THE EFFECT OF EARLY ENUCLEATION ON THE ORBIT IN ANIMALS AND HUMANS

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SIGNIFICANT COSMETIC DEFORMITY occurs frequently following removal of an eye. This fact does not eliminate the necessity for surgery when the indications are present. Careful surgical technique, the use of an implanted mass in the orbit, and the early use of a prosthesis have done much to reduce the deformity to a minimum. Despite these steps, general dissatisfaction in many cases warrants an attempt at better understanding of the basic changes that occur in the growth of the orbit following enucleation, particularly at an early age. Many clinical impressions are based on a minimum of experimental and clinical reports on this subject. Because of the limited number of these reports, a study was undertaken to determine more accurately the influence of early enucleation on the growth of the orbit in experimental animals, and in infancy and childhood.

REVIEW OF THE LITERATURE

Merkel[1] in 1891 makes the single sentence statement that—since Pétrequin you can find the notation that the orbit gets smaller after enucleation of the eye. This statement is credited to the latter's writings on ophthalmologic subjects around 1840.

In 1898 Byers[2] reported an investigation as to whether there was arrested development in the orbit following enucleation of one eye in childhood. He examined 10 cases as adults, five of whom had lost their eyes before the age of five years and five of whom had lost their eyes between age 10 and 13 years. Measurements were made externally through the skin and he reported that no arrest of development had occurred, at least as far as the external orifices of the bony wall of the orbit were concerned.

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In 1901 Thomson[3] attempted to determine the influence of the eyeball on the growth of the orbit by experimental enucleation of one eye in young animals. He chose young rabbits approximately three weeks of age, finishing with six survivors, which he sacrificed at seven to nine months of age. Only three of these skulls were macerated and direct readings taken from the dry bone skulls. Readings were also taken from the other wet specimens. With this limited number, his results showed conclusively that, in rabbits, a deficiency of growth occurs in the anophthalmic orbit. Averaging his figures for the anteroposterior (width) measurement with the vertical measurement of the orbit of the three dry skulls, this decrease was found to be in the magnitude of 11.1 per cent. He concluded that in certain animals the growth of the orbit was influenced by the presence of the eye. He assumed by inference that the same would hold true in other animals and in man.

In a series of experiments[4–6] from 1909 to 1921, Wessely demonstrated that the bony orbit will show retardation of growth, with a reduction of the orbital contents, even without enucleation. He decreased the size of the eye by various glaucoma procedures and by doing discissions of the lenses in young rabbits. This was followed by microphthalmos of one to two millimeters and a decrease in the diameter of the orbits by a similar amount. Following reduction of the orbital volume by removal of the gland of Harder in very young rabbits, Wessely also demonstrated reduction of growth of the bony orbit. He reported a 16-year-old patient, with microphthalmos (phthisis) after a penetrating injury at age one and a half years, whose roentgenograms revealed a smaller orbit on the affected side.

Sattler,[7] in 1922, in recommending fat transplant to the orbit to improve the cosmetic results after enucleation, made the following statement: "In nine one-eyed patients, age three to 18, I always found a clear difference between the sizes of the orbits on x-rays, and this as soon as one year after enucleation in spite of continuously wearing a glass eye." This was not further elucidated.

As recently as 1922, Heckel[8] reported three cases of enucleation in infants in which he stated he did not favor the implantation operations, nor did he believe that it made any difference in the development of the orbit whether or not implantation was performed.

Koch and Brunetti[9] in 1933 reported their roentgenologic technique to determine the volume of the orbit and the measurement of its depth. They applied their method to the measurement of the anteroposterior axis of the orbit in unilateral anophthalmos. They concluded the orbit of the affected side was smaller but retained the same depth as the unaffected side.

A clinical study of the effect of the enucleation of one eye in childhood, and the subsequent development of the face, was made by Taylor[10] in 1939. For this, 51 patients were reviewed in two series. All of the cases were studied by means of external measurements, and 36 had been X-rayed. He confirmed the occurrence of the same arrest in children that Thomson had reported in the experimental rabbits. He found that enucleation before the age of five could lead to a deficiency of the bone growth of the orbital margin, as much as 15 per cent on the enucleated side as compared with the normal side. This change persisted into adult life. He also found that enucleation at nine years and after apparently did not lead to appreciable alteration. He reported that the maxillary antrum of the anophthalmic side underwent overgrowth when the enucleation had been performed before the age of nine. None of Taylor's 51 patients had an orbital implantation.[11] Nine of the 51 patients had worn no prosthesis after enucleation. His findings in these cases, compared with those wearing a prosthesis, revealed no influence of the prosthesis on the development of the bony part of the orbit, but probably some influence on the soft parts around the orbit.

In 1945 Pfeiffer[12] made an excellent report on the effect of enucleation on the orbit. He summarized his observations in a critical analysis of 31 patients who were studied by photographs, external examination, and roentgen study. A group of children were included who had been X-rayed eight or ten years previously at the time of enucleation for retinoblastoma. He made the observation that removal of the eye arrested development of the orbit and led to a contraction of it, or to a reduction of its capacity. These changes were greater the earlier in life the eye was removed. He also found that the implantation of spheres tended to maintain the intraorbital pressure and counteract the contracting process. While the orbit still contracted even with a buried implant, it did not do so to the same degree as the orbit in which no implant had been used. The walls were more normal in contour. Diminution of the size of the orbit resulted eventually even with enucleation of the adult eye. He emphasized stereoscopic evaluation and even consideration for laminography. Asymmetry of the face of the child was also noted.

Other short statements or isolated case reports refer to, or show the effect of, this decrease in bone development of the orbit following enucleation.[13-21] A decrease in the size of the optic canal on the enucleated side has been noted.[12,19,22]

EXPERIMENTAL PURPOSE

An investigation was made into the influence of early enucleation of one eye and the subsequent development of the orbit in the rabbit, the cat, and in infants and childhood. The purpose was to determine and more firmly establish, both in animals and in the human, what bony changes occur in the orbit, the relation between age of enucleation and the changes in the orbit, the influence of an orbital implant, and the clinical consideration which might be governed by these findings. Furthermore, optic nerve canal and roentgen therapy bone changes were evaluated.

METHOD

A series of studies were carried out in three main parts:

(1) The right eyes of a group of young rabbits were enucleated. The rabbits were allowed to mature, were sacrificed, and the skulls macerated for direct measurement study.

(2) A similar study on a larger series of cats was performed. Silicone spherical implants were placed in some of the orbits following enucleation to determine their influence on subsequent orbital development.

(3) Forty-two humans who had lost one eye in infancy or childhood were studied by skull roentgenograms, and the measurements from these films were correlated. A control group of 20 normal skull roentgenograms from patients without eye pathology was reviewed in a similar manner.

PROCEDURE

RABBITS

This study primarily was to repeat and confirm the previously reported animal work of a similar nature by Thomson[3] on three macerated rabbit skulls. A total of 10 New Zealand White rabbits comprising two litters was studied. Two rabbits, of a litter of three, had the right eye enucleated under local Xylocaine anesthetic at age seven days, the third rabbit being left as a control. Six rabbits, of a litter of seven, had the right eye enucleated under local Xylocaine anesthetic at age 11 days, with the seventh rabbit being left as a control. These two litters were allowed to grow to maturity and were sacrificed at 228 days and 204 days respectively. The skulls of the 10 rabbits were macerated and craniometric determinations were made using the measuring rule, spreading calipers, sliding parallel compass, and a hole gauge.

The following craniometric determinations were made on each skull:

(*a*) The anteroposterior or horizontal internal orbital measurement at the rim. This measurement was made anteriorly from the rim of the orbit of the maxilla just below the lacrimal bone, posteriorly to the anterolateral wing of the temporal bone which extends to join with the zygomatic bone.

(*b*) The greatest vertical internal orbital measurement at the rim.

(*c*) The depth of the orbit as measured as close to perpendicular as possible from a vertical plane at the orbital rim to the optic foramen.

(*d*) A measurement from the mid-sagittal suture between the orbits to the cusp of the last molar tooth.

The three orbital measurements (*a*), (*b*), and (*c*) are those described by Davis.[23] The measurements were recorded for the right and left orbits with the percentage difference, or decrease, listed for each comparative measurement. The percentage differences for the two intraorbital rim measurements (*a*) and (*b*) were averaged for each rabbit, and these figures averaged for the entire group of operated rabbits and compared with the controls.

CATS

A larger series of cat skulls was studied. This animal was chosen in preference to the rabbit for more extensive study since the skull more nearly simulates the human in that the orbital rim is nearly intact. Also, the visual axis and orbital axis are more nearly similar to that of man as compared with many other laboratory animals. The cat also matures reasonably quickly and the skulls could be studied without as long a delay for maturation as other animals might require.

A total of six litters was studied, with the size of the litters ranging from three to five cats. Within each litter, one cat was left as a control and the other litter mates had the right eye enucleated under local Xylocaine anesthetic. A total of 25 cats was used initially, four of which died and were disposed of inadvertently during the study. This left a total of 15 cats which had been enucleated, and six control or unoperated animals. They were operated from eight to 23 days after birth and were sacrificed at various stages from 104 to 169 days after birth. Two of the 15 cats died prematurely at age 38 and 87 days and were included in the series.

In three of the six litters an attempt was made to determine the influence of orbital implantation on subsequent development of the orbit. Within each litter a control cat was present, a simple enucleation was performed on a litter mate, and a silicone sphere was placed in the other, or others, of the litters at the time of enucleation. The silicone spheres were of varying sizes, from 5 to 8 mm., and of the type described by Ruedemann.[24] They replaced enucleated eyes which were about 10 mm. in diameter. Despite conjunctival suturing and suturing of the lids, all of these implants extruded at various stages, the intervals for which were unknown for some. In two of the cats the implants remained for at least a month. Following sacrifice all 21 cat skulls were macerated and measured in the same manner as the rabbit skulls.

The following measurements were taken:

(*a*) Horizontal measurement: posteriorly from the frontal process extending anteriorly to the medial wall near the nasolacrimal canal at the suture junction at the orbital rim of the maxillary and frontal bones.

(*b*) Vertical measurement: the greatest vertical intraorbital measurement at the rim.

(*c*) The depth of the orbit, as measured from the optic foramen to the anterior inferior orbital margin in the region of the infraorbital foramen.

These were recorded for the right and left orbit with the percentage difference, or decrease, listed for each comparative measurement. The two orbital measurements at the rim were averaged for each cat and the average taken for the entire group of operated animals. These averages were compared with the control group.

HUMANS

A series of 42 humans was studied by roentgenograms. All of the cases had one eye removed surgically at varying young ages. They were studied at various intervals after enucleation. One patient with unilateral congenital anophthalmos was included. These patients became available by reviewing the operating room and history room records in five local hospitals to determine the patients who had enucleations performed at a young age. Many of the patients were contacted directly, and with the co-operation of many of my colleagues in supplying additional patients and records, the total of 42 cases was accumulated. Some were referred by opticians who had been fitting them with prostheses.

TABLE 1. AGE DISTRIBUTION AT TIME OF ENUCLEATION

Age	*Number*
0– 6 months	4
6–12 months	4
1–1½ years	4
1½– 2 years	2
2– 3 years	5
3– 4 years	3
4– 5 years	5
5– 6 years	2
6– 7 years	2
7– 8 years	2
8– 9 years	2
9–10 years	2
10–11 years	1
11–12 years	1
12–13 years	1
13–14 years	1
14–15 years	1
	42 TOTAL

Their age range at the time of enucleation is shown in Table 1. There were 21 males and 21 females. The right eye had been removed in 16 and the left eye in 26. The earliest enucleation was on the first day of life, and the oldest enucleation in this series was in the fifteenth year. The age at the time of examination ranged from two and one half years to 42 years of age. The intervals after enucleation ranged from 22 months to 40 years, with the average being 11¼ years. The diseases necessitating removal of the eye are shown in Table 2.

TABLE 2. REASON FOR ENUCLEATION

Trauma	25
Tumor	11
Congenital anophthalmos	1
Inflammation	2
Unknown	3
	42 TOTAL

The following eight roentgenographic projections were made: (*a*) the Caldwell view in an exaggerated projection so as to place the petrous pyramids below the rim of the orbit (stereoscopically); (*b*) a stereoscopic Waters projection; (*c*) the right lateral skull and the left lateral skull; (*d*) the right and left optic foramen. With five of the very young children who were examined, single Caldwell and Waters projections were made, since stereoscopic projections could not be accomplished satisfactorily.

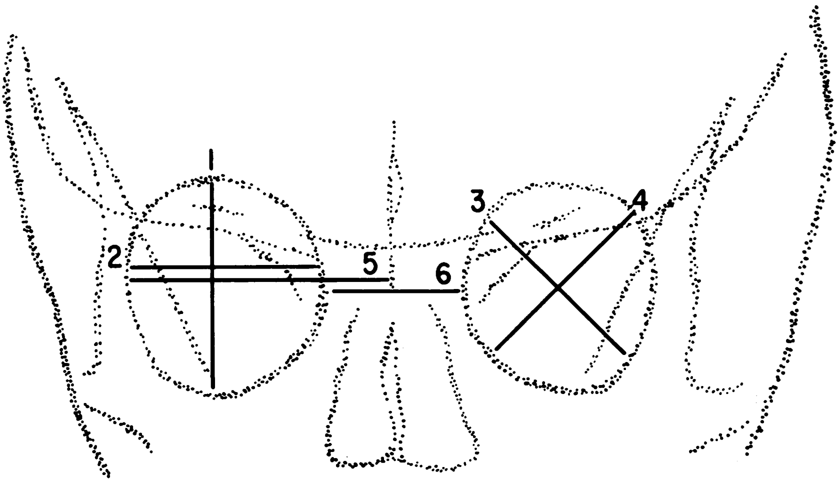

FIGURE 1. ROENTGENOGRAPHIC MEASUREMENTS.

Fifteen cephalometric determinations were made from the roentgenograms of each patient. They are shown in Figure 1 and Table 3. These measurements comparing the right side and the left side were tabulated, together with the percentage difference, or decrease, in that particular measurement. The average for the percentage difference of the four measurements, including the orbital height, width, and two diagonals was also recorded. This is used as the main single measurement to represent the percentage decrease in size at the orbital rim of the anophthalmic orbit, as compared to its fellow normal orbit.

Roentgenograms for 20 normal adult patients were studied in a

TABLE 3. FIFTEEN ROENTGENOGRAPHIC MEASUREMENTS

1. Greatest vertical orbital dimension, each orbit	2
2. Greatest horizontal orbital dimension, each orbit	2
3. Greatest diagonal (lower temporal-upper nasal) orbital dimension measured at 45 degrees to horizontal, each orbit	2
4. Same measurement, diagonal (lower nasal-upper temporal), each orbit	2
5. Midline to lateral orbital margin, each orbit, approximately nasion to ectoconchion	2
6. Minimum interorbital distance—horizontal line between most medial point of right and left medial orbital margins	1
7. Optic foramen, horizontal diameter, each side	2
8. Optic foramen, vertical diameter, each side	2
	15

similar manner. These had been taken for diagnostic evaluation of some other condition, such as sinusitis or a neurological disorder. These same measurements were made from the roentgenograms in this series. The percentage difference for each measurement, and the average for each measurement, were determined and used as a control group for comparison with the anophthalmic series of patients.

FIGURE 2. RABBIT 10.
Anophthalmic right side, enucleated 7 days, sacrificed 228 days. Smaller orbit with drooping and atrophy of supraorbital process of frontal bone and changes in maxilla, zygomatic, and temporal bones causing orbital deformity.

FIGURE 3. RABBIT 10.
Normal left side.

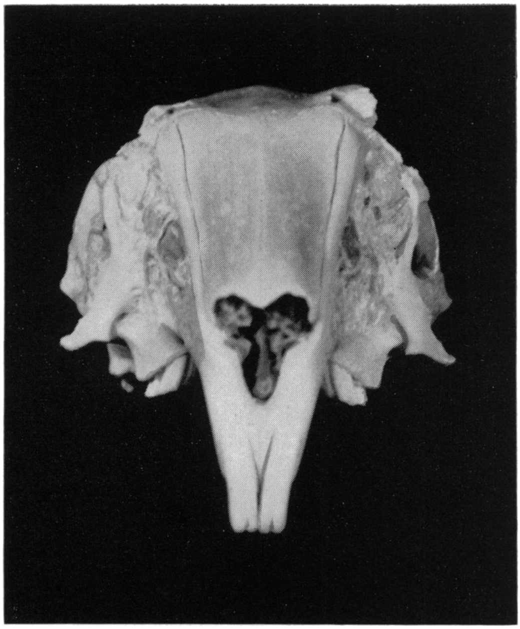

FIGURE 4. RABBIT 10.
Front view. Shows drooping of supraorbital process of frontal bone.

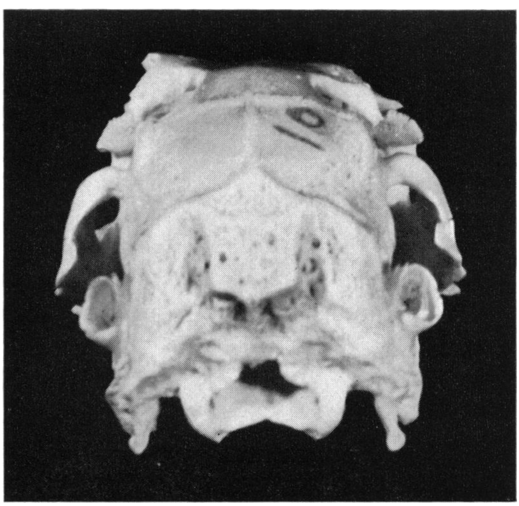

FIGURE 5. RABBIT 10.
Viewed from behind. Showing drooping of supra-orbital process of frontal bone.

RESULTS

RABBITS

The bony orbital changes presented a characteristic picture. These can be demonstrated in Figures 2 through 7. There was contraction in a purse-string effect of all of the bones making up the orbital rim. This was particularly prominent in the region of the supraorbital process of the frontal bone superiorly with its anterior and posterior projections. This showed shrinkage and depression. The zygomatic bone showed elevation and flattening medially. The depth of the orbit was somewhat

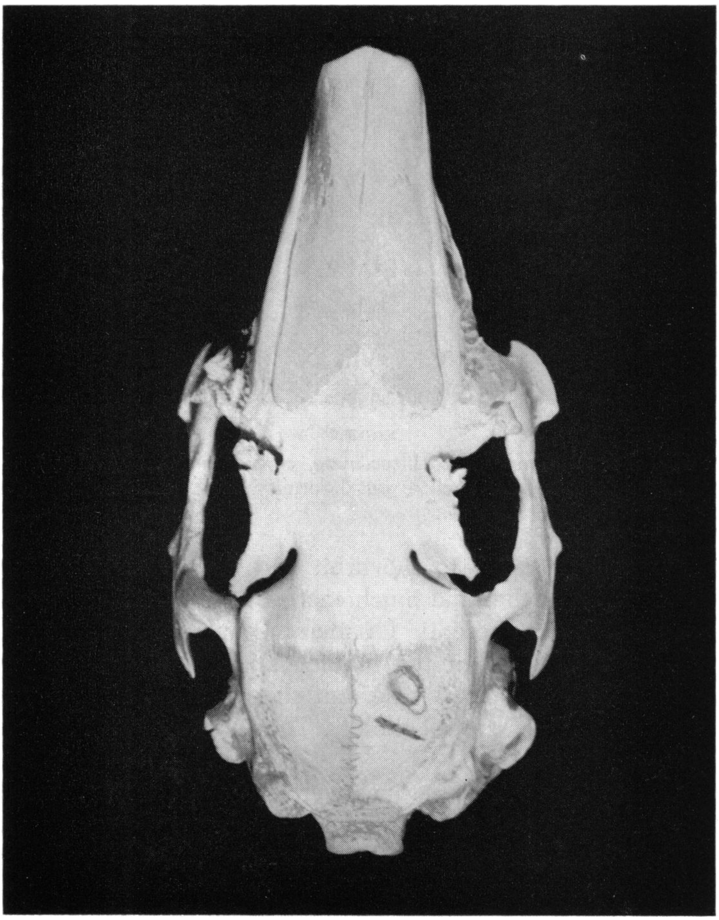

FIGURE 6. RABBIT 10.
Viewed from above. Deformity of right orbit. Atrophy of supraorbital process of frontal bone and zygomatic bone.

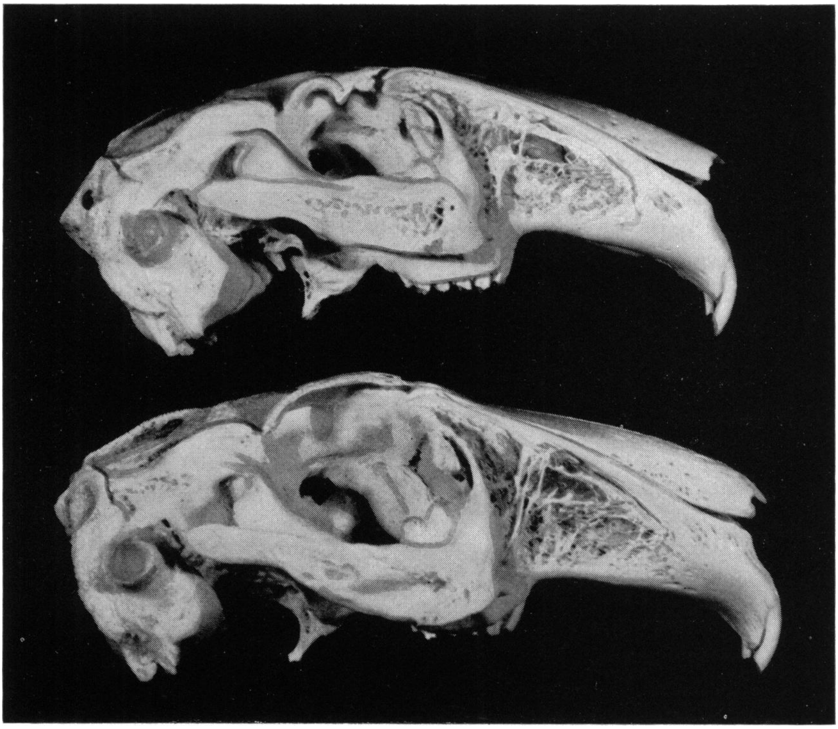

FIGURE 7
Rabbit 10 (above), compared to litter mate, control rabbit 9 (below), showing marked contracture and deformity of orbital rim.

decreased. The entrance to the orbit and its rim, which is usually nearly circular, had become much more oval with its long axis in a horizontal direction. The optic foramen has an anterior edge which is common to both orbits in the midline and therefore could not be compared with the opposite side, but showed little change over the optic foramina of the control rabbits. This is usually about 4 mm. in diameter.[25]

The craniometric determinations were recorded for each rabbit, an example of which is shown in Table 4. These bony changes resulted in the horizontal and vertical orbital rim measurements being less on the enucleated side for all of the rabbits. The measurements of the depth of the orbit, and the measurements from the mid-sagittal suture between the orbits to the cusp of the last molar tooth, as a suggestion of facial asymmetry, were equal or less on the enucleated side in all

TABLE 4. RABBITS: CRANIOMETRY AND PERCENTAGE DIFFERENCES FOR ORBITAL MEASUREMENTS

	Horizontal (mm.)			*Vertical (mm.)*			*Avg. % diff. horizontal & vertical*	*Depth of orbit (mm.)*			*Midline skull to molar tooth, mm.*		
	R	*L*	*% diff.*	*R*	*L*	*% diff.*		*R*	*L*	*% diff.*	*R*	*L*	*% diff.*
Rabbit 10	22	25	12.0	15	21	28.6	20.3	16	17	5.9	29	30	3.3
Range, operated rabbits	22–26	24.5–28	4–12	15–21.6	20–24	10.4–28.6	8.8–20.3	14–18	15–18.5	0–6.7	27–30	28.5–31.5	0–6.9
Control rabbit 9	27	27	0	23	23	0	0	18	18	0	30	30	0
Average % difference operated rabbits (8)			8.2			17.4	12.8			3.4			3.3
Average % difference unoperated controls (2)			1.0			1.2	1.1			0			0

TABLE 5. CATS: CRANIOMETRY AND PERCENTAGE DIFFERENCES FOR ORBITAL MEASUREMENTS

	Horizontal (mm.)			*Vertical (mm.)*			*Avg. % diff. horizontal & vertical*	*Depth of orbit (mm.)*		
	R	*L*	*% diff.*	*R*	*L*	*% diff.*		*R*	*L*	*% diff.*
Cat 17	17.5	22.5	22.2	11.5	19.5	41.0	31.6	23	26	11.5
Range, operated cats	15–20	18–27	16.7–30.6	11.5–17	16–23	21.9–41.0	19.3–33.6	17–30	19–32.5	6.7–20.8
Control cat 7	32	32	0	24	23.5	2.1	1.1	31	31	0
Average % difference operated cats (15)			22.8			30.8	26.8			11.5
Average % difference unoperated controls (6)			0.4			1.3	0.8			0.8

cases. The greater orbital rim changes were in the vertical diameter with the average per cent difference for the vertical measurement being 17.4, and for the horizontal distance 8.2. The average of these two was an over-all diminution of orbital measurements of 12.8 per cent. This compared with 1.1 per cent variation for the control animals (Table 4).

The age at the time of surgery appeared to be related to the degree of change in the orbit. The 12.8 per cent decrease was the average change for both litters. Litter 2, operated at seven days, showed a 16.2 per cent decrease compared to Litter 1, operated at 11 days, which showed an 11.7 per cent decrease. Thomson's series, operated at about 21 days, showed an 11.1 per cent decrease. Thus, the earlier the enucleation, the greater were the changes in the orbit.

In summary, the anophthalmic orbits of the rabbits showed uniform marked contraction of the rim of the orbit, in the magnitude of 12.8 per cent. The changes were more marked the earlier the enucleation was performed.

CATS

The characteristic bony orbital changes can be demonstrated in Figures 8 through 14. The rim of the orbit of the cat skull, which is normally made up of the frontal, maxillary, and zygomatic bones, with a frontal and zygomatic process joined by the orbital ligament, usually shows a 5- to 7-mm. gap between these sharp tips. This gap in the enucleated skulls was reduced to 2 to 4 mm. and the sharp tips of the processes were very blunted. The sharp edges of the rim of the orbit were much more smooth and rounded, and the bone at the rim appeared more porous and less dense. The zygomatic bone was very much flattened and elevated, contributing to a marked reduction in size of the orbital entrance. The oval entrance to the orbit was much more oval, with its long axis in a horizontal direction. The depth of the orbit was decreased. In every case the optic foramen was smaller on the enucleated side than on the opposite side. The orbital fissure at times was smaller. The nasolacrimal fossa was displaced posteriorly 3 to 5 mm. and the nasolacrimal canal, which usually measures 1.25 mm., was smaller. The infraorbital canal and foramen in the maxillary bone were always smaller.

The craniometric determinations were recorded for each cat, an example of which is shown in Table 5. These bony changes resulted in the horizontal and vertical orbital rim measurements being less on the enucleated side for all the cats. The greater orbital rim change was in the vertical diameter, with the average per cent difference for the

FIGURE 8. LITTER 1, CATS 1–5.

Four cats have had right eye enucleated showing characteristic changes which can be routinely reproduced. Top center skull is unoperated control. Operated on 15th day, sacrificed 146 days.

FIGURE 9. CAT 17.
Front view. Smaller right anophthalmic orbit. Irregular orbital rim. Flattened frontal area. Higher zygomatic bone. Smaller infraorbital foramen.

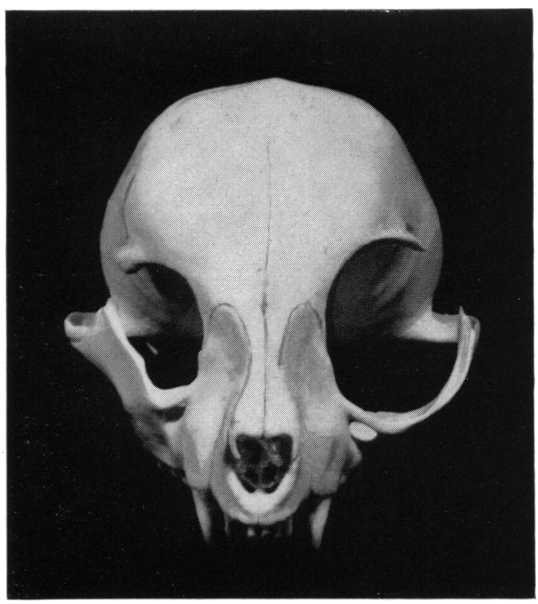

FIGURE 10. CAT 17.
Front view. Anophthalmic right side.

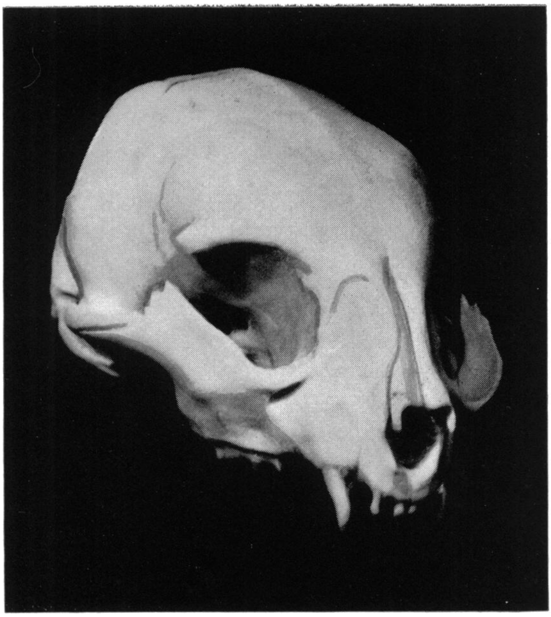

FIGURE 11. CAT 17.
Side view. Anophthalmic right side. Smaller orbit. Thickened orbital processes. Smaller optic foramen.

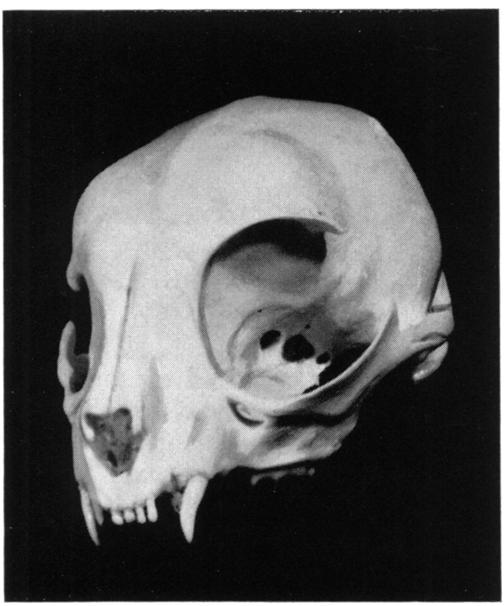

FIGURE 12. CAT 17.
Side view. Normal left side.

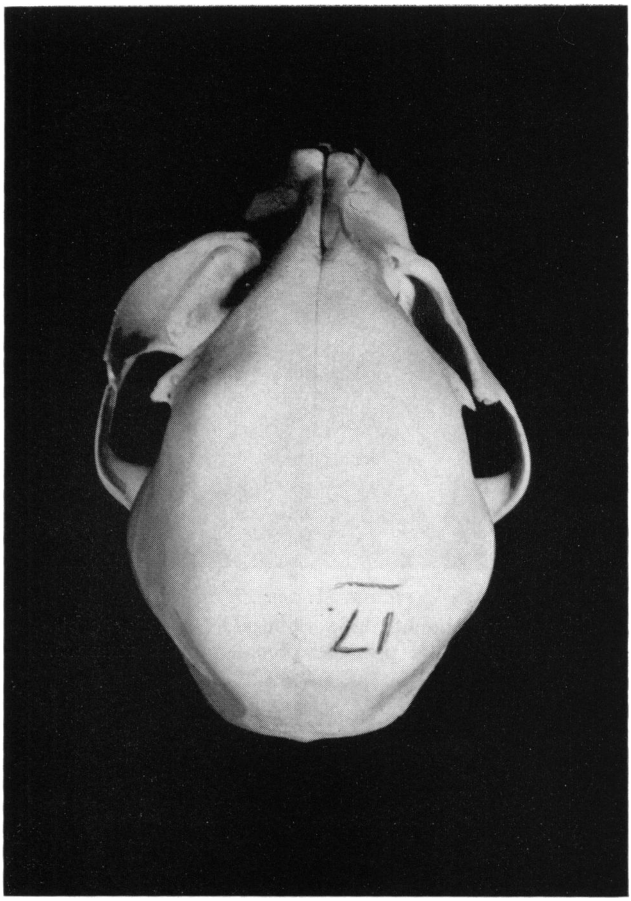

FIGURE 13. CAT 17.
Skull viewed from above. Flattened zygomatic bone on anophthalmic right side.

vertical measurement 30.8 per cent, and for the horizontal measurement 22.8 per cent. The average of these two figures was an over-all diminution of the orbital measurements of 26.8 per cent. This compared with 0.8 per cent for the control animals. The average decrease in the orbital depth was 11.5 per cent. While roentgenograms of the cat skull demonstrated these bony changes very adequately, as shown in Figure 15, their actual measurement from the dried skull was more practical.

An attempt was made to determine the effect of an orbital implant.

FIGURE 14. CAT 17.
Skull, viewed from below. Flattened zygomatic bone on anophthalmic side.

In five of the cats from Litters 4, 5, and 6, silicone implants of the type shown in Figure 16 had been placed in the orbits at the time of enucleation. The three implants in the case of Litter 4 all extruded within a few days. However, the one cat in this litter which had an enucleation with no implant showed the greatest percentage of decrease in bone development, suggesting the implants may have had some beneficial effect in the others. In Litters 5 and 6, an 8-mm. silicone implant had been placed in the orbit of one kitten in each litter. These remained in position at least a full month before extruding.

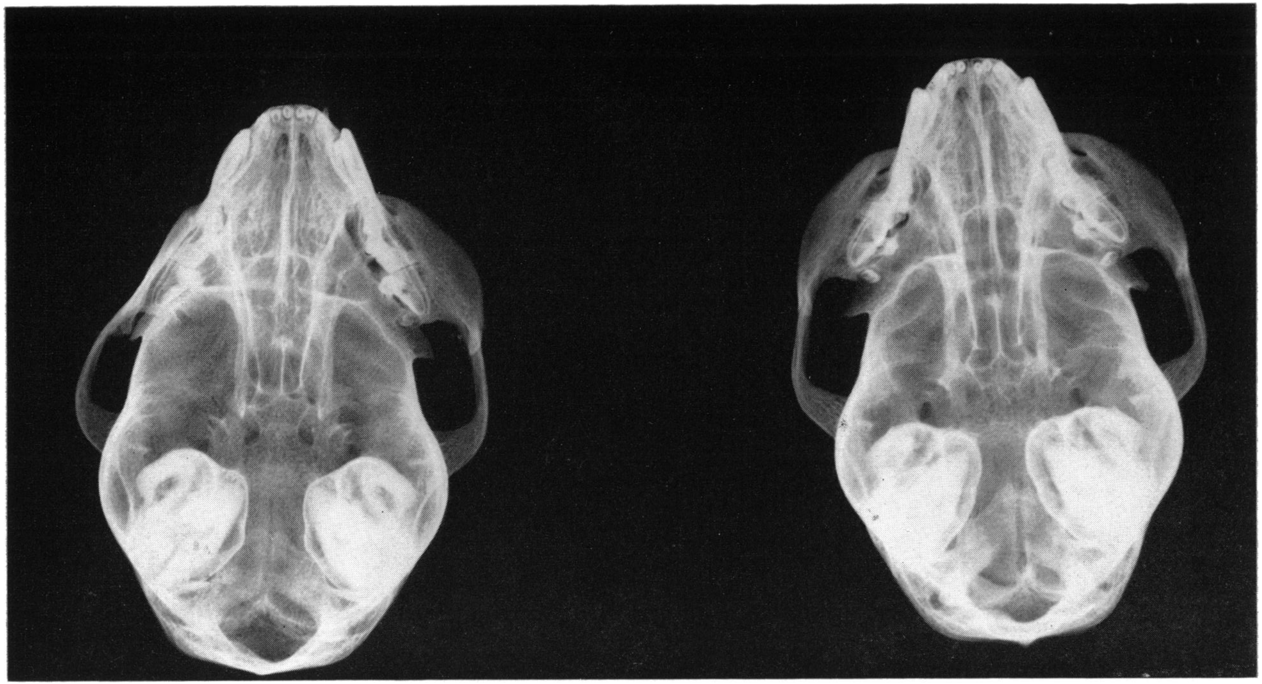

FIGURE 15

Cat 17 (left) with litter mate, unoperated control cat 18 (right). Roentgenogram shows marked flattening of zygomatic bone of cat 17.

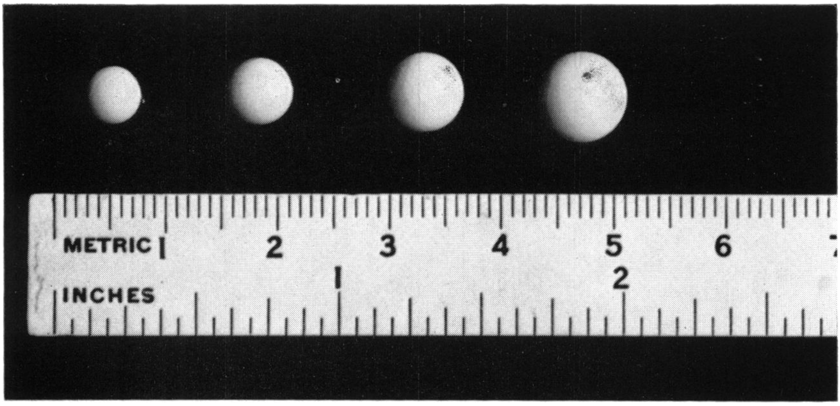

FIGURE 16
Silicone implants 5 to 8 mm. in diameter, for insertion in cat orbit.

In both instances the orbit with an implant showed a smaller percentage decrease (22.6 per cent) in the measurements than did litter mates that had a simple enucleation without implant (29.9 per cent). This suggests that an implant results in less change in the bony orbit after enucleation. However, in Litter 1, where none of the kittens had orbital implants, the variation in percentage decrease of the orbital measurements showed a range of difference up to 12.5 per cent.

In summary, the anophthalmic orbits of the cats showed a characteristic, marked decrease in the size, which was in the magnitude of 26.8 per cent. This reduction was not as great in the animals where a silicone implant had been inserted.

HUMANS

The cephalometric determinations were recorded from the roentgenograms of the 42 patients studied, an example of which is shown in Table 6. Four cases are not included in this section and are discussed separately, because of the marked bone changes and abnormal measurements as the result of roentgen ray therapy for malignancy. The roentgenograms from the other 38 patients showed a smaller orbit on the enucleated side. All measurements of the anophthalmic orbits were equal to or less than the fellow orbits. A greater percentage difference between the height and width of the orbit was about equally divided. The diagonals of the orbits showed a greater percentage decrease in the diagonal from the lower nasal to the upper temporal orbital rim, as compared to the lower temporal to the upper nasal, in

TABLE 6. HUMANS: CEPHALOMETRY AND PERCENTAGE DIFFERENCES FOR ORBITAL MEASUREMENTS

				Orbit height			Orbit width			Diagonal UN—LT			Diagonal LN—UT			Average of measurements	Approx. nasion ectoconchion				Optic canals			
																				Inter-orbital	R		L	
Patient	Age surg.	Age exam.	Implant	R	L	% diff.	R	L	% diff.	R/	\L	% diff.	R/	\L	% diff.	1,2,3,4	R	L	% diff.	distance	H	V	H	V
#11, right tumor	1½	42	0	38	46	17.4	35	40	12.5	43	47	8.5	37	39	5.1	10.9	50	57	12.3	30	2	3	3	4
Variations for measurements from roentgenograms of 20 normal patients						1.1 0–4.6			0.9 0–2.7			0.6 0–2.3			0.9 0–3.8	0.86 0–1.8			0.9 0–3.8	28.6 20–34				

the proportion of three to one. The comparative measurements from the midline to the lateral wall of the orbit showed this to be less on the anophthalmic side in 25, and equal in 13, roentgenograms.

The optic foramina could be compared in the roentgenograms of 33 patients. In some of the others the orbital implants obscured or superimposed the canal. All of these canals on the anophthalmic side were either equal to (6 per cent), or smaller than (94 per cent), the unoperated side by an amount ranging up to 50 per cent, with an average decrease in size of approximately 17 per cent. These measurements were determined by taking the average of a per cent decrease of a vertical and horizontal diagonal of the canal.

The percentage decrease in the size of the orbital entrance can be

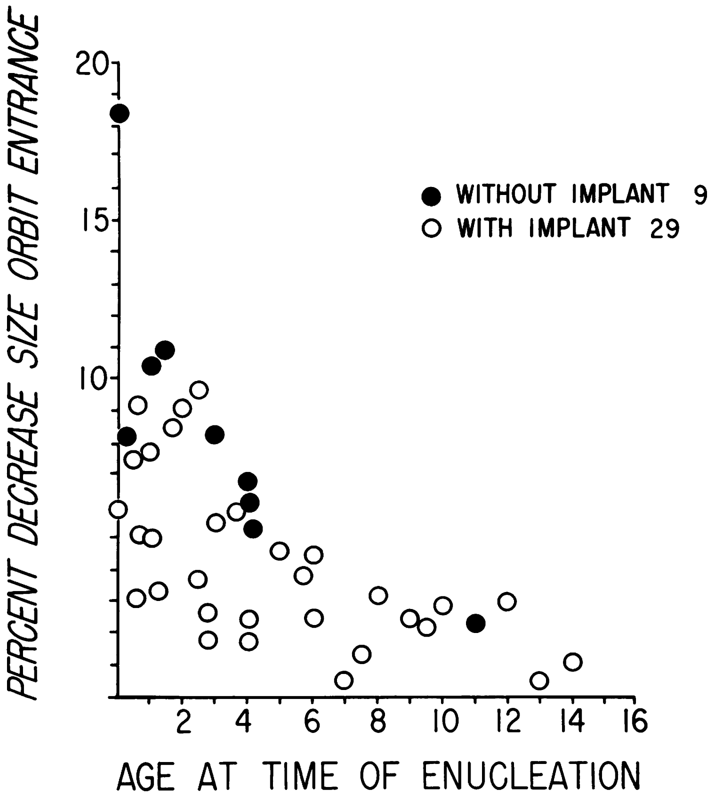

FIGURE 17

Scatter diagram showing distribution of patients with enucleations at various ages and their per cent decrease in size of orbital entrance. Total 38 patients. A wide variation is shown.

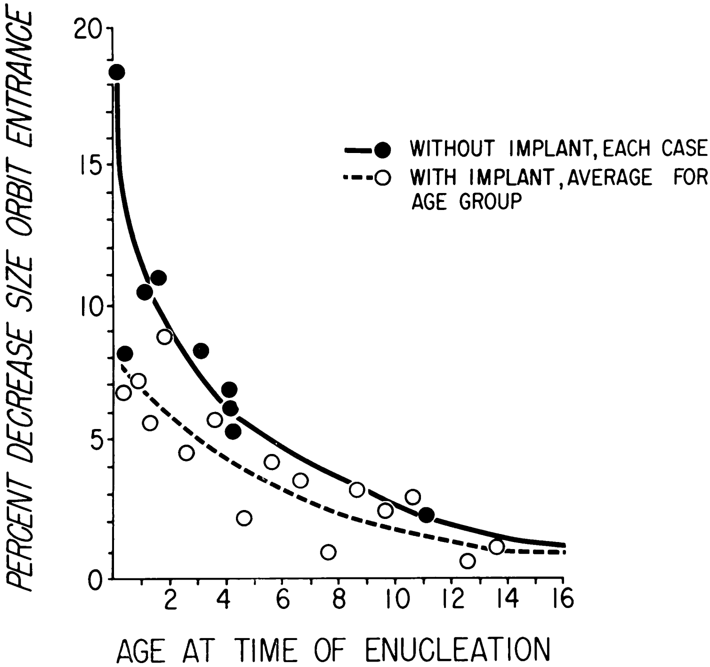

FIGURE 18
Comparison of per cent decrease in size of orbital entrance for patients with and without implants at various ages of enucleation. Total 38 patients.

compared with the age of the patient at the time of enucleation for this group of 38 patients, both with and without orbital implants (Figure 17). A wide scatter is noted for all age groups. Figure 18 converts this to a line graph showing the percentage decrease in the size of the orbits for enucleations at various ages, for those patients in whom no orbital implantation was made, and for those in whom an implant was inserted. With few exceptions the individual patient with an implant showed less orbital change. The average change for each age group was less for those with implants.

The length of the postoperative period varies in Figures 17 and 18. In an attempt to eliminate this variable, only those patients who had attained the age of 16 years, or full orbital growth, were plotted in a similar manner (Figure 19). The curve for percentage of change in size of the orbital dimensions compared to the age at the time of enucleation is shown for the patients without an implant. The coordinates for each patient with an implant can be seen to be quite scattered, with all but two falling below the line. Regardless of the age of enucleation, the changes in the orbit at full growth seem to be less for those patients who have had an implant. This variability in the amount of orbital change in patients with implants probably can be accounted for by several factors. The individual growth patterns would differ. Implants of different sizes, variations in surgical technique, hemorrhage at the time of surgery with absorption of orbital fat, all could contribute to this wide variation in the changes in the orbits.

ROENTGENOGRAM FINDINGS

The striking changes found by roentgenographic examination were characteristic but extremely variable. All of the anophthalmic orbits showed arrest in the development of the orbit with reduction in the orbital measurements. These changes tended to be more marked the

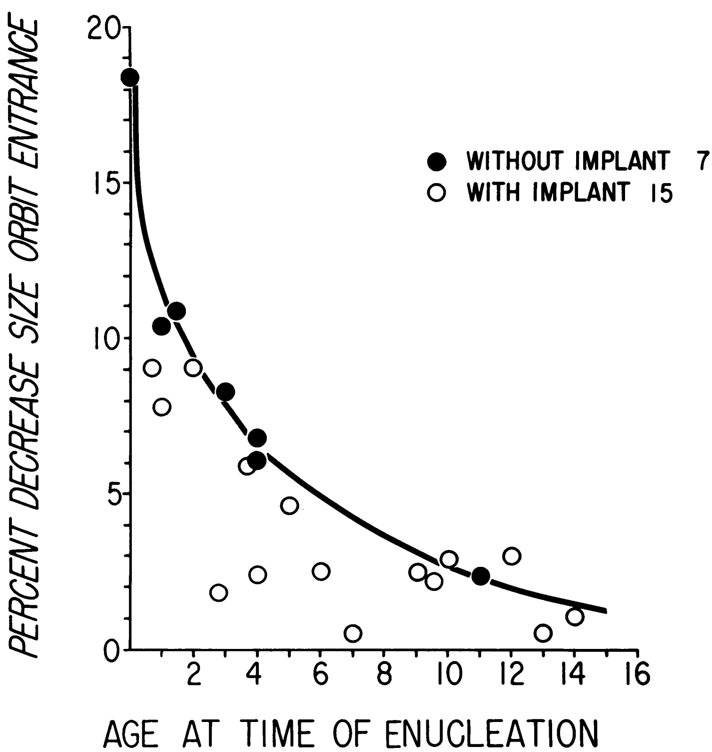

FIGURE 19

Per cent decrease in size of orbital entrance for all patients with full orbital growth, age 16 years or older. Total 22 patients.

earlier in life the enucleation had been performed and with a greater interval following enucleation. The orbital walls tended to show contraction and irregularity. The walls of the anophthalmic orbit showed the influence of compensatory changes of the surrounding structures which encroached upon it. This changed the normally concave walls so that they become flattened, or even convex. These changes were the greatest in the roentgenogram (Figure 20) of a 17-year-old girl who

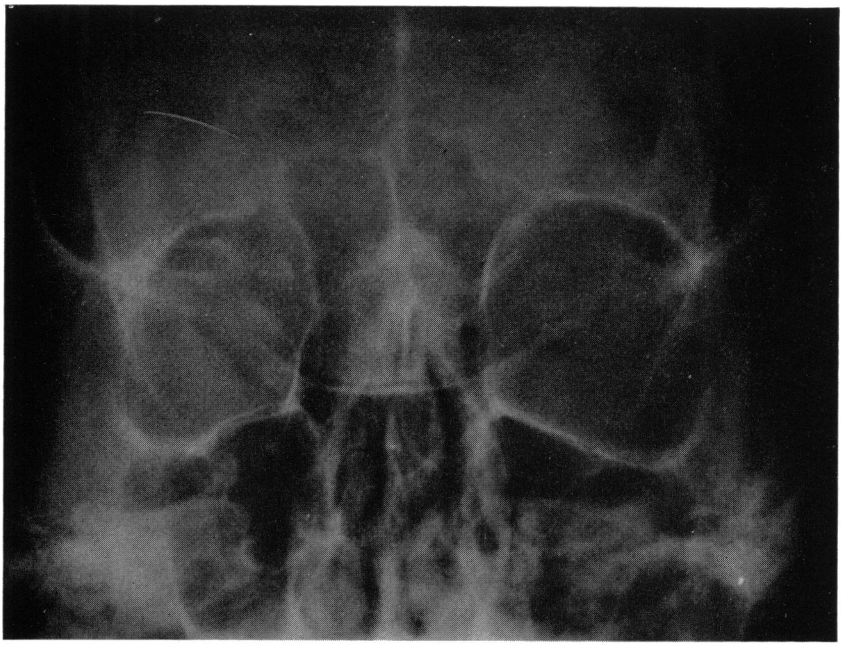

FIGURE 20. PATIENT 1.
Seventeen-year-old girl, congenital right anophthalmos. Marked contraction of orbit. No implant. 18.4 per cent decrease in orbital dimensions.

was born with a unilateral anophthalmos. No implant had been placed in the orbit. Figures 21 and 22 show similar changes and have no orbital implants. Figures 23, 24, and 25 have orbital implants and show these changes to a lesser degree. Figure 25 bears out the findings of Pfeiffer that an implant influences the shape of the anophthalmic orbit. Such orbits tend to be larger than the orbits without an implant, though smaller than their fellow orbits, and the walls are more normal in contour.

When the orbit gives up its volume after an enucleation the surrounding structures encroach upon it. Whitnall[13] states that "the orbit conforms to the law of adaptation of the organ to the function it is called upon to fulfill, and if the globe be removed before the orbit is fully formed, growth of the latter is checked." The pull of the extraocular muscles is thought to have a contributing influence in maintaining the normal size of the orbit. Figures 22, 23, and 24 particularly show the enlargement of the maxillary antrum, and ethmoid air cells to cause distortion of the orbit. Figure 21 shows an enlarged air cell

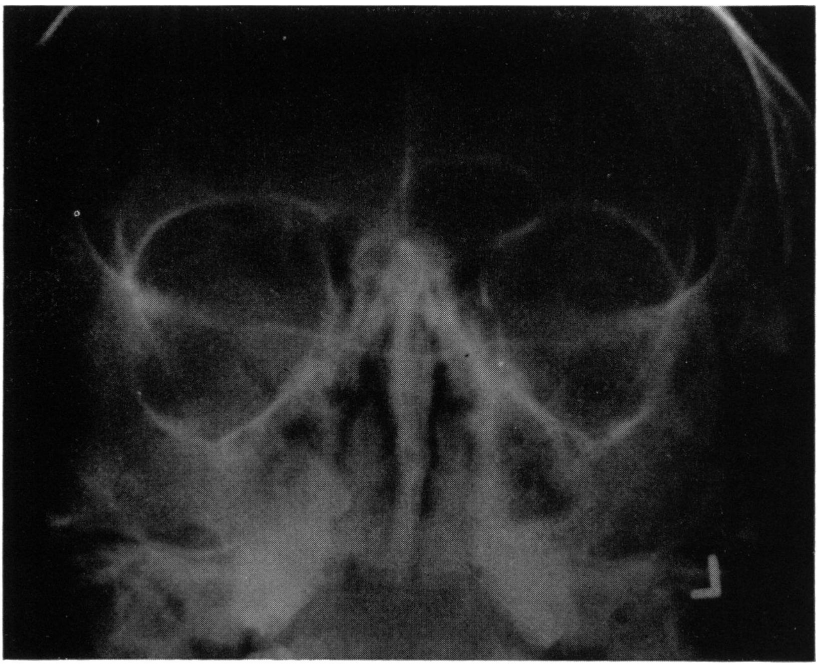

FIGURE 21. PATIENT 3.
Boy, 9½ years old, enucleated left eye age 4 months. No implant. Irregular contraction left orbital rim. 8.2 per cent decrease of orbital dimensions.

in the region of the frontal sinuses, but this was not a consistent finding, and frequently the frontal air cells on the contralateral side were much larger. Figure 23 shows the flattening of the roof of the orbit, presumably as a manifestation of the influence of the frontal lobe of the brain being willing to encroach upon the orbit. This resulted in the roof and superior rim of the orbit frequently superimposing upon each other to appear as a single line, as compared to the two separate lines seen in some of the roentgenographic projections.

Facial asymmetry may be manifested by a decrease in the distance between the midline and the outer wall of the orbit as shown particularly in Figures 20 and 22. Additional changes are evident. The temporal line viewed in the orbit may show either an inconsistent

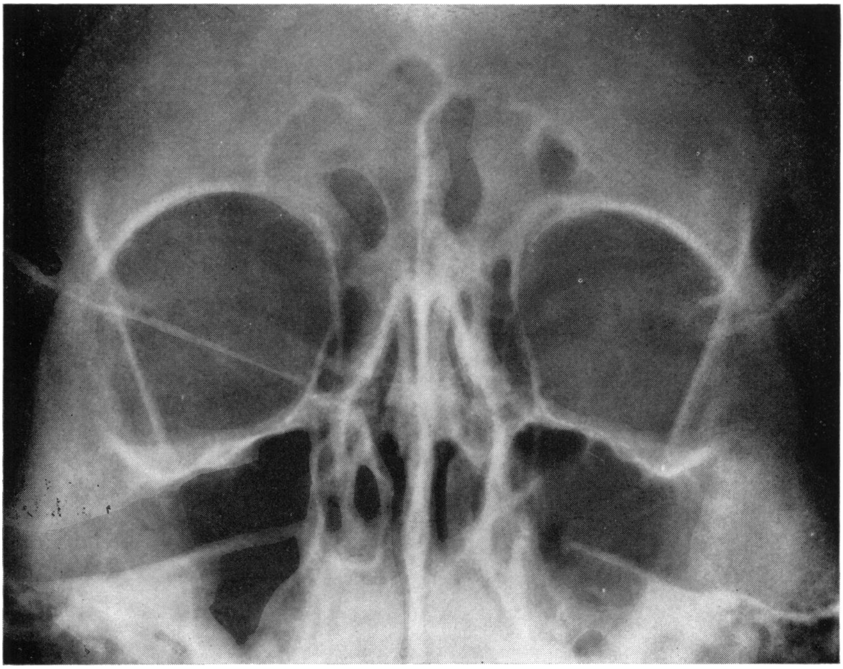

FIGURE 22. PATIENT 11.
Thirty-three-year-old man, enucleated left eye age one year, no implant. Contracted left orbit. 10.4 per cent decrease of orbital dimensions.

greater or lesser tilt and sometimes appears less pronounced. The temporal margin of the orbit tends to be less distinct and is probably associated with some atrophy of the bone. The decreased density of the anophthalmic orbit associated with loss of tissue volume is quite minimal. Figures 26, 27, and 28 show contraction of the optic canal in patients who lost their left eyes at age four months, four years, and fourteen years.

The variations for the measurements from the roentgenograms of 20 normal adults are shown in Table 6. The average of comparable

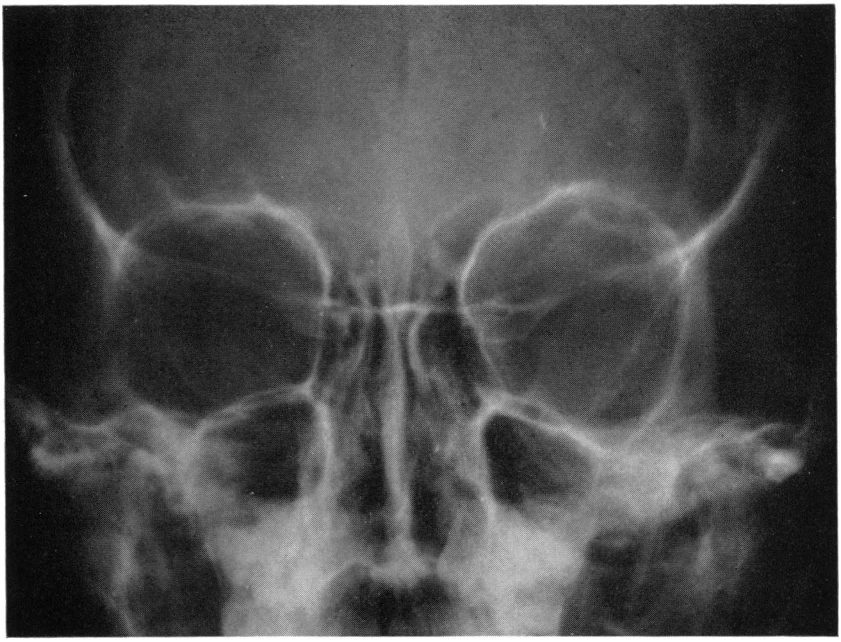

FIGURE 23. PATIENT 9.
Girl, 9½ years old, enucleated right eye age one year with plastic sphere orbital implant. More normal contour of anophthalmic orbit. Enlarged antrum on right. Roof of orbit somewhat flattened. Five per cent decrease of orbital dimensions.

measurements between the two orbits varied between 0.6 and 1.1 per cent. The four orbital rim measurements averaged to just under 1 per cent as the normal variation in the size of the orbit one might expect in the normal skull, with a range up to 1.8 per cent.

DISCUSSION

From these studies it is evident that there can be marked bone changes in the anophthalmic orbit, particularly when the enucleation has been performed at an early age. The changes which were shown in the rabbit by Thomson are here repeated and substantiated. The percentage decrease in the orbital measurement for the rabbit is in the magnitude of 12.8 per cent. Similar findings in the cat skull are in the magnitude of 26.8 per cent. In the human, at birth the percentage decrease in the orbital measurements without an implant would tend to be as high as 15 per cent, and with an implant about

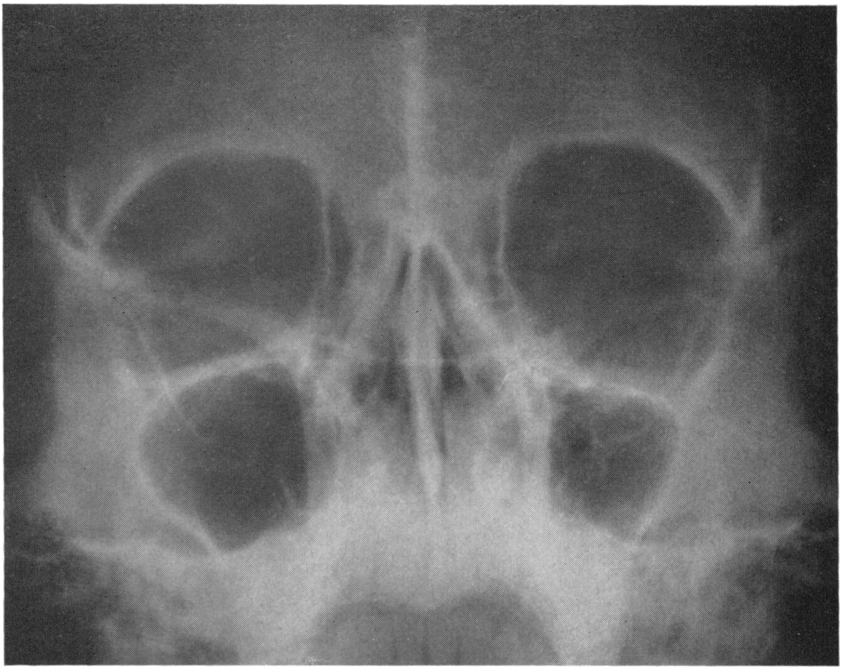

FIGURE 24. PATIENT 10.
Twenty-year-old patient, enucleated right eye at age one year, bone sphere implant. Marked enlargement of antrum on anophthalmic side. 7.8 per cent decrease of orbital dimensions. Bone implant appears to have absorbed.

8 per cent. These figures would be less the later the enucleation was performed. The differential for these figures between the animal and the human might be accounted for by the fact that the rabbit and the cat orbits have an incomplete orbital rim, as compared to the solid complete rim of the human. With the incomplete orbital rim of the animals, contraction changes might be expected to occur with more ease, and thus a greater magnitude of change. With measurements taken from Figure 18 the approximate anticipated percentage decrease in the orbital measurements after enucleation might be shown by Table 7.

The study of changes in the anophthalmic orbit in the human are dependent upon roentgenographic findings. An attempt was made to locate a dry skull in which it was known that one eye had been enucleated. Several medical centers and the Armed Forces Institute of Pathology were contacted with the hopes that such a skull might

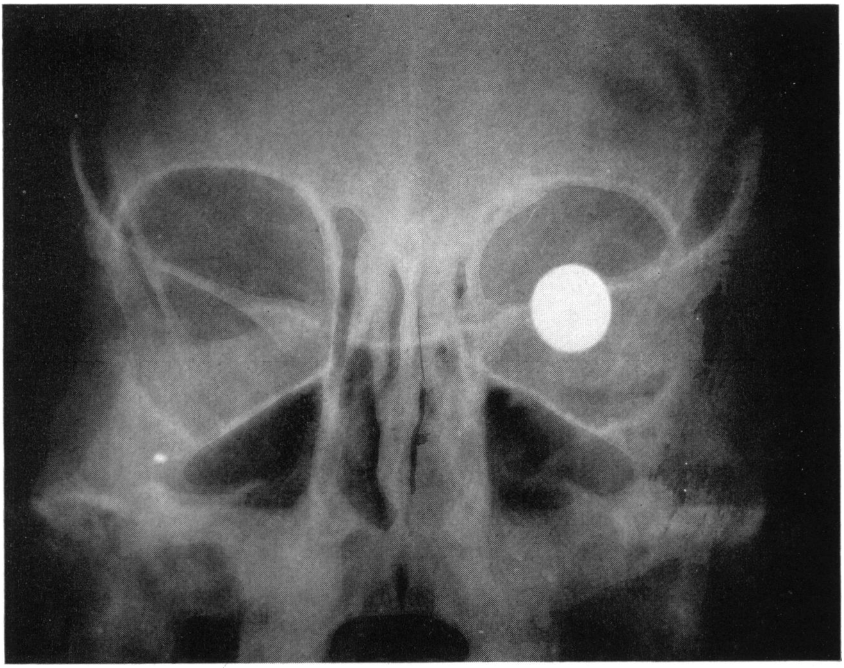

FIGURE 25. PATIENT 2.
Eight-and-one-half-year-old girl, enucleated left eye age one day with gold ball orbital implant. Left orbit is smaller than right but has more normal contour due to implant as compared to orbit without implant. 5.9 per cent decrease of orbital dimensions.

be available for examination and direct bone measurements. Unfortunately, none could be located.

A set of roentgenograms captures the moment of growth and change in such an anophthalmic orbit at a particular period of time after enucleation, which could be compared on occasion with preoperative films at an earlier age. It was hoped that films made by the serial roentgenographic cephalometric method might be located in order to show the progressive changes after enucleation. Two large series of children studied by this technique for their orthodontic problems to show their individual growth progress were evaluated, but, unfortunately, neither of them included a child who had an anophthalmic orbit.

Pfeiffer points out that it is not enough to study the orbital margins, but that the orbit must be considered as a cavity and studied as such.

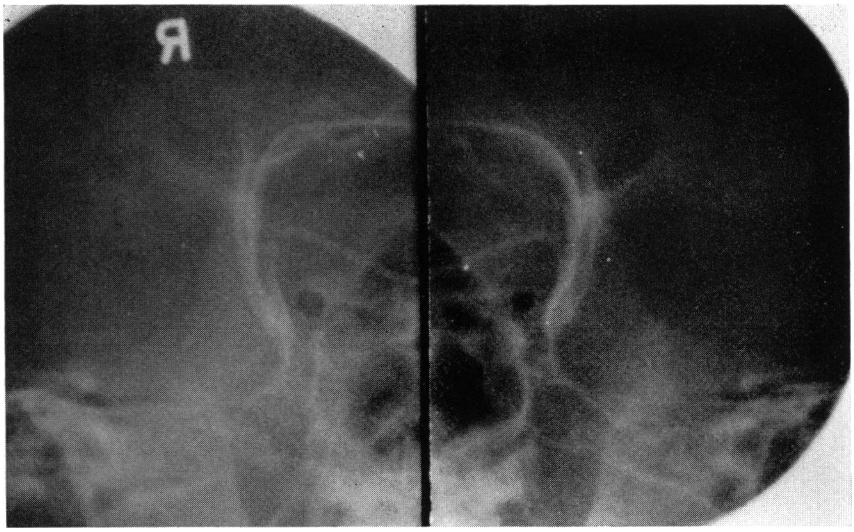

FIGURE 26. PATIENT 3.
Age 9½ years, enucleated left eye at four months, showing smaller left canal for optic nerve.

FIGURE 27. PATIENT 27.
Age 16, enucleated left eye at age four years showing smaller left canal for optic nerve.

FIGURE 28. PATIENT 42.
Age 25, enucleated left eye at 14 years, showing smaller left canal for optic nerve.

He points out that changes in the walls of the orbit may best be evaluated by stereoscopy and laminography. One certainly gets a much better appreciation of the anophthalmic changes in the walls from the stereoscopic projections. These demonstrate the marked reduction in the volume, or the capacity, of the orbit. The normal concave orbital walls can be seen to flatten, and at times even to become convex as they encroach upon the orbital volume. Because of the irregular walls, no true determination could be made as to the volume changes in this type of orbit. Neither the rabbit skull nor the

TABLE 7. PERCENTAGE DECREASE IN ORBITAL DIMENSIONS AFTER ENUCLEATION

Age—years	*Without implant*	*With implant*
Birth	15%	8%
1	11	7
2	9	6
4	6	4.4
6	4.5	3
8	3.5	2.3
12	2	1.3
16	1.1	1

cat skull, because of the lack of a floor of the orbit, lends itself to volumetric determination of the orbit by any of the usual methods. As was previous'y mentioned, Koch and Brunetti, in their report of the roentgenologic technique to determine the volume of the orbit and measure its depth, concluded that the orbit of the affected side, in the case of a unilateral anophthalmos, was smaller but retained the same depth as the unaffected side. Alexander, *et al.*[26] studied the orbital volume of 65 skulls by using a sand technique, and by taking roentgenograms of the skulls. Calculations involving three formulas were made from the roentgenograms and compared with those obtained by the sand technique in determining the orbital volume. They could make no relative or absolute correlations between real and X-ray orbital volumes. Therefore, it would be even more difficult to try to make some roentgenologic determination of the volume of these irregular anophthalmic orbits.

Since a decreased orbital volume must occur after enucleation, some approximate estimate of this decrease seems worthwhile. We might first assume a normal average orbit[13] with the following dimensions: height, 35 mm.; width, 40 mm.; depth, 40 mm.; volume, 30 cc. Empirically, if we assume the shape of the orbit to be a cone with an elliptical base corresponding to the entrance of the orbit, the volume of this form can be determined. For the normal average orbital measurements in the formula for a cone with an elliptical base, the volume would be 14⅔ cc. which actually is about one-half its true volume. If the normal average figures for the orbital entrance are reduced by 10 per cent, as was common with some of the cases presented in this series, the calculated decrease in volume for this cone with the reduced elliptical base would be 19 per cent. Applying this formula to the measurements of patients in this series, the decrease in the orbital volume ranged up to 19.5 per cent in patients with orbital implants, to 27.7 per cent in patients with no orbital implants, and to 36.2 per cent in the one patient with unilateral congenital anophthalmos. The normal orbital diameter is wider by 4 or 5 mm. at a depth of 10 mm. in back of the rim as compared to its diameter at the rim. Since the changes in enucleation are greater behind the rim, because of encroachment on the volume by surrounding structures, it can be assumed that the volume would be even further decreased, possibly in the magnitude of 35 to 50 per cent.

The study of Hare[27] concerning congenital bilateral anophthalmos is of interest in reference to the per cent decrease in the orbital measurements. He reported two cases, together with their roentgenograms. From these he made four measurements which included the vertical and horizontal, and the two oblique meridians. Comparing these roentgenograms with those of normal children in the same age group, he found approximately 35 per cent decrease in these orbital measurements. Applying the formula for the volume of a cone with an elliptical base to his figures, the volume decrease would be as high as 58 per cent. Mann[28] states that in congenital anophthalmos the orbit is well formed, though it may be slightly smaller than normal. The fact that the orbit will be present is self determined, and is in no way dependent on the presence or size of an optic outgrowth. The greater magnitude of change in congenital anophthalmos, however, shows the prenatal influence of the eye.

The orbital entrance at birth is nearly circular, with measurements given for the entrance at birth varying from 18 to 21 mm.[13,29,30] As in both the rabbit and the cat[25] the human eyeball fills the orbit more completely at birth than at maturity. The orbit almost doubles in vertical diameter throughout the growth years.[30] The growth of the anophthalmic orbit increases following early enucleation and only lags behind in measurements up to 15 per cent, or less, by full adult growth. This certainly points to the many other factors that influence the development of the orbit in addition to the globe, which is responsible only for this small amount.

Although the value of an orbital implant has been questioned,[8] the findings of Pfeiffer,[12] together with the findings in this study, certainly point to the beneficial effect of an implant. The implantation in the cat orbits is also suggestive of a beneficial effect. Pfeiffer[12] demonstrated the roentgenograms of two patients, including one whose eye was enucleated at age seven months in whom no orbital implant was placed. The roentgenogram was taken 11 years later. The second patient had an eye removed at age three years, an implant inserted, and the roentgenogram taken 10 years later. While these changes are characteristic in each case, there is a marked difference between the two roentgenograms which he demonstrated. The roentgenogram of the patient without an implant showed more irregular contraction of the orbit. However, by taking the average figures from Figure 18, the seven-month-old child might be expected to have a decrease in the size of the orbit of approximately 12 per cent, while the three-year-old might have a decrease of approximately 5 per cent. Therefore, more than half of this difference, or about 7 per cent, might be accounted for by the growth interval between the difference of the ages when these children had enucleations.

FIGURE 29. LITTER 5. CATS 17, 16, 18, FRONT VIEW.

On left, cat 17 with simple enucleation (31.6 per cent decrease orbital dimensions). Compare with cat 16 in center with 8-mm. silicone implant inserted at time of enucleation which was retained at least a month (23.9 per cent decrease in orbital dimensions). Implant appears to have reduced the amount of change. Cat 18 on right is the control. Operated on 12th day, sacrificed 116 days.

FIGURE 30. LITTER 5. CATS 17, 16, 18.
Same as Figure 29. Side view.

No report of animal experimentation was found concerning the influence of a buried orbital implant upon the development of the orbit after enucleation. In Litters 4, 5, and 6, the cats which had orbital implants inserted at the time of enucleation, showed less percentage change in the orbital dimensions. The changes in Litter 4 were not as marked because of the early extrusion of the implants. Figures 29 and 30 show the variations within Litter 5 which could be demonstrated. The first skull shows the decrease in the orbit after simple enucleation, which is a greater change than the second skull in which a silicone implant had been inserted. The third skull is the control. Figure 31 attempts to show this difference by varying the illumination of the skulls of two enucleated litter mates, one without an implant and one with an implant.

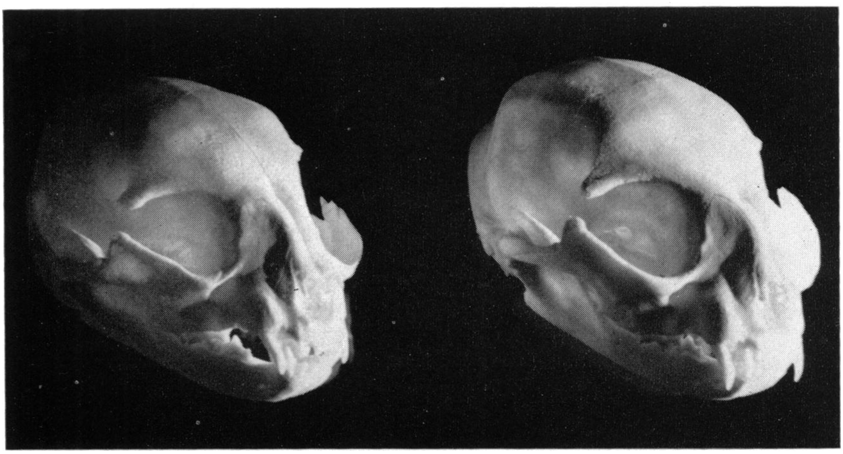

FIGURE 31. CATS 17 (LEFT), AND 16 (RIGHT).
Showing the larger orbit on the right skull where an implant had been retained at least one month, compared to simple enucleation and smaller orbit in skull on left. Illumination differs from that of Figure 30.

An orbital implant has been used more commonly in recent years. It is of interest that in the series of 51 patients reported by Taylor[10] in 1939 none had a buried implant.[11] More recently, in 1945, DeVoe[31] in reporting his experiences with surgery of the anophthalmic orbit, states that in more than 50 per cent of the patients no implant was in position. In the series now being reported an orbital implant was inserted in 78 per cent of the patients. Since shortly after World War II, with the wide variety of implants of all types, it seems they have found a more common use. Of the nine patients without an orbital implant in this series, four were enucleated since 1946. Of these, one extruded an implant one week after enucleation because of extensive orbital hemorrhage, and the other three patients had migrated from the South and no history was available as to whether an implant was considered.

The decreased size of the orbit begins, no doubt, immediately after enucleation. Whitnall[13,16] refers to Merkel who states that in early childhood the changes occur as soon as 10 weeks after operation. The method of determining this is not described. This appeared in a text-book published in 1901. Unless it was based on a direct anatomical specimen, it, no doubt, did not represent a roentgenologic finding, but must have been based on very astute clinical observations. Sattler[7] found a clear difference between the sizes of the orbit on X-ray as soon as one year after enucleation. The shortest interval after enucleation at which roentgenograms were made in this reported series was 22 months, when a decrease of 5.1 per cent in the dimensions was already evident. A cat (number 8), enucleated on the eighth day, died 30 days after surgery and showed marked changes, in the magnitude of 19 per cent (Figure 32).

Taylor[10] and Pfeiffer[12] describe the facial asymmetry seen in the human. This can be emphasized in the cat skull (Figure 33) where the sagittal suture of the skull, as it extends forward to join the

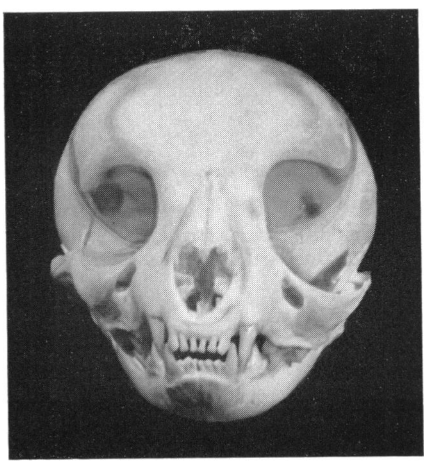

FIGURE 32. CAT 8.
Enucleated right eye eighth day, showing advanced changes at early stage after inadvertent death at 30 days following enucleation.

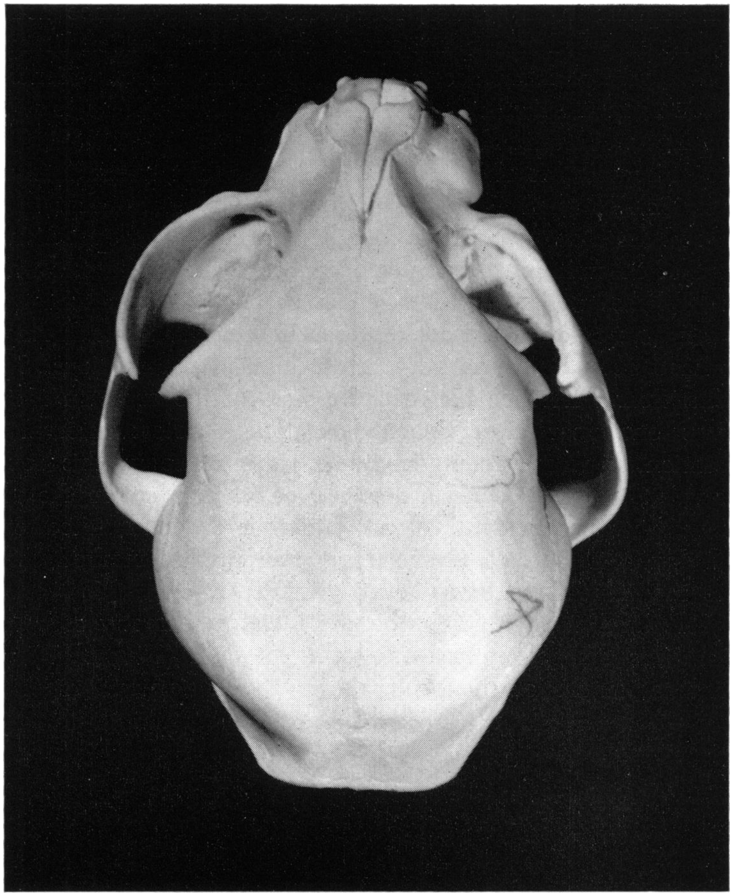

FIGURE 33. CAT 4.
Showing marked deviation toward enucleated side of sagittal suture of skull, with its extension forward to join midline suture of nasal bones.

midline suture of the nasal bones, can be seen to deviate markedly toward the enucleated side. The external changes evident in the cat are shown in Figure 34.

The interorbital region has been thoroughly studied recently.[21] The authors followed the growth of this region using serial cephalometrograms. They concluded that 50 per cent of growth of the interorbital region occurs by three years of age, and that only slight growth occurs after 12 years of age. These authors list the growth of the intraorbital structures as one of several forces involved in growth of

FIGURE 34. CAT 20.
Showing less fullness of face on anophthalmic side with flattening of frontal region of skull. Ear of involved side tended to be turned laterally.

the interorbital region, the other forces being growth of surrounding structures, growth of sutures, appositional growth, and pneumatization of bone. They mention that a contracted orbit may develop if the eye is removed before growth is completed. No specific mention is made of its effect on the development of the interorbital region. It is assumed the measurement would increase. They give as an adult mean measurement 24.62 mm. for the interorbital width after age 20 years. From the series of 40 anophthalmic patients reported in this study, 15 were age 20 years, or older, with an average measurement of 28 mm. This is less, however, than the 28.6-mm. average for this measurement taken from the 20 normal adult films studied as a control. It would seem, therefore, that the interorbital measurement is not significantly affected by enucleation of one eye at an early age.

Luzsa[22] has shown the influence of enucleation on the development of the canal of the optic nerve. He examined 37 patients who had one eye enucleated. There was no difference in the size of the canals in 18, four of whom had lost their eye before age 18 years. The remaining 14 were enucleated after age 20 years. Smaller measurements were found on the enucleated side for 15 patients who had one eye enucleated at ages ranging from three to 20. One patient showed an enlargement of the canal of the optic nerve on the enucleated side. Three of the 37 patients were not accounted for. Luzsa believed the development of the canal ceases in the eighteenth year. The shrinkage of the canal of the optic nerve also has been reported by Pfeiffer,[12,15] Pendergrass,[19] and Burki.[32] These authors and Goalwin[33] feel the optic nerve canal reaches full adult size at an earlier age ranging from the third to fifth year. Differences between the optic canals of the two sides may exist physiologically according to Goalwin.[34] His findings reveal an absolute symmetry in 45 per cent, a difference of 10 per cent, or less, in 40 per cent, and a difference of 10 to 40 per cent in 14 per cent. As previously noted, in this present series where the optic foramina could be compared in 33 patients, they were equal in two (6 per cent) and smaller in 31 patients (93 per cent) in an amount ranging up to 50 per cent, with an average decrease in size of 17 per cent. While none of the rabbits in this series showed a change in the canal as compared to the control, a comparison within the rabbit orbits cannot be made since the anterior edge of the optic canal is common to both orbits as a midline foramen. All of the 15 enucleated cat orbits showed a smaller optic nerve canal.

Growth retardation due to roentgen ray therapy of the bones of the orbit has been recognized. Tiburtius and Krokowski[35] have shown its experimental effect on the skulls and orbits of rabbits. Taking seven measurements on 17 rabbit skulls, 114 of the 119 measurements (96 per cent) were smaller on the roentgen-ray-treated side as compared to the normal side. Figure 35 is the roentgenogram of a 14-year-old boy who had roentgen ray therapy for an orbital malignancy at age five with subsequent loss of the globe. The marked bone atrophy of the rim of the orbit, particularly the superior and lateral walls, is evident with a percentage decrease in orbital dimensions in excess of 15 per cent. Normally at his age this would be expected to be about 3 per cent (Figure 18). In two patients (numbers 7 and 9), in whom an eye had been removed for retinoblastoma, roentgen ray therapy had been given to a retinoblastoma in the contralateral orbit. At the time of their evaluation they showed less decrease in the orbital dimensions of the anophthalmic orbit than the changes which might have been expected for the age of enucleation. This suggests that the

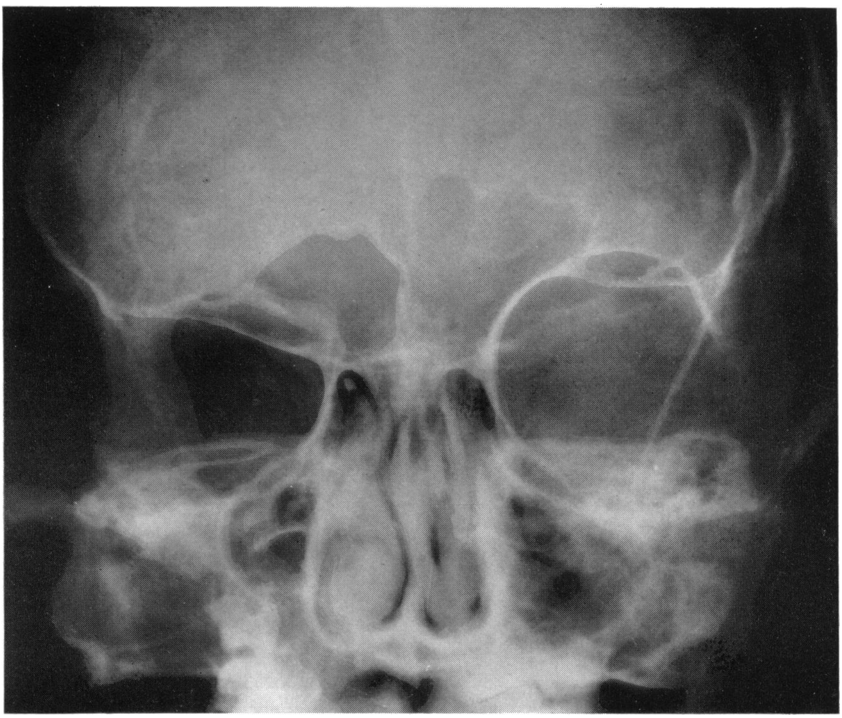

FIGURE 35. PATIENT 35.

Fourteen-year-old boy who had roentgen ray therapy to right orbit for malignancy age 5 years, with subsequent loss of right eye at age 9 years. Orbit shows 15.2 per cent decrease in size. This marked decrease is associated with irradiation.

roentgen ray therapy retarded development in the unoperated orbit so that the difference between this and the anophthalmic orbit was not as great. Figure 36 is the roentgenogram of a 13-year-old girl who had the left eye removed for a retinoblastoma at age seven months. Roentgen ray therapy was given to the right eye for retinoblastoma at the age of seven months following enucleation of the left eye. Despite therapy to the retinoblastoma in the remaining eye, it progressed and required enucleation. This was performed at age three years. This right orbit which had been irradiated, despite being enucleated two and one-half years later, is smaller by about 11.5 per cent than the first orbit that was enucleated. Such changes as the result of therapy will cause additional changes far in excess of those resulting from simple enucleation. The extent of decreased orbital growth on this basis might well be studied further.

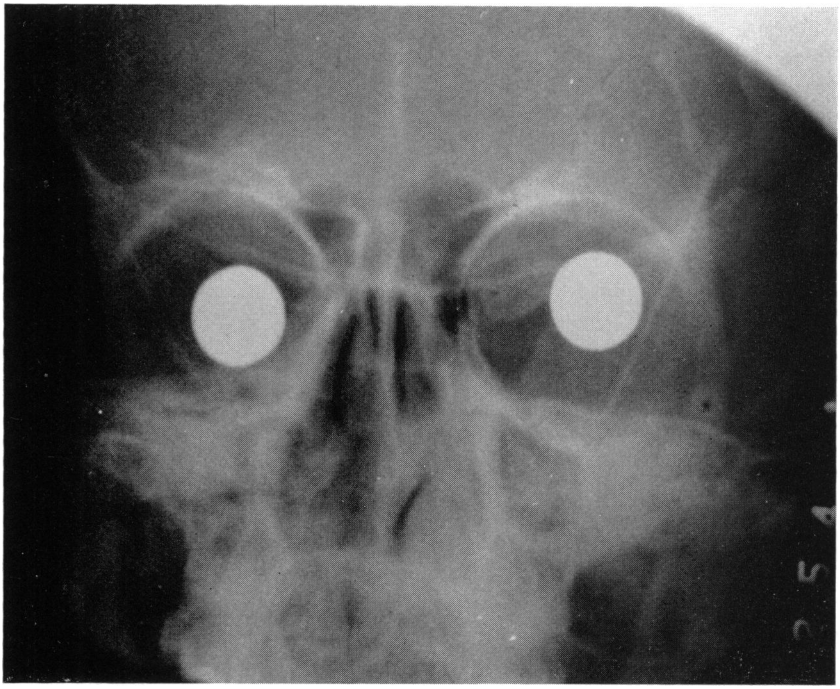

FIGURE 36. PATIENT 5.

Thirteen-year-old girl. At age 7 months left eye enucleated and right orbit irradiated for retinoblastoma. Right eye enucleated at age 3 years. Implants each orbit. Right orbit is smaller by 11.3 per cent despite enucleation at later age, showing effect of irradiation.

CLINICAL CONSIDERATIONS

Since early enucleation may result in lack of development of the orbit, facial asymmetry, and possible interference with the proper fitting of a prosthesis, elective enucleation in infancy is contraindicated. This, of course, cannot apply where there is a malignancy, a recent severe injury, infection, or pain. Since the orbit will decrease in size with a small phthisical eye, there is little reason to defer its removal.

This study further supports the importance of using an orbital implant at the time of surgery, which appears to be in more common clinical use in recent years. Since an orbit may show a decreased size even when a shrunken phthisical eye is present, probably a larger size implant in the range of 18 to 20 mm. diameter, as advocated by Sherman,[36] would be advisable. This might reduce the amount of diminution of the anophthalmic orbit.

When an orbital implant is being inserted as a secondary procedure, careful roentgenologic study is important if there has been a significant interval since enucleation so that bony changes may have occurred. Alterations in the size and contour of the orbit may call for consideration or modification in the size and shape of the implant. This would hold true for congenital defects such as anophthalmia and microphthalmia. Such an evaluation can be accomplished most satisfactorily by using stereoscopic projections with consideration for laminography.

SUMMARY

The striking and characteristic bone changes which occur in the orbit following enucleation of one eye at an early age are described for the rabbit, cat, and human. The previous experimental work on three rabbits reported by Thomson is repeated and substantiated. These changes are represented by a decrease in the orbital measurements in the magnitude of 12.6 per cent for the rabbit and 26.8 per cent for the cat as determined from the dry skulls.

In the human these bone changes in the anophthalmic orbit were determined from the roentgenograms of a series of 42 patients in whom the enucleation had occurred between the first day and the fifteenth year. Cephalometric roentgenographic determinations showed a decrease in the orbital measurements up to 15 per cent when no orbital implant had been used, and up to 8 per cent when an implant had been inserted. The magnitude of change decreased the later the enucleation was performed.

The insertion of an orbital implant results in less contraction of the developing anophthalmic orbit. This is suggested in the cat experimentally, and is evident in the human, with its benefit being greater the earlier in life the enucleation occurs. This supports the findings of Pfeiffer.

The altered orbital volume cannot be determined satisfactorily from either the dried animal skull or from the roentgenograms in the humans. Empirically, however, the decreased orbital volume in the human might be 20 to 30 per cent, and even as high as 50 per cent. An orbital implant appeared to reduce the loss in volume.

Facial asymmetry, as evidenced by increase in the midline to lateral orbital margin measurement, can occur in two-thirds of the patients. The interorbital region measurements show little variation.

TABLE 8. RABBITS

Litter	Rabbit number	Horizontal (mm.) R	Horizontal (mm.) L	Horizontal % diff.	Vertical (mm.) R	Vertical (mm.) L	Vertical % diff.	Avg. % diff. horizontal & vertical	Depth of orbit (mm.) R	Depth of orbit (mm.) L	Depth of orbit % diff.	Midline skull to molar tooth (mm.) R	Midline skull to molar tooth (mm.) L	Midline skull to molar tooth % diff.
1	1	24	25	4	16	20	20	12	27	29	6.9	14	15	6.7
	2	25.5	27	5.6	17	22	22.7	14.2	29	30	3.3	17.5	18	2.8
	3	24	26	7.7	18	20.5	12.2	10.0	30	30.5	1.6	16	16.5	3.0
	4	23	26	11.5	19	22	13.6	12.6	29.5	30.5	3.3	16	17	5.9
	5	22.5	24.5	8.2	17	20.5	17.1	12.7	28.5	28.5	0	16	16	0
	6	26	28	7.1	21.5	24	10.4	8.8	30	31.5	4.8	18	18	0
	7 (control)	26	25.5	1.9	20.5	21	2.4	2.2	27	27	0	17	17	0
2	8	23.5	26	9.6	20.5	24	14.6	12.1	30	31	3.2	18	18.5	27
	9 (control)	27	27	0	23	23	0	0	30	30	0	18	18	0
	10	22	25	12	15	21	28.6	20.3	29	30	3.3	16	17	5.9
Average % difference operated rabbits				8.2			17.4	12.8			3.3			3.4
Average % difference unoperated controls				1.0			1.2	1.1			0			0

Litter 1: operated 11 days, sacrificed 204 days; litter 2: operated 7 days, sacrificed 228 days.

TABLE 9. CATS

Litter	Cat number	Implant (mm.)	Horizontal (mm.) R	Horizontal (mm.) L	Horizontal % diff.	Vertical (mm.) R	Vertical (mm.) L	Vertical % diff.	Avg. % diff. horizontal & vertical	Depth of orbit (mm.) R	Depth of orbit (mm.) L	Depth of orbit % diff.	Operated	Sacrificed
1	1	0	18	25	28.0	13	21	30.1	29.1	27	30	10.0		
	2	C*	25	25	0	21	21	0	0	32	31	3.1		
	3	0	17	24.5	30.6	13	20.5	36.6	33.6	27	31	12.9	15	146
	4	0	19	25	24.0	15	21.5	30.2	21.1	28	30	6.7	Days	
	5	0	20	24	16.7	14.5	21	31.0	23.9	28	31	9.7		
2	6	0	20	27	25.9	17	23	26.1	26.0	30	32.5	7.8	23	169
	7	C*	32	32	0	24	23.5	2.1	1.1	31	31	0		
3	8†	0	15	18	16.7	12.5	16	21.9	19.3	17	19	10.5		
	9	0	18.5	25	25.0	15.5	22	29.5	27.3	28.5	31	8.1	8	158
	10	C*	25.5	25.5	0	21	21.5	2.3	1.2	30	30	0		
4	11	5	15	19.5	23.1	12.5	18	30.5	28.3	19	24	20.8		
	12	8	18.5	23.5	21.3	14	20.5	31.2	26.3	23	28	17.9		
	13‡	0	16.5	23.5	29.8	14.5	21	31.0	30.4	22	27	18.5	12	116
	14	7	18	23	21.7	13.5	21	34.1	28.1	23	27	14.8		
	15	C*	23	23	0	20	20.5	2.4	1.2	27	27	0		
5	16	8	20	24	16.7	14.5	21	31.0	23.9	24.5	26.5	7.6		
	17	0	17.5	22.5	22.2	11.5	19.5	41.0	31.6	23	26	11.5	12	116
	18	C*	22.5	22.5	0	19	19	0	0	26.5	26	1.8		
6	19	0	19	23	17.4	13.5	20.5	34.1	28.2	25.5	28	8.9		
	20	8	18	22	18.2	12.5	18.5	32.4	21.3	25	27	7.4	9	104
	21	C*	21.5	22	2.3	19	19	0	1.2	27	27	0		
Average % difference operated cats					22.8			30.8	26.8			11.5		
Average % difference unoperated controls					0.4			1.3	0.8			0.8		

*Control
†Cat 8 died 38 days.
‡Cat 13 died 87 days.

TABLE 10. HUMANS

Patient number	Eye	Age surgery	Age exam.	Implant	Orbit height R	Orbit height L	Orbit height % diff.	Orbit width R	Orbit width L	Orbit width % diff.	Diagonal UN—LT R/	Diagonal UN—LT \L	Diagonal UN—LT % diff.	Diagonal LN—UT R/	Diagonal LN—UT \L	Diagonal LN—UT % diff.	Avg. % diff.
1	R	—	17	0	35	40	12.5	28	38	26.3	40	44	9.1	29	39	25.6	18.4
2	L	1 d.	8¼	+	45	40	11.1	35	34	2.9	41	41	0	42	38	9.5	5.9
3	L	4 mo.	9½	0	41	40	2.4	34	32	5.9	43	37	14.0	35	32	8.6	8.2
4	L	6 mo.	4½	+	46	43	6.5	34	33	2.9	46	40	12.9	40	37	7.5	7.5
5*	R	7 mo.	14½	+	38	41	7.3	33	38	13.2	36	45	20.0	36	38	5.2	11.4
	L	3 yr.	14½	+													
6	L	7 mo.	35	+	46	43	6.5	36	33	8.3	47	42	10.6	37	33	10.8	9.1
7*	L	7 mo.	12⅓	+	46	44	4.3	34	34	0	43	42	2.3	36	34	5.6	3.1
8	R	8 mo.	2½	+	38	40	5	28	30	6.7	34	35	2.9	34	36	5.6	5.1
9*	R	1	9½	+	38	42	9.5	35	37	5.4	39	40	2.5	38	39	2.6	5
10	R	1	20	+	36	42	14.3	36	38	5.2	43	46	6.5	36	38	5.2	7.8
11	L	1	33	0	46	41	10.9	40	35	12.5	48	43	11.4	39	36	7.7	10.4
12	R	1¼	3¾	+	43	44	2.3	30	31	3.2	39	41	4.9	36	37	2.7	3.3
13	R	1½	42	0	38	46	17.4	35	40	12.5	43	47	8.5	37	39	5.1	10.9
14	L	1¾	5¾	+	40	37	7.5	35	33	5.7	42	38	9.5	36	32	11.1	8.5
15	R	2	22	+	40	47	14.9	35	37	5.4	43	46	6.5	38	42	9.5	9.1
16	L	2½	14	+	44	39	11.4	37	34	8.1	45	41	8.9	39	35	10.5	9.7
17	L	2½	7½	+	46	46	0	35	33	5.7	45	43	4.4	42	40	4.7	3.7
18	L	2⅔	9	+	48	48	0	36	34	5.6	45	44	2.2	41	40	2.4	2.6
19	L	2¾	26	+	47	46	2.1	37	37	0	46	46	0	40	38	5	1.8
20	L	3	20	0	45	42	6.7	38	34	10.5	46	42	8.7	42	39	7.1	8.3
21	L	3	9	+	45	43	4.4	35	31	11.4	43	43	0	41	38	7.3	5.5
22	L	3⅔	25	+	46	48	4.2	35	39	10.3	46	46	0	40	44	9.1	5.9
23	L	4	11	0	39	37	5.1	34	32	5.9	41	40	2.4	39	36	7.7	5.3
24	R	4	40	0	47	51	7.8	34	38	10.5	44	46	4.3	43	45	4.4	6.8

TABLE 10 *Continued*

Patient number	*Eye*	*Age surgery*	*Age exam.*	*Implant*	*Orbit height* R	*Orbit height* L	*Orbit height* % diff.	*Orbit width* R	*Orbit width* L	*Orbit width* % diff.	*Diagonal UN—LT* R/	*Diagonal UN—LT* \L	*Diagonal UN—LT* % diff.	*Diagonal LN—UT* R\	*Diagonal LN—UT* /L	*Diagonal LN—UT* % diff.	*Avg. % diff.*
25	L	4	16	0	50	47	6	39	37	5.1	50	47	6.0	41	38	7.3	6.1
26	L	4	7½	+	45	43	4.4	35	35	0	43	43	0	42	41	2.4	1.7
27	L	4	16	+	40	38	5	37	37	0	35	35	0	42	40	4.7	2.4
28	R	5	22	+	42	43	2.3	36	37	2.7	42	45	6.7	41	44	6.8	4.6
29	R	5⅔	12⅓	+	42	41	2.4	35	34	2.9	42	41	2.4	40	37	7.5	3.8
30	R	6	31	+	40	41	2.4	37	37	0	42	43	2.3	37	39	5.1	2.5
31	L	6	9½	+	42	40	4.7	36	34	5.6	41	40	2.4	38	36	5.2	4.5
32	L	7	28	+	45	45	0	39	39	0	48	47	2.1	46	46	0	0.5
33	R	7½	13	+	47	47	0	36	37	2.7	49	49	0	42	43	2.3	1.3
34	R	8	11	+	45	46	2.2	32	33	3.0	43	44	2.3	36	38	5.2	3.2
35*	R	8⅚	13⅚	0	43	47	8.5	33	40	17.5	37	44	15.9	34	42	19.0	15.2
36	L	9	17½	+	44	43	2.3	35	34	2.9	43	41	2.3	41	40	2.4	2.5
37	L	9½	23	+	44	42	4.5	39	39	0	45	43	4.4	38	38	0	2.2
38	L	10	16	+	44	42	4.5	36	35	2.7	44	42	4.5	38	38	0	2.9
39	R	11	16	0	41	42	2.4	41	42	2.4	50	51	2	39	40	2.5	2.3
40	R	12	17	+	44	45	2.2	37	37	0	41	43	4.6	38	40	5	3.0
41	R	13	20	+	46	47	2.1	39	39	0	46	46	0	40	40	0	0.5
42	L	14	25	+	45	45	0	40	39	2.5	50	49	2.0	42	42	0	1.1

*Cases 5, 7, 9, 35 received X-ray therapy.

The canal of the optic nerve is smaller on the enucleated side as reported by Luzsa and others. This was evident in all of the cats and in 93 per cent of the humans. The average decrease in humans was approximately 17 per cent, but may be as high as 50 per cent.

Roentgen ray therapy to the orbital region may cause additional decreased orbital measurements far greater than those resulting from simple enucleation.

Elective enucleation in infancy is contraindicated.

APPENDIX

Tables 8, 9, and 10 supply the complete set of measurements and percentage change determinations for the rabbit and cat skulls, and most of the measurements from the roentgenograms of the patients. Single examples of each of these have been given in Tables 4, 5, and 6.

ACKNOWLEDGMENTS

I am indebted to many colleagues for their kind permission to include their patients in this series and for supplying additional information concerning these patients. They include Doctors W. C. Caccamise, B. F. Donovan, E. Emerson, K. T. Fairfax, J. R. Fitzgerald, J. F. Gipner, S. J. Ianacone, E. W. Kennedy, P. H. Landers, H. A. Lerner, O. Pearson, G. A. Platt, M. H. Presberg, C. T. Sullivan, E. R. Vernou.

I am most grateful to Dr. Albert C. Snell for his interest, encouragement, and advice. He kindly read an early draft of the manuscript and offered suggestions on revision.

Mrs. Anne Smith devoted much effort in locating the patients and accomplishing their roentgenograms. Her perseverance was tested with the typing of several revisions of the manuscript. I am most grateful both for this and for her help in many other ways during the preparation of this material.

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