INTRODUCTION
The framework of the human larynx consists of an epiglottis, a thyroid, a cricoid, paired arytenoids, paired cuneiform and paired corniculate cartilages.

**THYROID CARTILAGE**

The thyroid cartilage consists of two quadrilateral plates called the laminae which are continuous with each other. Anteriorly in the middle line at an angle forming the laryngeal prominence, in the upper part of which there is a V shaped notch called the superior thyroid notch. Posteriorly at the junction of upper and posterior borders, a long slender process called the superior cornu extends upwards, slightly backwards and medially, its terminal end gives attachment to lateral thyrohyoid ligament which contains, a little distance above the tip of the cornua, a rounded cartilaginous nodule called the cartilago triticea. Similarly at the junction of inferior and posterior borders of the lamina a short process called the inferior cornua, extends downwards, slightly forwards and medially, which on the medial surface of its lower end possesses an oval facet with which it articulates with the cricoid cartilage. Each lamina, therefore, consists of a superior, an inferior, an anterior and posterior border. Angle formed by the two laminae at the laryngeal prominence is 90° in the males and 120° in females (Williams and Warwick 1980). The superior border of each lamina gives attachment to the thyrohyoid membrane. The inferior border is concave behind and almost straight anteriorly. At the junction of the two parts of the inferior border is located the inferior thyroid tubercle. The anterior cricothyroid ligament is attached above to the medial portion of the inferior border of thyroid cartilage extending caudally, it broadens itself to get attached to the upper border of the cricoid cartilage. No structure is attached to the rest of the inferior border of the cartilage. On the outer surface
of each lamina, a tubercle named the superior thyroid tubercle is present just below the superior border, about 0.75 cm anterior and 0.5 cm below the base of the superior cornua. From the superior thyroid tubercle an oblique faint ridge extends downwards and forwards over the outer surface of the lamina to reach the lower border of the lamina where an inferior thyroid tubercle is located. The thyrohyoid, sternothyroid and inferior constrictor muscles are attached to the oblique line.

A little below the superior thyroid notch, the internal surface of the thyroid cartilage gives attachment to a short thyro-epiglottic ligament with which the root of the epiglottis is attached to the thyroid cartilage. About midway between the thyroid notch and inferior border are attached the vestibular and vocal ligaments, the former are attached a little above the later.

CRICOID CARTILAGE

Cricoid cartilage is shaped like a signet ring. It is thicker and stronger than the thyroid cartilage. It consists of an arch anteriorly and a lamina posteriorly.

Arch is narrow anteriorly and measures vertically, in the middle from 5 to 7 mm (Williams and Warwick, 1980). As it is traced backwards, it widens itself and merges into the lateral part of the lamina. The outer surface of the cricoid cartilage on its front and lateral parts gives attachment to crico-thyroid muscle. Near the lamina the outer surfaces of arch just anterior to the crico-thyroid facet gives attachment to the inferior constrictor muscle.

At the junction of the arch with the lamina on the
lateral side about its middle, usually there is a circular articular facet for the articulation of the inferior cornua of the thyroid cartilage. The upper border of the medial part of the arch anteriorly gives attachment to anterior crico-thyroid ligament which extends upwards and is attached to the inferior border of the thyroid cartilage; laterally the upper border of the arch gives attachment to the lateral cricothyroid ligament which extends upwards towards the thyroid cartilage but extends inside it to form the basis of the vocal folds.

The cricoid lamina measures about 2 cm vertically and 3 cm from side to side (from one cricothyroid facet to the other). On the posterior surface there are two shallow depressions separated by a median ridge. The depressed areas give attachment to the fibres of the posterior crico-arytenoid muscle while the median ridge gives attachment to the longitudinal fibres of the oesophagus through the agency of a small tendenous slip.

**ARYTENOID CARTILAGES** (paired)

Each arytenoid cartilage is shaped like a pyramid and is located posteriorly on the superior border of the lamina of the cricoid cartilage a little lateral to the middle line forming a crico-arytenoid joint. It has an apex, a base and three surfaces.

Medial surface is smooth and faces the medial surface of other arytenoid cartilage. The distance between medial surfaces of the two cartilages constitutes the intercartilagenous rima glottidis.
Posterior surface is smooth and concave. The transverse arytenoid muscle covers it.

On the antero-lateral surface below the apex there is prominent elevation from where the arcuate crest extends first dorsally and then caudally and lastly downwards and forwards to reach the vocal process. The last portion of the crest divide the surface into upper fovea triangularis and lower fovea oblonga. The triangular fovea gives attachment to vestibular ligament and oblong fovea to vocalis and lateral crico-arytenoid muscle.

The base bears a depressed circular facet posteriorly directed medially and downwards for articulation with cricoid cartilage. Posterolateral to the articular facet there is a process called muscular process. At the junction of medial and antero-lateral surfaces and the base, a pointed process extends forwards and is called the vocal process.

Vocal process gives attachment to the vocal ligament while muscular process gives attachment to the posterior and lateral crico-arytenoid muscles. The lower part of the posterior surface near its inferior border gives attachment to the posterior crico-arytenoid ligament.

Apex extends upwards, backwards and medially, articulates with small conical module made of elastic fibrocartilage called the corniculate cartilage.

**EPIGLOTTIS**

The epiglottis is a thin leaf-like structure, the upper part of which is oblong in shape while its lower part
tapers to a short stalk called the petiole, which is attached by an elastic ligament (thyro-epiglottic ligament) to the back of the angle formed by the union of the two laminae of the thyroid cartilage, a little below the thyroid notch.

The upper border of the cartilage is said to be "rounded". The angles at the junction of the upper border and the lateral margins are also rounded. The cartilage stands obliquely upwards and backwards behind the hyoid bone and the root of the tongue. The entire posterior surface of the cartilage is covered by mucous membrane which is present anteriorly only on the upper part. At the junction of the lamina with the stalk, posterior surface presents a tubercle in the middle. On removing the mucous membrane from the posterior surface, a number of a small pits are visible.

The lower part of the anterior surface of the epiglottis is connected to the hyoid bone by an elastic hyo-epiglottic ligament and some fatty tissue.

The sides of the epiglottis are attached to the arytenoid cartilages by means of aryepiglottic folds of mucous membrane. The aryepiglottic fold extends laterally, backwards and then medially to reach the apex of the arytenoid cartilage.

**CORNICULATE CARTILAGE**

Corniculate cartilages are two small conical cartilaginous nodules located on the apex of each arytenoid cartilage.

**CUNEIFORM CARTILAGES**

The cuneiform cartilages are two small club-shaped cartilaginous nodules present in aryepiglottic fold, a short
distance anterior to the corniculate cartilage.

In this thesis only 4 main cartilages namely thyroid, cricoid, arytenoid and epiglottis will be studied. On account of limitation of time and the extreme variability of these cartilages it is not proposed to study corniculate, cuneiform and triticea.

Joints and ligaments
The joints of the larynx are:

1. Between the hyoid bone and thyroid cartilage
2. Epiglottis and thyroid cartilage
3. Crico-thyroid
4. Crico-arytenoid

The first can hardly be called a joint as the union is only by membrane. The thyro-hyoid membrane stretches between the upper border of the thyroid laminae, including the superior thyroid notch and superior cornua to the upper part of the posterior surface of the body of the hyoid bone and its greater cornua.

The root of the epiglottis is attached to the posterior surface of the angle of thyroid cartilage a few mm below the thyroid notch by means of thyro-epiglottic ligament. It is not proposed to study these membranes or thyro-epiglottic ligament in the present thesis.

The following minor joints will also not be studied:

1. Arytenoid-corniculate joint
2. Attachment of the epiglottis to the tongue, hyoid bone and aryepiglottic fold.
3. Anterior crico-thyroid ligaments - median (anterior) and lateral; the former running
between the adjacent margins of cricoid arch and thyroid cartilage and latter extending from the internal rim of superior border of cricoid arch upwards to become the vocal ligaments.

4. Mode of attachment of cartilago triticea or cuneiform cartilage.

There are only two joints which will be considered in this thesis. They are:

1. Crico-thyroid joint
2. Crico-arytenoid joint

The former is located on the postero-lateral aspect of cricoid cartilage while the latter is placed on the back of larynx.

Crico-thyroid joint (Posterior)

The inferior cornu of the thyroid cartilage bears a facet on its inner surface of its lower end which articulates with a similar facet on the lateral aspect of cricoid cartilage. The joint is enclosed in synovial membrane on the outside of which is a fibrous capsule in which three ligaments namely a posterior crico-thyroid ligament, lateral crico-thyroid ligament and anterior crico-thyroid ligament can be defined. Posterior crico-thyroid ligament extends from the capsule of the joint upwards and medially to reach the upper part of posterior surface of the lamina of the cricoid cartilage whereas the lateral crico-thyroid ligament extends downwards and medially to the lower part of posterior surface of the cricoid cartilage. The anterior crico-thyroid
ligament runs from the antero-inferior border of inferior cornua of thyroid cartilage forwards, downwards and medially to get attached to the lateral side of the cricoid arch above its inferior border.

Crico-arytenoid joint

This joint is between the facet on the base of the arytenoid cartilage and an articular facet on the lateral part of upper border of lamina of cricoid cartilage. This joint is also synovial and is enclosed in a fibrous capsule in which posterior crico-arytenoid ligament can be defined. This ligament is attached to the lower part of posterior surface of arytenoid cartilage above, extending downwards and slightly medially and is attached to upper part of posterior surface of lamina of cricoid cartilage.
Very little information is available on the dimensions of the human laryngeal cartilages even in the population of the Western countries. However, the dimensions of the larynx and description of its cartilages are given in most text-books of Anatomy e.g. Gray's (Williams and Warwick, 1980), Morris' Human Anatomy (Anson, 1960).

Bichat (1841) found the female larynx to be about one-third the size of the male larynx. He also noted that the development of the larynx took place mostly at puberty.

Luschka (1871) also stated that the rapid increase in the size of the larynx took place at puberty. He noted that the epiglottis increased in size in the proportion of 5:10 at puberty in the males while in females the proportion was only 5:7.

Huschke (1882) showed in his treatise that the increase in the size of laryngeal cartilages at puberty in the males was greater than in the females.

Sappey (1882) measured the vertical, horizontal and antero-posterior diameters of the larynges of 8 males and 8 females and found a striking difference in the two sexes in the antero-posterior diameter.

Kurz (1918) recorded the shape and size of the human larynx in a 25 years old Chinese female and studied a few measurements.

Noback (1925) studied the lineal growth of the respiratory system including the larynx in the foetuses and the newborns and found that it was constant in relation to total body length (C.H.) and foetal age. He gave a formula according to which the height of the larynx in mm could be calculated from body length (C.H.).
Donadei (1926) studied the pubertal development of laryngeal cartilages and estimated the volume of each cartilage; he observed that the growth curves were about equal in the two sexes till puberty and thereafter these curves were much "higher" in the males than the females; however, the epiglottis was an exception as it showed the same growth curves in the two sexes. The same author also recorded that the growth curves of the laryngeal cartilages were close to the growth curve of whole body.

Waldeyer (1927) measured the thyroid angle in its superior and inferior parts in the extensive material obtained from European population and found that the upper angle was below 90° (Maximum 95° and minimum 51°) in the males and above 90° (maximum 114° and minimum 80°) in the females. He also stated that the lower angle was usually smaller than the upper.

Castaldi (1928) observed that there were three phases in the development of the larynx. The first phase was present between birth and 2-3 years of age, second from the 3rd year to puberty, and third was from puberty to adolescence. He found that the growth of larynx occurred rapidly in the first and third phases but was slow in second phase.

Hallet (1952) measured the superior thyroid angle in 50 larynges and he found 3 instances of 50-60°, 40 of 60-80°, 4 above 80° and 3 of 90° angles. He did not investigate sexual difference in the angles.

Minnigerode* (1952) reported that the length of epiglottis as measured from the petiolus to the upper margin was 4-5 cm.

* He is a different author from Minnigerode (1955)
Balboni (1955) measured various diameters of laryngeal cartilages in 49 males and 51 females from birth to 91 years. He found that the growth of the larynx and its cartilages occurred mainly at the time of puberty; it was more rapid in the males than in case of females. Further according to him the growth was disproportionately more in the males than the proportional increase in the other organs of body. It was also noted by him that near the clivatrix there was a certain amount of further increase in the diameters. He also made some observations on the lumen of the cricoid cartilage and recorded that antero-posterior diameter at the upper border was ovoid in form while at the lower border the ovoid form was less marked. He made a comparison of diameters and found that "different" kind of development occurred in the two sexes; the antero-posterior diameter of larynx at the superior margin was longer than at the inferior margin. Further according to him the difference between the antero-posterior diameters at the superior and inferior margins was more than that between the two transverse diameters. He also noted that in the females the transverse diameter was slightly more than the antero-posterior diameter. He observed that the relative growth of various diameters of the laryngeal cartilages was more in the males than in females.

Minnigerode (1955) took measurements on laryngeal cartilages in 55 males and 45 females. He measured the angle at the superior thyroid notch and observed that the male thyroid cartilage, in general, had a marked angular disposition whereas the female cartilage was rounded in form; epiglottis in 48 male larynges had a length of 4-5 cm, one was 4 cm and 6 were more than 5 cm in length while in the females the length of the epiglottis was 3.5 to 3.9 cm in 26 instances, 4 to 4.4 cm in 15 and 3 to 3.4 cm in 4 specimens.
Malinowski (1967) measured the laryngeal cartilages in Polish population in 55 males, and 42 females from 5-80 years of age. He studied the size, shape and frequency of abnormal forms in the two sexes. He noted that the length of larynx as measured from the highest point of epiglottis to the inferior margin of the cricoid cartilage was 51.8 mm in the males and 47.4 mm in the females. The superior thyroid angle in both sexes was found to be larger than the inferior thyroid angle; in more than three-quarters of male specimens the superior angle was less than 90° while in three-quarters of female specimens the superior angle was more than 90°. He also noted that the superior cornua was absent in 2% instances in the Polish population. Further according to him the transverse diameter of cricoid cartilage was greater than the antero-posterior diameter in both sexes and the length of the right arytenoid cartilage was greater than the left in the females while reverse was the case in the males. He also observed that the length of epiglottis was 28.5 mm in both sexes and was slightly greater than in the Chinese population where according to Kurz (1918) it was 27 mm.

Maue and Dickson (1971) measured the various diameters of laryngeal cartilages in 10 white adult males and 10 white adult females from 37 to 80 years of age. They studied the normal configuration in shape, size and symmetry of these cartilages. They did not find much difference in the measurements of the various cartilages from specimen to specimen. However, a great variation was noted in the angle formed by the intersection of lines drawn through the longitudinal axes of the crico-arytenoid facets on the cricoid cartilage. They also noted a similarity in the measurements of the arytenoid cartilages, the distances between the apex and vocal process, and the apex and muscular process were found to be similar or slightly greater than the distance between the
muscular process and vocal process. The ratio between these measurements was 10:10:8 in the males and 10:11:8 in the females.

Chung and Green (1974) noted the rate of the growth of the cricoid cartilage in 43 males and 24 females; the ages of the male children varied from 1 day to 5544 days while in the females the ages were 1 day to 2518 days and correlated it to the size of the child.

Kahane (1978) recorded the measurements of prepubertal and pubertal larynges in 10 males and 10 females ranging in age from 9 to 18 years in Caucasian population. He noted the differences in the developmental morphology of the "circumpubertal larynx". He also found that pubertal larynges were significantly larger than prepubertal larynges in both sexes. No clear sexual dimorphism was found between the male and female prepubertal larynges though a clear sexual dimorphism was evident in the larynx by puberty. The thyroid angle was not significantly different in pubertal male and female larynges.

Ajmani et al. (1980) studied the laryngeal cartilages in 150 specimens ranging from 16 to 55 years. According to them measurements of the cartilages in the males were greater than in the females; however, the thyroid angle was an exception. In the males the thyroid angle was 78° while in the females it was 106°.

Kahane (1982) extended his observations to the larynges of 20 male and 20 female adults aged 37-70 years and found that the antero-posterior dimension in the males increased 3 times more than in the females (15.04 mm compared to 4.47 mm); this increase was more than the increase which took place in the width of cartilage postero-superiorly and postero-inferiorly.
Further according to him, in the males the various measurements of the cricoid cartilage also increased 2-3 times more than the females.

Černý (1982) recorded a few measurements of the thyroid cartilages obtained from skeletons ranging in age from 40-60 years; measurements of 5 cricoid cartilages were also given by him.

Ossification
A study of the literature on ossification of laryngeal cartilages shows that it was Vesale (1555) who first mentioned that ossification of thyroid cartilage took place during the middle age.

According to Gray (1858) the epiglottis, cuneiform and corniculate cartilages were composed of "yellow cartilage" which did not show any tendency to calcification but the remaining cartilages of the larynx which were like costal cartilages in structure became "more or less calcified in old age".

According to Rambaud and Renault (1864) out of all the laryngeal cartilages, the thyroid cartilage was the first to undergo ossification which commenced in the postero-inferior part of lamina near the inferior cornua, extend into the inferior cornu and upwards to the base of superior cornu. They further described the spread of ossification in the rest of the thyroid cartilage; at the age of 60 years or often later the entire cartilage became a bone. These workers also studied ossification of cricoid and arytenoid cartilages.

Chievitz (1882) studied ossification of thyroid cartilages in 92 males and 79 females. According to him ossification of thyroid cartilage was very erratic, even in
a 24 years male, posterior portion of lamina and both cornua could be found to have calcified whereas in a woman of 88 years, calcification was present only posteriorly. Further according to him usually ossification commences in the inferior tubercle and inferior cornua and lower part of posterior border; another centre appears in the lower part of anterior border, the two join and extend into the lamina.

Scheier (1902) recorded that the thyroid cartilage started ossifying at the age of 18 years.

According to Roncallo (1948) ossification of the thyroid cartilage started in its lower posterior zone at about the age of 20 years in the males and a little later in the females. Further, according to him the spread of ossification was similar in both sexes in the first instance but later it extended more slowly in the females than in the males.

Zeligman (1959) studied ossification in 492 males and 352 females ranging in age from 14 to 85 years. He distinguished two types of ossification: the "wedge-shaped type" and the "frame-type". The progress in ossification in the latter type was slow.

Leopold and Jagow (1961) published a result of x-ray examination of 281 male larynges between 0-89 years in the Czechoslovakian subjects. Their results were verified from autopsy material by Vlček (1974, 1980) in the department of forensic medicine and the departments of Pathology in Berlin and Leipzig, he published a scheme, for estimating the age of male individuals on the basis of degree of ossification present in the cartilage.

Hataly et al (1965) made a radiological study of the ossification in the laryngeal cartilages in 516 living
subjects (259 males and 257 females) of varying ages. They found the earliest ossification at 16½ years in females and 18 years in males. According to them ossification in the thyroid cartilage started in the inferior portion of the posterior third of the lamina and the inferior cornu and then extended to the upper portion of the posterior third of the lamina and also forwards along the inferior margin of the anterior two-thirds of the lamina. Further according to them ossification in the cricoid cartilage began first in the curvilinear superior border of the lamina; the anterior half of the arch was the last to ossify. Ossification in arytenoid cartilage was also described by them.

Malinowski (1967) studied the process of calcification in the laryngeal cartilages of Polish population in 55 males and 42 females from 5 to 80 years of age. He noted that calcification started in the postero-inferior corner of the lamina including the inferior cornu and extended upwards along the posterior border to the superior cornu and also along the inferior border towards the middle. Further according to him calcification in the cricoid cartilage started near the crico-thyroid and crico-arytenoid facets. He also observed that calcification in the arytenoid cartilages started at two separate centres, one near the base and the other in the muscular process; the apex and the vocal process did not undergo calcification. He found that in the arytenoid cartilage there were no sexual differences in calcification. His observations were in agreement with the findings of Chievitz (1882) and Scheier (1901, 1910). Malinowski (1967) did not find any focus of calcification in the epiglottis.

Ajmani et al (1980) recorded the extent of ossification in laryngeal cartilages in 92 male and 50 female north Indian (U.P.) subjects in the age group 30 to 55 years. According to them incidence of ossification in the thyroid was 42.6% in the
males and 47.6% in the females; in the cricoid and arytenoid cartilages, in the males the incidence was 48.5% and 44.2% respectively while in the females it was only 33.3% in both cartilages.

According to Gray's Anatomy (Williams and Warwick), calcification in the thyroid cartilage starts at the age of twenty-five years and a little later in the cricoid and arytenoid cartilages and by the age of sixty five years these cartilages in x-ray pictures usually show patchy calcification and may even get ossified.

**Joints and Ligaments**

Information about the joints and ligaments is extremely limited. There are two joints one between the inferior cornua of thyroid cartilage and the body of cricoid cartilage and other between arytenoid and cricoid cartilages. Both joints are synovial.

The crico-thyroid and crico-arytenoid joints have not been described in detail in any text books of Anatomy. The modern text-books of Anatomy (Williams and Warwick, 1980) and of Otolaryngology neither give details of these joints nor describe the ligaments fully. The joint between apex of arytenoid cartilage and corniculate cartilage is also said to be some times synovial and at other times fibrous.

The only paper available on the joints is by Maue and Dickson (1971), their observations will be discussed and compared with those of present findings.
Aims and Objectives

(1) To study the measurements of larynx as a whole and its individual cartilages in both male and female newborns, children and adults.

(2) To study these measurements in foetuses of various ages.

(3) To correlate the various measurements to the age, weight, height and neck-length.

(4) To find out sexual differences in measurements in various age groups.

(5) To study the ossification of the laryngeal cartilages.

(6) To study the development of thyroid angle particularly after puberty in the two sexes.

(7) To study the symmetry or otherwise of the two laminae and cornua of the thyroid cartilage, two halves of the cricoid and two arytenoid cartilages.

(8) To study the ligaments and joints of the laryngeal cartilages.