Computer assisted tomography in orbital disease

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Computer assisted tomography (CAT) in the transverse axial plane, a fundamentally new method of x -ray diagnosis, was developed from 1967 to 1972 by G. N. Hounsfield (1973) at the Central Research Laboratories of E.M.I. Ltd. Clinical evaluation of this technique by J. Ambrose (1973) at Atkinson Morley's Hospital has indicated the enormous value of the investigation in patients with intracranial disease. Minor modifications of the examination technique have enabled us to study the orbit, and this report presents our initial findings.

A conventional radiograph is obtained by passing an x -ray beam through a structure and measuring the emergent x rays by their ability to expose photographic film. All the component tissues of the structure will absorb energy from the beam, but the absorption increases proportionally with increasing tissue density. A radiograph thus presents a record in two dimensions of the varying tissue densities encountered by an x -ray beam traversing a three-dimensional structure. Only when component tissues differ quite markedly in density can they be distinguished, and all tissues lying in the long axis of the beam appear superimposed on the radiograph. This difficulty in resolving tissues of similar density, particularly 'soft tissues', and the problem of envisaging the original three-dimensional anatomy have been serious limitations in radiology. In order to define tissues of similar density by conventional means, it has been necessary to alter the density of one tissue by administering a contrast medium. Radiographs in several planes and conventional tomography give only an incomplete picture in three dimensions. These difficulties have limited the investigation of soft tissue masses within the orbit.

Computer assisted tomography replaces relatively insensitive photographic film by a sodium iodide crystal which serves as the x -ray detector. The crystal gives off visible light (scintillation) in a proportional fashion when exposed to x -rays and an electrical signal is generated *via* a photomultiplier system. In this way a very large number of individual readings are taken of a collimated x -ray beam scanning transverse axial "slices" of the head. The readings are processed by a computer and the anatomy of the "slice" is reconstructed

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by a mathematical method. The resolution achieved allows distinction of soft tissues whose densities are only slightly dissimilar. A series of transverse axial "slices" in a vertical sequence displays the anatomy in three dimensions. Orbital examination displays the globe, optic nerve, and retrobulbar fat. Soft-tissue masses in the retrobulbar space can be readily identified.

Method of examination of the orbit

The patient lies supine on an adjustable table with the upper part of his head inserted into a rubber cap which projects into a Perspex water-filled box. Water is pumped into the box thus moulding the cap firmly onto the patient's scalp and largely excluding intervening air. Scanning the head through water is important, partly to reduce the large density gradient between air and the bones of the skull. Inflation of the rubber cap over the eyes is uncomfortable but retention of a thin film of air between the closed eyelids and the cap usually produces satisfactory results. Alternatively one of us (J.G.) has developed a soft plastic case containing oil which can be moulded over the patient's eyelids (Fig. 1).

FIG. 1 *Patient under examination with oil bag in position*

The water box is surrounded by a rotating frame which supports the scanning equipment. An x-ray tube with its collimator and paired collimated x-ray detectors are mounted on opposite sides of the frame. The x-ray source and detectors are linked so as to remain in constant alignment on opposite sides of the patient's head. The x-ray beam is set with a mean width of 16 mm. in the vertical axis of the head. Since each receptor records from half the beam, a single scan examines a pair of contiguous axial "slices" each 8 mm. thick (Fig. 2).

The x-ray beam and detectors track in a linear fashion across the patient's head and 160 readings of x-ray transmission are taken at regular intervals by each detector. The frame rotates for 5 min.

FIG. 2 *Scanning system*

through 180° around the head in steps of 1° . At each step the linear sequence is repeated, generating 28,800 (160×180) readings from each "slice". The x-ray beam is continuously monitored at source, so that the x-ray absorption from each of these 28,800 beam paths is known. The "slice" examined is considered to consist of a series of cells of equal size, each having a calculable absorption value. Each of the beam paths may now be envisaged as passing through a number of these cells or segments of them. 28,800 simultaneous equations can therefore be constructed with the individual cell absorption values as variables. The computer solves these equations, calculating the absorption values of 6,400 cells, each measuring 3×3 mm. in the transverse plane and 8 mm. in depth. These individual absorption coefficients are made available through a line printer which presents them as an 80 by 80 matrix (the numerical print-out). The anatomy of the "slice" is thus reconstructed in terms of density (Fig. 3).

FIG. 3 *Computer print-out showing absorption coefficients*

The matrix is displayed simultaneously on a cathode-ray oscilloscope which has an adjustable grey scale between black (low absorption values) and white (high absorption values). The image is adjusted to contrast areas of different density and the display photographed with a polaroid camera to provide a pictorial record of the anatomy of the "slice" (Fig. 4).

FIG. 4 Polaroid record of normal subject (a) and explanatory diagram (b)

Absorption (attenuation) coefficients are expressed on an arbitrary scale where water has a density of zero, air -500 (-100 per cent.), and dense bone values between $+300$ and $+700$ (mean $+100$ per cent.). Fat gives mean values of -50 (-10 per cent.) and other soft tissues generally fall within the 0 to 30 range. The standard deviation of absorption coefficients calculated by this method is below 0.5 per cent., which allows resolution of individual soft-tissue structures when they are reconstructed anatomically by the computer.

Examination of the orbits requires careful positioning of the head. A line between the lateral canthus and the external auditory meatus is drawn on the patient's face (orbito-meatal line). The head must be inserted deeply into the water box until the midplane of the x -ray beam is 10 – 20 mm. above the orbito-meatal line. The head is now extended by 5 to 10° until the midplane of the beam coincides with the midplane of both orbits. A single scan will now examine a contiguous pair of 8 -mm. transverse "slices" above and below the midplane of the orbit clear of its bony roof and floor (Fig. 5, opposite).

It is essential to ensure that the x -ray beam passes clear of the orbital roof and floor, for should either of these structures be "grazed" by the beam the absorption values will be markedly elevated at this site.

The reconstruction algorithm used by the computer works most accurately when the beam passes through a series of structures which are not markedly different in density. Examination of the orbit does involve a sequence of marked changes in density (*i.e.* from bone to air in the paranasal sinuses) which may introduce artefact in the region of these high-density interfaces. Artefact takes the form of spurious high or low values in a linear sequence and gives the scan a streaked appearance. Any head movement by the patient during the 5 minutes of scanning increases this type of artefact.

The maximum radiation dose to the skin and eye for the single scan required to examine the orbits is estimated to be 0.5 r using an x -ray tube voltage of 120 kV. This exposure is less than that required for a conventional radiograph.

FIG. 5 Radiographic demonstration of plane of transverse 'slices'

Normal findings

The orbits are displayed in the transverse plane on either side of the nasal and paranasal cavities. The bony medial and lateral orbital walls mark out a triangular space with the eye anteriorly at its base. The junction of the superior and inferior orbital fissures can be identified as a break in the bony contour at the orbital apex.

Seen in transverse section, the eye appears as a peripheral ring of moderate density (absorption coefficients 0 to 25) produced by the sclera and its attached musculature. The less dense vitreous (absorption coefficients -25 to +5) can be seen within the ring, but further resolution of the eye is not possible. As there is an air-tissue interface anteriorly, the numerical values representing the anterior aspect of the globe are often inaccurately high. When the "slice" incorporates the superior or inferior aspect of the globe, the ring-like appearance is replaced by a more uniformly dense area (absorption coefficients 5 to 25). If the patient's head is slightly oblique during the examination, the x-ray beam will "cut" through the eyes at a different level on the two sides. This has the effect of making one eye appear larger than the other. The "larger" eye will also appear to extend further forward than its fellow; the erroneous diagnosis of proptosis must therefore be avoided.

Because the retrobulbar space is occupied by fat, absorption values obtained from this region are negative (-10 to -70). The optic nerve can always be identified in the retrobulbar space as a higher-density structure contrasted against the surrounding orbital fat. The numerical values that identify the nerve range between -10 and +10. The intracanalicular and intracranial course of the optic nerve cannot be identified. It is not possible to demonstrate other intraocular nerves and the extraocular muscles cannot be resolved on the 80 by 80 matrix.

Clinical application

Examination of the orbits by computerized tomography often provides information about pathological processes which cannot be obtained by conventional radiological methods.

Examination takes 10 to 20 minutes, and the result is available after a further 10 minutes. There is no risk to the patient and the procedure is painless. The following selected case reports will be used to demonstrate clinical situations in which this technique has proved to be of diagnostic value.

SUPRASELLAR MENINGIOMA

Case 1, a 44-year-old oenologist was referred for assessment of ventricular size after the removal of a suprasellar meningioma.

In 1964 he had undergone a craniotomy for a large suprasellar meningioma which was partially removed. He received postoperative radiotherapy.

During 1973 the visual acuity of the left eye had deteriorated and reinvestigation disclosed a recurrence of the suprasellar tumour and hydrocephalus. At craniotomy in 1974 an extensive tumour was found in the suprasellar region. Tumour tissue was also present behind the dorsum sellae in both parasellar regions, and appeared to extend forward into the left orbit. Again only partial removal was possible and he made an excellent postoperative recovery.

At the time of examination he had 6 mm. of proptosis on the left and a blind left eye. The visual acuity of the right eye was 6/12, but there was a right temporal hemianopia. Both discs were pale. There was a partial third and a complete sixth nerve palsy on the left (Fig. 6a).

FIG. 6a

The CAT scan (Fig. 6b i-iii) showed a left retrobulbar mass, 2 cm. in diameter, extending into the orbit through a defect in the medial end of the left sphenoid wing (Absorption coefficients 17–29). Visualization of the mass in two tomographic “slices” (4A inferior 4B superior) gives an approximate indication of the vertical extent of the lesion. Residual tumour was identified in both parasellar regions. The patient was referred for further radiotherapy.

FIG. 6b (i) 4A inferior

(ii) 4B superior

(iii)

SPHENOIDAL RIDGE MENINGIOMA

Case 2, a 64-year-old woman, was investigated for right-sided proptosis which had been present for 1 year.

In 1966 a large meningioma had been removed from the right greater sphenoid wing. This was followed by radiotherapy because a thin sheath of tumour had been left adherent to the right internal carotid artery. After this she remained well until 1972 when she developed diplopia. Examination showed 3 mm. of right-sided proptosis. The visual acuity was 6/18 in the right eye, and 6/6 in the left. Both optic discs were normal. She had a partial right sixth nerve palsy. Though a clinical diagnosis of recurrent meningioma was made, this was not confirmed by skull x ray, isotope brain scan, or right carotid arteriography. During 1973 the visual acuity deteriorated on the right and the proptosis increased. When re-admitted to hospital she had a marked irreducible right proptosis with periorbital oedema. The right eye was blind with a pale optic disc. There was complete internal and external ophthalmoplegia on the right. The skull x -ray was unchanged, but the CAT scan demonstrated an enormous mass arising in the region of the greater sphenoid wing and extending anteriorly into the orbit (Fig. 7) (Absorption coefficients 15–21). Isotope brain scan showed an ill-defined increase in uptake in the anterior part of the right middle cranial fossa. As the tumour was considered inoperable, further angiography was not undertaken.

FIG. 7 (a)

(b)

SPHENOIDAL RIDGE MENINGIOMA (EN PLAQUE)

Case 3, a 69-year-old woman, was noted during an examination for a minor injury to the left eye to have a bony swelling of the right temple and slight right proptosis. She had no symptoms referable to the right eye. Examination revealed a 3 mm. right proptosis but there was no abnormality of the visual acuity, visual fields, fundi, or eye movements. There were no neurological signs. The CAT scan (Fig. 8a) showed enormous bony thickening of the lateral walls of the right orbit, which encroached medially on the retrobulbar space. No soft-tissue tumour extended into the orbit. A skull x ray (Fig. 8b) revealed marked sclerosis of the greater and lesser sphenoid wings on the right. Isotope brain scan was positive superficially at the anterior end of the right middle cranial fossa. A diagnosis of meningioma *en plaque* was made and further investigation was not undertaken.

FIG. 8a (i)

(ii)

(b)

OPTIC NERVE GLIOMA

Case 4, a 9-year-old girl, was referred with a 6-months history of left-sided proptosis. In June, 1973, she noted progressive loss of vision in the left eye, followed after a few weeks by proptosis of the eye. Vision was reduced to hand movements, she had 5 mm. of proptosis and disc oedema. Views of the optic foramina showed increased width on the left (Fig. 9a i, ii); left carotid arteriography and air encephalography, however, were both normal.

FIG. 9 (a) Optic canals. Right; left

She was thought to have an optic nerve glioma and was started on steroids. There was some improvement in visual acuity to finger counting, but when she was examined in December, 1973, the visual acuity in the left eye was reduced to hand movements in a small area above fixation. There was a convergent strabismus (Fig. 9b), proptosis (3 mm.), and disc oedema.

FIG. 9 (b)

FIG. 9 (d) *Left optic nerve, 13 mm. in diameter. Distal end of nerve at top of photograph*

The CAT scan (Fig. 9c) demonstrated a mass measuring 2 cm. in the anteroposterior plane and 1.5 cm. in width, reaching from the orbital apex to the globe, centrally in the retrobulbar space (Absorption coefficients 8 to 28). The clinical diagnosis of a left optic nerve glioma was supported and the orbit was explored. This revealed a grossly thickened optic nerve extending from the apex of the orbit to the optic disc. Pathological examination confirmed that it was a benign optic nerve glioma. (Fig. 9d).

FIG. 9c (i)

(ii)

METASTATIC MELANOMA

Case 5, a 92-year-old woman with long-standing chronic simple glaucoma, was referred with right-sided proptosis. In 1973 a malignant melanoma had been removed from her left great toe. She presented 6 months later with pain in the right eye, deteriorating vision, and diplopia. Examination showed 7 mm. of proptosis on the right and the eye was elevated 5 mm. A soft-tissue swelling was palpable on the floor of the right orbit. The visual acuity was limited to hand movements in each eye with constricted fields. The intraocular pressure and pupillary responses were normal, and there were bilateral cataracts and glaucomatous cupping of both optic discs.

General examination revealed hard glands in the left groin, a firm mass in the left iliac fossa, and a hard enlarged liver.

The CAT scan (Fig. 10) demonstrated a mass in the right retrobulbar space measuring 1.5 cm. in the anteroposterior plane and 1 cm. in width, lying against the medial wall of the orbit (Absorption coefficients 24 to 28). No further investigation was felt to be necessary and she was referred for radiotherapy with a presumptive diagnosis of metastatic melanoma.

FIG. 10 (a)

(b)

CHONDROSARCOMA OF SINUSES

Case 6, a 45-year-old woman, was referred for examination with a history of blindness in the left eye. In August, 1973, she was found to have a mass in the nasopharynx. The tumour was partially removed from the posterior ethmoid and basisphenoid regions and proved to be a chondrosarcoma.

During January, 1974, the visual acuity in the left eye deteriorated and she was re-admitted to hospital. Examination demonstrated 3 mm. of proptosis on the left. The left eye was blind with an afferent pupillary defect, all ocular movements were seriously reduced, and there was moderate disc oedema. The right eye was normal.

The CAT scan (Fig. 11) showed a small extension of the tumour, about 1 cm. in diameter, into the apex of the left orbit, and a thin layer of tumour along its medial wall (Absorption coefficients 8 to 30). The findings were confirmed at operation when the left orbit was exenterated.

FIG. 11 (a)

(b)

ETHMOID SINUS CARCINOMA

Case 7, a 58-year-old man, was referred for CAT scanning with a 2-month history of visual deterioration in the left eye and numbness of the left side of his face. Vision was reduced to perception of light, and there was a complete ophthalmoplegia and disc oedema. The right eye was normal. The left corneal reflex was absent but facial sensation objectively normal.

The CAT scan (Fig. 12a) showed expansion of the medial wall of the left orbit in its middle third and destruction of its posterior third. A soft-tissue mass was continuous posteriorly with the expanded ethmoid region, and extended through a defect in the medial third of the sphenoid wing into the middle cranial fossa. The appearances were thought to suggest a malignant tumour arising in the ethmoid sinuses. Skull x ray showed destruction of the posterior bony orbit. The ethmoid sinus was explored at an emergency operation, and the orbit decompressed. Histologically, there was no evidence of malignant disease.

FIG. 12 (a)

The patient was re-admitted to hospital 2 months later with a 3-day history of loss of vision in the right eye. He was now blind in both eyes but otherwise there was no change in the findings on examination.

The CAT scan (Fig. 12b) showed further expansion of the medial wall of the left orbit and an extensive soft-tissue mass along the medial wall of both orbits which extended posteriorly into the suprasellar region, particularly on the left.

FIG. 12 (b)

The skull x ray (Fig. 12c) showed further destruction of the left orbit, and a right carotid arteriogram confirmed the presence of a suprasellar mass and encasement of the ophthalmic artery (Fig. 12d).

At craniotomy a large suprasellar and parasellar tumour extending into both orbits was found. Both optic nerves were decompressed and there was some return of vision in the right eye.

Histological examination of the intracranial tumour showed that it was a carcinoma.

WEGENER'S GRANULOMATOSIS

Case 8, a 46-year-old woman, was investigated for right-sided proptosis. In 1968 she had presented with pain and discharge from the right ear together with a right seventh nerve palsy. She was found to be deaf on the right and an initial diagnosis of otitis media was made. She was also found to have a mass in one breast and biopsy showed a granuloma. In 1969 she developed a right-sided proptosis and biopsy of the lacrimal gland confirmed a diagnosis of Wegener's granulomatosis. Chest x ray had revealed three opacities in the right lung, and she had been treated with steroids since the diagnosis was confirmed. Her chief complaint at the time of examination was pain and watering of the right eye. The visual acuity, visual fields, and fundi were all normal. There was 9 mm. of proptosis on the right; swelling of the right lacrimal gland, and slight limitation of ocular movements in all directions.

The CAT scan (Fig. 13) demonstrated an extensive mass in the right orbit extending from the orbital apex to the globe and probably over the globe in the region of the lacrimal gland (Absorption coefficients 15 to 31). This presumably represents granulomatous tissue, but exploration has not yet been undertaken.

FIG. 13 (a, b)

ORBITAL HAEMATOMA

Case 9, 64-year-old woman, was investigated for right-sided proptosis. In December, 1973, she awoke with pain and swelling of the right eye, and later that day she fell and was unable to stand again. On admission to hospital there was right proptosis, chemosis, and conjunctival injection (Fig. 14a). The visual acuity, visual fields, and fundi were normal. There was limitation of movement of the right eye in all directions. Neurological examination revealed a left hemiparesis.

The skull x-ray was normal. A right carotid arteriogram showed occlusion of some middle cerebral branches but gave no indication of the cause of the proptosis. The CAT scan (Fig. 14b) demonstrated a well-defined area of increased density in the right retrobulbar space, strongly suggesting a haematoma (Absorption coefficients 7 to 39). There was also a zone of diminished density in the region of the right internal capsule. The patient died suddenly 2 weeks later from a massive pulmonary embolus. Autopsy confirmed the haematoma in the right orbit and a 1-cm. area of liquefaction in the right internal capsule.

DIFFERENCE IN SIZE OF EYES AND ORBITS

Case 10, a 65-year-old woman, was referred for investigation of right proptosis. At the age of 12 years she had become aware of drooping of the right eyelid and poor vision in the right eye. In 1972, an optician had noted proptosis and further examination showed diminished elevation of the right

FIG. 15 (a, b)

eye. The visual acuity in the right eye was reduced to counting fingers, whereas in the left eye it was 6/6 and J1. There was a cataract on the right side, but the left fundus was normal. Though a congenital myopia was diagnosed, the recent changes raised the possibility of alternative orbital pathology.

A skull x ray showed the right orbit to be slightly larger than the left, but views of the optic foramina and orbital phlebography were normal. The CAT scan (Fig. 15) showed the right eye to be considerably larger than the left, and excluded the presence of a retrobulbar mass. The difference in size of the eyes in this patient was not artefactual (*i.e.* not due to oblique examination) because the right eye is seen to be the larger on both tomographic "slices".

ABSENCE OF POSTERIOR WALL OF ORBIT

Case 11, a 16-year-old girl, was referred with pain in the left eye. She had been known since birth to have a pulsating left eye. Examination confirmed pulsation of the left eye in time with her pulse. There were no other abnormal findings (in particular the visual acuity, visual fields, and fundi were normal). No stigmata of neurofibromatosis could be identified.

The CAT scan (Fig. 16a) showed that the posterior aspect of the bony orbit was absent. The tip of the left temporal lobe extended anteriorly into the orbital apex through this bony defect and the optic nerve was displaced anteriorly and medially.

FIG. 16 (a) i

ii

FIG. 16 (b)

Skull x ray (Fig. 16b) confirmed the bony defect at the back of the left orbit but was otherwise normal. A left carotid arteriogram was normal. The patient was thought to have congenital absence of the posterior bony aspect of the left orbit with herniation of the left temporal lobe into the retrobulbar space.

Discussion

The importance of computer assisted tomography, a fundamental advance in the radiological examination of the orbit, has been amply demonstrated by the preceding cases. These selected examples also emphasize the wide spectrum of disease that can be detected. Soft-tissue tumour masses, usually difficult to identify by conventional methods, can be delineated clearly in the retrobulbar space. This applies equally to tumours which arise primarily within the orbit and to those extending into the retrobulbar space from the nose, paranasal sinuses, or parasellar region. The very low density of orbital fat provides a natural contrast against which soft-tissue masses are seen as areas of increased density. The limit of resolution is based on a $3 \times 3 \times 8$ mm. cell, and it is therefore possible to estimate the size of an orbital mass in the transverse projection. Localization without accurate measurement can also be made in the vertical axis of the orbit by assessing a pair of tomographic "slices". The practical limits of resolution have not yet been established, though visualization of the optic nerve (3 mm.) and small tumours (1 cm.) is possible. The bony roof and floor of the orbit, of necessity, remain "blind" areas, and presumably small tumours lying on them will not be identified until they project inwards far enough to be incorporated into the x-ray beam. In our group of patients the ability to detect a glioma of the optic nerve is of particular importance. This commonly benign tumour has usually evaded accurate diagnosis until the retrolaminar or intracanalicular portion of the nerve has become involved. The present technique may facilitate early diagnosis and continued follow-up, and provide an index against which the efficacy of radiotherapy can be assessed. It is also expected to be of value in the detection of infiltrative and metastatic lesions of the optic nerve. The therapeutic implications of detecting the orbital spread of tumours are considerable, whether surgery or radiotherapy is contemplated. Accurate localization is a helpful pre-requisite for biopsy when the diagnosis is in doubt. The exact location of a small tumour was corroborated in one patient (Case 6) in whom pathological examination was possible.

The negative scan in patients presenting with proptosis has been equally valuable, and has helped to exclude retrobulbar tumours. In two of our patients we were able to demonstrate that benign enlargement of the globe was responsible for their proptosis.

Haemorrhage into the orbit has also been readily demonstrable when the clinical diagnosis was conjectural and we were fortunate enough to obtain pathological confirmation of this diagnosis in the patient described (Case 9).

It is hoped that further study will enable us to trace the presence of orbital haemorrhage in patients with vascular malformations or bleeding after head injury. In such circumstances the CAT scan may provide vital information if surgical intervention is contemplated for failing vision.

While granulomatous masses within the orbit produce clear abnormalities (Case 8), dysthyroid eye disease, even when proptosis is present, usually gives a negative result. One patient with severe dysthyroid ophthalmopathy and bilateral proptosis did, however, show a small area of increased density at the apex of each orbit which we interpreted as thickening of the extraocular muscles.

The location of conjunctival and intraocular foreign bodies with computer assisted tomography has been unsuccessful because patients have difficulty in keeping their eyes still for 5 minutes. Furthermore, a small foreign body may have little effect on density when measured as part of a $3 \times 3 \times 8$ mm. cell.

Although the E.M.I. Scanner was developed for computerized tomography of the intracranial compartment, its application to the orbit has produced most encouraging results. It is anticipated that certain modifications to the basic equipment will in future permit more sophisticated orbital examination and enhance the diagnostic potential of this method.

Summary

Computer assisted transverse axial tomography (a revolutionary method of *x*-ray diagnosis developed to investigate brain disease) has been applied to the orbit. Early results indicate that the method is proving reliable in detecting soft-tissue masses. Meningiomas, optic nerve gliomas, and orbital metastases are readily detected and the orbital spread of perisellar and sinus tumours clearly seen. Orbital haematomas and granulomatous masses also produce easily recognizable abnormalities.

The technique and practical aspects of examination are described and the results illustrated by selected cases.

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