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Modifications and Additions to the Pediatric and Adult Mathematical Phantoms

J. M. L. Hwang
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HEALTH PHYSICS DIVISION

MODIFICATIONS AND ADDITIONS TO THE
PEDIATRIC AND ADULT MATHEMATICAL
PHANTOMS

SEPTEMBER 1976

J. M. L. Hwang, R. L. Shoup and J. W. Poston

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INTRODUCTION

Mathematical representations of humans one year, five years, and twenty years (adult) of age have been modified and are discussed in detail in the following sections. These modifications include the addition of a mandible and salivary glands in the head section and the inclusion of the gall bladder to the trunk region. Originally, these phantoms consisted of 22 internal organs, a skeletal system consisting of ten individual sections and the lungs as reported in ORNL-TM-5293 for the one year and five year old phantoms and MIRD Pamphlet #5 for the adult. These changes were incorporated into the newborn phantom during its design which are reported in ORNL-TM-5453 and hence are not included in this report.

These mathematical phantoms are undergoing continuous refinement in response to their increasing usefulness in absorbed dose calculations for both external and internal emitters and x-ray procedures. The addition of a gall bladder in the cavity slightly to the left of the liver is useful because this organ is studied by both diagnostic x-ray and nuclear medicine procedures. Certain radiopharmaceuticals concentrate in the gall bladder and techniques are needed to calculate the absorbed dose to the gall bladder wall (Fig. 1).

The head sections are modified to include the facial bones--a mandible and maxilla--and will be referred to as the mandible for simplicity. In the past, the skull was designed to be thicker at its

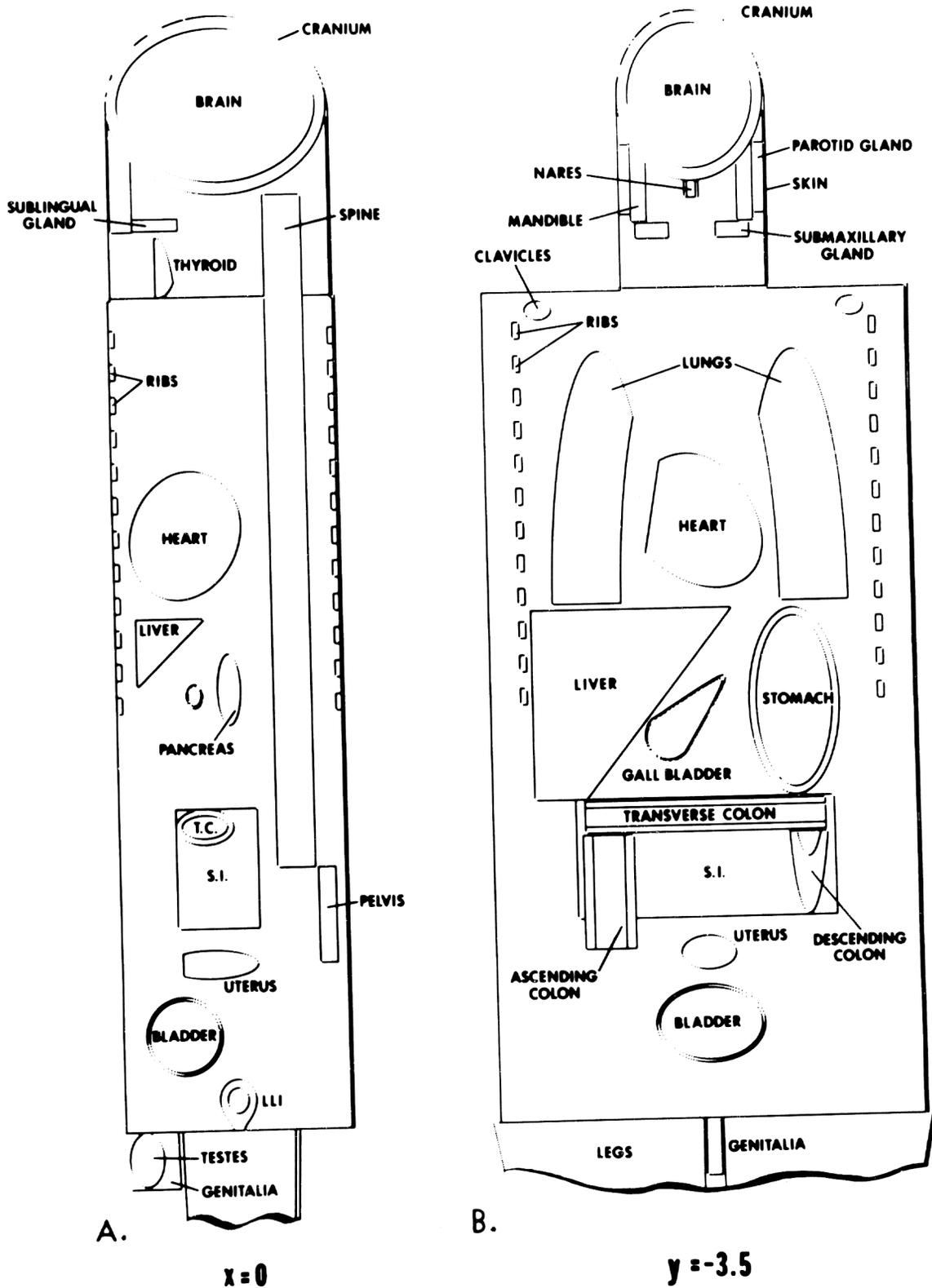


Figure 1. Y-Z and X-Z Sectional Plots of the Adult Phantom.

base to compensate for the absence of the skeletal mass of the mandible. This precluded the ability of performing dental dosimetry calculations.

The skull (cranium) is redesigned to a spheroidal shell of constant thickness where the outer spheroid maintains nearly the same mathematical description as the upper hemispheroidal geometry as before. The added mandible is mask-like in shape being placed in the front lower section of the head and with radii slightly less than that of the elliptical shape of the head in order to accommodate the parotid salivary glands (Fig. 2). The submaxillary and sublingual salivary glands are placed in the appropriate positions proximal to the mandible with the thyroid gland being moved slightly back towards the center of the lower head section and in a more natural position. With these head section modifications, absorbed doses to the mandible and salivary glands can be calculated for x-rays. The salivary glands are of interest because of the manifestations of cancers in these glands which have been attributed to x-ray exposures.

Data for gall bladder mandible, and salivary gland shapes, sizes and weights were obtained from the ICRP Task Group Report on Reference Man¹ and anatomical references.^{2,3} The remaining sections describe, mathematically, these changes to the one year, five year, and twenty year-old phantoms respectively.

MODIFICATION OF THE ONE YEAR-OLD PHANTOM

Modification of the head section and the addition of two new organs—salivary glands and gall bladder—to the one year-old phantom are described below.

ORNL-DWG 76-1947

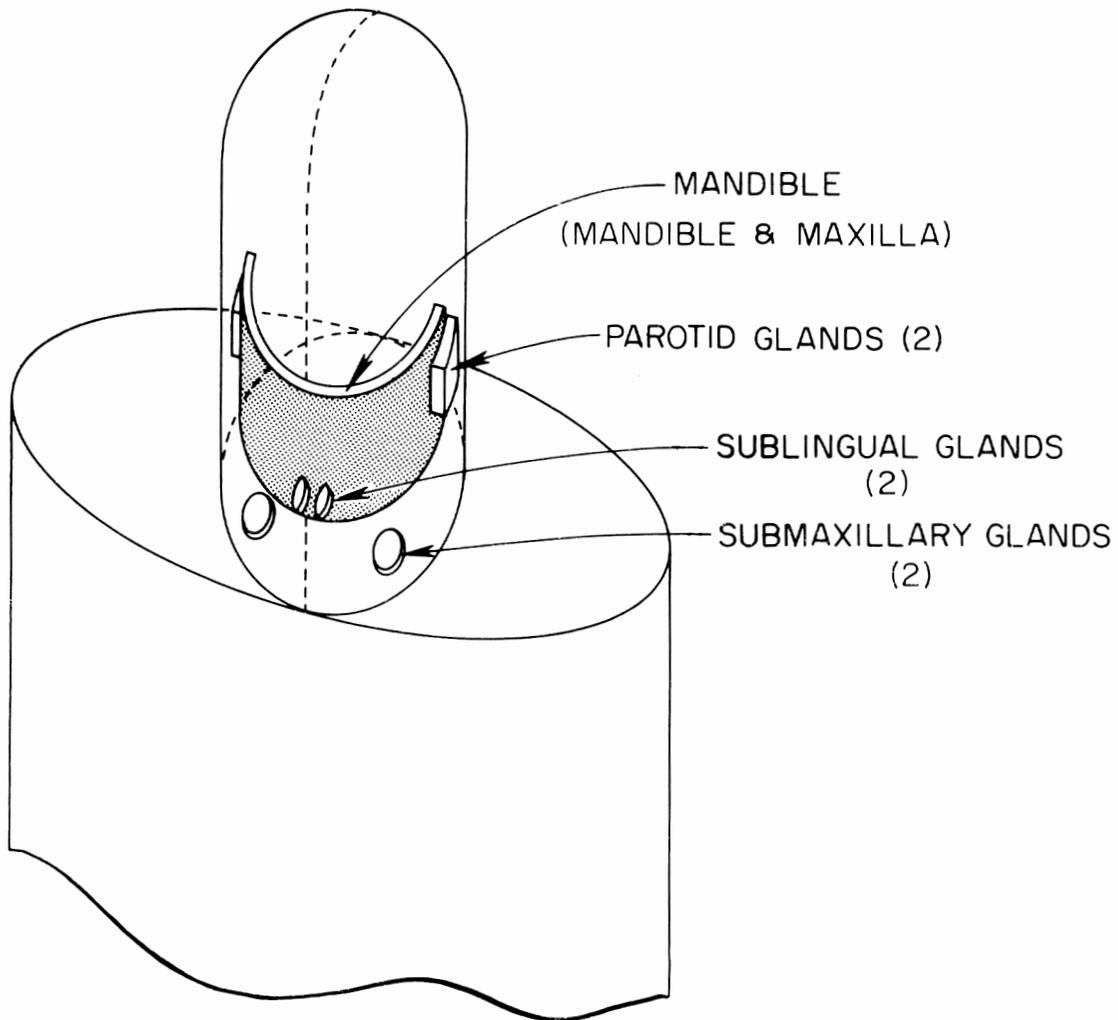


Figure 2. Head Section of Phantom Illustrating Approximate Location of Salivary Glands.

Mandible. The mandible is a portion of the volume between two concentric elliptical cylinders. The upper rear portion of these cylinders intersect the cranium and brain, and this volume is subtracted off. The mandible is described by

$$\left(\frac{X}{4.5}\right)^2 + \left(\frac{Y}{6.4}\right)^2 \geq 1$$

$$\left(\frac{X}{5.6}\right)^2 + \left(\frac{Y}{7.8}\right)^2 \leq 1$$

$$Y \leq 0$$

$$34.5 \leq Z \leq 42.3$$

and

$$\left(\frac{X}{6.6}\right)^2 + \left(\frac{Y}{7.8}\right)^2 + \left(\frac{Z - 43.1}{6.3}\right)^2 \geq 1 .$$

The total volume of the mandible is 196.71 cm^3 , and the mass is 135.4 g.

Cranium. The cranium is the volume between two concentric ellipsoids defined by

$$\left(\frac{X}{5.9}\right)^2 + \left(\frac{Y}{7.1}\right)^2 + \left(\frac{Z - 43.1}{5.5}\right)^2 \geq 1$$

$$\left(\frac{X}{6.6}\right)^2 + \left(\frac{Y}{7.8}\right)^2 + \left(\frac{Z - 43.1}{6.3}\right)^2 \leq 1 .$$

The total volume of the cranium is 393.5 cm^3 , and the mass is 550.8 g.

The total volume of the skeletal parts of the head section is 490.16 cm^3 , and the mass is 686.22 g.

Brain. The brain is an ellipsoid given by

$$\left(\frac{X}{5.9}\right)^2 + \left(\frac{Y}{7.1}\right)^2 + \left(\frac{Z - 43.1}{5.5}\right)^2 \leq 1$$

and the volume is 965 cm^3 , and the mass is 993 g.

Thyroid. The lobes of the thyroid lie between two concentric cylinders and are formed by a cutting surface. The expressions for this organ are

$$X^2 + (Y + 2.8)^2 \leq (1.6)^2$$

$$X^2 + (Y + 2.8)^2 \geq (1.4)^2$$

$$Y + 2.8 \leq 0$$

$$32 \leq Z \leq 35.6$$

$$[(Y + 2.8) - |X|]^2 \geq 2[X^2 + (Y + 2.8)^2]\tau^2 ,$$

in which

$$\tau = \frac{5}{9} (\sqrt{2} - 2)(Z - 32) + 1 \quad \text{for} \quad 0 \leq Z - 32 \leq \frac{9}{10}$$

and

$$\tau = \frac{5(2 - \sqrt{2})}{27} (Z - 32) + \frac{2\sqrt{2} - 1}{3} \quad \text{for} \quad \frac{9}{10} \leq Z - 32 \leq \frac{18}{5}$$

The volume is 2.26 cm^3 and the mass is 2.38 g.

Salivary Glands. The salivary glands consist of three pairs of glands located proximal to the mandible within the head section. These three pairs of glands are described below:

-Parotid Glands. These glands are triangular shaped and lie between the skin and mandible on the right and left sides of the head.

Their volumes are described by sections of two concentric elliptical cylinders cut by an elliptical surface in the Y-Z plane. These parotid glands are given by the equations

$$\left(\frac{Y + 2.6}{2.6}\right)^2 + \left(\frac{Z - 38.5}{3.6}\right)^2 \leq 1$$

$$-2.6 \leq Y \leq 0$$

$$34.9 \leq Z \leq 38.5$$

$$\left(\frac{X}{5.6}\right)^2 + \left(\frac{Y}{7.8}\right)^2 \geq 1$$

$$\left(\frac{X}{6.6}\right)^2 + \left(\frac{Y}{7.8}\right)^2 \leq 1 .$$

The total volume of parotid glands is 14.7 cm^3 and the mass is 15.3 g.

-Submaxillary Glands. These glands are elliptical disks which are located immediately below and towards the front part of the mandible. They lie symmetrically on the right and left sides of X-axis. They are described as:

$$\left(\pm \frac{X - 3.6}{1.1}\right)^2 + \left(\frac{Y + 3.8}{1.2}\right)^2 \leq 1$$

and

$$33.5 \leq Z \leq 34.3 ;$$

the volume of both submaxillary glands is 6.63 cm^3 , and the mass is 6.9 g.

-Sublingual Glands. These glands are elliptical disks and are located interior to and near the bottom of the mandible. They lie

symmetrically on the left and right sides of the X-axis. They are given by:

$$\left(\pm \frac{X - 1.2}{0.3} \right)^2 + \left(\frac{Y + 4.7}{1.4} \right)^2 \leq 1$$

and

$$35.65 \leq Z \leq 36.35 .$$

The volume of both sublingual glands is 1.84 cm^3 and the mass is 1.93 g.

Gall Bladder. The gall bladder is defined by the frustrum of a cone capped with a hemisphere. A rotation and translation are then effected. The gall bladder is represented by

$$X_1 = 0.8516(X - 0.1) + 0.4226(Y + 1.8) - 0.3099(Z - 12.7)$$

$$Y_1 = -0.3971(X - 0.1) + 0.9063(Y + 1.8) + 0.1445(Z - 12.7)$$

$$Z_1 = 0.342(X - 0.1) + 0.9396(Z - 12.7)$$

if $Z_1 < 0$

$$X_1^2 + Y_1^2 + Z_1^2 \leq (1.3)^2$$

$$X_1^2 + Y_1^2 + Z_1^2 \geq (1.2)^2$$

if $0 \leq Z_1 \leq 2.6$

$$X_1^2 + Y_1^2 \leq \left(1.3 - \frac{1.1}{2.6} Z_1\right)^2$$

$$X_1^2 + Y_1^2 \geq \left(1.2 - \frac{1.1}{2.6} Z_1\right)^2 .$$

The volume is 2.1 cm^3 , and the mass is 2.16 g. The contents have a volume of 7.9 cm^3 and a mass of 8.1 g. This represents a moderately full gall bladder.

MODIFICATION OF THE FIVE YEAR-OLD PHANTOM

Modification of the head section and the addition of two new organs—salivary glands and gall bladder—to the five year-old phantom are described below:

Mandible. The mandible is a portion of the volume between two concentric elliptical cylinders. The upper rear portion of these cylinders intersect the cranium and brain and this volume is subtracted off. The mandible is described by:

$$\left(\frac{X}{4.5}\right)^2 + \left(\frac{Y}{7.2}\right)^2 \geq 1$$

$$\left(\frac{X}{5.6}\right)^2 + \left(\frac{Y}{8.6}\right)^2 \leq 1$$

$$Y \leq 0$$

$$45 \leq Z \leq 53$$

and

$$\left(\frac{X}{6.6}\right)^2 + \left(\frac{Y}{8.6}\right)^2 + \left(\frac{Z - 54.6}{6.5}\right)^2 \geq 1 .$$

The total volume of the mandible is 136.4 cm^3 , and the mass is 190.9 g.

Cranium. The cranium is the volume between two concentric ellipsoids defined by

$$\left(\frac{X}{5.9}\right)^2 + \left(\frac{Y}{7.9}\right)^2 + \left(\frac{Z - 54.6}{5.87}\right)^2 \geq 1$$

$$\left(\frac{X}{6.6}\right)^2 + \left(\frac{Y}{8.6}\right)^2 + \left(\frac{Z - 54.6}{6.5}\right)^2 \geq 1 .$$

The total volume of the cranium is 399.3 cm^3 , and the mass is 559 g.

The total volume of the skeletal parts of the head section is 535.76 cm^3 , and the mass is 750 g.

Brain. The brain is an ellipsoid given by

$$\left(\frac{X}{5.9}\right)^2 + \left(\frac{Y}{7.9}\right)^2 + \left(\frac{Z - 54.6}{5.87}\right)^2 \leq 1$$

and the volume is 1146 cm^3 , and the mass is 1179 g.

Thyroid. The lobes of the thyroid lie between two concentric cylinders and are formed by a cutting surface. The expressions for this organ are

$$X^2 + (Y + 3.3)^2 \leq (1.9)^2$$

$$X^2 + (Y + 3.3)^2 \geq (1.6)^2$$

$$Y + 3.3 \leq 0$$

$$42 \leq Z \leq 46.2$$

$$[(Y + 3.3) - |X|]^2 \geq 2[X^2 + (Y + 3.3)^2]\tau^2$$

in which

$$\tau = \frac{10}{21} (\sqrt{2} - 2)(Z - 42) + 1 \quad \text{for} \quad 0 \leq Z - 42 \leq 1.05$$

and

$$\tau = \frac{10}{63} (2 - \sqrt{2})(Z - 42) + \frac{2\sqrt{2} - 1}{3} \quad \text{for} \quad 1.05 \leq Z - 42 \leq 4.2 .$$

The volume is 4.62 cm^3 and the mass is 4.85 g.

Salivary Glands. The salivary glands consist of three pairs of glands located proximal to the mandible within the head section. These three pairs of glands are described below.

-Parotid Glands. These glands are triangular shaped and lie between the skin and mandible on the right and left sides of the head. Their volumes are described by sections of two concentric elliptical cylinders cut by an elliptical surface in the Y-Z plane. These parotid glands are given by the equations:

$$\left(\frac{Y + 3.2}{3.2} \right)^2 + \left(\frac{Z - 49.5}{4.4} \right)^2 \leq 1$$

$$-3.2 \leq Y \leq 0$$

$$45.4 \leq Z \leq 49.8$$

$$\left(\frac{X}{5.6} \right)^2 + \left(\frac{Y}{8.6} \right)^2 \geq 1$$

$$\left(\frac{X}{6.6} \right)^2 + \left(\frac{Y}{8.6} \right)^2 \leq 1 .$$

The total volume of the parotid glands is 22.1 cm^3 and the mass is 23 g.

-Submaxillary Glands. These glands are elliptical disks which are located immediately below and towards the front part of the mandible.

They lie symmetrically on the right and left sides of the X-axis. They are described as:

$$\left(\pm \frac{X - 3.6}{1.1} \right)^2 + \left(\frac{Y + 4.3}{1.3} \right)^2 \leq 1$$

and

$$44.1 \leq Z \leq 44.9 .$$

The volume of both submaxillary glands is 7.18 cm^3 , and the mass is 7.5 g.

-Sublingual Glands. These glands are elliptical disks and are located interior to and near the bottom of the mandible. They lie symmetrically on the left and right sides of the X-axis. They are given by:

$$\left(\pm \frac{X - 1.3}{0.4} \right)^2 + \left(\frac{Y + 5.1}{1.6} \right)^2 \leq 1$$

and

$$46.3 \leq Z \leq 47 .$$

The volume of both sublingual glands is 2.81 cm^3 and the mass is 2.95 g.

Gall Bladder. The gall bladder is defined by the frustrum of a cone capped with a hemisphere. A rotation and translation are then effected. The gall bladder is represented by

$$X_1 = 0.8516(X + 0.3) + 0.4226(Y + 2.3) - 0.3099(Z - 17.5)$$

$$Y_1 = -0.3971(X + 0.3) + 0.9063(Y + 2.3) + 0.1445(Z - 17.5)$$

$$Z_1 = 0.342(X + 0.3) + 0.9396(Z - 17.5)$$

if $Z_1 < 0$

$$X_1^2 + Y_1^2 + Z_1^2 \leq (1.8)^2$$

$$X_1^2 + Y_1^2 + Z_1^2 \geq (1.7)^2$$

if $0 \leq Z_1 \leq 2.6$

$$X_1^2 + Y_1^2 \leq (1.8 - 0.31 Z_1)^2$$

$$X_1^2 + Y_1^2 \geq (1.7 - 0.31 Z_1)^2 .$$

The volume is 4.98 cm^3 , and the mass is 5.13 g. The contents have a volume of 26.87 cm^3 and a mass of 27.56 g. This represents a moderately full gall bladder.

MODIFICATION OF THE ADULT PHANTOM

Modification of the head section and the addition of two new organs—salivary glands and gall bladder—to the adult phantom are described below.

Mandible. The mandible is a portion of the volume between two concentric elliptical cylinders. The upper rear portion of these cylinders intersect the cranium and brain and this volume is subtracted off. The mandible is described by:

$$\left(\frac{X}{4.4}\right)^2 + \left(\frac{Y}{8.0}\right)^2 \geq 1$$

$$\left(\frac{X}{5.7}\right)^2 + \left(\frac{Y}{9.8}\right)^2 \leq 1$$

$$Y \leq 0$$

$$75.5 \leq Z \leq 85.1$$

and

$$\left(\frac{X}{6.8}\right)^2 + \left(\frac{Y}{9.8}\right)^2 + \left(\frac{Z - 86.1}{7.7}\right)^2 \geq 1 .$$

The total volume of the mandible is 162.4 cm^3 , and the mass is 227.4 g.

Cranium. The cranium is the volume between two concentric ellipsoids defined by

$$\left(\frac{X}{5.9}\right)^2 + \left(\frac{Y}{8.9}\right)^2 + \left(\frac{Z - 86.1}{6.68}\right)^2 \geq 1$$

$$\left(\frac{X}{6.8}\right)^2 + \left(\frac{Y}{9.8}\right)^2 + \left(\frac{Z - 86.1}{7.7}\right)^2 \leq 1 .$$

The total volume of the cranium is 608 cm^3 , and the mass is 952 g.

Brain. The brain is an ellipsoid given by

$$\left(\frac{X}{5.9}\right)^2 + \left(\frac{Y}{8.9}\right)^2 + \left(\frac{Z - 86.1}{6.68}\right)^2 \leq 1$$

and the volume is 1469.28 cm^3 , and the mass is 1450.29 g.

Thyroid. The lobes of the thyroid lie between two concentric cylinders and are formed by a cutting surface. The expressions for this organ are

$$x^2 + (Y + 4)^2 \leq (2.2)^2$$

$$x^2 + (Y + 4)^2 \geq 1^2$$

$$Y + 4 \leq 0$$

$$70 \leq Z \leq 75$$

$$[(Y + 4) - |x|]^2 \geq 2[x^2 + (Y + 4)^2]\tau^2$$

in which

$$\tau = \frac{2(\sqrt{2} - 2)}{5} (Z - 70) + 1 \quad \text{for} \quad 0 \leq Z - 70 \leq \frac{5}{4}$$

in which

$$\tau = \frac{2(2 - \sqrt{2})}{15} (Z - 70) + \frac{2\sqrt{2} - 1}{3} \quad \text{for} \quad \frac{5}{4} < Z - 70 \leq 5 .$$

The volume is 19.89 cm^3 and the mass is 19.63 g.

Salivary Glands. The salivary glands consist of three pairs of glands located proximal to the mandible within the head section. These three pairs of glands are described below.

-Parotid Glands. These glands are triangular shaped and lie between the skin and mandible on the right and left sides of the head. Their volumes are described by sections of two concentric elliptical cylinders cut by an elliptical surface in the Y-Z plane. These parotid glands are given by:

$$\left(\frac{Y + 4.5}{4.5}\right)^2 + \left(\frac{Z - 82}{6}\right)^2 \leq 1$$

$$-4.5 \leq Y \leq 0$$

$$76 \leq Z \leq 82$$

$$\left(\pm \frac{X}{5.7} \right)^2 + \left(\frac{Y}{9.8} \right)^2 \geq 1$$

$$\left(\pm \frac{X}{6.8} \right)^2 + \left(\frac{Y}{9.8} \right)^2 \leq 1 .$$

The total volume of parotid glands is 46.65 cm^3 and the mass is 48.5 g.

-Submaxillary Glands. These glands are elliptical disks which are located immediately below and towards the front part of the mandible. They lie symmetrically on the right and left sides of X-axis. They are described as

$$\left(\pm \frac{X - 3.5}{1.5} \right)^2 + \left(\frac{Y + 3.9}{1.75} \right)^2 \leq 1$$

and

$$74.1 \leq Z \leq 75.4 ;$$

the volume of both submaxillary glands is 21.44 cm^3 , and the mass is 22.38 g.

-Sublingual Glands. These glands are elliptical disks and located interior to and near the bottom of the mandible. They lie symmetrically on the left and right sides of the X-axis. They are given by

$$\left(\frac{X - 1.4}{0.5} \right)^2 + \left(\frac{Y + 5.5}{2} \right)^2 \leq 1$$

and

$$75.6 \leq Z \leq 76.6 .$$

The volume of both sublingual glands is 6.28 cm^3 and the mass is 6.58 g.

Gall Bladder. The gall bladder is defined by the frustrum of a cone capped with a hemisphere. A rotation and translation are then effected. The gall bladder is represented by

$$X_1 = 0.64085(X + 3) + 0.4226(Y + 3) - 0.6408(Z - 32.2)$$

$$Y_1 = -0.2988(X + 3) + 0.9063(Y + 3) + 0.2988(Z - 32.2)$$

$$Z_1 = 0.7071(X + 3) + 0.7071(Z - 32.2)$$

if $Z < 0$

$$X_1^2 + Y_1^2 + Z_1^2 \leq (2.12)^2$$

$$X_1^2 + Y_1^2 + Z_1^2 \geq (2.0)^2$$

if $0 \leq Z_1 \leq 8$

$$X_1^2 + Y_1^2 \leq (2.12 - 0.2275 Z_1)^2$$

$$X_1^2 + Y_1^2 \geq (2 - 0.225 Z_1)^2 .$$

The volume is 9.74 cm^3 , and the mass is 9.61 g. The contents have a volume of 54 cm^3 and a mass of 53.3 g. This represents a moderately full gall bladder.

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