CHAPTER IV

OSTEOLGY AND LIGAMENTS OF THE SKULL

The many fascinating adaptations illustrated by the greatly varied bill structure has been a topic of interest to the avian biologists. The various bill types as the diagnostic characters of the birds have attracted the attention of the avian biologists ever since the earliest observations in the ornithology. A vast array of the literature reveals that the beak displays wide variations as
far its architectural dimensions and epidermal structures are concerned. In achieving the maximum operational efficiency of the jaw apparatus, the osteological components of the beak which are the main spring boards of anchorage and muscle action evince wide structural variations in their disposition. Any structural variations in the feeding apparatus is reasonably recognized to reflect in the organization of the osteological components of the skull. It is reasonable to assume that the advent of diverging devouring operations highly influence the adequate availability of the surface of the bony elements for the attachment of the various muscles. The structural variations in this "extremely plastic" feature of evolution (Bock, 1960) is of immense importance as Burt (1930) has pointed out "the skull probably reflects in its structure, the habits of birds more conspicuously than does any other part of the skeleton".

The study of the skull structure and the significant role of its various osteological components in the feeding apparatus of birds has been a topic of interest in the past and any text book on ornithology perpetuates immense amount of these informations. A good deal of work has been done in the past in this field by Moller (1931), Beecher (1951, 1962)Sims (1955), Bock (1960, 1964, 1966) and several others. Fisher and Goodman (1955) observed significant correlations in the variation
of the skull structure in a number of birds. Goodman and Fisher (1962), have also attempted the quantitative studies in various skull components and correlated the ratios obtained with the specific feeding behaviour of the Anatids. The observations of Bock (1963) in the skull of the paradise birds and bower birds revealed the evident structural peculiarities of various osteological components of the bill associated with their peculiar skull eating habits. Recently Malhotra (1967) and Mansuri (1969) observed quite interesting structural modifications of the skull with the peculiar feeding habits of a number of Indian birds.

The present investigations pertain mainly to the study of the skull structure of the Domestic fowl (Gallus domesticus) in relation to the functional anatomy of the feeding apparatus. Before describing the structural peculiarities of the skull in the chickens it is considered desirable to state briefly the nature of the avian skulls in general.

The avian skull is a 'glorified reptilian skull' showing many antique characteristics like the single occipital condyle, high inter-orbital septum and a movable quadrate which is articulated with the lower jaw. The presence of the large orbit which is separated by a thin septum of the sphenoid and ethmoid bone permits a ready distinction of the arched cranium and the
pointed beak. The short cranial cavity is bulged out posteriorly to form a round lobulated brain case which is completely filled with the brain tissue. The complete fusion of the various osteological elements of the brain case obliterates the traces of all the structures in the adult and the structural obliteration is possible associated with the extreme pneumatization of the skull components (Bellaris and Jenkin, 1960; George and Berger, 1966).

The roof of the braincase is formed by the perietals and the large frontals which envelop the orbit of the eyes. The frontal articulates with the nasal at the posterior side of the beak and the lacrimal (Prefrontal) lies dorsal to the orbit, enveloping the former. The frontal articulates with the nasal dorsall behind the beak and the lacrimal lies in front of the orbit, which is instantly perforated by a canal for the lacrimal duct in some birds. The postorbital process of the frontal is placed posterior to the lacrimal, the squamosal with its prominent zygomatic process lies posterior to the orbit forming the side wall of the brain case. A thin inter-orbital septum separates the two big orbital cavities which are generally comprised of the anterior alisphenoid, drosal orbitosphenoid and posterior laterosphenoid together forming a bridge between the interorbital septum and the posterior extremity of the orbit.
A small vacuity is generally found between the postorbital process of the frontal and the zygomatic process of squamosal. This is comparable to the supratemporal fossa of the reptilian ancestors.

The upper beak is formed chiefly by the fused premaxillae which undergoes great variations in different avian forms. The nostrils are placed far back (holorhinal) or may be linear or slit like (schizorhinal) and are bound by two or three bones, the premaxilla, nasal and in some birds the maxilla. A triangular vacuity known as the antorbital vacuity which corresponds with the antorbital fossa of the reptilian ancestors is generally observed in birds. This vacuity enhances the plasticity of the beak and is important for the Gramal kinesis (Bellaris and Jenkins, 1960). The nasal septum is generally horny or sometimes cartilagenous.

The palatine shows great variations in the form of modifications resulting in great variety of shapes in various birds. This bone is slender anteriorly but becomes gradually wider posteriorly assuming broad and flat in shape and forms the broad palatal fold. A long, dagger shaped parasphenoid bone is situated towards the posterior end of the palatine. The parasphenoid becomes posteriorly broad and abuts with the basisphenoid and the laterosphenoid. A short pterygoid lies
articulating with the sides of the sphenoid which slants backwards laterally uniting with the broad quadrate.

Ventrally towards the orbital cavity, spreads a thin slender bar called the quadratojugal bar extending laterally in between the maxilla and the quadrate. This bar is made up of the zygomatic process of the maxilla, the jugal and the quadratojugal bones. This slender bar is posteriorly attached to the quadrate on the postero-lateral surface of the quadrate base.

The quadrate is generally well developed with a long orbital, otic and an outer lateral processes. The otic process abuts movably with the periotic and squamosal bones which bear special articulating surfaces. The orbital process slides over the pterygoid antero-dorsally towards the interorbital septum for some distance in the orbital cavity. The outer lateral process of the quadrate (also called the ventral process) has two articulating facets. Posteriorly a small third facet is also observed in some birds. The quadrate articulates with the pterygoid by a small facet present in between the outer lateral process and the orbital process of the quadrate.

The avian mandible is composed of all the five bones bearing obscure identities, viz., a large dentary, a splenial an angular, a surangular and an articular. The surangular is
supplied with a distinct coronoid process in all the birds.

The avian hyoid apparatus consists of three medial segments and a pair of thin curved processes attached posteriorly to the medial element. The anterior most i.e., the first medial segment is the entoglossum which is generally sagitate in shape and forms the bony support for the gengue. The next segment is known as the basihyal. The basihyal in turn is joined to a long and thin bone, the urohyal. The urohyal is partly bony and partly cartilagenous. Each of the lateral processes consists of two rod-like bones which are attached to the lateral surface of the basihyal, the basibranchial and the ceratobranchial.

GALLUS DOMESTICUS (PLATE - VI, Fig. 1,2)

The skull structure of the chick has been figured and described in the past by a number of workers including Parker (1869), Newton and Gadow (1893, 1896), Heilman (1926), Latimer and Rosenbaum (1926), Stressman (1934, 1965), Schinz and Zangeril (1937), Nelson (1942), Bradley (1950), King (1956) Jollie (1957), Buchholz (1957) and Kitoh (1962). Many textbooks on comparative anatomy and poultry science often deal with the gross anatomy of the chick skull. Most of these descriptions are mainly concerned with morphological accounts of the skeletal elements as such and not much information is available on the
Skeletal elements of the skull of the adult chick:

1. Adult male (lateral view)
2. Adult female (lateral view)

ART = articular, DEN = dentary, EX = exoccipital, FR = frontal, INS = interorbital septum, MX = maxilla, NAS = nasal, OR = orbital process of quadrate, OT = otic process of quadrate, P = pterygoid, PAL = palatine, PAR = parietal, PRES = premaxilla, POP = postorbital process of squamosal, Q = quadrate, QJB = quadrato-jugal bar, SQ = squamosal.
functional aspects of the skull and ligaments associated with them. Furthermore, practically very little mention is made of the sex-linked adaptations associated with the skull. The information available on the development of muscular and bony elements is extremely scanty. The present observations are mainly aimed towards the better understanding of the structure of the skull and hyoid apparatus in relation to the various functional requirements and modifications for the attachment and disposition of the muscle complex operating the jaw and tongue.

It is considered desirable to present a brief description of the general structure of the skull of chick before dealing with the individual variations and other aspects studied during the present work.

BRAINCASE

As Bock (1964) has pointed out, the braincase may be considered as the foundation for the entire jaw-apparatus and evinces notable structural modifications for the attachment of the muscles associated with the feeding apparatus. The braincase of the chick is a rigid mass of bony capsule housing the brain. A remarkable feature of the braincase is the association of a large wide tympanic cavity on either side of the posterior end housing the auditory apparatus. The lateral
Skeletal elements of the skull of adult chick:

1. Adult male (dorsal view)

2. Adult male (ventral view)

BAS.OC = basioccipital, BAS.SP = basioccipital, DENT = dentary, EX.OC = exoccipital, FR = frontal, L = lacrimal, MX = maxilla, NAS = nasal, P = pterygoid, PAL = palatine, PAR = parietal, PRE = premaxilla, QJB = quadrato-jugal bar.
sides of the skull are widely separated by a more or less complete interorbital septum. The septum is heavily ossified in chick contributing extra rigidity to the skull and providing "increased support for the enlarged jaws and palate" (Zusi, 1962). The wide and compact fronto-nasal hinge appears as a continuous thin flexible strip of bone with a shallow notch in the middle. This well developed fronto-nasal hinge exhibits the existence of a well developed kinesis in the skull. The lateral surface of the braincase is mainly obliterated by a deep, well distinct temporal fossa and a shallow rudimentary squamosal fossa. The temporal fossa is separated by a depression present on the lateral wall of the parietal known as the suprameatal ridge. Towards the tympanic cavity the squamosal fossa is lined by an elevated crest, the lambdoidal crest. The temporal fossa is separated from the squamosal fossa by a long slender zygomatic process of the squamosal bone. The anterior rim of the temporal fossa is limited by a massive triangular process, the postorbital process of the frontal which unites ventrally with the zygomatic process leaving a deep triangular temporal vacuity. The surface of the postorbital process is crescent-shaped and broad and serves as a plain surface for the attachment of adductor muscles.

The upper rim of the orbit is formed by broad frontals spreading forwards and laterally bearing two well developed
postorbital processes described earlier. The mesethmoid bone exposed dorsally between the anterior tips of both the frontals is comparatively broad and slightly depressed. The perpendicular expansion of the mesethmoid bone (also termed as ethmoid by Bradley, 1950) is stout and heavily ossified forming the anterior part of the interorbital septum.

The lacrimal and ethmoid bones which occupy an antero-dorsal position in the orbit, invite special attention. As pointed out by Cracraft, (1968), it enforces "a vast amount of valuable information on function, variation and taxonomic value of the bird". A large triangular supraorbital process projecting laterally outwards over the orbit towards the lateral level of the frontal is the horizontal head of the lacrimal. The descending process of the former which is moderately developed, traverses ventrally as a narrow pointed cylindrical piece towards the orbital cavity. The squamosal is well developed and covers the lateral side of the braincase. This bone houses the main articular sockets for the quadrate ventrally and a short zygomatic process dorsally. The rostral part of this zygomatic process is flat and broad dorso-ventrally contributing an extra area for the origin of the adductor set of muscles.

The nasal bones are thin and pliable with broad notches anteriorly forming the opening to the nasal chamber.
Skeletal elements of the skull of chicks:

1. Lower jaw (dorsal view)

2. Lower jaw (ventral view)

ANG = angular, ART = articular, ART surf = articular surface, DENT = dentary, INT.Prog = internal process of articular, Med. Face = medial face of articular, Retr.Proc = retroarticular process, Splen = solenial, Surang = surangular.
PLATE VIII

SKELETAL COMPONENTS
The pramaxilla is long and stout spreading backwardly over the nasal cavity, gradually overlapping the anterior end of the mesethmoid and has flat cutting edges. The three processes of the pramaxilla viz., the maxillary, palatine and the frontal are well developed and directed backwards towards the orbital cavity. The maxilla is highly reduced in size and there are two processes - the rod-shaped zygomatic process to the jugal and the broad palatal process towards the palatine. The maxilla is attached to the quadratojugal bar which is made up of a jugal and a quadrato-jugal element. The jugal is small and splint-like whereas the quadrato-jugal is thin and flattened laterally giving more space for the passage of the adductor set of muscles. The quadrato-jugal forms the posterior part of the bar articulating with the quadrato base laterally.

The quadrato is a stout, strong and 'Y'-shaped bone which is more or less disposed vertically on the cranium. The quadrato possesses two well distinct processes dorsally, the anterior orbital and the posterior otic. The otic process and the posterior rim of the quadrato base are smooth and depressed dorso-ventrally providing a wider surface for the origin of the adductor mandibulae posterior muscle. The orbital process and the anterior side of the quadrato base
together contribute to form a triangular elevated surface for the origin of the retractor muscle. The broad massive base of the quadrate bears three well developed articulating condyles, the anterior, the median and the posterior, for the articulation of the quadrate with the dentary. The median condyle is more predominant among its fellows and is separated by a deep groove from the posterior and a shallow depression from the anterior condyles.

The lower jaw is highly modified in structure as it "serves as a point of attachment for most of the jaw muscles and most of the jaw ligaments" (Bock, 1964). The mandible appears more or less as a single piece because of the early embryonic fusion of the various components. The mandible towards the posterior half is perforated by a characteristic mandibular foramen which is narrow and compact. The anterior end of the mandible bears sharp cutting edges coinciding with the dorsal jaw while the posterior half is variously modified for the attachment of the muscles and ligaments operating them.

The dentary, the largest element of the lower jaw, is broad and flat anteriorly fusing firmly with its fellow from the other side forming the symphysial. A trigangular groove extends along the entire inner surface of the dentary and traverses posteriorly towards the quadrate. The splenial is
thin and plate-like extending internally covering much of the inner aspect of the mandible. The broad aurangular contributes almost to the posterior third or more of the upper border of the mandible. It is supplied with a rudimentary spine dorsally towards the distal end over which the adductor muscles get attached. Laterally, the aurangular bears a triangular depression over which the adductor mandibulae externus gets attached. The articular is well developed and broad covering the entire articulating area of the quadrates. A broad stout upturned retro-articular process is present on the articular towards the inner side which tapers distally. The angular is slender and strip-like possessing a long, narrow, tapering retroarticular process. The articular and the angular together bulge dorso-ventrally giving more area for the attachment of the retractor muscles.

PALATE

The palate of the chick invites special attention since the arrangement and disposition of the various bony constituents have significant role in the cranial kinesis. Moreover it serves as an area for the origin of several retractor muscles and ligaments. The main function of the palate is the transmission of the force and direction of the movement of the muscles of the upper jaw. In chick the palate is of schizognathus type with an extensive cleft towards the
middle line which is confluent with the internal nares. The palate as the main functional unit, consists of several individual bones which are all well developed. The quadrate articulates with the flat, broad, obliquely placed pterygoid. The pterygoid is strong and highly ossified bone which gets articulated with the palatine anteriorly. It is dorso-ventrally flattened and slightly clefted towards its articulation with the palatine. The pterygoid is drawn into extensive convex elevations for the attachment of the internus muscle. The palatine is a long and flat bone which bounds the posterior aperture of the nasal chamber. Anteriorly they unite with the maxilla and posteriorly with the pterygoid. Both the palatines meet along the mid-ventral line. Each of these is expanded into flat wings. It is highly pliable and spears sliding along the base of the interorbital septum, giving a greater flexibility for the kinetic movements of the upper jaw. The palatal wings are well raised and obliquely placed. The palatine is broad and flat towards its articulation with the pterygoid. At this area the palatine is supplied with an articular facet which corresponds with its fellow of the pterygoid. The lateral edges are flat and slightly grooved giving extra area for the attachment of the retractor set of muscles. The vomer is slender, small and spreads internally within the nasal chamber. It is partly bony and partly cartilagenous in nature.
HYOID APPARATUS (PLATE - IX)

The gross anatomy of the hyoid apparatus of the chick has been described in the past by Bradley (1950), Jollie (1957) and Stettenheim (1965). The complex elements of the hyoid apparatus are significantly important since they form the main springboards for the attachments of various lingual muscles. The hyoid apparatus in the chick is simple in form and the bony elements are long and highly ossified. It spreads more or less in the middle plane in comparison with what is observed in other birds. The anterior most element is the broad lanceolate entoglossum forming the main bony support for the tongue. It is dorsally-ventrally flattened and bears a cartilagenous paraglossal element. The paraglossa of both the sides fuse together anteriorly leaving a narrow medial space at its distal end. The basihyal is long, stout and highly ossified. Its lateral surface bears two shallow grooves which are separated by a common raised median ridge. The basihyal becomes considerably broad towards the distal end where it articulates with the posterior element of the hyoid apparatus. These articulating surfaces are in the form of three condyles, two lateral for the attachment of the cornue and a medial one for the attachment of the urohyal. The urohyal which lies immediately behind the basihyal is flat and stout and movably articulated with the former.
Hyoid apparatus of the adult chick

1. Dorsal view
2. Ventral view

BAS.HY = basihyal, CERAT.BR = ceratobranchial,
ENT.GL = entoglossum, PARA.GL = paraglossum,
URO.HY = urohyal.
Each of the cornue of the hyoid apparatus is made up of three elements, viz., an anterior hypobranchial, a median ceratobranchial and a posterior epibranchial. The hypobranchial is the largest among the fellows and is more ossified. It is flat dorso-ventrally. The ceratobranchial is long and rod-shaped and comparatively poorly ossified. The epibranchial is the smallest element of the cornue and is mostly cartilagenous in nature. It bears long cartilagenous extension posteriorly turning upwards towards the cranium.

ARTHROLOGY OF THE QUADRAT-ARTICULAR JOINT

A detailed observation of the quadrate-articular joint is desirable since it is directly connected with the movements of the beak and the skull. The mobility of the various functional components of the palate, viz., the quadrate, the pterygoid, the palatine, etc., are mainly dependent on this "complex sliding rotational hinge" (Bock, 1964). Valuable accounts on the significance of the quadrate-articular joint in various birds are available from the works of Zusi (1962, 1967), Bock (1964), Malhotra (1967), Mansuri (1969), etc.

Zusi (1967) published excellent observations on the role of the quadrate-articular hinge in the cranial kinesis of Gallus domesticus in general. As described earlier, the broad quadrate base possesses three articulating condyles, viz., an
anterior, a median and a posterior, all prominently elevated with shallow depressions in between them. The median condyle is considerably broad and elevated. It is separated from the moderately developed posterior condyle by a deep and prominent depression. As Zusi (1967) describes this median condyle "slides along the well defined medial face of the broad flattened articular surface" providing guidance to the movements of the jaw.

The articular bears four articulating surfaces and three facets on its posterior surface. As described by Bock (1964) they are the external, retroarticular, internal and the pseudotemporal processes. The retroarticular and the internal processes are long and well developed. The external process appears as a short raised bony ridge on the lateral side of the articular. The pseudotemporal process is short and poorly developed. The median condyle of the quadrate abuts against the broad, shallow depression situated between the external and the retroarticular processes. The anterior and posterior condyles of the quadrate abut against the concave margin of the retroarticular and internal processes. This arrangement of the condyles of the quadrate embracing the mandibular facets prevents a sideward and backward displacement of the mandible during gaping actions.
SECONDARY ARTICULATION OF THE MANDIBLE

As Bock (1960) has emphasised, in most of the birds there exists a secondary support to the mandible other than the quadrate-articular hinge serving as an additional brace for the mandible when the jaws are open. The internal processes of the articular element of the mandible are elongated and well developed for the attachment of the strong jaw muscles. As further described by the same author, "the selective force may have played over those processes and it has become considerably long that it rubs against the base of the skull as the bill is opened and closed".

Bock (1960) has also given a comprehensive account of the existence of a secondary articulation in the family of chicks. The present observations have also revealed the occurrence of the abovementioned articulation in the mandible. The internal process of the articular is broad and long and abuts against the body of the basi-temporal plate when the mandible is moved. This articulation prevents a backward displacement of the lower jaw during the wide gaping operations.

KINESIS OF THE UPPER BEAK

The visible dorso-ventral movement of the upper jaw on the cranium is described as the kinesis in birds (Goodman and Fisher, 1962). According to Bock (1964) it denotes the
dorso-ventral movement of the entire or part of the upper jaw relative to the braincase. This movable hinge of the upper bill adds to the versatility of the beak as an efficient tool for the food capture. As Beecher (1962) has pointed out, this "was a major adaptation as important to the whole class of aves as the origin of flight". Furthermore "the basic structures of the facial and palatal portions of the skull are understandable only in terms of the kinetic properties of the skull" (Zusi 1969).

Kinesis of birds was known to ornithologists ever since the earliest observations of Herissant (1752), and Nitzsch (1817). Considerable work has been done on the kinesis of different birds and the works of Davids (1952), Goodman and Fisher (1962), Zusi (1962, 1967), Beecher (1962) and Bock (1964).

The skull of chick is mesokinetic and prokinetic. The quadrate forms the key points for all the movements of the jaw. When the mandible is depressed, a considerable thrust is exerted on the mandibular attachments pushing it away from the articulation. But this forward movement is prevented by the inextensible postorbital ligament which keeps the articulation tight towards the cranium. This operation results in the mandibular attachment to a fulcrum, of the
lever system. The depressor muscle provides the effective force to the system. The distance from the attachment of the depressor muscle to the postorbital ligament is the work arm. This lever system exerts a force along the ventral plane. The quadrate swings forwards at its squamosal articulation effecting a considerable thrust on the quadrato-jugal as well as the pterygoid. The thrust asserted on the quadrato-jugal bar results in the forward movement of the bar which in turn pushes the maxilla and the nasal bones upward. On the other hand the pterygoid pushed by the forward movement of the quadrate slides over the basi-sphenoid rostrum and strikes the choanal folds of the palatine. The forward movement of the palatine initiates an upward movement of the upper beak on the fronto-nasal hinge, the latter providing an ideal pivot for the kinetic movement. Under the pressure the frontonasal hinge acts as a spring, forcing the upper jaw downward along the palatine and the quadrate back to its original position.

During the present work attempts were also carried out to measure the quantitative kinetic properties of the skull during various periods of development and the results obtained are tabulated as follows:

### TABLE 1. KINESIS OF THE UPPER BEAK

<table>
<thead>
<tr>
<th>AGE OF THE BIRD</th>
<th>NUMBER OF BIRDS STUDIED</th>
<th>APPROXIMATE ARC TRAVERSED BY THE UPPER BEAK (DEGREE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 DAY OLD</td>
<td>12</td>
<td>3°</td>
</tr>
<tr>
<td>10 DAY OLD</td>
<td>12</td>
<td>7°</td>
</tr>
<tr>
<td>20 DAY OLD</td>
<td>12</td>
<td>10°</td>
</tr>
<tr>
<td>30 DAY OLD</td>
<td>12</td>
<td>15°</td>
</tr>
<tr>
<td>40 DAY OLD</td>
<td>12</td>
<td>16°</td>
</tr>
<tr>
<td>60 DAY OLD</td>
<td>12</td>
<td>18°</td>
</tr>
<tr>
<td>100 DAY OLD</td>
<td>12</td>
<td>20°</td>
</tr>
<tr>
<td>120 DAY OLD</td>
<td>12</td>
<td>21°</td>
</tr>
<tr>
<td>ADULT MALE</td>
<td>12</td>
<td>24°</td>
</tr>
<tr>
<td>ADULT FEMALE</td>
<td>12</td>
<td>22°</td>
</tr>
</tbody>
</table>

The table reveals a progressive increase of the kinesis of the upper beak during the postnatal growth. At 10 day EX OVO a remarkable increase (about double) in the kinetic property was observed. On the other hand the kinetic value showed by and large a steady increase during later periods of growth and senility. The kinetic value obtained for the male is slightly higher than that of the female bird.
LIGAMENTS OF THE SKULL (PLATE - X)

A number of ligaments are associated with the jaw articulation and other parts of the jaw apparatus forming an integral part of the kinetic mechanism of the skull. The various ligaments supporting the lower jaw of birds have been studied in the past by several workers including Hofer (1951), Davids (1952), Goodman and Fisher (1962), Bock (1964), Malhotra (1967), Mansuri (1969), Stark (1940) has described the collagenous fibre properties of the ligaments while Davids (1952), Bock (1964), and Zusi (1967) stressed mainly on the role played by these ligaments in the maintenance of the quadrato-mandibular articulation and the cranial kinesis. However, the ligaments of the chick have not been studied fully so far and the present attempt was made to understand the functional significance of the important ligaments associated with the jaw articulation and the kinetic movements of the upper jaw.

Post-orbital ligament

This is a long, broad, strap-like ligament observed spreading from the lower extremity of the post-orbital process of the frontal to the external process of the articular slightly anterior to the quadrate-articular joint. The ventral part of the ligament remains partly enveloped by
Ligaments of the skull:

1. 1 day **EX OVO**
2. 10 day **EX OVO**
3. 30 day **EX OVO**
4. 60 day **EX OVO**
5. Adult male.

**EJML =** external jugomandibular ligament,
**LAC.L =** lacrimalojugal ligament, **OML =** occipito-mandibular ligament, **POL =** postorbital ligament.
PLATE X

CRANIAL LIGAMENTS
the external jugomandibular ligament. This ligament maintains the upward tension of the articular on its articulation with the quadrate and provides a strong fulcrum for the mandible. As Zusi (1969) points out these ligaments in chick "serve to coordinate motions of both the jaws during depression of the lower jaw".

**The external jugomandibular ligament:**

This is a long, narrow, ribbon-shaped ligament whose one end is attached to the posterior end of the quadratojugal bar and the other end to the outer border of the articular. The ligament is comparatively narrow and stout anteriorly while broad and thin at its posterior end towards its articulation with the quadrato-jugal. This ligament prevents the forward displacement of the mandible and maintains a strong upward tug on the depressed mandible.

**Occipitomandibular ligament:**

This is a large, well developed ligament extending in between the posterior margin of the auditory capsule and the posterior process of the articular. The ligament is narrow and stout at its cranial articulation while broad and sheet-like at the mandibular attachment. This ligament maintains an upward tension on the mandible when it is adducted. The ligament also helps in keeping the quadrate-articular joint tight towards the cranium.
Lagrimo-jugal ligament

This is a thin, long and strap-like ligament which is attached dorsally to the medial surface of the lacrimal and ventrally to the jugal. The ligament is stout and compact towards the lacrimal end while broad and transparent at its articulation with the jugal. As stated by Cracraft (1968) "lacrimojugal ligament serves as a protractor stop by preventing the jugals from moving too forward during protraction".

MECHANICAL ADVANTAGE

The orbital process of the quadrate sets in motion a number of remarkable chain of movements in the skull. When the retractor muscle which is attached to the orbital process of the quadrate contracts, the latter works as a first class lever at its squamosal hinge. The orbital process works as the work arm, the squamosal hinge forming the fulcrum. The body of the quadrate from this hinge to its attachment with the articular forms the resistance arm. Contraction of the retractor muscle pulls the quadrate backward on its cranial articulation making it a first class lever. The drag thus exerted on the quadrato-jugal bar draws the bill downward on its fronto-nasal hinge. The bill functions as a third class lever, the length of the bill from the fronto-nasal hinge to its tip forming the resistance arm while the effort