COMPUTERIZED TOMOGRAPHY IN NEURO-OPHTHALMOLOGY

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Computerized Tomography in Neuro-Ophthalmology

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Preface

'Any fool may write a valuable book' observed the eighteenth century poet Thomas Gray 'if he will only tell us what he heard and saw with veracity'. Accepting this advice we have largely described our personal experience of computerized tomography (CT) in relation to clinical neuro-ophthalmology. The need for this book evolved with the recognition that the clinician could now recognize the anatomical and pathological substrate of the CT slices, and the radiologist was equipped with a more powerful tool for examining small areas and needed greater clinical appreciation. This book is therefore intended to provide sufficient clinical information for the ophthalmologist or neurologist to relate this accurately to the CT appearances, and for the radiologist to perform his duties closely attuned to the clinical environment.

The text is aimed to cover general aspects of neuro-ophthalmology with emphasis on special areas of relevance to CT. The bibliography is similarly defined. We recommend the well established textbooks by Walsh and Hoyt (*Clinical Neuro-ophthalmology* Williams and Wilkins), by Jones and Jakobiec (*Diseases of the Orbit*, Harper and Row), and by Glaser (*Neuro-opthalmology*, Harper and Row) as supplying complementary information. Illustrations have been profuse and range from common to extremely rare disorders, for which we have provided detailed descriptions. These elaborate case histories are aimed at involving the reader in the complexity of neuro-ophthalmic diagnosis and to provide a firmer foundation for this book, as advancing technology will inevitably supersede the current CT scans.

The clinical material has largely been referred to the Department of Neuro-Ophthalmology at the National Hospital and the Department of Ophthalmology at St. Thomas' Hospital. We are grateful to those who allowed us to use their patients and in particular Dr C.J. Earl, Dr R.W. Ross Russell, Professor W.I. McDonald and Mr D.S.I. Taylor at the National Hospital and Mr J. Winstanley and Mr T.J. ffytche at St. Thomas' Hospital. Radiological colleagues have been generous with time and material and we are indebted to Professor G. du Boulay, Dr B. Kendall and Dr D. Sutton at the National Hospital. Other departments or individuals may have assisted, but their recognition is associated with the material supplied, though D.S.I. Taylor, D. Spalton and T. Buchanan reviewed some of the chapters.

Special credit and an essential ingredient of this book is due to the photographic skill of Mr Rolf Sennhenn, and to the secretarial and organizational help of Miss Josephine Lace. Additional help was provided by Mrs P. Byrne, Miss J. Cox and Mrs G. Jurewicz. The CT studies were performed by a group of skilled radiographers in the Lysholm Department or Radiology, and we are indebted to Miss V. Fullom for her special interest.

We are grateful to the publishers for organizing the large number of illustrations, and particularly to Dr Barry Shurlock for his encouragement.

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1.1 HISTORICAL

The first practical technique for computerized tomography (CT) was developed by Sir Godfrey Hounsfield, working in the laboratories of Electrical and Musical Industries in England and this achievement was recognized by the award of the Nobel Prize for Medicine in 1979. The most suitable region for study by this revolutionary method was the head, since immobility was necessary for several minutes, and a water surround which was more or less cylindrical and symmetrical, facilitated reconstruction of the images.

The first clinical apparatus was installed in 1972 at Atkinson Morley's Hospital in Wimbledon, South London, and other machines were soon operating in the Mayo Clinic, in Manchester and at the National Hospital for Nervous Diseases, Queen Square. Very quickly it was noted that, in addition to the intracranial structures, both normal and pathological, the orbits and their contents could be seen on the computed tomograms in a way which had previously been quite impossible (Gawler *et al.*, 1974).

Since the introduction of computerized tomography the trend has been to increase the spatial and contrast resolution and to decrease the scanning time. Hounsfield's bench model required several days for scanning a brain section and computing the results, and the first production models gave a picture composed of elements (pixels), representing blocks of tissue 3 × 3 × 13mm in size (voxels). Current machines can be used to produce sections with elements as small as 0.375 × 0.375 × 2mm in a few seconds, without major increase in radiation dose.

1.2 THE PHYSICAL PRINCIPLES OF COMPUTERIZED TOMOGRAPHY

When a beam of X-rays transverses any structure, attentuation occurs, to a degree with is related to: (a) the atomic number of the element of which the structure is composed, or the effective atomic number of a complex structure and (b) the concentration of the substances forming that structure. Thus, the density of electrons, or effective electron density, determines the degree to which a given beam of X-rays will be attenuated. X-ray beams are, however, composed of X-rays of different energies: the greater the effective energy of a particular beam, the less attenuation occurs on passing through a given structure.

These facts are made use of in classical radiography by placing an X-ray or photosensitive film alongside the object to be radiographed, so that it lies perpendicular to the incident rays (Fig. 1.1). The large majority of X-rays emerging from the object will also be perpendicular to the film, but some are scattered; their influence may be reduced by the use of grids designed to prevent non-perpendicular rays reaching the film. Photographic emulsions are, however, relatively insensitive to modulation of the beam intensity by biological tissues, and it has been estimated that they register in a useful form only about 1% of the information potentially extractable from the emergent beam.

If all the information contained in the beam emerging from the skull, for example, were registered on the film, the overlapping of the many different tissue planes would render the picture virtually uninterpretable. The technique of tomography is used to render one plane sharply defined by blurring out adjacent planes. This is usually achieved by causing the X-ray source and

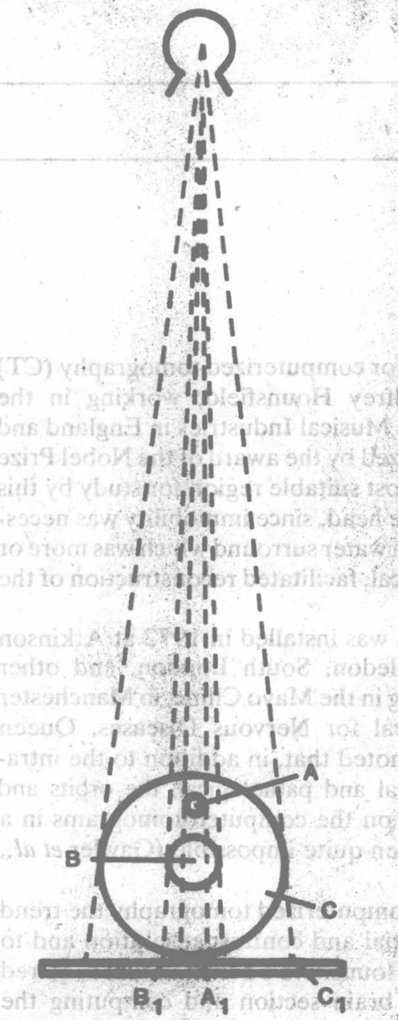

Fig. 1.1 Conventional radiography. The shadows A_1, B_1, C_1, of the elements, A,B,C, of the body being examined are completely superimposed on the final image.

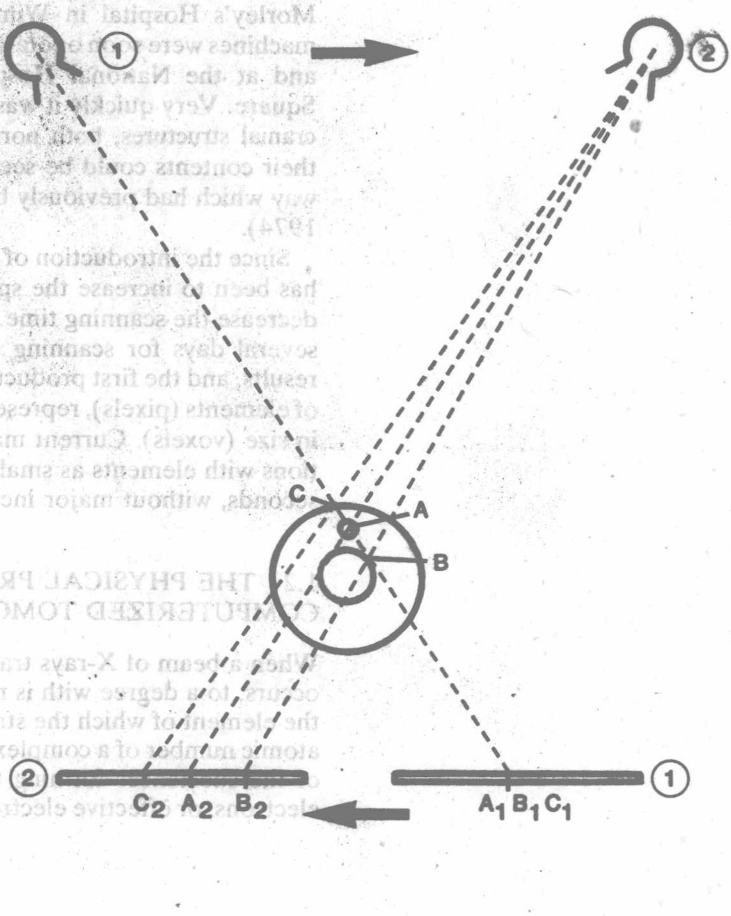

Fig. 1.2 Conventional X-ray tomography. If A is the structure under study, it is isolated from adjacent structures by being made the pivotal plane of the movement of tube and film during the exposure. (1) Initial positions; (2) final positions. Whereas the image of A (A_1, A_2) is projected on the same spot on the film throughout the exposure, the images of B and C, initially superimposed (B_1, C_1), are blurred out by being projected over a wide area ($B_1 - B_2$, $C_1 - C_2$).

film to move relative to the patient during a prolonged exposure, such that the pivotal point of the movement is the plane which is desired to be defined clearly (Fig. 1.2). There is no relative motion between the X-ray source and the film during the exposure. Examples of conventional tomograms obtained in this way are seen on p.113.

In autotomography, an alternative system of tomography, the object being radiographed oscillates about the desired plane during the exposure, the other elements, i.e. X-ray tube and film, remaining stationary. A sophisticated version of autotomography permits examination of planes at right angles to the long axis of the body and this is termed axial tomography.

Computerized axial tomography is similar only in that movement is used to isolate a plane within the body for radiographic purposes. The two fundamental innovations which make it possible are that sensitive emulsion is no longer used for recording the modulations of intensity of the emergent beam, and that the image is reconstructed by a computer.

In the most basic 'translate-rotate' system (Fig. 1.3), of which many currently available techniques are developments, one or more highly sensitive X-ray detectors (sodium iodide crystals, Xenon tubes etc.) are rigidly connected to a finely collimated or 'focused' source of X-rays. The detectors and tube scan across on either side of the object to be examined, the detectors recording a series of X-ray beam intensities. By reference to a detector which monitors the incident beam, the degree of X-ray attenuation can be measured. The angle at which the X-ray beam enters the object is then altered, in steps of 1°, by rotating the detector/X-ray tube assembly (the gantry) around the object. The passage across the object is then repeated, and a similar series of readings is obtained. This procedure is repeated until a given number of series, usually at least 180, has been recorded. It is then relatively simple for the computer to reconstruct from these series a plan of the object through which the scans were made. Several different mathematical procedures are used, which are beyond the scope of the present description.

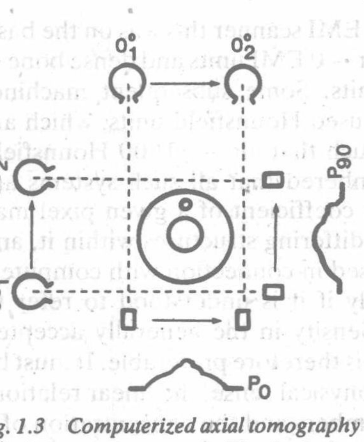

Fig. 1.3 Computerized axial tomography (translate–rotate system). The body being examined is similar to that in Fig. 1.1. and 1.2. In the initial position (0_1°) the rays from the tube are directed at the detector (d); the two then traverse the body together (to 0_2°). Po = profile of X-ray *attenuation* during this traverse. This is repeated (usually 180 times), giving 180 profiles at one degree angles; 90_1° – 90_2°; traverse after indexing 90°; P_{90} corresponding profile. The data from the profiles is then used to reconstruct an axial section in the plane of the page. See text for a further explanation.

The reconstruction takes the form of a number of data points to each of which a capacity for attenuation of the X-ray beam can be assigned. Since, however, the beam of X-rays is of finite depth at right angles to the axial plane which has been scanned, each of these data points, or pixels (picture elements) represents the scanned X-ray attenuation coefficient of a volume of tissue (the voxel or volume element), the dimensions of which will depend on the individual machine. On the original commercially available EMI Scanner, the reconstruction was on a matrix of 80 × 80 pixels, each representing a voxel 3 mm × 3 mm in a plane 13 mm deep. In practice, the machine was constructed to scan two adjacent 13-mm planes simultaneously.

The attenuation coefficient of that pixel is given in terms of an

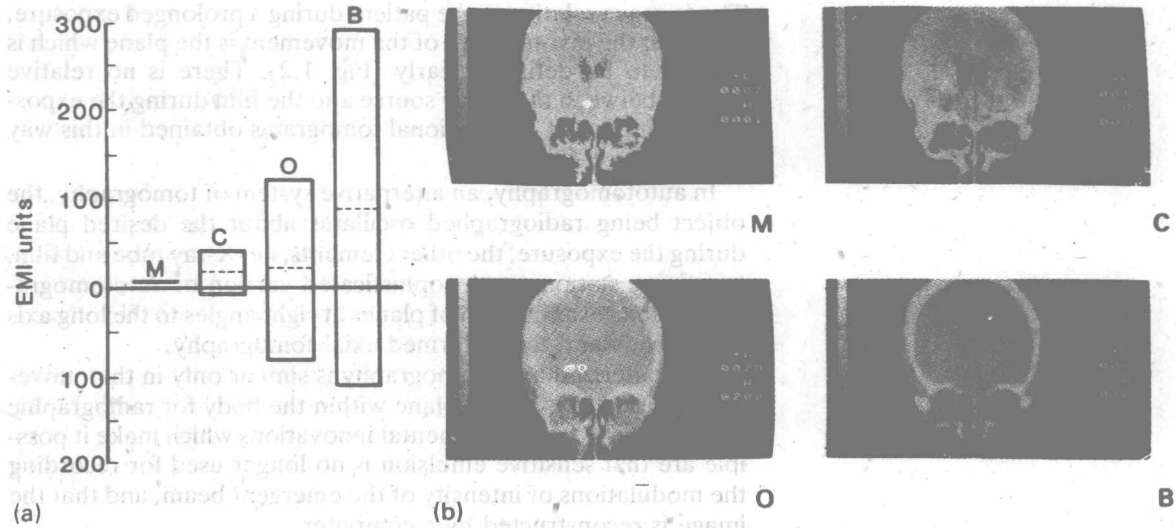

Fig. 1.4 Effect of window level and width on CT image. (a) Graph showing level (dotted line) and range of EMI numbers covered by grey scale at various width settings; (b) coronal section imaged in the same way; M: measure (window level 7 EMI units, window width 1 EMI unit) showing in this example the ventricular CSF and the orbital fat (EMI numbers below 7) in black; C: level 18, width 40 for brain imaging; O: level 20, width 200 for the orbits; B: level 80, window width 400 for bone detail.

arbitrary scale: for the original EMI scanner this was on the basis of air = −500 EMI units; water = 0 EMI units and dense bone = approximately +500 EMI units. Some subsequent machines from the same company have used Hounsfield units, which are half the value of EMI units, such that air = −1000 Hounsfield units, etc. It should be remembered that all such systems are arbitrary, that the attenuation coefficient of a given pixel may represent a voxel with greatly differing structures within it, and that the term 'density' often used in connection with computerized tomograms is correct only if it is understood to refer to electron density, and not to density in the generally accepted sense; 'attenuation coefficient' is therefore preferable. It must be emphasized that in the purely physical sense, the linear relationship between EMI or other numbers and the concentration of a given salt (e.g. calcium) is very close.

A digital/analogue converter is then employed to convert the numerical matrix into a picture for diagnostic purposes, usually by relating the attentuation coefficients to a suitably graduated grey scale, which is displayed on a cathode ray tube (CRT). An important aspect of the CT picture is that it is not a single immutable object, like the conventional X-ray film. The CRT display can be modified at will so that the extremes of the grey scale represent pixels having a difference of attenuation coefficient of only 1 EMI unit, or of several hundred units; this variation of grey scale extent is referred to as 'window width'. Similarly, the attenuation coefficient which lies at the central point of the grey scale can also be altered, throughout the entire range of coefficients which the apparatus can determine; this is referred to as 'window level'.

Typical window width and level settings for routine work are (in EMI units) for the orbits: width 200, level 20; for the intracranial structures: width 40, level 18; and for the skull base: width 400, level 80 (Fig. 1.4).

Many of the CT images reproduced in this book have been made with a modification of the translate-rotate system, which enables more rapid examination. Instead of a single detector and finely collimated beam, a fan beam is directed at an array of approximately ten angled detectors; each traverse of the X-ray tube/detector array is thus equivalent to ten traverses of the system described above, and only 18 traverses are required to scan the full 180°. 'High resolution' scans referred to in the text are obtained by decreasing the voxel size by more rapid switching of the detectors, without increase in X-ray dosage to the patient.

Descriptions of more advanced systems – rotate only, fixed detector, nutating, etc. – are to be found in standard texts.

1.3 CONDUCT OF THE EXAMINATION

Patient preparation

No special preparation is required, although most patients find the examination more tolerable after a sympathetic explanation. Some children and uncooperative adults will require sedation or general anaesthesia (the latter undoubtedly being preferable for children).

All accoutrements such as wigs, hair pieces, ear-rings and spectacles should be removed, as should false teeth with metallic components and ocular prostheses. When the orbits are being scanned, the patient should be instructed to keep the eyes in the primary position or to direct the gaze at a certain object. (Slight elevation is an advantage for optic nerve imaging.) It should be noted that, should the scan be carried out under general anaesthesia, the eyes may be slightly divergent.

Plane of section

Planes of section are usually described relative to the orbitomeatal line, which is drawn from the outer canthus of the eye to the external auditory meatus. The plane can be changed by flexion (OM+) or extension (OM−) of the head and neck or, in some machines, by angulation of the whole X-ray tube/detector assembly (the gantry).

For examination of the *orbit*, the head is extended such that the plane of section is at approximately 10° to the orbito-meatal (OM) line. This OM−10° position gives a plane which passes through the lens, optic nerve and canal region. Van Damme *et al.* (1977) suggested that this 'neuro-ocular plane' was reliably indicated by the lower orbital margin and the upper border of the external auditory meatus. For the *intracranial structures*, angulation of between OM+0° to OM+25° are employed, the former being preferred for the sellar region, and OM+10−15° for sections of the cerebrum; the latter gives a better view of the structures in the posterior cranial fossa. Some workers simply perform all scans in the orbito-meatal plane. This plane is probably the most suitable for examination of the sella turcica and suprasellar region, being parallel to the plane of the chiasmatic cistern. However, the inclination of the chiasm and intracranial optic nerves is sufficiently variable to render any given plane of section unsatisfactory in many cases. Although some standardization of position is desirable, the radiologist controlling the CT study should choose those positions and planes which appear to produce optimal demonstration of anticipated sites of abnormality.

Sections in the coronal plane can be obtained in a variety of ways: in the prone position, by resting the head on the chin; in the supine position by letting the head fall backwards, to rest on the vertex; in the sitting position, with the neck slightly extended. The latter is the easiest position for older patients who may be suffering from spondylosis, but is not possible on many machines, where the couch on which the patient normally lies cannot be separated from the gantry. Angulation of the gantry is particularly useful in these elderly patients.

Coronal sections are particularly helpful in the assessment of orbital and parasellar lesions. However, dental fillings may cause unacceptable artefacts on such sections, and it is often necessary to choose a plane which is not strictly orthogonal to the axial plane in order to avoid such degradation of the images.

Oblique sections can be obtained in many planes, by appropriate positioning of the head, but they are of limited value because of problems in interpretation. A coronal oblique plane, the head turned at approximately 45°, will demonstrate the relationship of the lateral rectus muscle to the lateral wall of the orbit on the side away from which the head is turned. These structures are sectioned very obliquely in the usual coronal sections. On some whole body scanners, the head aperture is large enough to accept the head in the lateral position, giving a direct sagittal plane. With other machines direct sagittal sections may be rendered possible, e.g. in the lateral decubitus position, with lateral flexion of the neck and angulation of the gantry.

Section thickness (Fig. 1.5)

The choice of section thickness is governed by two opposing factors. Firstly, the thinner the section, the more homogeneous

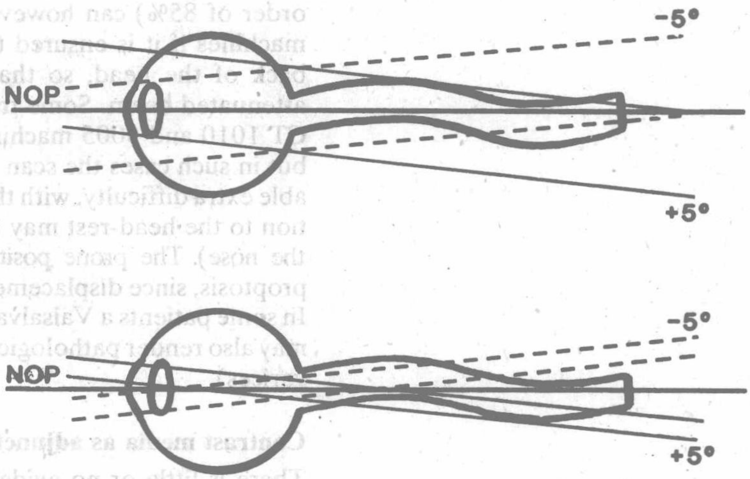

Fig. 1.5 The effects of section thickness on images of a normally undulating optic nerve. (Top) 13-mm sections; (bottom) 3-mm sections, correctly centred on the optic nerve head, but with +5° (solid lines) or −5° (dotted lines) angulation to the neuro-ocular plane (NOP). Even with this slight degree of angulation, much of the optic nerve is excluded from the thin sections. The disadvantage of the 13-mm sections is the inclusion of a relatively large proportion of orbital fat in the sections which demonstrate the nerve.

the voxel, and therefore the more truly representative the pixel. Thus, if a scan of the orbits is carried out using a section thickness of 13 mm, the optic nerve will occupy considerably less than half the height of the section; the pixels which show it will therefore represent more than 50% orbital fat. If the thickness is reduced to 3–5 mm, the section which passes through the equator of the nerve will have voxels composed almost entirely of optic nerve. Secondly, to obtain such thin sections in which the attenuation coefficients are reliable, it is necessary to increase the radiation dose. The principal reason for this is that in thin sections the electronic 'noise' is increased. Also, the shape of the section is such that, if small volumes of tissue are not to be excluded from adjacent sections these must overlap slightly, and with thinner sections this overlap is proportionately more significant.

It is therefore desirable to use the thickest section which will not degrade the anatomical detail or diagnostic potential of the CT examination. Section thickness of 3–5 mm for the orbits, 5–8 mm for the sellar region and 10–13 mm for the cerebrum would appear to represent suitable compromises.

Such thin sections can be 'piled up' by the computer, and sections in other planes reconstructed. In this way, sagittal images can be obtained, which although inferior in quality to direct sagittal sections, are nevertheless of diagnostic utility in the orbit and, particularly, the parasellar region.

Radiation dosage with most CT scanners is comparable to that resulting from plain radiographs, and considerably less than that from conventional multidirectional tomography. Furthermore, it is not spread over a wide area. However, the most radiosensitive structure in the orbit is the lens, and this cannot be excluded from many of the sections. A substantial reduction in dose (of the order of 85%) can however be achieved using translate-rotate machines if it is ensured that the X-ray tube passes across the back of the head, so that the lens is exposed to an already attenuated beam. Some translate-rotate scanners, e.g. the EMI CT 1010 and 5005 machines, have the tube above the patient, but in such cases the scan can be carried out, without considerable extra difficulty, with the patient lying prone; some modification to the head-rest may be helpful (i.e. a slit to accommodate the nose). The prone position is probably preferable in cases of proptosis, since displacement of the globe may then be maximal. In some patients a Valsalva manoeuvre sustained during the scan may also render pathological changes more apparent (e.g. orbital varices).

Contrast media as adjuncts to CT

There is little or no evidence that the use of intravenous iodinated contrast media adds to the detection rate in CT examinations (Moseley, 1977), apart from in certain well-recognized conditions, such as recent cerebral infarction and arteriovenous malformations. The injection of contrast medium adds to the discomfort, risk, duration, radiation dose and overall cost of the study. Nevertheless, there is no doubt that the *differential diagnostic yield* and *anatomical information* are substantially increased by the use of intravenous contrast medium. This is particularly true of intracranial disorders, where disturbances of the blood–brain barrier produce a higher concentration of contrast medium in the abnormal tissues. In the orbit, however, the blood–brain barrier is insignificant and contrast medium provides a lower diagnostic yield and is less useful in differential diagnosis.

From the foregoing it is evident that intravenous contrast media should be used whenever necessary, but that *routine*, pre- and post-contrast medium scans are not essential, particularly when the orbit is being examined. Specific indications will be indicated in the following chapters.

REFERENCES

Gawler, J., Sanders, M.D., Bull, J.W.D., du Boulay, G. and Marshall, J. (1974), Computer assisted tomography in orbital disease. *Br. J. Ophthal.*, **58** (6), 571–87.

Moseley, I.F. (1977), The use of contrast media as an adjunct to CT scanning. *In*: *Computer Assisted Tomography*, (ed. W.J. Kuhler), Exerpta Medica, Amsterdam, pp.26–45.

Van Damme, W., Kosmann, P. and Wackenheim, C. (1977), A standardized method for computed tomography of the orbits. *Neuroradiology*, **13**, 139–40.

2 Anatomy

2.1 THE ORBIT (Tadmor and New, 1978) (Fig. 2.1)

The orbital walls

The medial wall of the orbit, the lamina papyracea, is extremely thin and is formed largely by the ethmoid bone, which is normally slightly convex towards the orbit. Loss of this convexity may suggest expansion of the orbit. Despite the ease with which the thin bone is displaced, it does not show the defects due to absorptive changes which may be seen in the orbital roof in later life. Anteriorly, the lacrimal fossa may be identified as a rounded depression in the medial wall about 5 mm deep, bounded by the anterior and posterior lacrimal crests.

The lateral wall is thicker than the medial, particularly anteriorly and in its mid portion. The orbit expands behind the thick orbital rim and is widest about 1.5 cm behind its margin, with a focal expansion superolaterally accommodating the lacrimal gland. The superior orbital fissure is seen as a defect in the superomedial part of the lateral wall, while above and medial to this, the medial and lateral walls form the borders of the optic canal, which runs posteromedially at an angle of about 35°; its lateral border is the better defined. Since the optic canal is only about 5 mm in diameter, precision is necessary in obtaining the CT section which passes exactly through it, and the superior orbital fissure may be mistaken for the canal. The anterior clinoid process, which lies above it, may obscure visualization of the canal, but the latter may be seen if the window width and level are adjusted.

Neither the short floor nor the roof of the orbit can be assessed adequately in axial sections. It is important to note the irregularity of the latter in relation to the frontal cerebral convolutions; this may cause it to appear discontinuous or to show as isolated areas of high attenuation which appear to lie within the frontal lobes. The floor is traversed in the anteroposterior direction by the infraorbital sulcus and canal, which may also produce apparent discontinuity. The floor slopes downwards from the medial to the lateral side, so that in sections through the inferior part of the orbit, the subjacent maxillary antrum may appear to bulge into the orbit from the medial aspect. These features are well demonstrated on coronal scans.

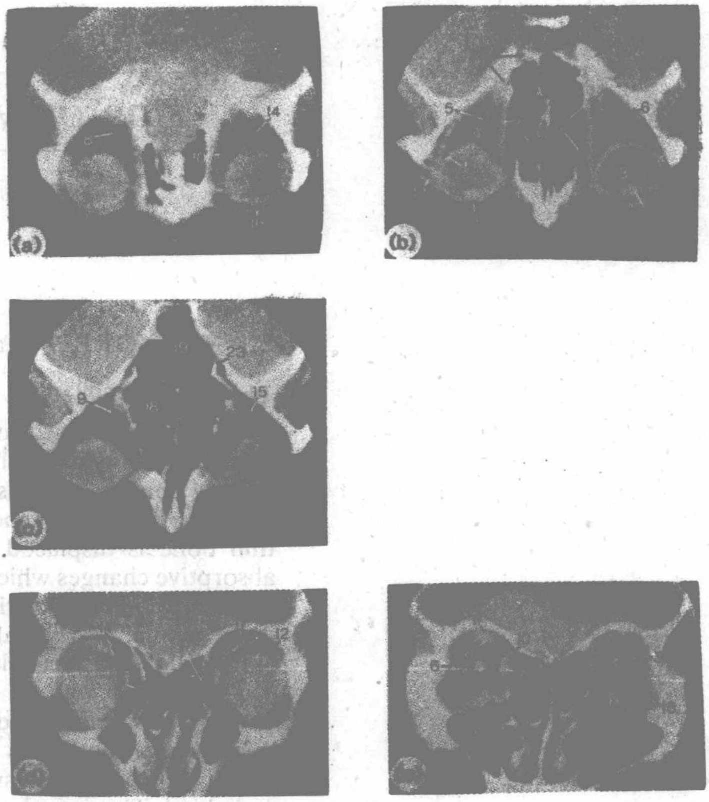

Fig. 2.1 Normal orbits. (a, b, c) **Upper, mid-orbit and lower axial sections; (d, e) anterior and retrobulbar coronal sections. (1) Dense outer layer of globe, formed principally by sclera; (2) lens; (3) vitreous; (4) anterior chamber; (5) optic nerve; (6) lateral rectus muscle; (7) medial rectus muscle; (8) superior rectus muscle; (9) inferior rectus muscle; (10) superior oblique muscle; (11) levator palpebrae superioris muscle; (12) intermuscular septum; (13) lacrimal gland; (14) superior ophthalmic vein; (15) orbital fat; (16) eyelid; (17) lamina papyracea; (18) ethmoid sinuses; (19) sphenoid sinuses; (20) maxillary antrum; (21) region of superior orbital fissure; (22) optic canal; (23) inferior orbital fissure; (24) anterior clinoid process; (25) dorsum sellae.**

The globe and optic nerve

The eye occupies only about 20% of the volume of the orbit. Its normal position can be defined in the axial plane relative to a line passing between the lateral orbital margins on either side. However, minor asymmetry of positioning in the scanner, or of the face, can cause considerable variation in the apparent position of the globe, so that CT measurement of proptosis is of limited value. The equatorial diameter of the eye in the anteroposterior plane is between 21–26 mm, the transverse and vertical diameters varying between 23–25 mm, while at birth the anteroposterior diameter is 16–17 mm. A fine high attenuation line is seen around the globe, to which the sclera is probably the main contributor. The lens lies between a small area of lower attenuation anteriorly, representing the anterior chamber and the slightly higher attenuation of the main portion of the globe, representing the vitreous. The lens is approximately 3.5 × 6.5 mm in size in newborn infants and 4.5 × 9.0 mm in adults. There is considerable variation in size and shape during accommodation, and the posterior surface is relatively flattened.