvis could not be used for comparison with the pelvic standards of Speiger (1950). The maturation denominators suggested by Acheson (1954), and Acheson and Hewitt (1954) apply only from birth to 5 years, and have not been worked out for later childhood.

Cumulative incidence charts and tables such as those of Lurie, Levy, and Lurie (1943) and of Harding (1952) are designed for the determination of the skeletal maturity of known chronological ages. Moreover, many of the maturity determinators used in these charts are not available here—the absence, for instance, of such critical data as the evidence of appearance or absence of many of the late secondary centres, and the lack of information about the growing ends of some of the long bones.

There are, however, a number of useful markers which serve to indicate upper and lower limits of chronological age range. An upper limit of 14+ is indicated by:

(a) segmental condition of the sternum, in particular the separate halves of the third body segment; (b) un-united coracoid epiphyses, (c) acetabular non-union of pubis and ischium; (d) separate trochlea epiphysis at the lower end of the humerus; and (e) non-union of the capitulum epiphysis. Indicators defining the lower limit of the age range at 11+ are: (a) presence of trochlea epiphysis; (b) the union of odontoid epiphysis; (c) presence and union of the epiphysis of the lateral epicondyle with capitulum; and (d) the tongue-shaped extension (tibial tuberosity) of upper tibial epiphysis.

Figs. 4, 5, and 6 show comparison of humerus, femur, and tibia, with bones of known age. A consideration of the condition of the bones of known age.

FIG. 4.—A, X-ray picture of right humerus; note lower epiphysis. B, Lower end of left humerus of boy aged 12½ years for comparison.

FIG. 5.—A, Left femur, showing lower deficiency in shaft, to compare with B, right femur of boy aged 13+.

tion of skeletal maturity as indicated by the separate bones suggests an age of 13±6 months. Although according to Tanner (1955) there are no reports of reliable correlations between dental maturity and skeletal age, the independent assessments provide a useful check.

Sex Determination

The problem of determining the sex was made difficult by the absence of any articulated part of the skeleton, and the need to reconstruct the long bones and, in particular, the pelvis. Moreover, many of the sex differentials of the

adult skeleton are not present in the pre-adolescent bones and develop only as a result of the adolescent growth spurt at puberty. For example, such sex characteristics of the female pelvis as the size of the pubic angle, ischio-pubic index, conjugate diameter, and shape of the obturator foramen appear only after the differential growth rate of the pubic bone, associated with the activity of the cells of the triradiate cartilage, preceding ossification (Washburn, 1946).

There are, however, some “inborn” differences between male and female innominate bones; and the shape of the sciatic notch, absence of the pre-auricular groove, extent of the sacral articular surface, and the degree of eversion of the ischio-pubic ramus all point to male innominate bones. The sacrum has also the characteristics of a male bone, as assessed by the smaller sacral index ($B \times 100/L$) and the large proportion of the superior surface of the bone formed by the body of the first sacral vertebra. The immature and incomplete long bones of the limbs, and deficient scapulae and clavicles (with no cartilage or secondary centres), give no useful clue to the sex of the bones, and the diagnosis of male rests on the evidence from the pelvis. This is further confirmed by the large size of the roots of the permanent teeth.

FIG. 6.—A, Tibia. B, Knee-joint of male child 12+.

Height

The height was estimated from the length of the reconstructed left femur, right humerus, left tibia, and combinations of these three bones, using the coefficients and constants given by Simpson (1948). Altogether six different formulae were used, with results ranging from 59 to 58 in. (150 to 147 cm.). The obvious sources of error in these calculations are: (1) the measurements are based on the length of the reconstructed bones; and (2) the formulae were devised for the determination of adult height from mature bones.

It is well known that the segmental proportions of the body change throughout the growth period. Meredith and Knott (1938) studied the trend of the skelic index

$$\frac{\text{Length of lower limb} \times 100}{\text{Stem length}}$$

in a large number of children from birth to 18 years. They reported an increase of from 49 to 93 during the period from birth to 13½ years and a decrease from 93 to 89 from 13½ years to 18.

According to Tanner (1955) the pubertal growth spurt for the various systems and parts of the body does not necessarily correspond in time. For example, the leg spurt

precedes, and reaches its peak about a year before that of the trunk, so that during this period the proportion of leg to trunk with regard to total height would change. The height spurt as a whole is, however, due to a relative increase in the sitting height. Again, as the onset of the growth spurt is later in the male than in the female, the pre-pubertal differential growth rate continues to act for a longer time in the male, giving the relatively greater male limb length.

A comprehensive study of the growth of the long bones of the limb relative to height and sitting height has been made by Maresh (1943, 1955) in two age groups: birth to mid-childhood, and mid-childhood to maturity.

From the collected data she concludes (1) that there is not necessarily a uniform increase in bone length throughout childhood and adolescence—the growth rate may shift at any one time above or below the mean for the age group as a whole; and (2) that the change in growth rate need not affect all the long bones of the limb at the same time or to the same extent. Thus the relative bone lengths—that is, the percentage of height formed by the long bones—may vary throughout the growth period.

With the many variables affecting the length of a limb bone during growth, and in particular puberty, any estimate of height from immature bones is at best only an approximation. A further difficulty in this case was that we had to estimate the chronological age from skeletal age and therefore were unable to assess the chronological progress of the maturational status. We reported that the bones were part of the skeleton of a male age of from 12½ to 13½ years, with an estimated stature of 4 ft. 10 in. (147 cm.).

Eleven months before the discovery of the bones, in March, 1956, an orphan aged 13 years 11 months had been reported missing from an institution within the county. He had previously absconded for periods of three days and two days, and had been found living on shellfish in a cave on the first occasion, and in a barn, starving, on the second occasion. There was a record of his height and weight during the period January to April, 1954. The last height measurement was 4 ft. 5½ in. (136 cm.). He had, however, grown 1½ in. (3.2 cm.) in the preceding four months, and so it is reasonable to assume that he would have been 2 to 3 in. (5 to 7.5 cm.) taller when he disappeared in April, 1955. There was a dental record which corresponded to the dental condition as indicated by the eruption pattern and the dental casts.

Thus there was strong presumptive evidence sufficient to satisfy the authorities that the recovered bones were those of the missing boy. How he escaped notice living on the fringe of habitation, how he lived, and how long he survived on the hillside, will remain unknown.

The absence of all soft parts was probably in part a result of the prevailing subtropical conditions in the summer of 1955, and the scatter and partial destruction of the bones due to the action of indigenous mammals.

Summary

The assessment of the age, sex, and height was attempted from a collection of immature human bones consisting of a skull, mandible, loose teeth, and 128 separate bits of bone, some partially destroyed. The teeth were replaced in the jaws, dental casts were made, and the dental age was estimated from a consideration of the eruption pattern in the upper and lower jaws. The chronological age was estimated by consideration of the skeletal maturity, using as "markers" the presence/absence, union/non-union of secondary epiphyses. The sex was determined from the reconstructed pelvis and the condition of the teeth. The height was estimated from the length of the reconstructed left femur, right humerus, left tibia, and combinations of these three bones; and the difficulties of estimating the height from immature bones are discussed.

We are indebted to Dr. W. Gibson, of the Glasgow Dental Hospital, who made the dental casts and helped us in the analysis of the dental condition.

REFERENCES

- Acheson, R. M. (1954). *J. Anat. (Lond.)*, **88**, 498.
 — and Hewitt, D. (1954). *Brit. J. prev. soc. Med.*, **8**, 59.
 Clements, E. M. B., Davies-Thomas, E., and Pickett, K. G. (1953). *Brit. med. J.*, **1**, 1421.
 Greulich, W. W., and Pyle, S. I. (1950). *Radiographic Atlas of Skeletal Development of the Hand and Wrist*. Stanford Univ. Press.
 Harding, V. S. V. (1952). *Child Developm.*, **23**, 247.
 Lancer, 1955, **2**, 384.
 Lurie, L. A., Levy, S., and Lurie, M. L. (1943). *J. Pediat.*, **23**, 131.
 Maresh, M. (1943). *Amer. J. Dis. Child.*, **66**, 227.
 — (1955). *Ibid.*, **89**, 725.
 Meredith, H. V., and Knott, V. B. (1938). *Child Developm.*, **9**, 49.
 Simpson, S. L. (1948). *Proc. roy. Soc. Med.*, **41**, 192.
 Speijer, B. (1950). *Belekenis en Bepaling van de Skeletteeltijd*, p. 153. With summary and atlas in English. Leiden.
 Spier, L. (1918). *Amer. Anthropol.*, **20**, 37.
 Tanner, J. M. (1955). *Growth at Adolescence*. Oxford.
 Todd, T. W. (1937). *Atlas of Skeletal Maturation (Part I, Hand)*. London.
 Washburn, S. L. (1946). *Anat. Rec.*, **95**, 353.

TREATMENT OF ASCARIASIS WITH VARIOUS SALTS OF PIPERAZINE

BY

L. G. GOODWIN, M.B., B.S.

AND

O. D. STANDEN, D.Sc.

From the Wellcome Laboratories of Tropical Medicine,
London

Since the original observations by Boismare, cited by Fayard (1949), on the anthelmintic properties of piperazine, much has been published confirming the value of this drug in the treatment of ascariasis and enterobiasis. Numerous salts of piperazine have been used in attempts to improve upon the efficacy of piperazine hexahydrate, to render the various preparations more palatable, and to overcome the potential instability of hexahydrate solutions. Claims have been made concerning the greater efficacy of piperazine adipate over piperazine citrate in the treatment of whipworm (Dunn, 1955) which were not confirmed by Hucker and Schofield (1956), who demonstrated that piperazine citrate, adipate, phosphate, and sebacate were all inactive against this parasite; piperazine citrate has been shown to be inactive or only minimally active against *Taenia saginata* (Goodwin and Standen, 1957a); piperazine phosphate and piperazine adipate proved ineffective in the treatment of hookworm (Goodwin and Standen, 1957b).

The evidence is clear that while piperazine may possess minimal activity against other human helminths its great value in human medicine rests almost entirely in its high activity against *Ascaris lumbricoides* and *Enterobius vermicularis*. Hartley (1955) propounded an unsubstantiated theory that, owing to the deposition of adipic acid in the presence of gastric hydrochloric acid, piperazine adipate was less well absorbed in the stomach and therefore available to the worms in greater quantity in the small intestine than were piperazine salts of greater solubility. This claim was shown to be untenable in the light of laboratory experiments and observations on absorption and excretion in human volunteers (Standen *et al.*, 1955).

Against this background of claim and counter-claim made during the evaluation of piperazine as an anthelmintic it was decided that investigation should be made into the relative value of different salts of piperazine in the treatment of ascariasis under carefully controlled conditions of clinical trial. Also, since a single large