6. RADIOGRAPHIC ASSESSMENT OF SKELETAL AND DENTAL AGE

6.1 AGE

Marshall (1976) describes the word 'age' to denote one of the stages of human life. As a measure of developmental capacity, representing indices of maturity, it may be expressed as chronologic, skeletal or dental age.

6.1.1 Chronologic Age

The chronologic age is that measured by the calendar. It may be a period of intrauterine development, or the time lapsed from birth to death (Woods, 1968).

6.1.2 Skeletal Age

The skeletal age refers to the development of numerous anatomical features, which are known to occur at particular times in the average individual (Noble, 1976). In the female, skeletal development is about one year earlier than in the male.

6.1.3 Dental Age

Dental age, as with skeletal age, refers to the various stages of development of the human deciduous and permanent dentitions, which are known to occur at particular times and the changes that occur in the permanent dentition, which result from their use, throughout life (Gustafson, 1966, Noble, 1976, Sopher, 1976 and Cottone and Standish, 1982).

In forensic investigations, the assessment of the age of human remains may represent a critical aspect of the identification,

especially in cases of incineration, gross decomposition or skeletonisation.

6.2 ANTHROPOLOGICAL AND RADIOGRAPHIC ASSESSMENT OF SKELETAL AGE

A great deal of information is available regarding the developmental variability of the skeleton. Data from studies by researchers such as Greulich and Pyle (1959), Krogman (1962), Fazekas and Kosa (1978) and Stewart (1979) have provided such information as :-

(i) standards for various stages of development, enabling the range of age variation of these stages to be defined in populations of normal children and

(ii) the factors which influence variation in the sequence and chronology of these developmental stages, e.g. ethnicity, sex, nutrition, childhood diseases, etc., may act independently or in combination to accelerate or retard growth processes.

To determine skeletal age, the human life span may be divided into several sub-periods, reflecting various stages of development.

6.2.1 The Foetal-Infant

The foetal-infant period extends from approximately the second month of pregnancy to the second year following birth (Fazekas

and Kosa, 1978). This period of skeletal development is reflected by the appearance of the primary centres of ossification, seen on radiographs, and their union to form the precursors of adult bone (Cottone and Standish, 1982).

Estimates of age in the foetal-infant period are based on the morphological maturity of these precursors as well as their absolute size (Fazekas and Kosa, 1978).

6.2.2 The Child

Skeletal maturation from the third year of life to the mid-teens is characterised by appearance of the secondary centres of ossification, the epiphyses (Greulich and Pyle, 1959 and Marshall, 1976).

In assessing skeletal age of skeletons from the child sub-period, radiography plays an important part. Much of the available developmental data is contained in radiological atlases based on sequential radiographs of living children, from which postmortem radiographs can be compared.

6.2.3 The Adolescent and Young Adult

The majority of the secondary centres of ossification have usually formed by the mid-teens. Cottone and Standish (1982) suggest that for about the next decade the principal feature of skeletal maturation is the union of the epiphyses to the diaphyses.

Age estimations are determined radiographically, by comparison

with developmental atlases. In the estimation of the age of females it must be remembered that skeletal maturation at every chronologic age to full development in the female is in advance of males by one or two years (Miles, 1963, Marshall, 1976 and Noble, 1976).

6.2.4 The Adult

Suture closure in the skull shows a great degree of variability and is an unreliable indication of age (Biggerstaff, 1977). Closure of the cranial sutures usually begins on the inside of the skull (endocranially) and proceeds to the outside (ectocranially). Generally, the cranial sutures are patent in young adults and begin to close in the third and fourth decades of life and are often completely closed in old age. Figure 23, gives an indication of the ages of closure of the major sutures in the adult skull, as does Table 1.

The spheno-occipital synchondrosis, often incorrectly referred to as the basilar suture, is, unlike the cranial sutures, a reliable indicator of age. This synchondrosis is generally obliterated at around 18-20 years of age (Biggerstaff, 1977 and Cottone and Standish, 1982).

Examination of the pubic symphysis permits the estimation of age at death to within three to five years in males and five to ten years in females. This broader range in females is the result of remodelling of the symphysis associated with pregnancy. The pubic symphysis as such, is the best single indicator of age of the gross adult skeleton and this determination should be left to the expert anthropologist.

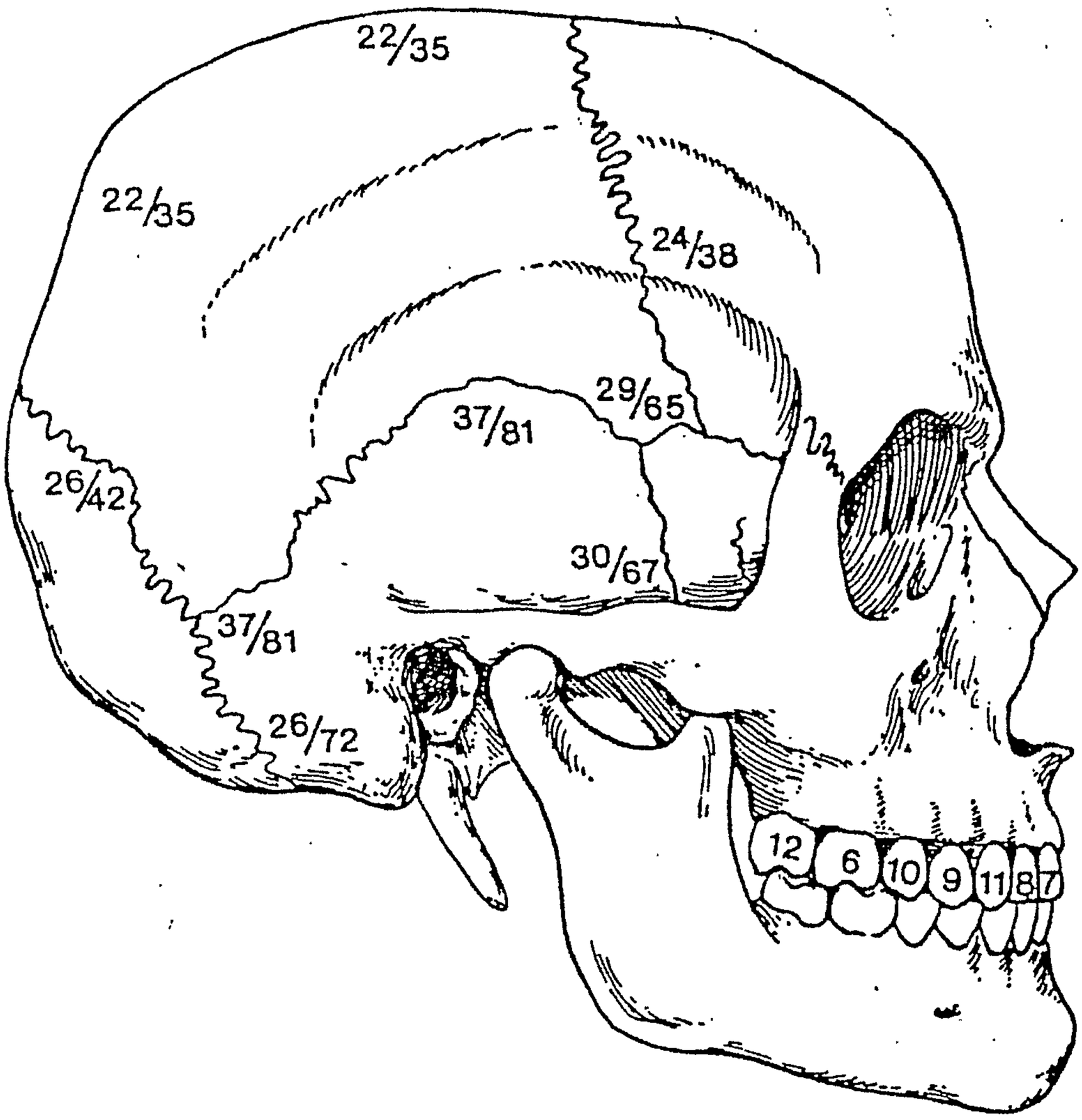


Figure 23. Average ages of suture closure (Biggerstaff, 1977).

Average Age of Sutural Closure in Males

Suture	Endocranial Initial	Ectocranial Termination
Sagittal	22	35
Sphenoparietal	29	65
Coronal	24	38
Squamosal	37	81*
Sphenotemporal	30	67
Lambdoid	26	42
Masto-occipital	26	72
Splrenofrontal	22–26	64

*Rarely undergoes complete closure.

Table 1. (Biggerstaff, 1977).

6.3 RADIOGRAPHIC ASSESSMENT OF THE DENTITION

The radiographic examination of the stages of formation and the progress of development of the teeth, represent the most reliable means of assessing chronologic age, from about five months in utero to 15 years (Miles, 1963, Cameron and Sims, 1974, Biggerstaff, 1977 and Whittaker, 1981). Sopher (1976) suggests the reason for this is the fact that, during this period, there is continual growth, development and intermixture of the primary dental follicle, through the various stages of tooth mineralisation, ending in mature root formation with the closure of the apical foramen. Dental development during this period of life is less variable than skeletal maturation.

From fifteen to twenty years of age, the radiographic assessment of dental age is confined to the development of the roots of the second and third molar teeth. The variable development of these teeth makes age assessment in this period less reliable (Sassouni, 1963, Gustafson, 1966 and Cottone and Standish, 1982). Miles (1963) however, indicated that age estimation from the radiographic assessment of the third molars, produced an error of not more than two years.

Beyond the age of twenty years, age assessment from the dentition is based upon non-radiographic data such as regressive changes in the structure of enamel, dentine, cementum and the peridental apparatus (Gustafson, 1962, Sassouni, 1963, Miles, 1963, Noble, 1976, Biggerstaff, 1977, Whittaker, 1981 and Parker, 1983).

6.3.1 Development of the Dentition

The deciduous dentition is initiated at approximately ten weeks in utero, by soft tissue ingrowths from the oral mucosa. Calcification of the cusps of these teeth becomes apparent histologically at about 12-16 weeks (Biggerstaff, 1977 and Whittaker, 1981) and radiographically at about 20 weeks in utero (Schour and Massler, 1941; Figure 24). Tooth formation continues until the completion of the roots of the second deciduous molar, at about 3½ to 4 years of age (Figure 25).

The permanent dentition commences calcification just before birth and extends over a nine-year period (Whittaker, 1981). The third molar does not commence calcification until approximately 8-9 years of age.

The permanent dentition progressively replaces the deciduous dentition from about seven to fifteen years (Cameron and Sims, 1974) and is complete by about twenty to twenty-five years of age (Figure 26 and Figure 27). During this period, the jaws contain teeth in various stages of development which reflect the age of the individual.

6.4 CHRONOLOGICAL CHARTS

In forensic investigations, radiographs of the dentition are compared with standard charts, developed from the radiographic data collected from dental surveys of children and young adults, which show the developmental stages of the dentition for each year of age.

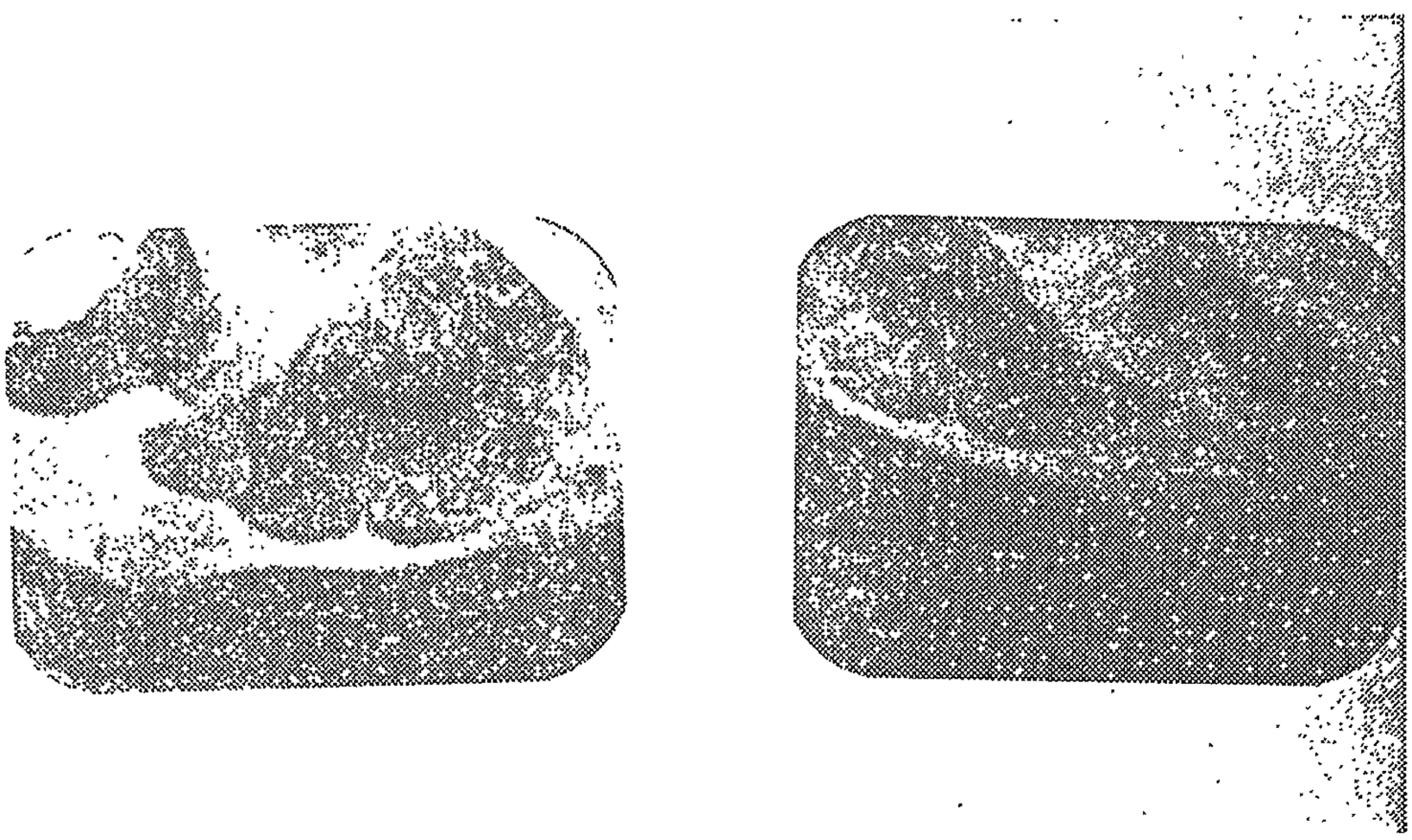


Figure 24. Lateral radiograph, upper and lower jaws, foetal skull.

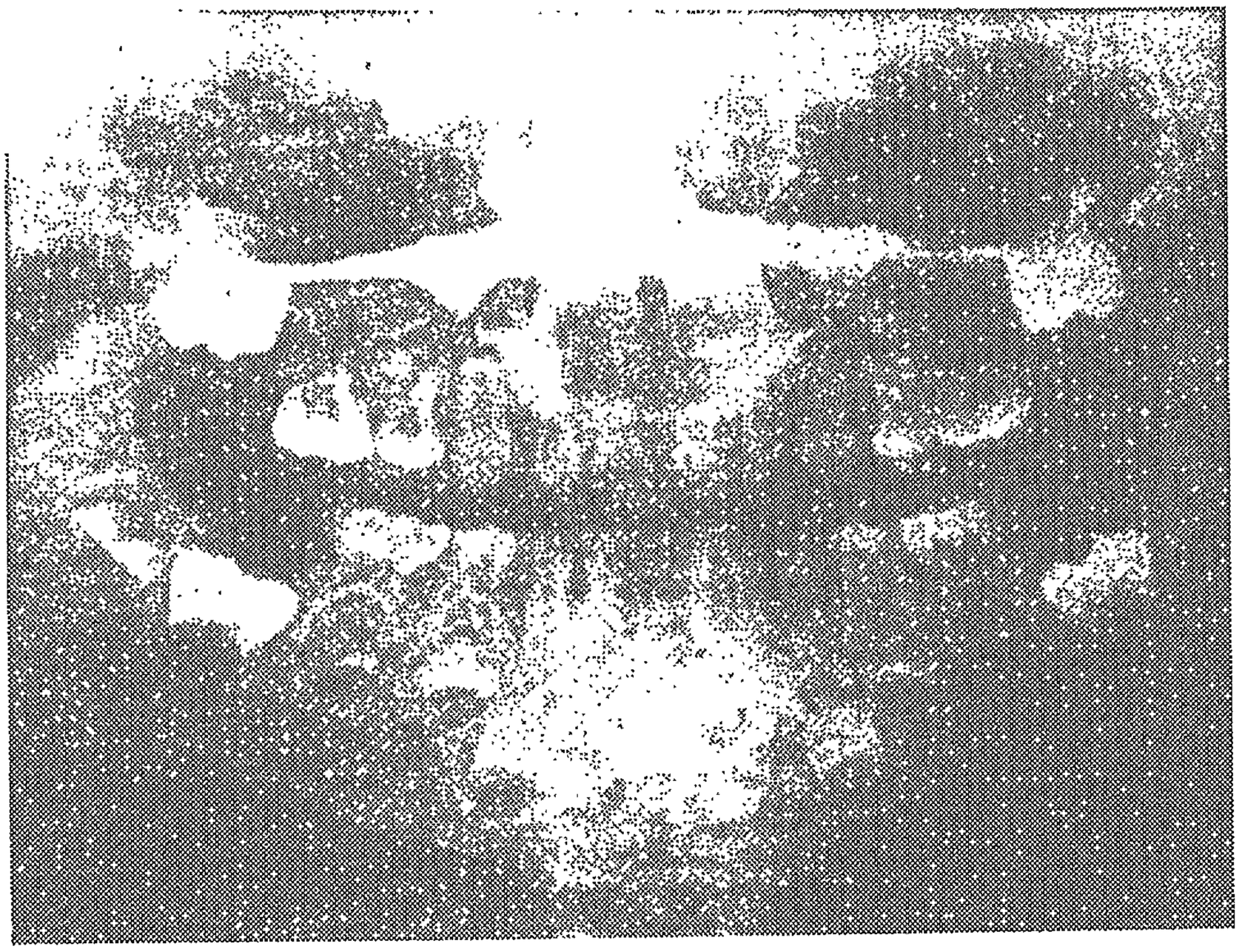


Figure 25. OPG 3-4 year old.
(Courtesy, Westmead Hospital
Dental Clinical School).

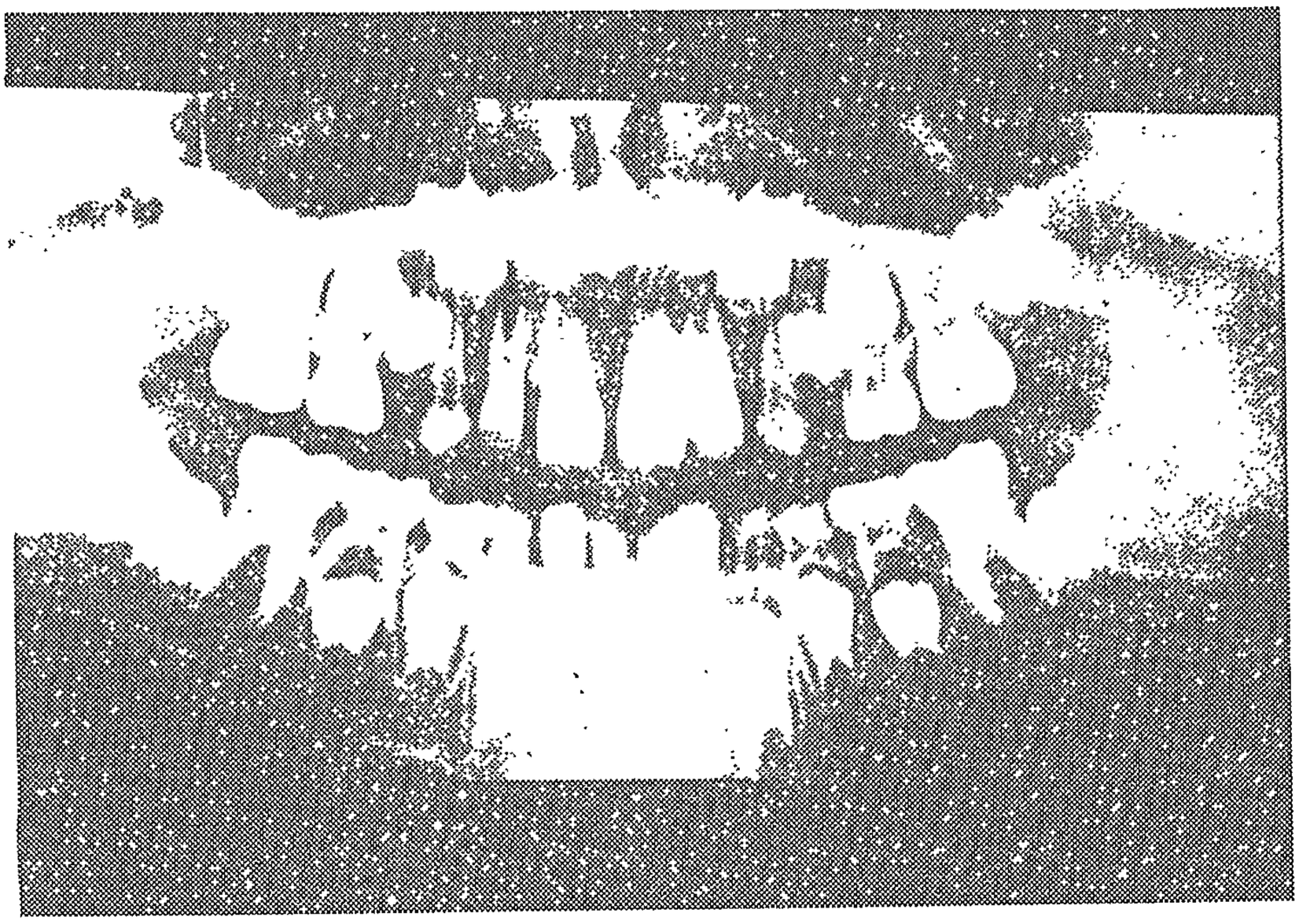


Figure 26. OPG 7 year old.
(Courtesy, Westmead Hospital
Dental Clinical School).

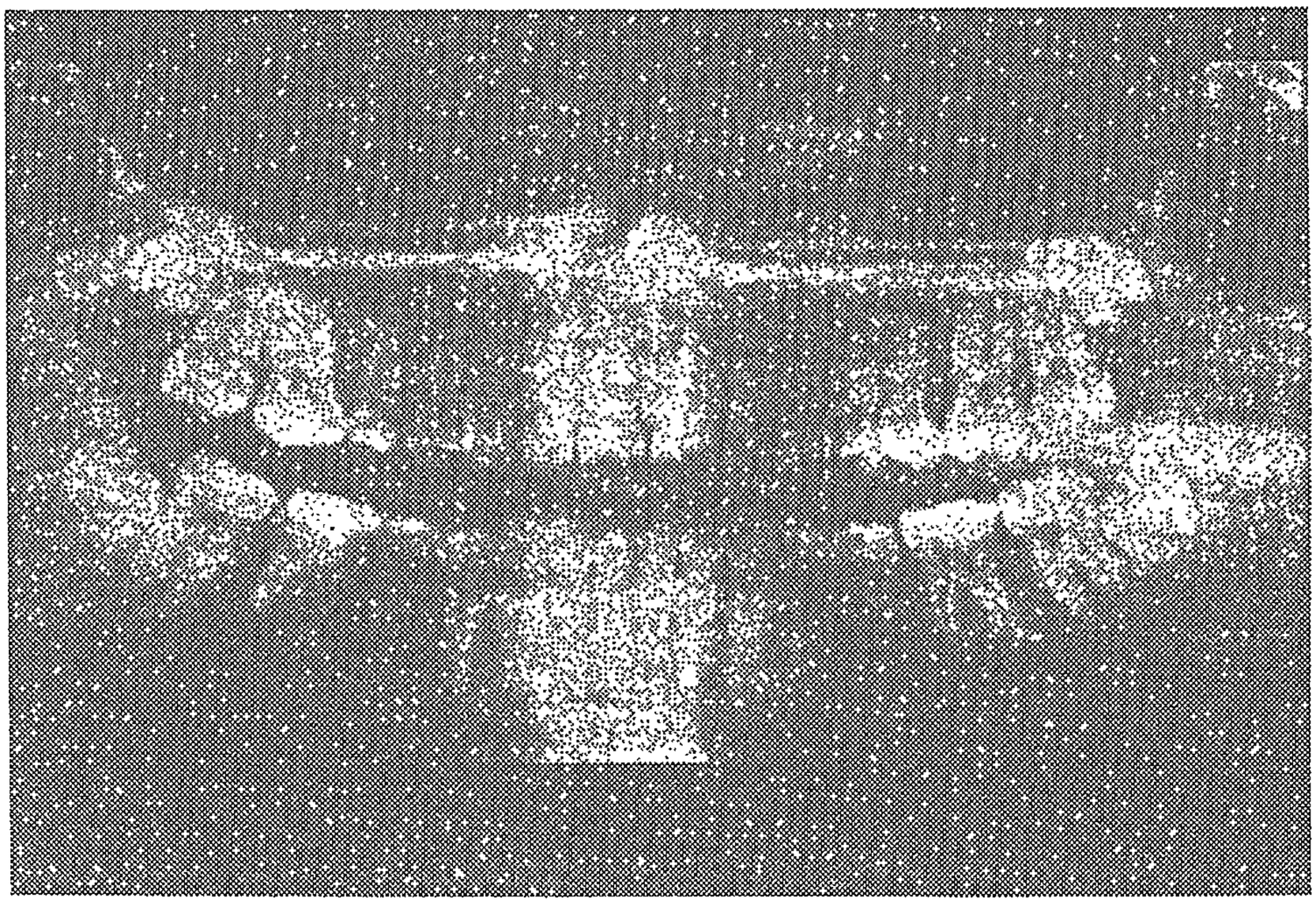


Figure 27. OPG 15 year old.
(Courtesy, Westmead Hospital
Dental Clinical School).

6.4.1 The Schour and Massler Chart

Schour and Massler (1941) prepared a developmental chart based to a large extent on the observations of Logan and Kronfeld in 1933 (Figure 28). This chart has received great acceptance, even though the data was based on a relatively small group of thirty children. The chart depicts chronological stages of tooth development, from five months in utero to thirty-five years of age. Growth stages for the third molar teeth are not recorded and therefore the chart is limited to ages up to fifteen years (Miles, 1963).

Whittaker (1981) suggests that the Schour and Massler chart may not accurately depict the range in variation of the various stages of development, because of the small sample size on which information was based. Biggerstaff (1977) however indicates that the chart is "remarkably accurate" and most valuable because it considers radiographic evidence of crown and root formation as well as eruption times.

Cameron and Sims (1974) described the forensic use of the chart:

> "Radiographs taken of the jaws for identification are compared with the chart, and the drawing which most nearly approximates to the state of tooth development shown in the radiograph will give an indication of the age. If the state of the development shown in the radiograph falls between two drawings an intermediate age estimation is made."

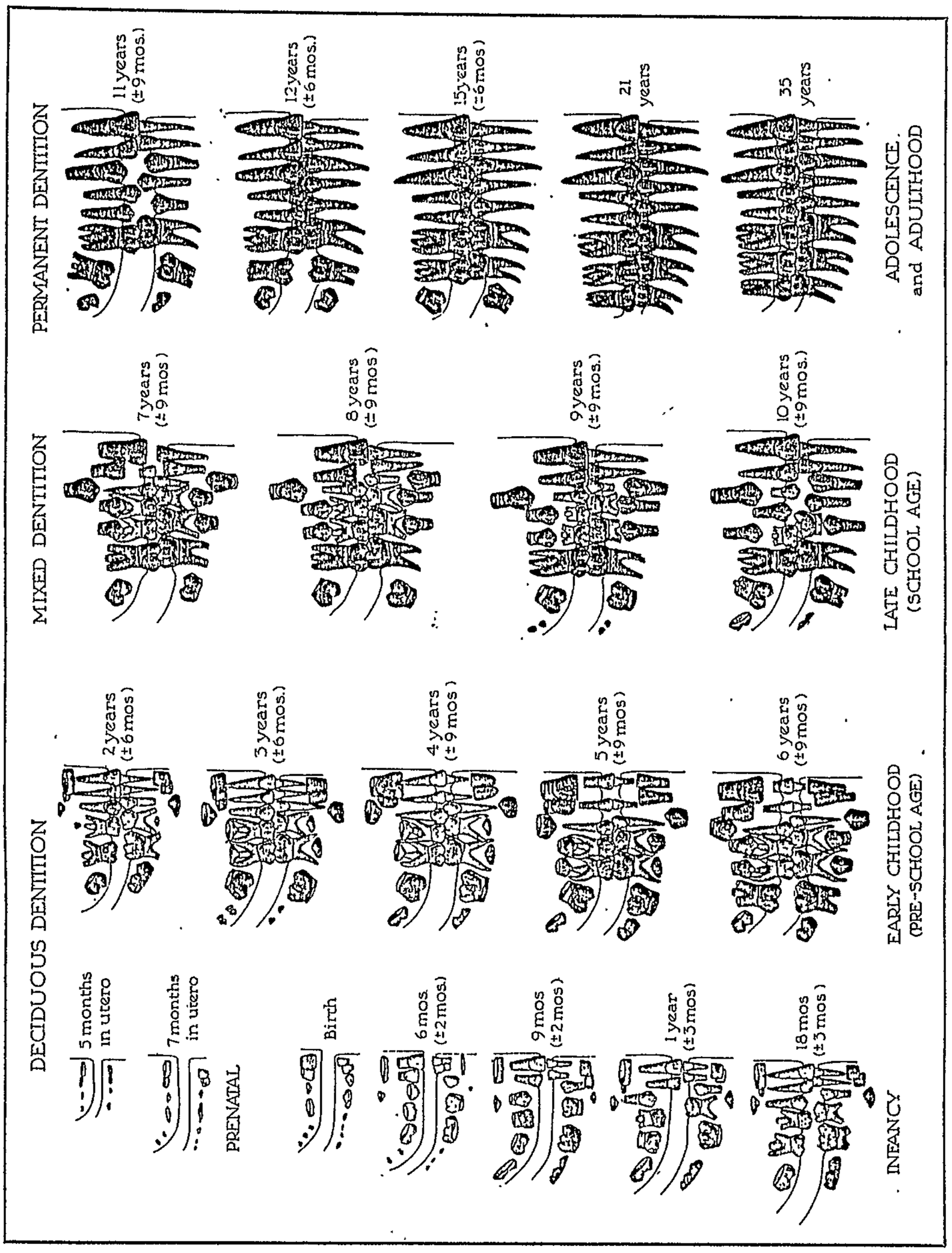


Figure 28. Dental Development Chart (Massler and Schour, 1941).

6.4.2 The Moorrees, Fanning and Hunt Chart

A more recent chart, developed in 1963 by Moorrees, Fanning and Hunt, recognises some of the limitations of the Schour and Massler chart. Moorrees, Fanning and Hunt (1963) conducted a longitudinal radiographic study of 134 children and presented data depicting, in graphic form, the mean ages of crown, root and root apex development; as well as standard deviations for both boys and girls, to the age of twelve years (Figure 29 and Figure 30).

Cameron and Sims (1974) indicate that when using this chart for radiographic comparisons, not only is the average age for attaining a developmental stage given, but also the range of the standard deviations on either side of that age. The range between these deviations represents the range in which 95% of the population would be expected to reach the appropriate developmental stage.

6.4.3 The Gustafson and Koch Chart

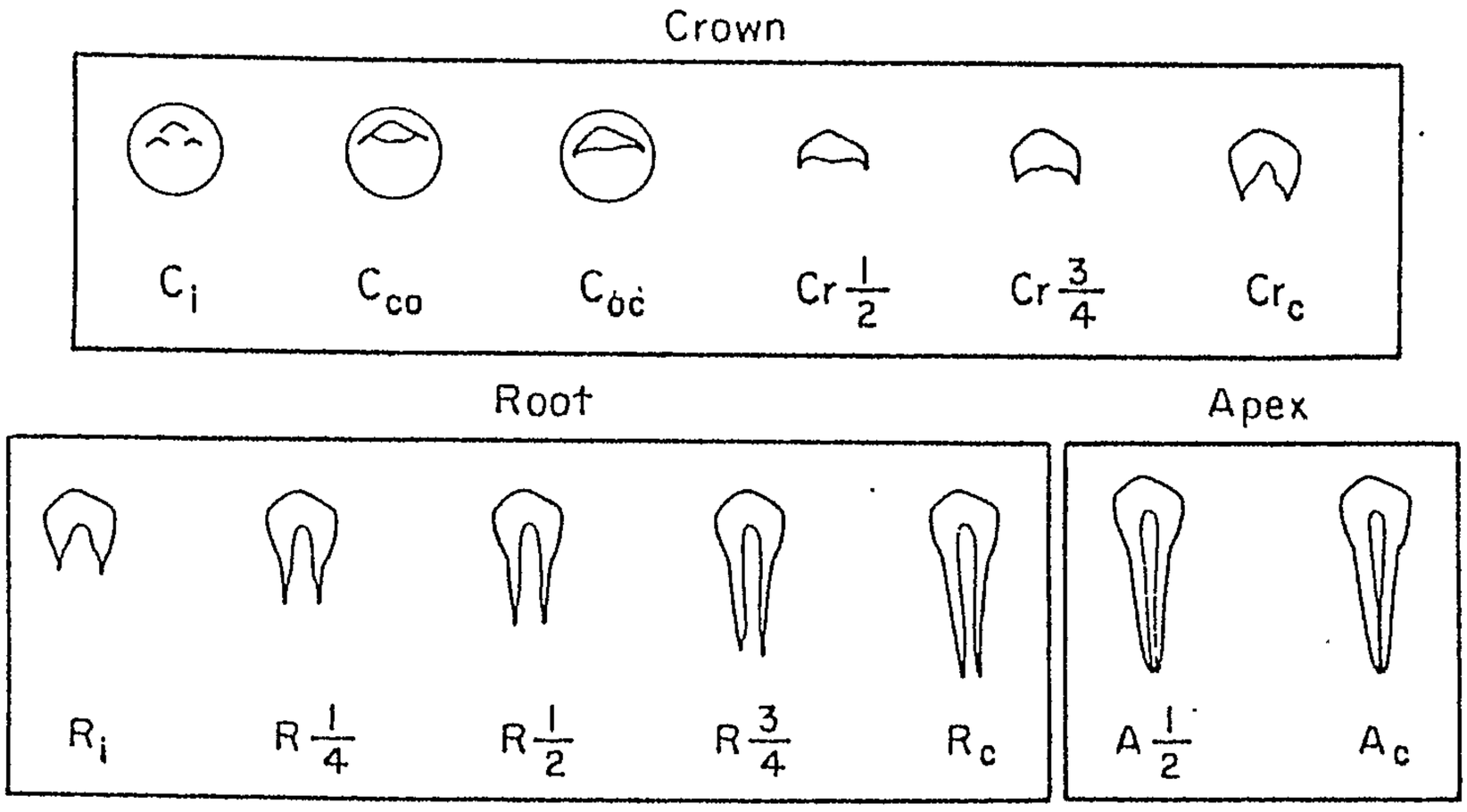
Gustafson and Koch (1966) developed a chart of the development of the dentition, based on the published works of various authors, including Logan and Kronfeld (1933), Schour and Massler (1941) and Lysell, Magnusson and Thilander (1964), covering the various stages of development, from one month in utero to sixteen years of age (Figure 31). The chart depicts various stages in tooth development, such as :-

(i) commencement of calcification

(ii) completion of crown formation

(iii) completion of eruption and

(iv) completion of root formation



Key:	Initial cusp calcification	Cl
	Coalescence of cusps	Cco
	Cusp outline completed	Coc
	Crown ½ complete	Cr½
	Crown 3/4 complete	Cr3/4
	Initial root formation	Rl
	Root ½ complete	R½
	Root ¼ complete	R¼
	Root 3/4 complete	R3/4
	Root length complete	Rc
	Apex ½ closed	A½
	Apex closure complete	Ac

Figure 29. Dental Development Chart
(Moorrees, Fanning and Hunt, 1963).

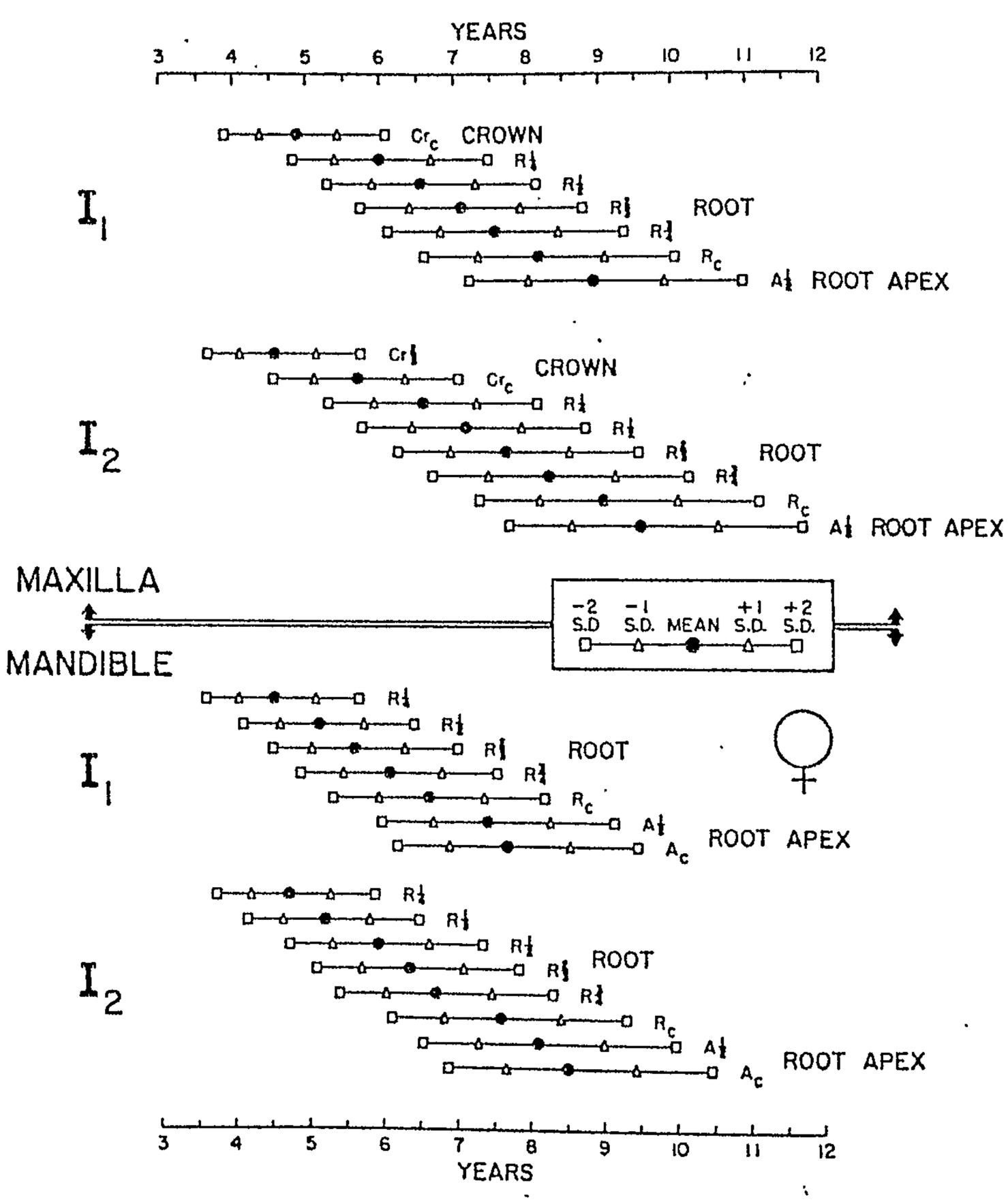
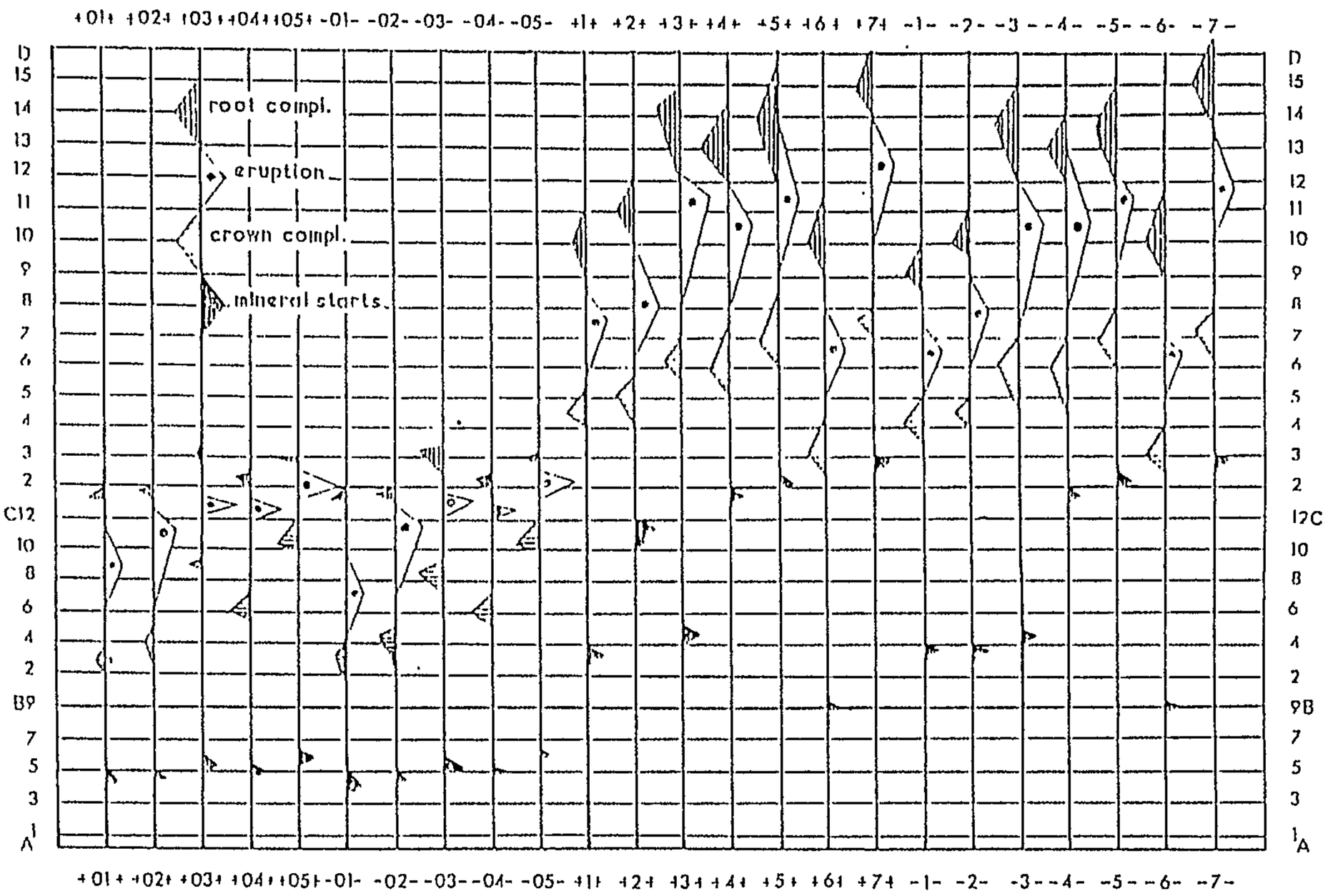


Figure 30. Dental development chart for upper and lower deciduous and permanent incisor teeth (Moorrees, Fanning and Hunt, 1963).



Diagrammatic representation of dental development
Each triangle represents one of four landmarks in tooth formation; the commencement of mineralisation, the completion of crown formation, eruption, or the completion of root formation. For each landmark, the apex of the triangle represents the average age, and the upper and lower angles the oldest and youngest ages encountered in the study.

Figure 31. (Gustafson and Koch, 1966).

and indicates the average age of each stage of development, as well as the earliest and latest ages at which the stages may be found.

Cottone and Standish (1982) adapted the Gustafson and Koch chart, clarifying the information presented (Figure 32).

Cameron and Sims (1974) suggest that the Gustafson and Koch chart is not as accurate as those mentioned above. The chart shows four stages of development for each tooth and it is not possible, therefore, to measure intermediate ages between the stages of crown and root formation, to be able to make comparisons with the results of Schour and Massler (1941) or Moorrees, Fanning and Hunt (1963).

6.5 RADIOGRAPHIC DEVELOPMENT OF THE THIRD MOLAR

The third molar is an extremely variable tooth in terms of its development. Miles (1963) reported the results of his studies of third molars and indicated that by eighteen years of age, the roots of the teeth are almost complete in length and that the apical foramina are beginning to close, having closed completely by twenty years of age. Furthermore, on radiographs, by the age of twenty-two years, the apical foramina are not only closed but are distinctly more constricted than at earlier periods.

Woods (1968) described the work of Dalitz (1963) based on a radiographic investigation of a "large number" of third molars in people between the ages of twelve and thirty years.

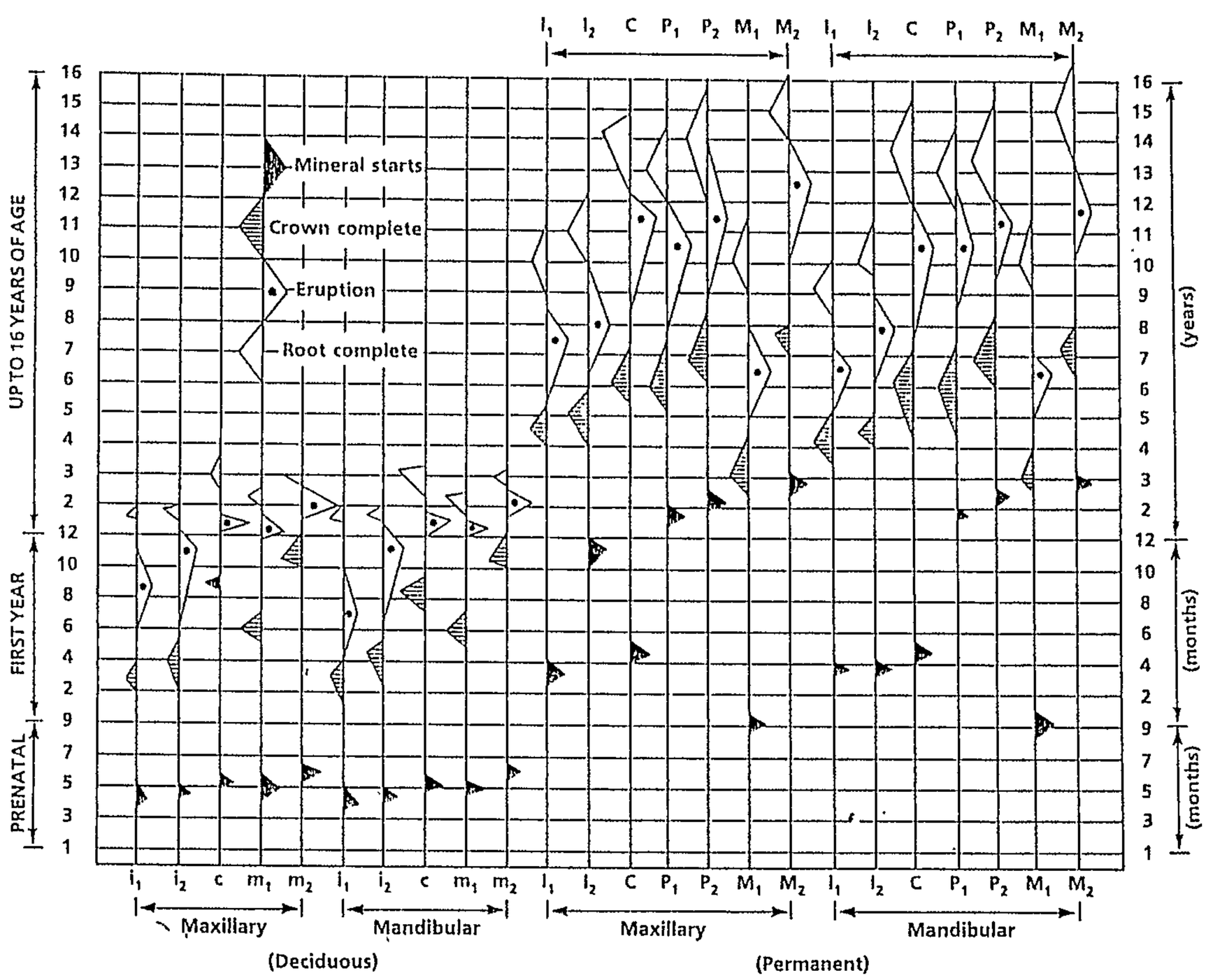


Figure 32. Dental development chart, Refinement of the Gustafson and Koch chart, 1963 (Cottone and Standish, 1982).

Radiographs were taken of each subject "at regular intervals under constant conditions of angulation and exposure". Dalitz (1963) concluded that :-

(i) where only the formation of the crown or early root development was exhibited, age may be considered as being nineteen years or younger.

(ii) Where the root formation was approximately equal in length to the length of the crown, age was considered to be fifteen to eighteen years, but with a variation of fourteen to twenty-two years.

(iii) Where root formation was almost complete but exhibited divergent root canal walls at the apex, age was considered to be fifteen to twenty-four years.

(iv) Where root formation was complete, indicated by convergent root canal walls at the apex, age was considered to be fifteen years or older.

Johanson (1971) in a radiographic study of 78 boys and 77 girls, having taken intraoral and panoramic films of 563 third molars, concluded that :-

(a) there was no significant difference between the development of molars in the upper and lower jaws neither on the right nor left sides.

(b) the most important time factors in the development of the third molar was the closure of the apex, i.e. the time when all third molars have completed their development.

(c) The earliest time for completion of development was 16.3 years and the latest time for completion was 20.2 years.

(d) The development of root formation begins after 14 years of age and is usually fully completed after 20 years of age, and

(e) that the radiographic evaluation of the development of the third molars with respect to age determination in forensic investigations, can be considered as a complement to other methods of age determination in the range of 14 to 20 years.

6.6 RADIOGRAPHIC CORRELATION OF HAND, WRIST AND TOOTH DEVELOPMENT

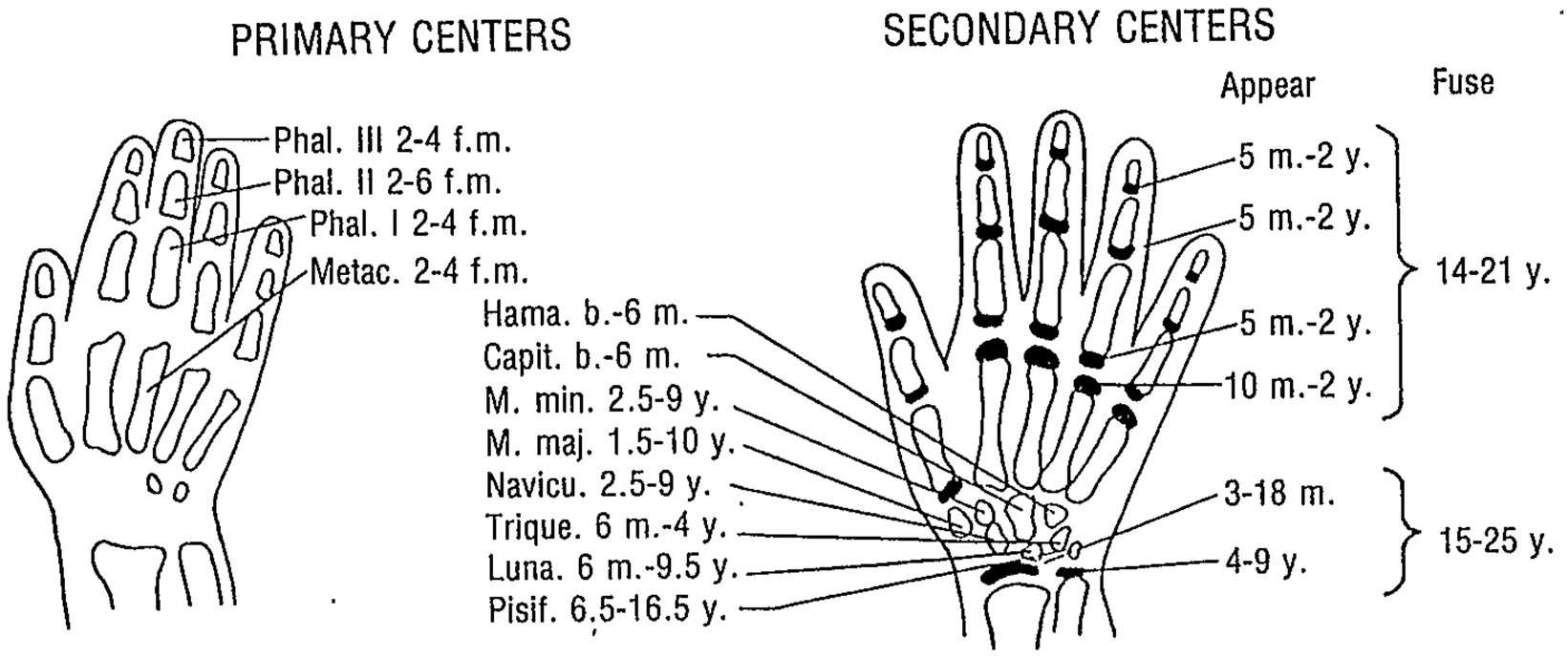
Bone is a dynamic substance, with ossification and resorption proceeding continuously throughout life. The value of age estimation from the bones, is due to the fact that, until the early 20's, the developmental processes of bone growth and maturation are able to be observed (Sopher, 1976).

Skeletal maturation is greatly influenced by sex. Marshall (1976) indicated that at every chronologic age, to full skeletal maturity, the developmental age of females is in advance of males.

Maturation and developmental change may be observed in every part of the skeleton and is able to be identified readily in the transformation of fibrous tissue and cartilage into bone. Radiographic studies, to record these developmental growth and maturation changes of the skeleton have been conducted, for every age group from birth to adulthood (Greulich and Pyle, 1959, Hoerr and Pyle, 1962 and Roche, Wainer and Thissen, 1975) and charts derived from these studies are useful in forensic investigations, as a means of age assessment.

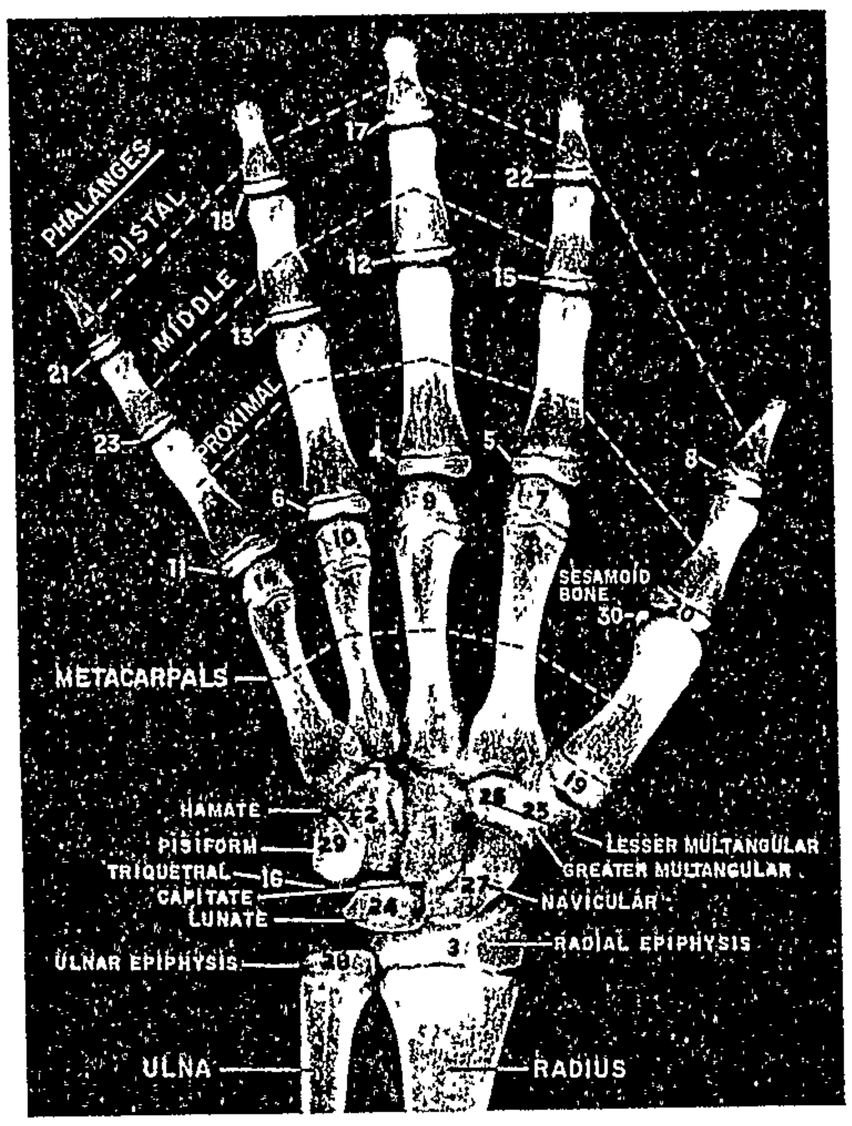
Hand and wrist radiography is a particularly useful adjunct to radiographic assessment of the dentition, in age assessment, for forensic purposes (Gleiser and Hunt, 1955). The appearance of primary and secondary centres of ossification in the hand and wrist, and the progressive enlargement of the ossified portion of an epiphysis (known to occur at specific times) or of a short bone, can be assessed by the comparison of antero-posterior radiographs of the hand and wrist, with developmental charts (Figure 33 and Tables 2 and 3).

Marshall (1976) referring to the often extensive individual variation in the maturation of the skeleton, determined that even so, skeletal maturation proceeded "roughly parallel" with skeletal and dental growth. Miles (1963), however, suggested that when the sex of



f.m. = fetal months; b. = birth; m. = postnatal months; y. = years

—Development of the bones of the hand and wrist.



—Bones of the hand and wrist.

Order of onset of ossification of bone growth centers

1. Capitate
2. Hamate
3. Distal epiphysis of the radius
4. Epiphysis of proximal phalange of third digit
5. Epiphysis of proximal phalange of second digit
*6. Epiphysis of proximal phalange of fourth digit
7. Epiphysis of the second metacarpal
8. Epiphysis of distal phalange of the first digit
9. Epiphysis of the third metacarpal
10. Epiphysis of the fourth metacarpal
11. Epiphysis of proximal phalange of fifth digit
12. Epiphysis of middle phalange of the third digit
13. Epiphysis of middle phalange of the fourth digit
14. Epiphysis of the fifth metacarpal
15. Epiphysis of middle phalange of second digit
16. Triquetral
17. Epiphysis of distal phalange of the third digit
18. Epiphysis of distal phalange of the fourth digit
19. Epiphysis of the first metacarpal
20. Epiphysis of proximal phalange of the first digit
21. Epiphysis of distal phalange of the fifth digit
22. Epiphysis of distal phalange of the second digit
23. Epiphysis of middle phalange of the fifth digit
*24. Lunate
*25. Greater multangular (trapezium)
*26. Lesser multangular (trapezoid)
*27. Navicular (scaphoid)
28. Distal epiphysis of the ulna
29. Pisiform
30. Sesamoid of adductor pollicis

*Irregularities in the order of appearance are most apt to occur in these centers.

Figure 33. Ossification centres of the hand and wrist (Marshall, 1976).

—Correlation of dentition and hand calcification

First evidence of calcification of deciduous teeth		Calcification of primary centers of the hand	
Central incisors	5 F.M.	Metacarpals	2-4 F.M.
Lateral incisors	5 F.M.	Proximal phalanges	2-4 F.M.
Cuspids	6 F.M.	Middle phalanges	2-6 F.M.
First molar	5 F.M.	Distal phalanges	2-4 F.M.
Second molar	6 F.M.		
Eruption of deciduous teeth		**Beginning of calcification in the hand**	
Central incisors	6-8 M.	Hamate	B.-6 M.
Lateral incisors	8-10 M.	Capitate	B.-6 M.
Cuspids	16-20 M.	Epiphyses of the distal, middle and proximal phalanges appear	5 M.-2 Y.
First molar	12-16 M.	Epiphyses of the metacarpals appear	10 M.-2 Y.
Second molar	20-30 M.	Epiphysis of the radius appears	3-18 M.
		Triquetral	6 M.-4 Y.
		Lunate	6 M.-9.5 Y.

Legend • F.M. Fetal months • B. Birth • M. Postnatal months • Y. Years

Table 2. Developmental chart (Marshall, 1976).

–Dentition eruption sequence

First evidence of calcification (Maxilla)		Eruption of permanent teeth
Central incisors	3-4 M.	7- 8 Y.
Lateral incisors	1 Y.	8- 9 Y.
Cuspids	4-5 M.	11-12 Y.
First bicuspid	1½-1¾ Y.	10-11 Y.
Second bicuspid	2-2¼ Y.	10-12 Y.
First molar	B.	6- 7 Y.
Second molar	2½-3 Y.	12-13 Y.
Third molar	7-9 Y.	17-21 Y.
First evidence of calcification (Mandible)		**Eruption of permanent teeth**
Central incisors	3-4 M.	6- 7 Y.
Lateral incisors	3-4 M.	7- 8 Y.
Cuspids	4-5 M.	9-10 Y.
First bicuspid	1¾-2 Y.	10-12 Y.
Second bicuspid	2¼-2½ Y.	11-12 Y.
First molar	B.	6- 7 Y.
Second molar	2½-3 Y.	11-13 Y.
Third molar	7-10 Y.	17-21 Y.

Legend • F. M. Fetal months • B. Birth • M. Postnatal months • Y. Years

Table 3. Developmental chart (Marshall, 1976).

human remains was known, an allowance could be made for the fact that tooth development in females was more advanced than in males, at all stages, even before puberty; the differences in development being approximately one month in infancy and four months at 9 years of age.

Considering osseous development, sex differences with regard to the female were up to three times greater than those for tooth development, over a similar period. In skeletal material of unknown sex, estimates of age based on the assessment of the teeth were more likely to be correct than estimates based on osseous development.

In 1965, Steel undertook to determine the exact relationship between dental age and skeletal age, by examining lateral jaw radiographs and hand, wrist radiographs of a group of twelve year old children. No correlation was found between the degree of skeletal maturity and the degree of dental development in the group studied. These results were contrary to those achieved by Gleiser and Hunt in 1955, who found that the skeletal and dental ages corresponded very much in the male, but in the female, the skeletal age was found to be about one year ahead of the dental age.

Cottone and Standish (1982), referring to age assessment in forensic dentistry, concluded that:

> "... age assessments made by experienced forensic anthropologists and odontologists are usually in fairly close agreement and both skeletal and dental estimates are subject to about the same degree of error."

7. DENTOFACIAL RADIOGRAPHY IN IDENTIFICATION

Medico-legal identification depends upon sets of individual characteristics, that a person possesses, which make him an unique being. These characteristics can be used to single that person out of a large population and to identify him.

Sassouni, in 1963, said :

> "In our civilisation the face and hands are the only remnants of the original nakedness of man. As such, they are more accessible, more familiar socio-biologically, and have been extensively studied. It is not surprising that these parts have been used commonly for identification purposes, ..."

Modern dental science is concerned with the entire craniofacial complex, not just the teeth and adjacent structures. Dentists therefore, are experts on the growth and development of the skull and the contribution that this structure makes to facial characteristics used in identification.

Radiography is an essential part of the diagnosis and treatment of conditions of the teeth and jaws; so much so, that almost every patient who has had a course of treatment, will have had radiographs taken showing various features of these structures. Under certain circumstances, radiographs may have also been taken of the craniofacial structures, e.g. in oral surgery and orthodontics

In forensic dentistry, pre-existing dental and facial radiographs are a considerable aid to antemortem dental record charts and often provide valuable information not previously recorded, and are

extremely valuable for positive examination and identification, when compared with postmortem radiographs of unknown human remains.

Information that may be derived from radiographs includes such detail as the incidence of dental caries and periodontal bone loss, the specific morphology of restorations, the presence of linings under restorations, intertooth relationships, root angulations, tooth and pulp chamber outlines, bony trabecular patterns, periapical pathology, root canal therapy and the presence of retained root apices following previous extractions. In cases of previous oral surgery or prosthetic treatment, implanted wires, plates or other devices may be detected, related to jaw fractures or remodelling procedures.

With regard to forensic examinations, Cameron and Sims (1974) stated:

> "Radiological examination ... can be performed without tissue removal, and it should be carried out early in an investigation, and not as an after-thought! The radiological appearance of teeth, and of the bones of the face, is a permanent record of those tissues, and is available for reference even when teeth, and sections of bone, have to be removed for histopathological examination."

7.1 RADIOGRAPHIC APPARATUS

In the investigation and identification of unknown human remains, radiography of the dental structures is an important aspect of the procedures undertaken.

Most hospital mortuary facilities have access to radiographic apparatus for whole body radiography, but rarely have machines capable of being used for dental purposes (Griffiths, 1977 and Parker, 1983). Machines generally available are unacceptable for dental radiography because of the size and limited angulation of the tube head.

In the writer's experience, in cases involving decomposition, mutilation or severe burning of the head, it is often preferable to remove the jaws and complete the dental examination and radiography in a dental facility, under ideal conditions.

In cases of mass disaster, where temporary mortuary facilities need to be established, portable radiographic equipment is particularly useful and should have a tube head which is small and flexible, easily positioned and be capable of not only whole body radiography, but radiography of dental structures as well. Cameron and Sims (1974) suggest that the kilovoltage of such a machine should be adjustable within the range of 60 kV and 90 kV.

7.1.1 Portable Radiography Units

Griffiths in 1977 mentioned that forensic dental teams should have access to portable dental radiographic machines and indicated that in Europe and Australasia, the Philips portable Oralix and, in the United States, the Min-X-ray, were the machines commonly used. The Min-X-ray is the lighter and more portable machine, operating on a 110-130 volt, 60 cycle AC power supply. The Philips

portable Oralix operates on either 240 volt, 50 cycle AC or 110-130 volt, 60 cycle AC power supplies.

Frommer in 1981 made reference to the Siemens Portaray transportable X-ray examination unit, as a machine capable of being easily used for the dental radiography of bed-ridden patients. Such a machine would obviously be suitable for forensic purposes.

7.1.1.1 Flash radiography units

The flash radiography unit is a machine which operates on the field emission electron principle. The technique of taking radiographs with the unit is comparable to the taking of photographs with a flash of light. An intense beam of X-rays may be produced for periods as short as 1/10,000,000 of a second, with this apparatus. A conventional mains power supply or a battery system may be used to operate the unit.

In 1973, Weuhrmann and Manson-Hing described a portable flash radiography unit weighing approximately 20kg with a tube head housed in a probe-like assembly, connected to the unit by a flexible cable.

A refinement of the above unit is the "Bendix-Ray Model 105". This unit, together with controls, weighs less than 7kg and also has the capacity of operating from a mains power supply or battery system, making it a very versatile unit (Figure 34).

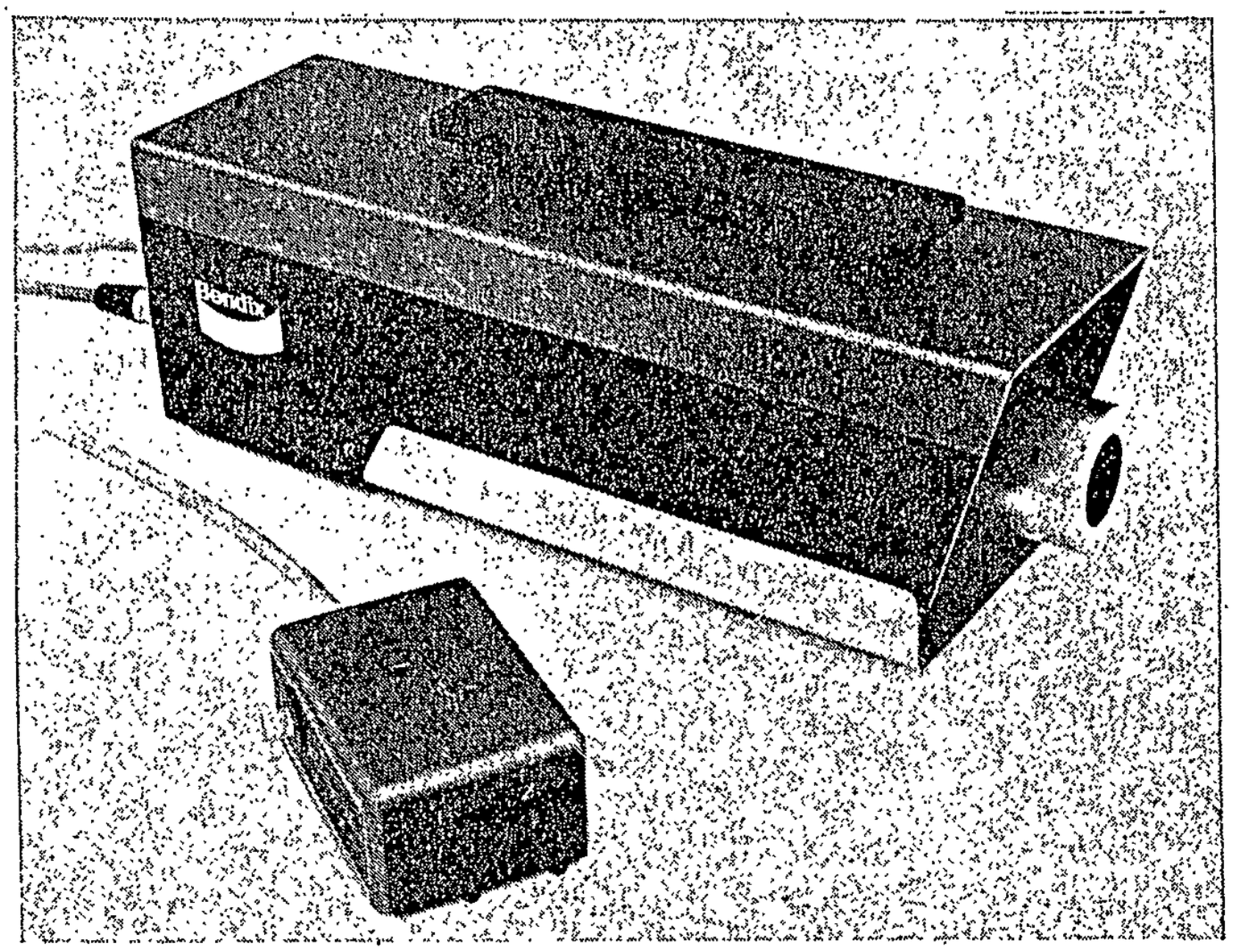


Figure 34. The "Bendix-Ray Model 105" Flash Radiography Unit (Cameron and Sims, 1974).

The technical characteristics of the "Bendix-Ray Model 105", as described by Cameron and Sims in 1974 are :-

" (i) A 'Cold Cathode', pulsed x-ray unit operating on the principle of field emission.

(ii) A pulse rate of five pulses per second with the duration of each pulse of 40 nanoseconds.

(iii) A dose per pulse of one milliroentgen at a distance of 30 cms. This is with built-in 2.5 mm aluminium filter.

(iv) A beryllium window.

(v) kVp rating is 110.

(vi) The diameter of the focal spot is 1.5 mm."

This type of unit is intended to be used where low-dose radiographs are needed and can be set up for permanent bench type use or can be easily transported to remote sites and operated with the optional battery converter.

7.1.1.2 The Iodine 125 unit

The need for an easily transportable radiographic unit, capable of being used for identification purposes in remote sites, led to the development of a miniature radioactive roentgen apparatus, using radioactive Iodine 125 as the radiation source (Henrikson, Soremark and Frykholm, 1962). Cameron and Sims (1974) indicate that this apparatus is extremely useful in forensic examinations, especially where large numbers of bodies are involved, e.g. the Super Caravelle aircraft accident near Dubai in the Persian Gulf as described by Frykholm, Henrikson and Frykholm in 1973.

The unit is approximately the size of a ballpoint pen (Griffiths, 1977) and is activated by a means similar to a photographic release cable.

The unit is essentially a sealed metal tube with a rod inside, (Parker, 1983). The radioactive nucleotide is deposited at the end of a silver wire 0.5 mm in diameter on a 1 mm ball of resin, which is shielded in a chamber (Cameron and Sims, 1974). The Iodine 125 is advanced from the chamber to produce an X-ray exposure (Figure 35) at an emission level of 27.4 KeV (Henrikson, Soremark and Frykholm, 1962). This is just above the K-edge of silver in the silver bromide grains in photographic emulsions, meaning that there will be a good relation between the response in the emulsions of the film and the dose retained in the exposed material (Henrikson, Soremark and Frykholm, 1962, Graham and Corless, 1970 and Parker, 1983).

In use, the head of the apparatus is introduced into the mouth, between the teeth or through an appropriate gap in the occlusion. In cases of severe burning of the head, access to the oral cavity may be obtained by inserting the apparatus into an opening created in the floor of the mouth, by introducing a trochar and cannula from a submandibular approach (Cottone and Standish, 1982). Exposures of from 3 to 6 minutes are required for the teeth and surrounding structures, depending of the age of the Iodine 125 (Cameron and Sims, 1974), which has a half-life of sixty days.

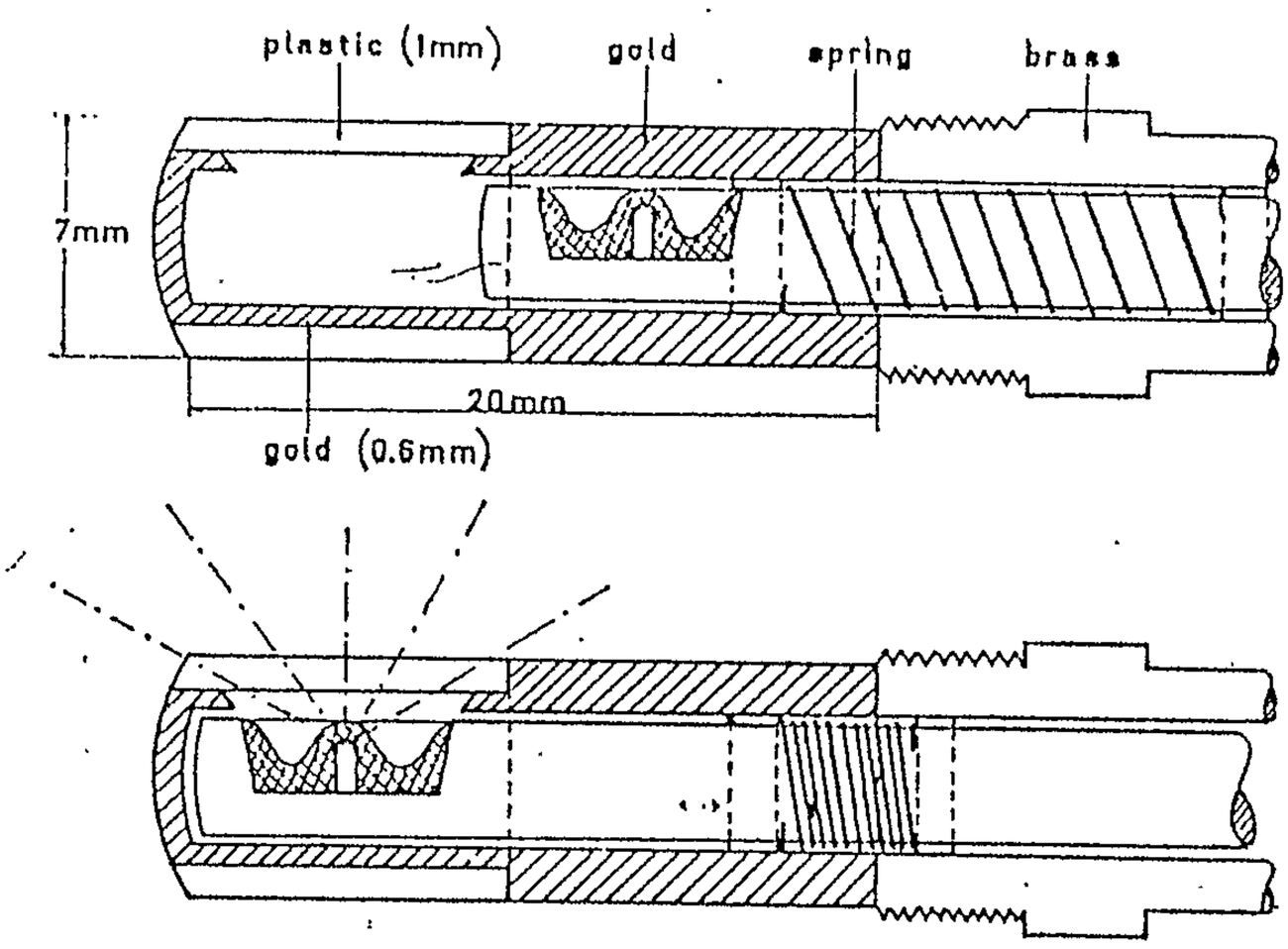


Figure 35. Diagramatic representation of the internal parts of the Iodine 125 radiation source (Frykholm, Henrikson and Frykholm, 1973).

A panoramic film of the teeth and jaws or conventional dental radiographs may be produced, using appropriate film holders (Gustafson, 1966). Frykholm, Henrikson and Frykholm (1973) suggest that, in difficult circumstances, dental film with built-in developing and fixing solutions such as the "Phil X-30" may be used to good advantage with this radiographic unit, making dark-room or portable processing facilities unnecessary.

Two principal disadvantages of the Iodine 125 unit as explained by Cottone and Standish (1982), limiting its use are:-

(a) "The radiation source is expensive as it is prepared by neutron irradiation of Xenon 124, and"

(b) "once prepared it has a half-life of sixty days. As decay progresses in an even progression, the exposure time must be proportionally increased."

7.1.2 Panoramic Radiographic Units

Panoramic radiography is a technique that produces a broad view of the maxillary and mandibular dental arches and their associated structures (Frommer, 1981).

Cottone and Standish (1982) describe the technique as highly reliable and that it is able to circumvent some of the problems associated with conventional postmortem radiographic techniques. For practical purposes though, a machine capable of accommodating a body in a prone position is required and these are generally not readily available.

7.1.3 Processing Facilities

The processing of radiographs in hospital facilities is rarely a problem, but can be a major problem in field facilities established in remote sites (Lichtenstein, Madewell, McMeekin, Feigin and Wolcott, 1980).

Cameron and Sims (1974) suggest that the processing of exposed film should, if possible, be carried out at the site of the forensic investigation. This will enable radiographs to be examined quickly and enable repeat radiographs to be taken if necessary. Griffiths (1977) indicated that in such circumstances, a light-weight, self contained developing unit such as the "Prilomat" is ideal and obviates the need for dark room facilities.

In circumstances where many victims are being examined and both dental and larger films need to be processed, quality assurance is a prime consideration (Petersen and Kogan, 1971) and it may be advantageous to send films for processing to a large hospital facility.

As mentioned above, the use of dental film with built-in developer and fixer, such as the "Phil X-30" (Figure 36) which enables the radiograph to be processed whilst still in its original packet, is a very good alternative to conventional processing methods (Frykholm, Henrikson and Frykholm, 1973, Cameron and Sims, 1974 and Griffiths, 1977).

Wing, Soremark and Hulting (1971) described the use of Polaroid

EXPOSURE CHART

	OBJECT	ANGLE	TIME 60 Kv 10 mA	TIME 90 Kv 15 mA
Maxillary	Molars	+ 35°	0,8	0,5
	Bicuspids	+ 45°	0,6	0,35
	Cuspids	+ 50°	0,5	0,3
	Incisors	+ 55°	0,5	0,3
Mandibular	Molars	—5 °	0,6	0,35
	Bicuspids	—10°	0,5	0,3
	Cuspids	—15°	0,4	0,25
	Incisors	—20°	0,4	0,25

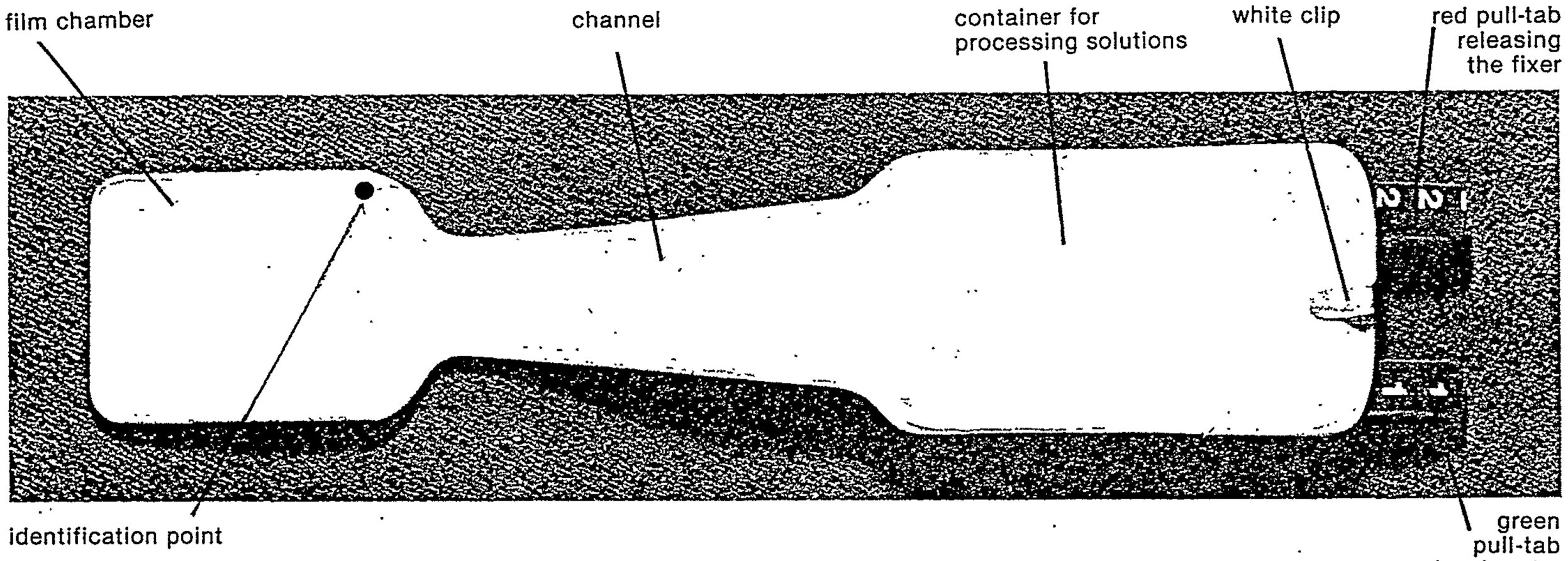


Figure 36. **PHIL-X S.p.A.** (Advertising pamphlet)

Land film as an alternative to conventional techniques, with the radioactive Iodine 125 radiographic apparatus. This may also be used with units such as the "Bendix-Ray Model 105" or other portable radiographic units for views such as the oblique lateral of the mandibular body and ramus.

Lichtenstein et al (1980) stress that accurate labelling of all films taken should be an important part of the radiographic process and examination procedure.

7.2 DENTAL RADIOGRAPHS

Cameron and Sims (1974) outlined the uses to which dental radiographs may be put in postmortem identification procedures as :-

> "(i) For direct comparison between antemortem and postmortem radiographs.
>
> (ii) To reveal hidden details present in the jaws and teeth of the victim, and recorded on the original dental chart, but where no antemortem radiographs can be found. The postmortem films can demonstrate the presence of details not visible on clinical examination .... This knowledge helps considerably in the process of exclusion.
>
> (iii) To elucidate insufficent antemortem clinical charting. A dental practitioner when charting work on the dental diagram may record only that done by himself and show no previous conservation or extractions. Similarly, congenital or acquired abnormalities not recorded may be visible on the antemortem radiographs."

7.2.1 The Dentition

The normal adult dentition is comprised of 32 teeth, which are

subject to variations of size, shape, presence or absence and angulation within the alveolar processes. Apart from the absence of teeth, the features mentioned may appear to change, according to the angulation of the X-ray beam at the time of the radiographic exposure (Whittaker, 1981).

For identification purposes, properly exposed, developed and mounted dental radiographs are as good, if not better, than fingerprints (Cottone and Standish, 1982).

7.2.2 Tooth Shape

The crowns of teeth are extremely useful in comparison exercises (Whittaker, 1981) but, because of the variability of crown shape that may occur through dental caries or the loss of restorations, the roots of the teeth may be more useful to the forensic dentist, for comparison purposes (Cameron and Sims, 1974 and Whittaker, 1981). The roots of teeth tend to retain their shape and angulation and are often an identifying feature when postmortem radiographs are compared to antemortem radiographs. This is so, even following such devastating effects to the oral tissues as may be caused by severe burning or mutilation.

As with crown shape, root shape is also very variable. The roots may be curved in various directions and often show change in progressive radiographs as the result of cementum apposition or by resorption (Cameron and Sims, 1974).

The variability of tooth shape increases correspondingly, when the tooth has more than one root. The angulation of the tooth in the socket relative to other teeth or to the alveolar crest (Figure 37), may be characteristic and an identifying feature, even when no other teeth are visible on a particular radiograph.

Radiographic features noted by the forensic dentist in comparison exercises include: the size and shape of the pulp chamber, the relationship of the cemento-enamel junction to the alveolar crest, root shape and angulation, periodontal membrane width, the lamina dura, the root apex and the relationship of both periodontal membrane and lamina dura to the apex of the tooth.

Apparent inconsistencies may be seen during radiographic comparisons where the roots of the teeth, either on the antemortem radiograph or postmortem radiograph are superimposed. In such instances, the angle of projection of the postmortem radiographs should be changed, to correspond to that of the antemortem radiograph (Mertz, 1977, Lichtenstein et al, 1980, and Whittaker, 1981).

Pedersen, in 1965, described the Dobkin murder, a classic case in which the roots of only a single tooth were present on postmortem radiographs. Comparison with antemortem radiographs, taken eight years previously, led to a positive identification of the victim.

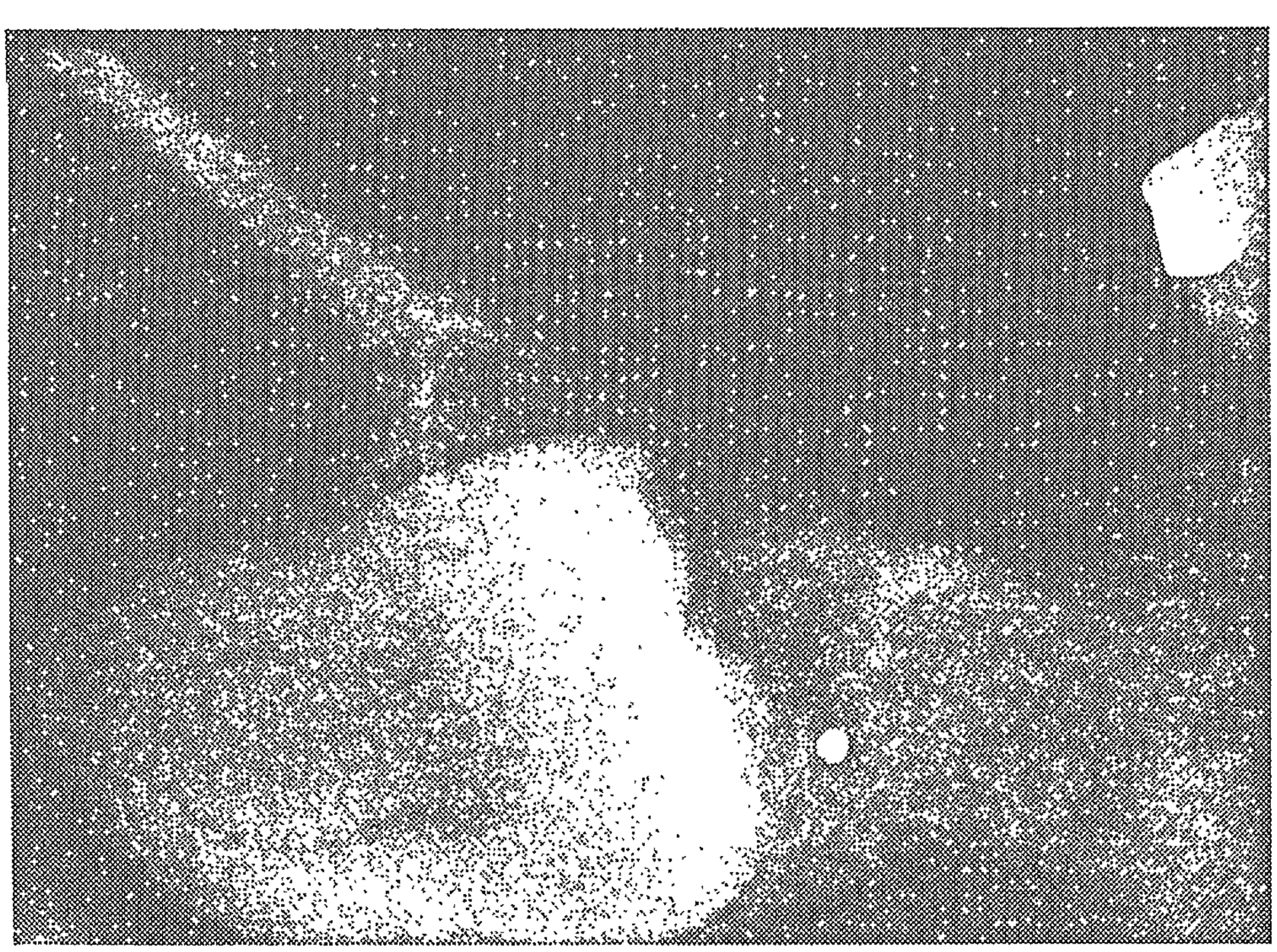


Figure 37. Tooth shape and position (postmortem radiograph).

7.2.3 Dental Caries

Dental caries is a common and progressive disease and for this reason, in the opinion of Cameron and Sims (1974), is not reliable in establishing identification. Whittaker (1981), however, suggests that the distribution of carious lesions as depicted on radiographs, especially bitewing radiographs, may be unique for a particular person and be of some value for identification purposes.

An interesting feature of dental caries is that the process arrests at or shortly after death.

Special care should be taken when comparing antemortem radiographs with the postmortem record, such that initially depicted lesions on the radiographs are checked against the treatment card to ensure that the carious area was not removed and replaced by a restoration (Griffiths, 1977).

An important consideration is the date of the antemortem radiograph. The main reason for taking radiographs is to demonstrate interproximal carious lesions, not obvious on visual examination (Sopher, 1976). Affected teeth, in the course of treatment, are usually restored or extracted and, for this reason, the most recent antemortem radiograph provides a more accurate and less confusing evaluation, for the purposes of comparison.

7.2.4 Restorations

The restoration of a carious lesion in a tooth will produce a distinctive and usually unchangeable pattern in the cavity shape of

the restoration (Mertz, 1977 and Whittaker, 1981). This remains the case until the restoration is either removed for replacement or lost. Silicate cements, used in former years for the restoration of anterior teeth, may present exceptions. This material has a high solubility in saliva as do some of the lining materials placed under permanent restorations. These may show radiographic change on subsequent radiographs.

Akester in 1979 reported that lining materials of the calcium hydroxide type, e.g. "Dycal", may become completely absorbed below amalgam restorations and comparison of antemortem and postmortem radiographs in these circumstances may be difficult.

The majority of restorative materials are radiopaque and are very distinctive on radiographs (Cameron and Sims, 1974, Mertz, 1977 and Whittaker, 1981). The more complicated the shape of a restoration, the more useful it will be in identification procedures. The angle of projection of the antemortem radiograph must be appreciated however, such that confusion does not arise when comparisons are made with postmortem radiographs (Figure 38).

In cases where more complex restorations, such as crowns and bridges have been placed, identification has been able to be proven, even when the restorations have been found out of the mouth (Gustafson, 1966). Such an example was described by Waaler, in 1960, following a hotel fire in Norway. Radiographs of a bridge and two metal fillings soldered together, were compared with antemortem radiographs of two of the suspected victims which demonstrated identical features.

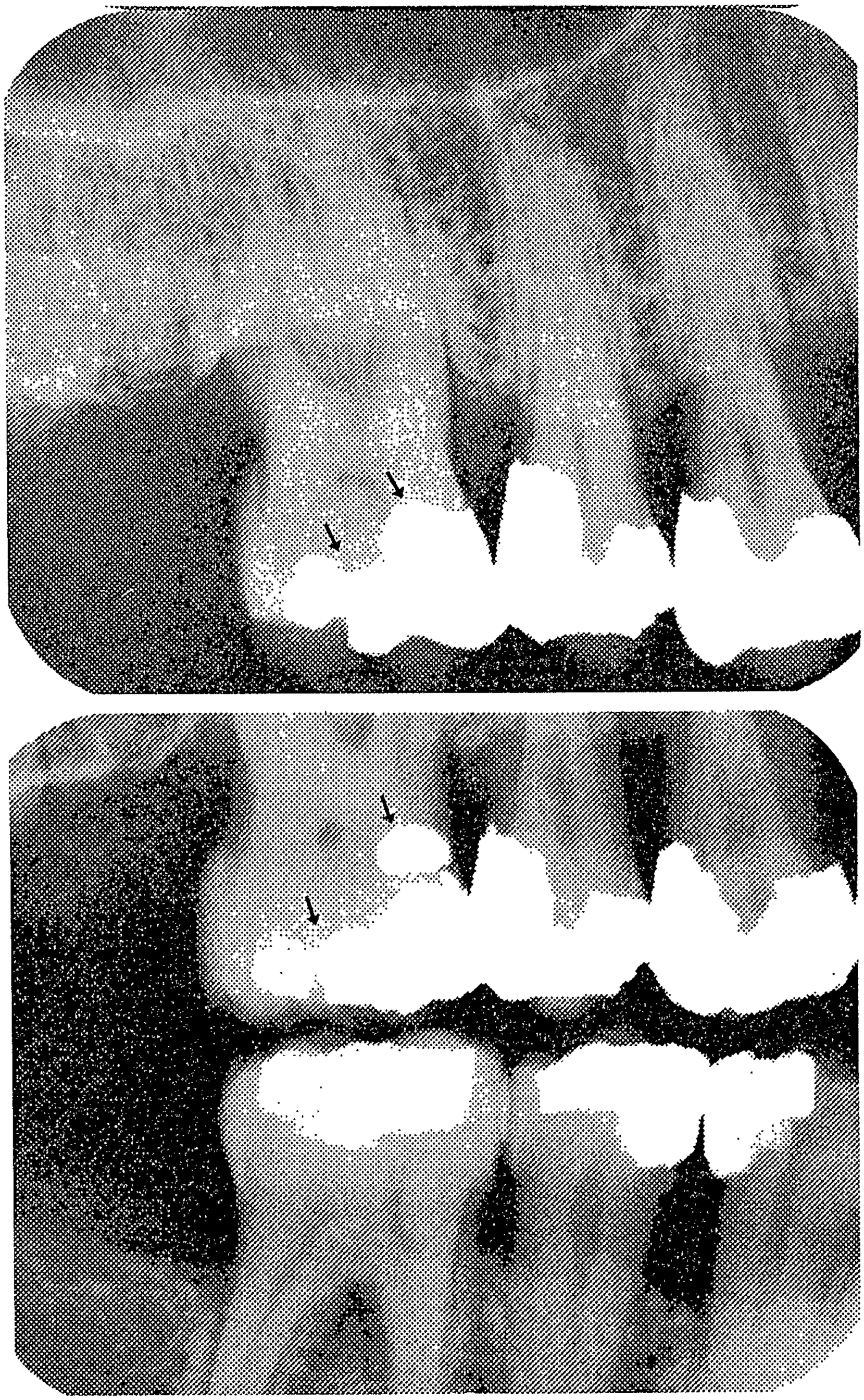


Figure 38. Altering the angle of projection may vary the appearance of features on a radiograph.

7.2.5 Endodontics

Endodontic therapy is a specific treatment, much less common than other restorative procedures, and is immediately conspicuous on dental radiographs (Sopher, 1976 and Griffiths, 1977).

In many cases where endodontic therapy has been undertaken, radiographs of the treatment may be comprehensive (Cameron and Sims, 1974) as various stages of the procedure, including the completed case are radiographed.

Root fillings have a characteristic shape (Whittaker, 1981), caused by the adaptation of the filling material to the root canal (Figure 39 and Figure 40).

Radiographs of such teeth may not only show the root filling material, but will also detail imperfections in the instrumentation of the canal (Sopher, 1976), and more distinctive features such as overfilling of the canal (Cameron and Sims, 1974 and Sopher, 1976) and the presence of posts and crowns.

Antemortem radiographs of a supposed victim may disclose inconsistencies, as with cases showing overfilling of a canal. It must be remembered that some filling pastes are resorbable and therefore this feature may not be seen in subsequent radiographs. Detail of canal shape and root morphology, therefore, must be the basis of comparison.

Figure 39. Root canal therapy: adaptation of filling material to canals (from Schroeder, 1981).

Figure 40. Root canal therapy: adaptation of filling material to canals (from Schroeder, 1981).

Mertz (1977) noted that some radiolucent endodontic filling materials are used in Europe and other parts of the world and that this may present as an area of confusion, when trying to verify treatment with radiographs, in such cases. Parker (1983) suggested that, if no filling material is apparent in a tooth which should show a root filling, then the radiograph should be examined for any signs of periapical pathology.

The correct angle of projection of the X-ray beam must be stressed, in cases of the root filling of multirooted teeth or in cases where false canals may have been created during instrumentation. Superimposition of the canals on radiographs may lead to non-identification.

7.2.6 Bone Patterns

Martel, Wicks and Hendrix, (1977) indicated that there is "little question" as to the reliability of the use of bony landmarks as a method of human identification. Mertz, also in 1977, suggested that, in the absence of restorations or teeth, bone trabecular patterns may be distinctive and give added weight to dental identification.

Radiographs show a certain regularity of trabecular pattern, with specific width, density and arrangement. These patterns are quite stable unless surgical interference has occurred. Antemortem radiographs, therefore, can be compared with similar postmortem views, to help establish identity (Parker, 1983).

Cancellous or trabecular bone lies between the cortical plates in both the mandible and the maxilla and is composed of thin radiopaque plates and rods of bone, which surround many small radiolucent pockets of marrow. The normal radiographic pattern of trabeculae shows considerable variability (Goaz and White, 1982), but often, meticulous attention to detail must be paid (Martel et al, 1977) to establish identity, based upon these patterns.

Particular areas of the jaws may show a characteristic trabecular pattern, e.g. in the anterior maxilla, where the pattern is very fine, granular and dense; whereas in the anterior mandible the pattern is thicker and coarser. Frequently the trabecular plates are orientated horizontally (Figure 41), but in the region of the apices of the mandibular molars, the pattern may change to show an area almost devoid of trabeculae. Occasionally, the trabecular spaces in this region may be very irregular in size, with some so large as to resemble pathologic lesions (Goaz and White, 1982).

Extraction sockets, when examined radiographically, may show the first signs of healing to be a "fuzziness" of the lamina dura, due to resorption (Cameron and Sims, 1974). New bone is laid down progressively on the socket walls, until the socket is full. Eventually, this new bone is replaced by mature bone and a normal trabecular pattern is established. Sometimes the lamina dura remains intact, it is not resorbed and the socket outline remains visible on radiographs for many years following the extraction of a tooth (Whittaker, 1981). In some cases, the extraction socket fills with sclerotic bone, giving the appearance of a retained root with a central root canal (ibid).

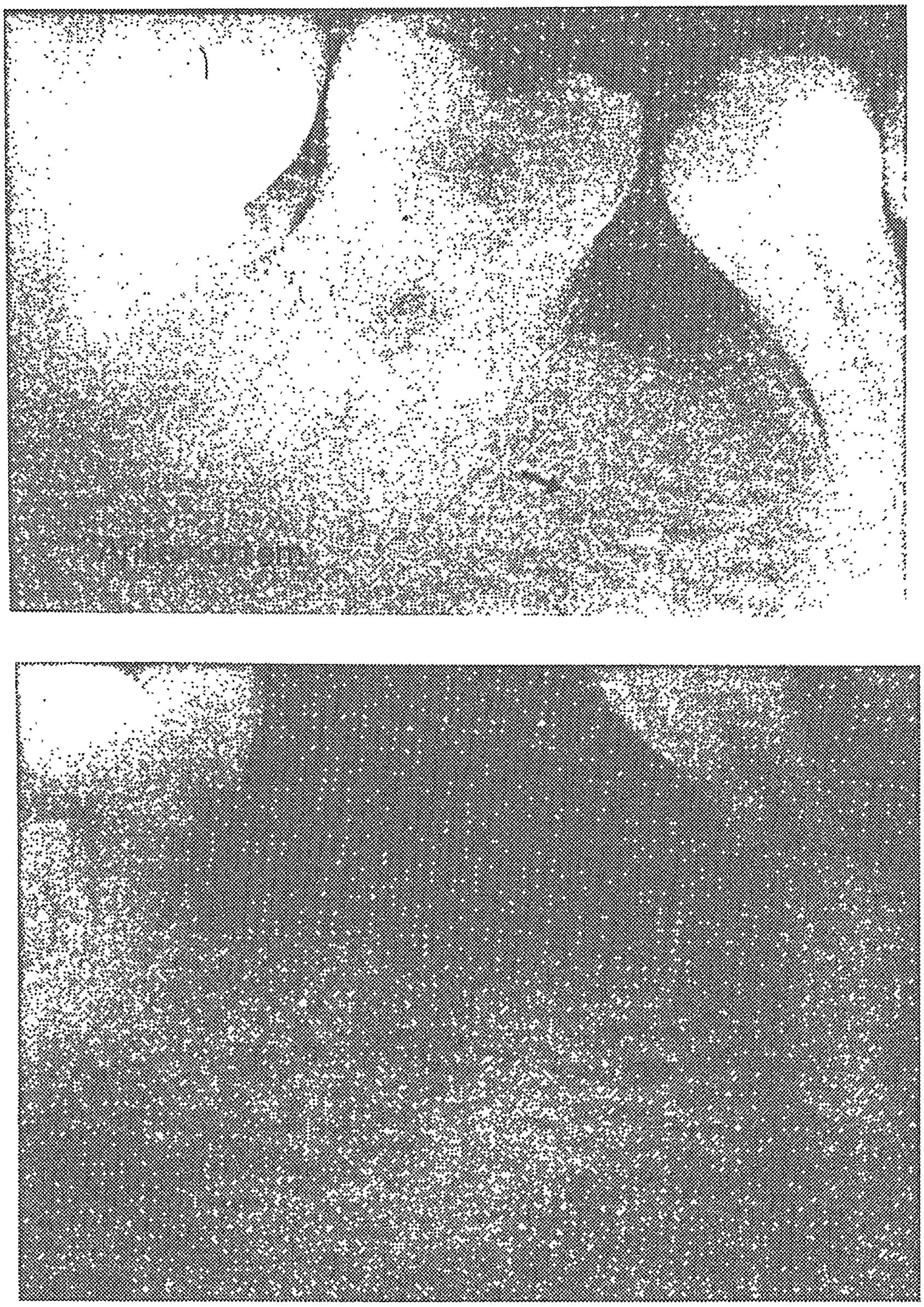


Figure 41. Two radiographs: antemorten/postmorten bony trabecular patterns.

Examination of other bony features that are often seen on dental radiographs may also give added weight to dental identification.

These features may be listed as:- nutrient canals, nerve foramina, the intermaxillary suture, the nasal fossa and the floor of the maxillary sinus, etc. Each is distinctive (Mertz, 1977) and each may prove helpful in establishing identity in the difficult case.

7.3 EXTRA-ORAL RADIOGRAPHS

Apart from the teeth and jaws, the most helpful area of the body for comparison radiography is the skull (Lichtenstein et al, 1980 and Evans and Knight, 1981). The forensic dentist must be familiar with the peculiarities of the anatomical features of the skull, as it may be necessary from time to time to comment on extraoral radiographs or to use them as the basis of comparison (Whittaker, 1981). The object of such comparison is to discover some combination of anatomic detail, sufficiently unique to establish a convincing identification (Lichtenstein et al, 1980).

7.3.1 Panoramic Radiography

Panoramic radiography is a technique for examining the curved layers of the jaws by blurring out structures not in a preselected plane (Langland and Sippy, 1968). The patient is immobile whilst the X-ray tube and a curved cassette rotate in opposite directions around the patient's head. The cassette also rotates around its own axis. A narrow X-ray beam turns successively around three rotational axes.

All points in the plane of the rotational axis have an equal relative linear velocity, to the moving film and become sharply defined, because they are stationary on the film. Other objects will be blurred, because they move during exposure.

The thickness of the sharply defined image layer is controlled by the amplitude of the sweep of the tube, with a greater amplitude producing a thinner section and by the source-film distance, a shorter distance for a given amplitude, producing a thinner section (Langland and Sippy, 1968).

Patient positioning is critical. Blurring is less effective for points nearer the image layer, than for points further away.

Mertz (1977) and Cottone and Standish (1982), indicate that panoramic radiography is being used with greater frequency in many dental surgeries. Langland, Langlais and Morris (1982), suggested that there are several reasons for the propensity of this form of radiography; they are:- an increased overall coverage of the dental arches and associated structures, as compared with conventional extraoral techniques; the relatively undistorted anatomic images produced (Figures 42 and 43); the reduced radiation dosage to the patient and the simplicity of operation.

Notwithstanding the above reasons, Sassouni, in 1963, indicated that panoramic views are obtained with an accurate head fixator and therefore the technique offers a high degree of standardisation.

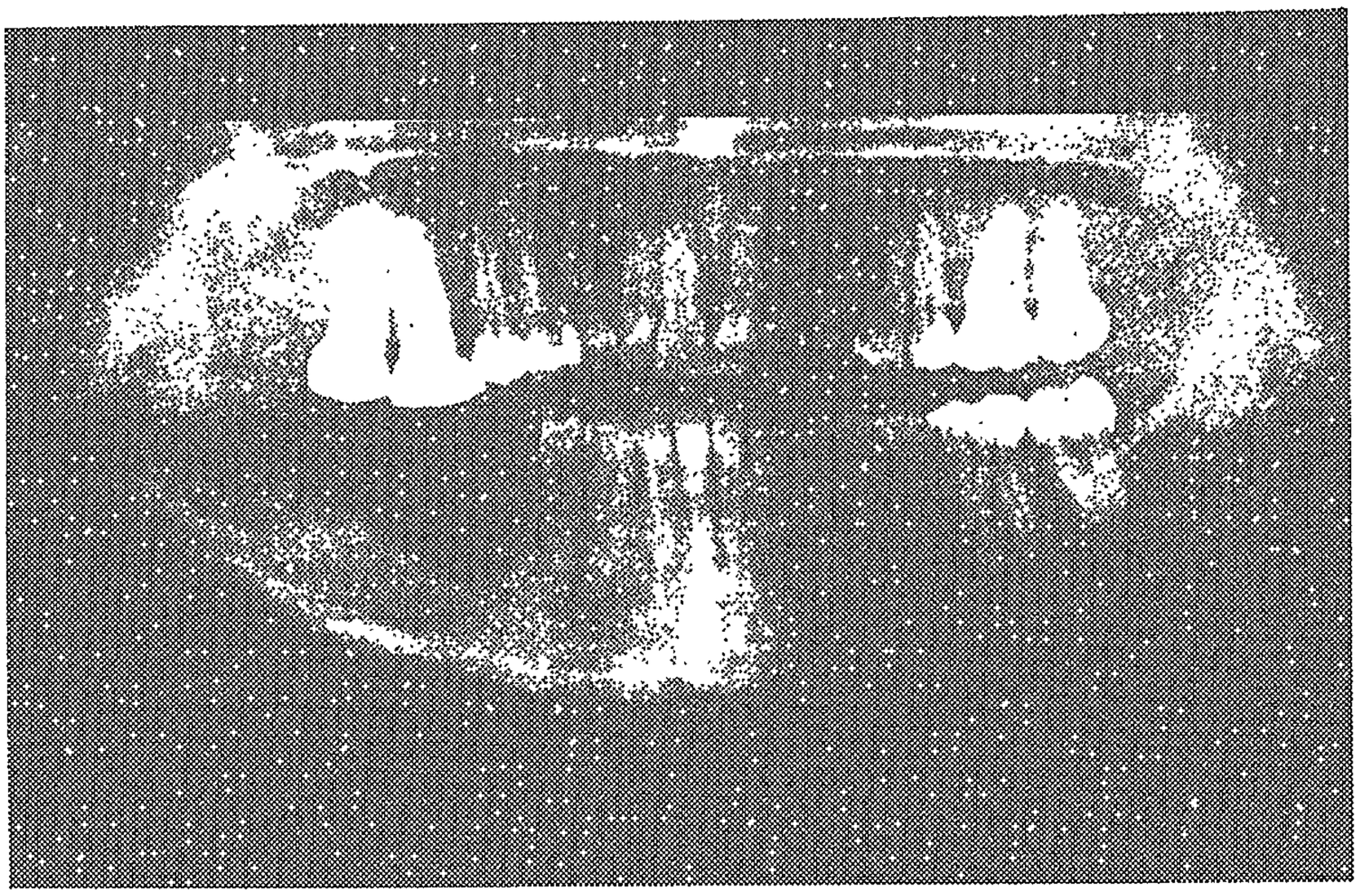


Figure 42. OPG (Courtesy, United Dental Hospital).

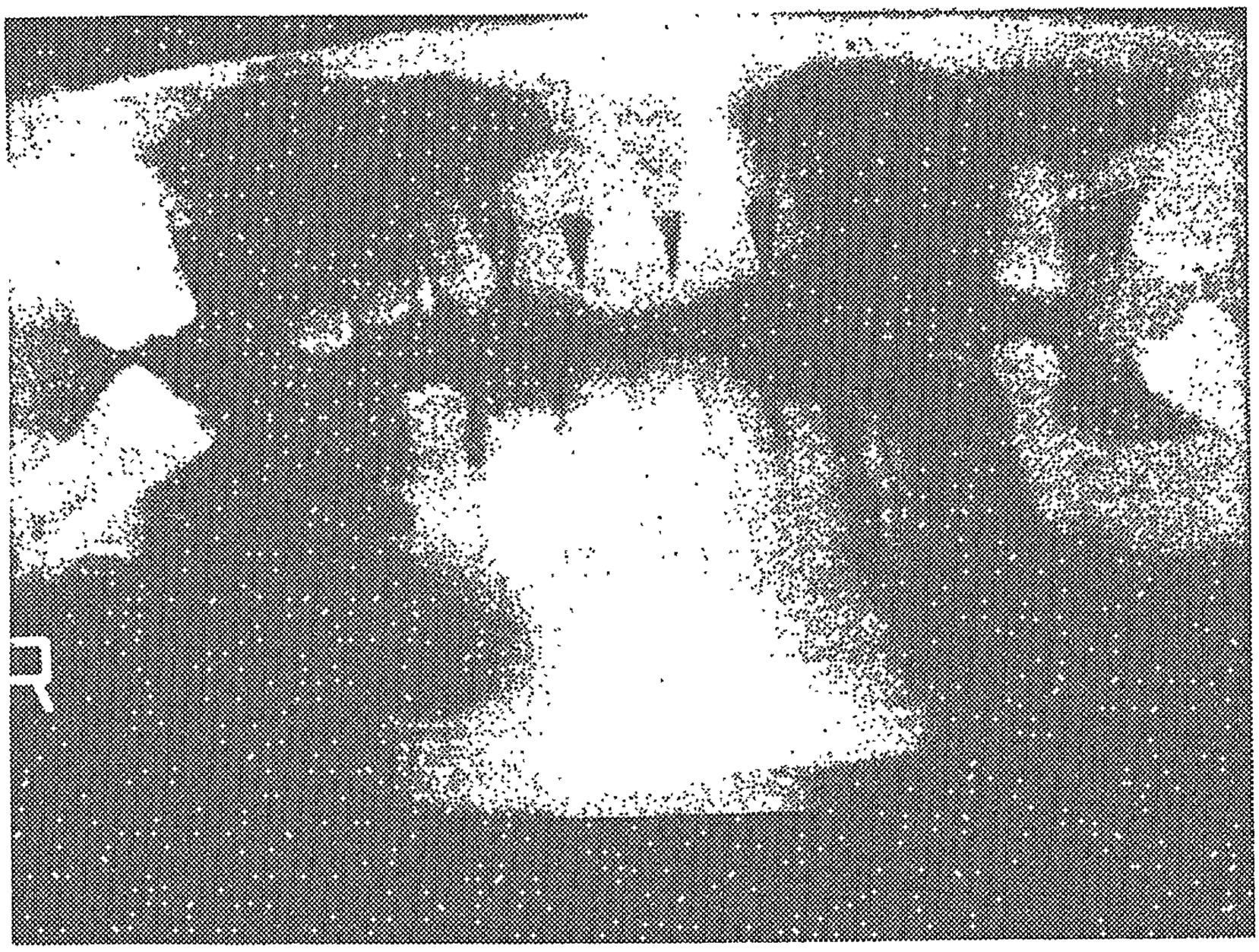


Figure 43. OPG (Courtesy, United Dental Hospital).

Serman and Nortje, (1982) and Harris, (1983) stress the value of routine panoramic radiography in clinical practice. Serman and Nortje, (1982) support their assertions with regard to the edentulous individual, for whom postmortem identification is often a problem.

A radiographic record of the jaws shows "many highly individualistic features, which can be rediscovered and compared in postmortem remains." Some of these features may be listed as :-

(i) the position of the mandibular foramen;

(ii) the length and thickness of the styloid process;

(iii) the shape of the coronoid process;

(iv) the length, size and shape of the head of the condyle;

(v) the depth of the glenoid fossa;

(vi) pneumatisation of the maxillary sinuses;

(vii) the position of the incisive and mental foramina and

(viii) amalgam tattoos.

Mertz (1977), suggests that in many forensic examinations, the only antemortem radiographic record available may be a panoramic view.

Postmortem panoramic radiographs are, however, of limited use for direct comparison, since it is difficult to take postmortem panoramic radiographs, unless the head is disarticulated or skeletonised (Figure 44). The radiographs are useful for screening and elimination purposes.

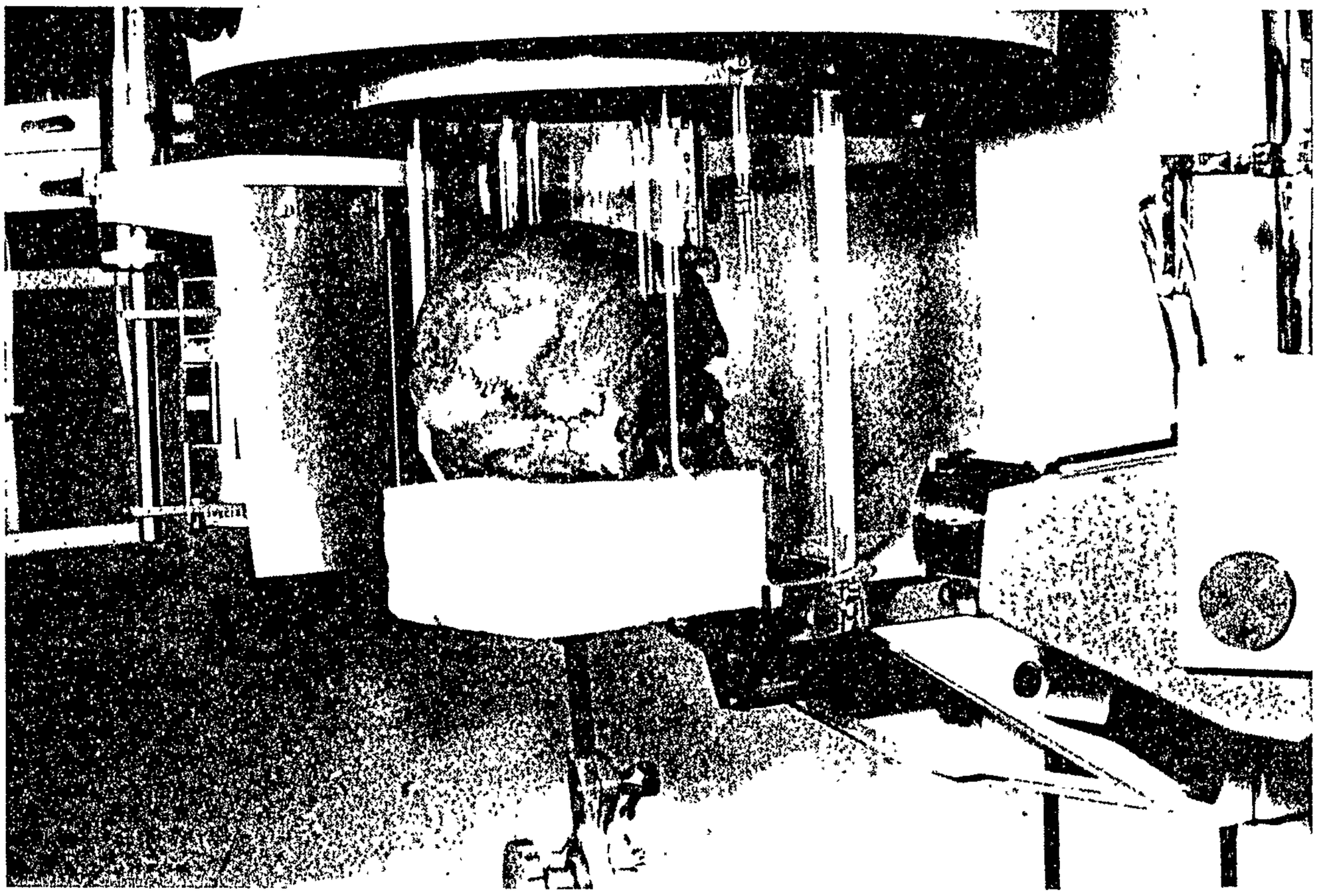


Figure 44. Taking OPG of skeletonised head (Cameron and Sims, 1974).

the degree of magnification of the dental structures, as recorded on the radiograph, varies from one type of machine to another and from one region of the film to another, therefore, direct superimposition of antemortem and postmortem films is difficult. For these reasons, antemortem panoramic films are often compared with postmortem periapical and bitewing films. Such comparison of radiographs for bone detail and restoration size and shape, must take into account the inherent distortion characteristics of the panoramic radiograph (Mertz, 1977 and Cottone and Standish, 1982).

7.3.2 Radiographic Cephalometry

Gustafson (1966), describes radiographic cephalometry as being a means of radiographic identification, based upon measurements of "craniofacial diameters and proportions", taken from radiographs of the skull. Sassouni (1963), in an extensive investigation of systematic classification based on "cephalo-facial" radiographs, suggested the use of lateral and postero-anterior (PA) X-rays as a method of identification of human remains.

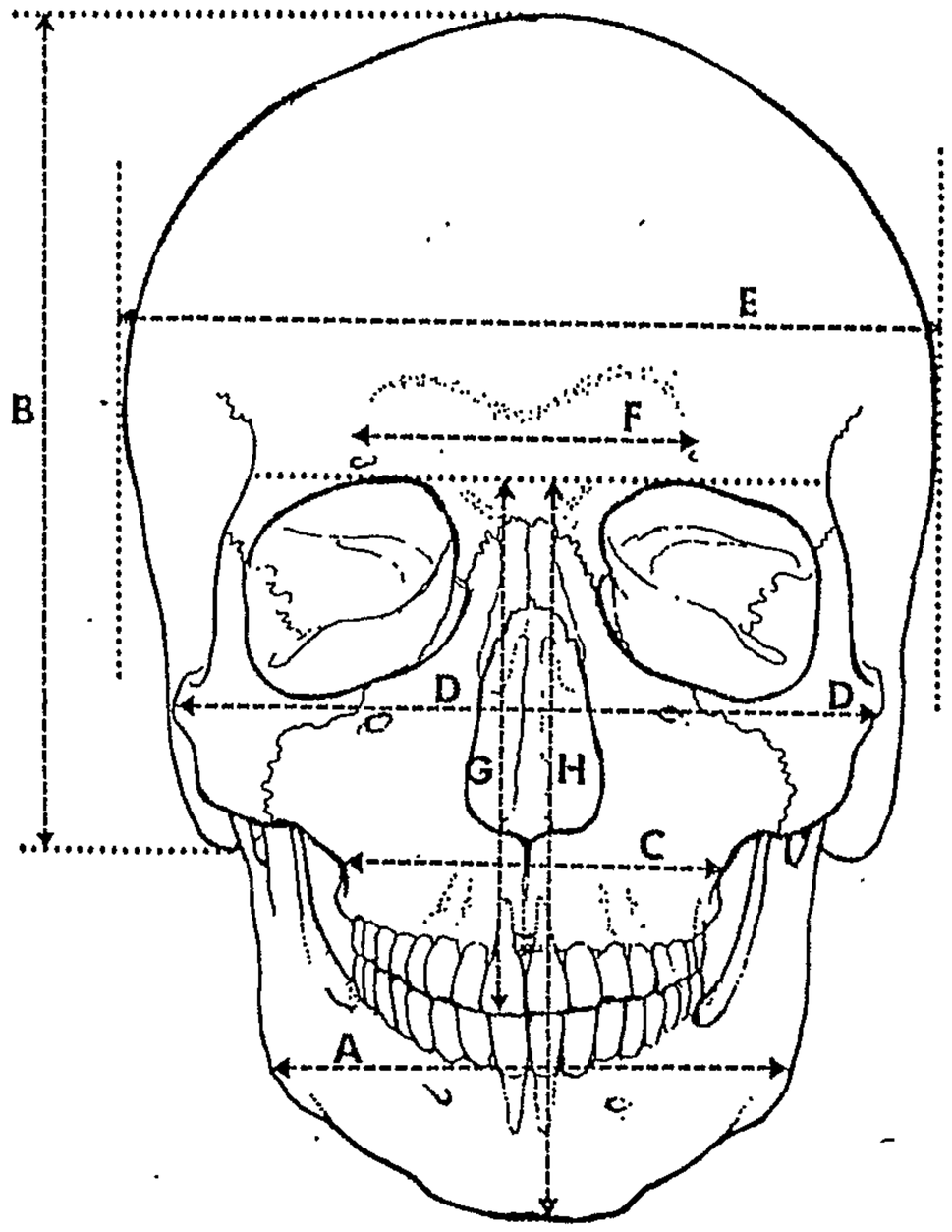
For the purposes of diagnosis and treatment, a lateral skull radiograph is used to survey the skull and facial bones for evidence of developmental abnormality, trauma or disease. Postero-anterior radiographs are used to examine the skull for similar features as well as to detect progressive changes in the mesiolateral dimensions of the skull and also to visualise facial structures such as the frontal and ethmoid sinuses, the nasal fossa and the orbits (Goaz and White, 1982).

Sassouni (1963), determined that cephalometric radiographs of the skull were able to constitute very accurate antemortem records. In an experiment to determine the validity of using radiographs of the skull for identification purposes, lateral and postero-anterior projections were taken twice of 498 soldiers, using a cephalostat for standardisation. One set was designated the ante-mortem record, the other set the postmortem record. In order to obtain the greatest variability for the minimum error, linear dimen-sions were selected as a method of comparison.

On the antemortem postero-anterior radiographs, eight measurements were obtained (Figure 45); the frontal sinus breadth, the facial height, the bigonial breadth, the cranial height from mastoid to apex, the incisor height, the bizygomatic breadth, the bimaxillary breadth and the maximum cranial breadth.

Eight measurements were also obtained from the antemortem lateral radiographs; the height of the cranium, selected distances from the centre of the sella turcica, the facial height and the cranial length as measured in selected positions.

An attempt was made to use only the postero-anterior film for the purposes of identification, and a test was made to identify 100 of the postmortem postero-anterior films, from the 498 antemortem films. With the aid of a computer and in some cases visual compar-ison, positive identification was established in each case.



Some of the measurements proposed by Sassouni, 1963. (a) Bigonial breadth; (b) cranial height (mastoid apex); (c) bimaxillary breadth; (d) height from A to temporal crest; (e) maximum cranial breadth; (f) frontal sinus breadth; (g) incisor height; (h) facial height.

Figure 45.

(Cameron and Sims, 1974).

The relevance of this identification method in forensic examinations has been endorsed by Gustafson (1966), Cameron and Sims (1974), Shuff (1976), Evans and Knight (1981) and Whittaker (1981).

7.3.3 Anatomic Features

Evans and Knight (1981), state that the skull has more characteristic features than any other part of the skeleton. As mentioned above, radiographs of the skull are taken for a variety of diagnostic and treatment purposes, and when available, constitute a very accurate antemortem record. Anatomic features of the skull most often used in establishing identity are the sinuses and air spaces and the sella turcica.

7.3.3.1 The sinuses and air spaces

> "Of all the bony structures of the cranium, the air sinuses have been most often used in identification procedures." (Whittaker, 1981; Figure 46).

The frontal sinuses appear in the second year of life, and continue their development and increase in size, until about the twentieth year of life. In about 5% of adults the frontal sinuses may not be seen radiographically and in approximately 1% of adults, the sinuses may be unilateral (Evans and Knight, 1981). The sinuses tend to be smaller in females than males, and tend to show smaller scalloped and more numerous upper archings. The walls of the sinuses become thinner and the sinuses appear larger, in old age. In senile states (Evans and Knight, 1981) the sinuses may be seen to communicate with the diploic spaces between the outer and inner tables of the skull.

Figure 46. Frontal sinuses - an identifying feature (Courtesy, Westmead Hospital Dental Clinical School).

The first suggestions that the frontal sinuses, as seen radiographically, may be useful for identification purposes, were made by Schuller in 1921, and Culbert and Law in 1927. Poole, in 1931 (cited by Whittaker, 1981), outlined a classification of the sinuses and Schuller, in 1943, proposed a more comprehensive classification.

Schuller's classification (1943), based upon orienting the skull in the "forehead-nose position" for radiography, with the axis of the X-ray tube level with the supra-orbital margins, includes such features as: the shape and deviation of the septum; the characteristics of the upper border; the presence or absence of a partial septum; any extensions into the ethmoid bone; the height from the planum and the breadth of the sinuses and the positions of their midline (Figure 47).

For visualising the frontal sinuses, Asherson, (1965) recommends taking a radiograph in the occipito-mental plane. This, Asherson (1965) states, is a rapid and simple procedure. If taken accurately, such radiographs show a constant outline of the frontal sinuses. The technique is precise, so far as head positioning is concerned, and radiographs taken over a period of time reveal identical and superimposable views of the frontal sinuses.

Sassouni (1963) and Cheevers and Ascencio, (1977) note that pathological changes such as Pagets' disease, osteoma, osteosarcoma or endocranial tumours may produce severe deformities in the sinus outlines. Under normal circumstances, however, the shape of the

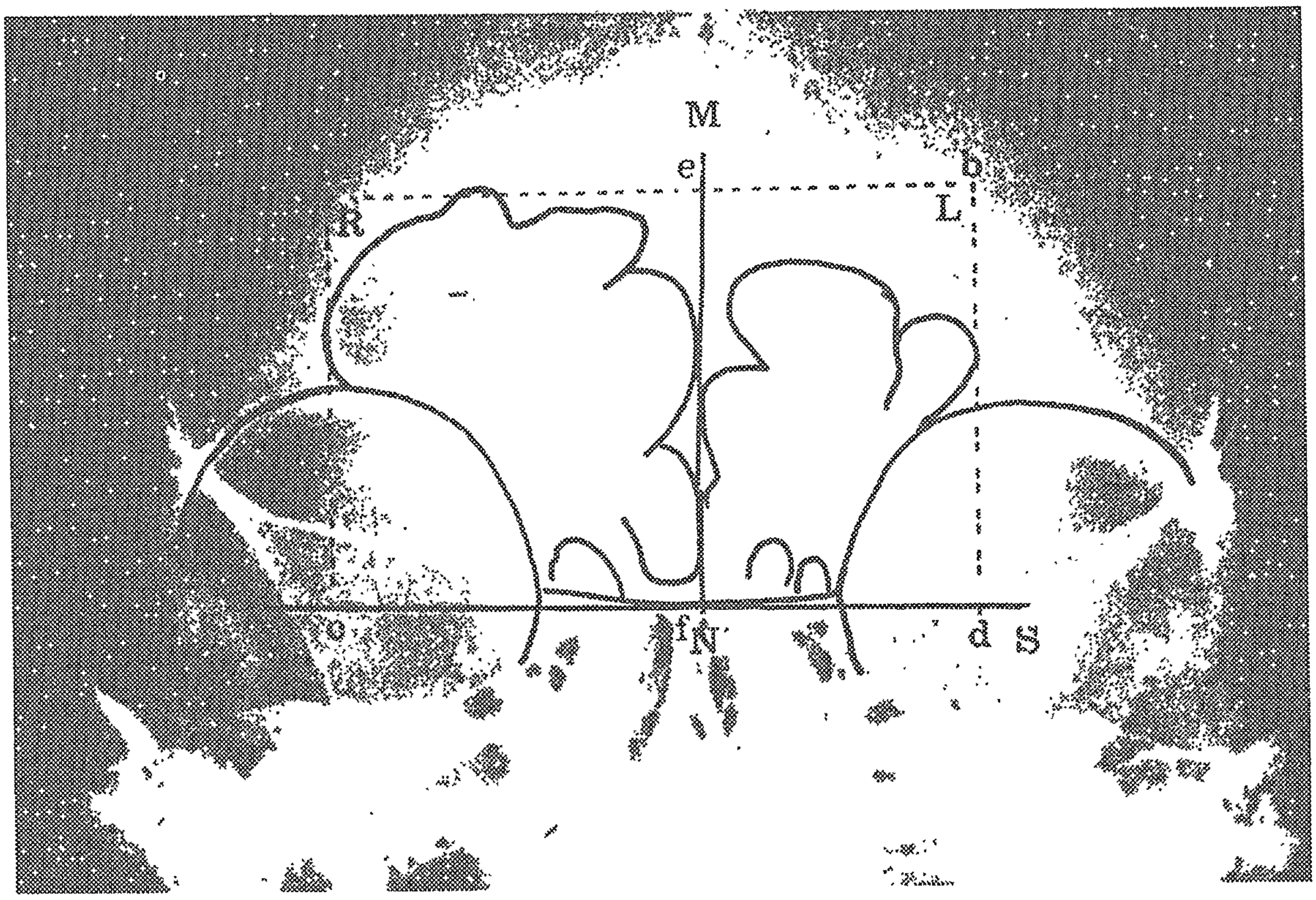


Figure 47. Outline of frontal sinuses and orbits and measurements of the frontal sinuses (Evans and Knight, 1981).

adult frontal sinuses should remain unchanged throughout adult life and are characteristic for an individual.

Gustafson, (1966) mentions that, as well as the frontal sinuses being useful in helping to establish identity, the mastoid air spaces and the pattern of the nasal cavity are highly individualistic features and should be included in radiological comparison exercises.

7.3.3.2 The sella turcica

Voluter (1960), suggests that the sphenoid bone and its various components may be useful for comparison purposes. The sella turcica is of particular importance as it is one of the last areas of the skull to be damaged by fire or decomposition. Voluter (1960), selected such features as the shape and volume of the sella turcica; the angle formed by the clivus and the cranial base; the morphology of the anterior and posterior clinoid processes; the structure of the sphenoid bone and its configuration; as well as the extent and position of air cells around the sella turcica, and claims these as being as unique as fingerprints.

Sassouni (1963), and Whittaker (1981), point out, however, that the shape of the sella turcica may change with age (such as the bridging of the clinoid processes), and also in the presence of tumours and conditions such as acromegaly and Hand-Schuller-Christian disease. It may not, therefore, always be an accurate identifying feature.

Cameron and Sims (1974), indicate that a major disadvantage in the use of skull radiographs for identification purposes is that, in many injuries, especially high velocity injuries, the bones of the skull may be fractured and grossly distorted.

7.3.4 Radiographic Superimposition

Radiographic superimposition is a technique occasionally employed to gain additional information in the identification of unknown human remains. In this technique, full face photographs of the suspected victim are superimposed over appropriate radiographs of the skull, to show an approximate correlation in size and contour of the facial structures (Furuhata and Yamamoto, 1967, Mertz, 1977, Simpson, 1980 and Whittaker, 1981).

The technique was first used with success in 1937, in the infamous Ruxton dismemberment case (Figure 48). Simpson (1980), states that the technique

> "requires the joint collaborative skills of the photographer and radiologist and must anticipate critical test of its accuracy, by meticulous attention to certain details of technique."

It is essential that the radiograph of the skull be taken at the same angulation as the head in the photograph, to be superimposed. De Vore (1977), suggests that concordant points between radiograph and photograph should include:- the orbital rims, the zygomatic processes, the nasal cavity, the teeth and the chin.

Radiographic superimposition techniques are confined to cases where facial features are partially decomposed and visual identification

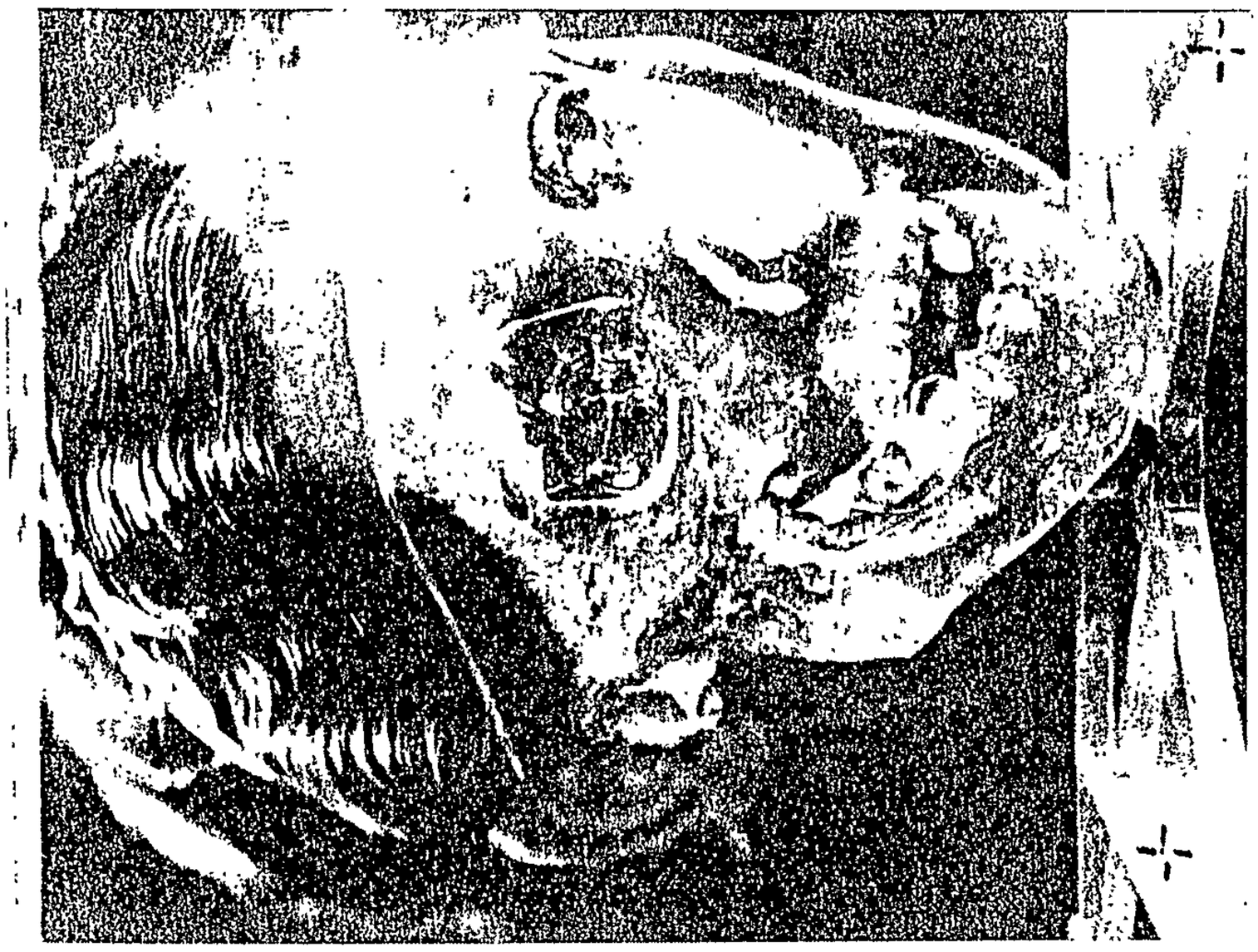


Figure 48. Radiographic Superimposition (Simpson, 1980).

is not possible (Furuhata and Yamamoto, 1967). In the majority of cases, superimposition is carried out using photographs of skulls (Figure 49), whereby the angulation of the skull can be more easily matched to that of the head in an antemortem photograph (Furuhata and Yamamoto, 1967, De Vore, 1977 and Teixeira, 1985). The photographic technique has been used with success most recently by Teixeira, (1985), in establishing the identity of Josef Mengle, "the world's most hunted Nazi war criminal."

In consideration of the above intraoral and extraoral radiographic techniques, used in helping to establish the identity of unknown human remains, it is possible that, at the end of an investigation, a body may remain unidentified. It is suggested that, in such cases, the jaws be disarticulated and removed from the body and retained. Other potentially identifiable features should be recorded and specimens retained, e.g. fingerprints, blood, hair, specimens of all available organs, a long bone to aid in height estimation and whole body radiographs, to be used for comparison purposes when and if antemortem data becomes available (Stevens and Tarlton, 1963 and Cameron and Sims, 1974).

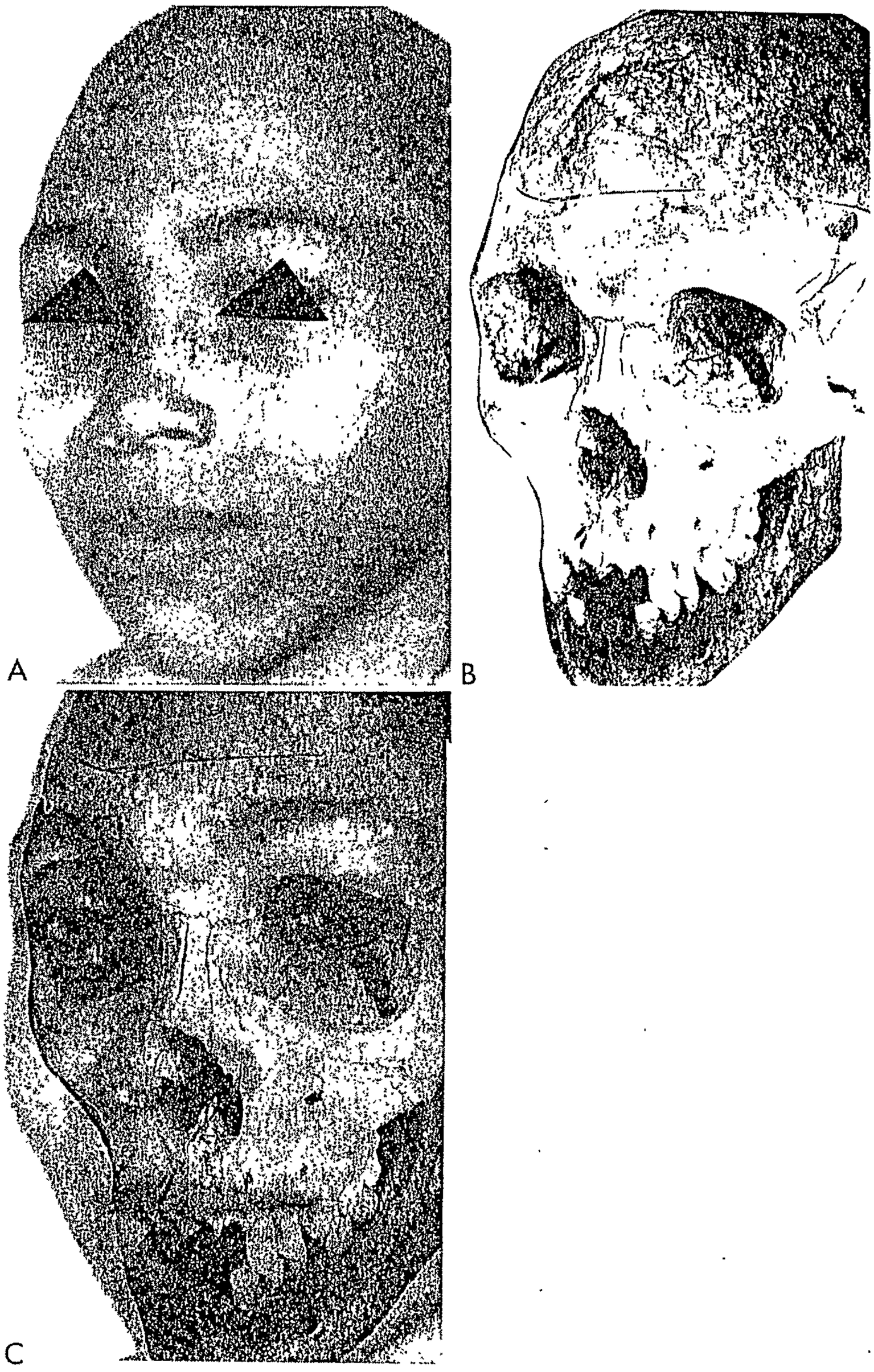


Figure 49. The various steps in photographic superimposition.

8. SOME CONSIDERATIONS IN POSTMORTEM RADIOGRAPHY

Dentists have usually been trained in proper intraoral radiographic techniques and understand the criteria for acceptable radiographs. In clinical practice, the maintenance of radiographic standards by individual practitioners may often be a problem, and it is reflected in the quality of antemortem radiographs submitted for postmortem comparison. This is the basis of the statement "... that the value of a radiograph in identification is always positive, even if it is not technically perfect," made by Keiser-Nielsen, Johansen and Solheim, in 1981.

It is appropriate to outline the criteria for diagnostically acceptable radiographs (Frommer, 1981) and to use these criteria to maintain radiographic standards not only in clinical dental practice, but also in postmortem investigations :

(i) "The radiograph should show proper definition and a degree of density and contrast so that all structures can be easily delineated.

(ii) The structures should not be distorted either by elongation or foreshortening.

(iii) The radiograph should show the teeth from the occlusal or incisal edges to 2-3 mm beyond their apices.

(iv) In a full mouth survey, the entire alveolar processes of the mandible and maxilla must be seen. This means as far distal as the tuberosity in the maxilla and the beginning of the ascending ramus in the mandible.

(v) All interproximal surfaces of the teeth should be seen without overlapping, provided that all teeth are not overlapped in the mouth.

(vi) The X-ray beam should be centred on the film so that there are no unexposed parts of the film (cone cuts).

(vii) The radiograph should not be cracked or bent or have any other artifacts.

(viii) The radiograph should be processed properly".

8.1 RADIOGRAPHY OF POSTMORTEM SPECIMENS

As radiographs are the most important adjunct to clinical recording and an objective form of registration of information, not otherwise able to be recorded, the postmortem radiographic examination should be carried out as comprehensively as possible (Keiser-Nielsen, 1980). Radiographs may form part of the antemortem clinical data, submitted for dental comparison at some stage of the postmortem investigation, of unknown human remains. Failure to carry out a radiographic examination of unknown remains may mean that conclusive evidence is missed.

Dental radiography of postmortem specimens may be carried out intraorally on a visually identifiable body or in cases of decomposition, mutilation or severe burning, on resected jaws.

8.1.1 Intraoral Radiography

The taking of intraoral dental radiographs is dependent upon the availability of a suitable X-ray machine.

The radiographic techniques employed in taking postmortem intraoral X-rays differ from those used for antemortem X-rays, with

respect to head position and support, film placement and support and exposure times (Luntz and Luntz, 1973).

Access to the mouth for radiography may be difficult in the presence of rigor mortis (Cameron and Sims, 1974, Stimson, 1977 and Cottone and Standish, 1982). It may be necessary in such cases, to delay examination for twenty-four to thirty-six hours (Stimson, 1977) until the jaws are able to be manipulated, as attempts to pry open the jaws may result in teeth being damaged. Mouth props may be necessary, to maintain jaw opening (Cottone and Standish, 1982).

8.1.1.1 Head position and support

Luntz and Luntz (1973) suggest that, when the dentition is to be radiographed postmortem, and when antemortem radiographs are available for comparison, the dentition should be placed as far as possible in the same position seen in the antemortem film. The head may be positioned and supported with sandbags, a head stand or, as described by Pert (1980), a wooden pole. Since the body is supine, the head being horizontal as compared to vertical in the living patient, the angulation of the X-ray cone in relation to the occlusal and sagittal planes must be carefully adjusted (Luntz and Luntz, 1973).

In the supine patient the occlusal plane becomes vertical rather than horizontal, the sagittal plane remains vertical and is used as a reference plane only, to maintain constant head position. The coronal plane of the head now becomes significant in relation to X-ray beam angulation and must be parallel with the floor.

Head positions in the supine patient have application in modern dental practice, as many practitioners take radiographs of their patients in this position. The need therefore exists to recalculate angles of projection with reference to the occlusal plane and coronal plane, otherwise radiographs taken will not depict the information required.

8.1.1.2 Film placement and support

For postmortem radiography, the film must be placed in the proper relationship to the dentition and the head of the X-ray machine. Luntz and Luntz (1973) indicate that this is done by positioning the film relative to the teeth and then by adjusting the cone of the X-ray machine to the correct vertical and horizontal angulations to the film (Sopher, 1976 and Keiser-Nielsen, 1980).

The film, once placed relative to the dentition, must be maintained in that position, during the exposure of the radiograph. This may be achieved by using such devices as plastic dental film holders, home-made wooden film holders (Sopher, 1976), haemostats (Luntz and Luntz, 1973 and Cottone and Standish, 1982), or cotton-wool or gauze wadding stuffed into the mouth.

8.1.1.3 Exposure times

Sopher (1976) maintains that postmortem radiography is not difficult if the dentist standardises his equipment, with regard exposure

time and kVp settings. These will tend to vary according to the machine used, the instructions of the film manufacturer or in the experience of the dentist, the settings which have been demonstrated to produce the highest quality radiographs with the least radiation exposure (Goaz and White, 1982).

In general terms, the exposure time should be reduced in postmortem radiography. This reduction may vary from between one-third to two-thirds the normal exposure times, depending on the thickness of the tissue being X-rayed (De Vore, 1977 and Brannon, 1983). De Vore (1977) suggests that several trial exposure times be used and radiographs developed by hand, to duplicate the density of available antemortem radiographs. For comparison purposes, it is not the intention of postmortem radiography to produce "a text-book radiograph", but one similar to the antemortem radiograph.

8.1.2 Radiography of Resected Jaws

In the visually unidentifiable body, it is recommended that the jaws be resected (De Vore, 1977, Vale and Noguchi, 1977, Keiser-Nielsen, 1980, Whittaker, 1981 and Brannon, 1983) and removed to a location, where they can be radiographed under ideal conditions (Stimson, 1977, Keiser-Nielsen, 1980 and Whittaker, 1981).

Stimson (1977) and Keiser-Nielsen (1980), suggest that radiography of a macerated, clean, dry specimen is the ideal. However, if radiographs are required quickly, specimens still covered with soft tissue may be wrapped in several layers of thin plastic food

wrap. This will enable them to be more easily handled and will eliminate the odours associated with decomposition, that may otherwise be very difficult to eradicate from a clinical area (Stimson, 1977, Whittaker, 1981 and Cottone and Standish, 1982).

In grossly decomposed or skeletonised bodies, it may be noted that teeth have loosened or may have been lost from the jaws (Cameron and Sims, 1974). In such circumstances, any teeth recovered from the location site should be identified, replaced in the jaws and pressed firmly into position (Cameron and Sims, 1974 and Whittaker, 1981). Failure to relocate teeth firmly within their sockets may cause confusing variation in periodontal ligament thickness, when postmortem radiographs are compared with antemortem films (Whittaker, 1981).

8.1.2.1 Position and support of the resected specimen

Luntz and Luntz (1973) indicate that, in radiography of resected jaws or detached, skeletonised heads, the usual angles of projection of the X-ray beam relative to the film are used. This is so because the dentition is able to be positioned, as in the living patient, i.e. with the occlusal plane parallel to the floor (Figure 50). The jaws or skull may be maintained in position by supporting with sand bags or modelling clay (Brannon, 1983).

A technique described by Stimson (1977) and supported by Vale and Noguchi (1977) and Cottone and Standish (1982) may have application in the radiography of resected specimens, in a disaster situation.

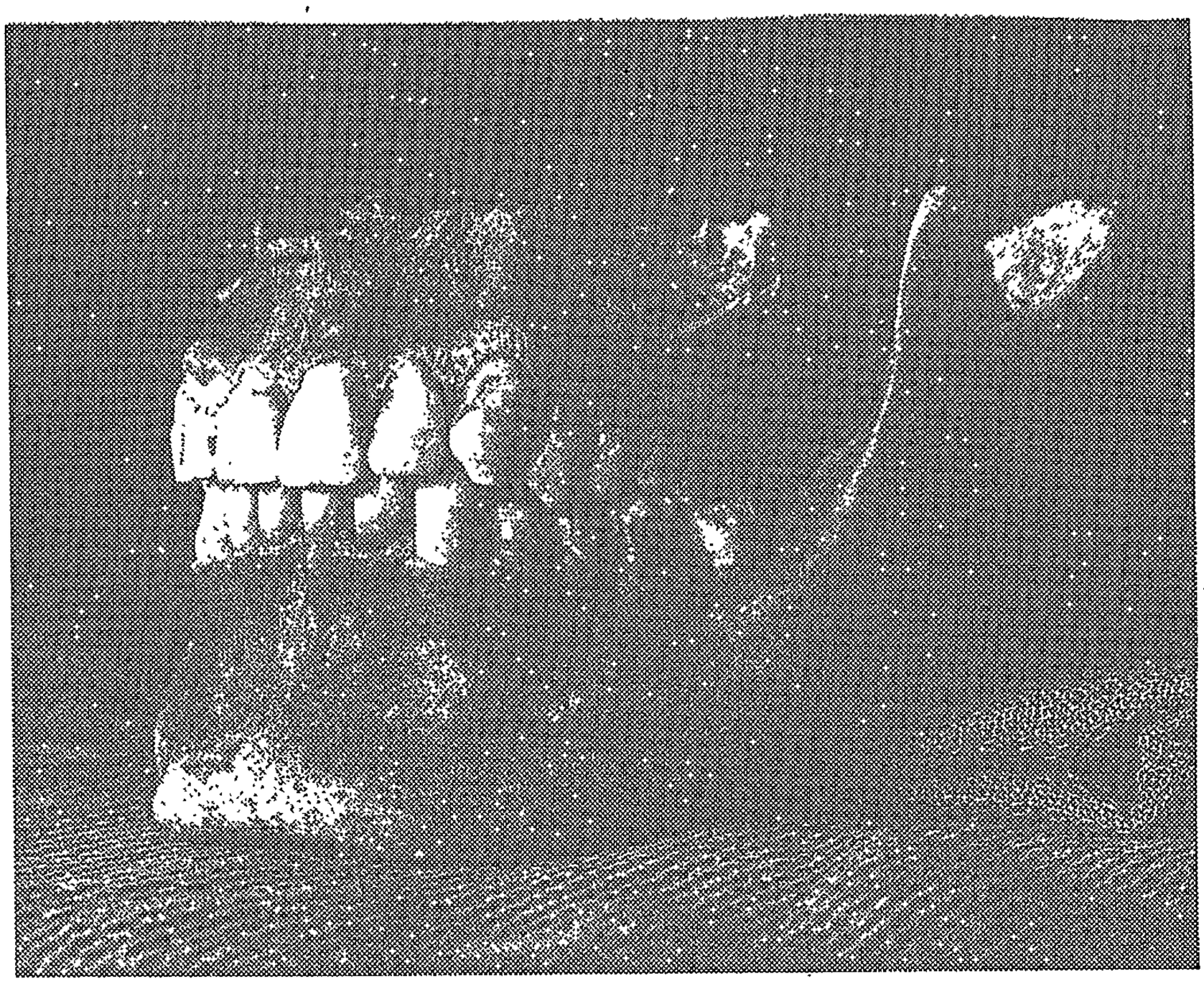


Figure 50. Resected specimen.

The resected maxilla is disarticulated through the intermaxillary suture; half of the maxilla is laid on an occlusal film with the buccal surfaces of the teeth essentially parallel to the film. The mandible is placed on the same film, so that the lingual surface of the teeth of one side touch the film and the other half of the mandible extends around, under the film, and is not seen. The film is exposed, the resultant radiograph being an "enlarged bite-wing" radiograph, with root structures present. The procedure is repeated for the opposite side. Supplemental films may be taken as necessary (Vale and Noguchi, 1977).

8.1.2.2 Positioning and exposure of the film

Dental radiography of resected or skeletonised specimens, as mentioned above, is similar to intraoral radiography in the living patient. The film is placed on the lingual or palatal of the dentition and maintained in position, by plasticine, modelling clay, masking tape, commercial plastic film holders or by any other convenient means (Sopher, 1976 and Brannon, 1983).

Brannon (1983), suggests that a reduction of kVp, milliamperage and/or exposure time by one-third to one-half, is necessary to compensate for the loss of overlying soft tissues, when working with resected or skeletonised specimens.

Cameron and Sims (1974), citing Seward (1972), mention that it may be necessary to increase exposure time in resected specimens that may have been stored in fixing solution, as such specimens become relatively more radiopaque.

Variation in exposure times, as determined by trial and error, may also be required to clearly reveal anatomical detail or the morphology of restorations, the filling material or base for teeth that have undergone some changes in density, as a result of incineration, prolonged immersion in water, or have been subjected to harsh environmental conditions (De Vore, 1977). Differentiation between tooth and filling material density, for example, may be enhanced by reducing milliamperage and increasing exposure time.

If antemortem radiographs are available at the time of the postmortem radiographic examination, the forensic dentist must endeavour to duplicate film placement, relative to the dentition and the angulation of X-ray tube to film of the original radiographs, to enable positive comparison (Sopher, 1976, De Vore, 1977, Cottone and Standish, 1982 and Brannon, 1983).

Keiser-Nielsen (1980) states that it is seldom known at the time of the postmortem examination, what antemortem radiographs may become available for comparison, at a later stage in the investigation. It is suggested that resected, clean, dry specimens be retained by the forensic dentist until radiographs become available, at which time suitable postmortem radiographs may be taken for comparison purposes.

8.2 RADIATION PROTECTION

The object of forensic dental radiography is to obtain a radiographic image of the dentition and supporting structures of a dead body,

for the purposes of comparison with submitted antemortem clinical radiographs. Radiation safety in forensic dentistry, therefore, must be directed towards the dentist and personnel working within the vicinity of radiographic equipment (Lichtenstein et al, 1980).

8.2.1 Radiation Control

Modern dental X-ray machines have inherent properties of filtration and collimation which limit the primary radiation at the site of examination and help prevent unnecessary secondary and scattered radiation (Frommer, 1981, Goaz and White, 1982 and Eastman Kodak Company, 1985). This is achieved by preferentially absorbing low-energy photons produced by the X-ray machine with a 2.5 mm aluminium filter and by restricting the size and shape of the X-ray beam to 7 cm, with a lead diaphragm (Goaz and White, 1982).. An advantage in using as small a beam as practical is that scattered radiation will be minimised, thereby reducing fogging of the film, resulting in a sharper radiographic image, with better contrast.

8.2.2 Protection of Personnel

Frommer (1981), states that the maximum permissible dose (MPD) of whole body radiation for personnel employed in the use of ionising radiation is 5 R per year or 100 mR per week. An operator should never receive more than 3 R of radiation in any thirteen-week period; if so, he should avoid all work with ionising radiation for the rest of the year. Even though the stated MPD is 5 R per year, personnel should strive for an occupational dose as close to zero as possible.