It is an established fact that, in beginning of their story, all the birds subsisted on animal diet and the earlier birds probably were unselective carnivores (Weller, 1969). During the Tertiary period, with the prey species multiplying at a staggering rate, the earlier unselective carnivorous birds took over to specific hunting habits. In due course of evolution, genetic variations fixed under selection pressure gradually resulted in a multiplicity of wing shape, beak form and foot in the form of adaptations well suited for the specific feeding behaviour. Some of the present day birds have undergone very little change from their tertiary progenitors and, as birds of prey, possess a short hooked tearing beak and large raptorial toes, each ending in a hooked claw. The four birds investigated here, share all these characters as well as a number of interesting structural peculiarities. None the less, these birds, belonging to different genera and known for their different feeding behaviour, have also developed a variety of organization characteristic of the particular species. It would therefore, be interesting to examine the various structural patterns discovered during the present investigation and find out how far the feeding apparatus of
these birds serves as an efficient tool in the collection and ingestion of the particular diet.

THE EPIDERMAL STRUCTURES

a) Jaw Apparatus:

As stated earlier, the culmen is highly arched and it continues anteriorly as a strongly pointed and a hooked nail. The nail, in this position, can strike the prey almost vertically and as a highly pointed structure, it provides the bird with a powerful piercing organ. Piercing is soon followed by tearing operations. The hook of the nail is helpful in holding flesh during tearing. The maxillary tomia with their sharp edges help in tearing flesh to small pieces. The pointed nail and the sharp tomia seem to be characteristic structures of the predatory birds which tear flesh of their victim. The presence of such structures has also been noted in the Shrike (order: Passeriformes) by Malhotra (1967). The mandibular tomia are sharp toward their anterior part and blunt posteriorly. The sharp edges help in applying high pressure on the food during biting. Both the tomia are highly vascular. Zusi (1962) has noted a high vascularity in the beak structures of Rynchops nigra. He states that such a high blood supply facilitates the replacement of the parts worn out during skimming. The lateral grooves observed along the maxillary tomia serve to accommodate the corresponding mandibular tomia.
when the bill is closed and thereby provide for a firm grip over the prey.

In the Kestrel, the maxillary tomium bears a pointed denticle and a corresponding notch is present on the mandibular tomium. Such a notched bill ensures a firm grip over the neck of the victim and crack it. Grossman et al., (1965) have described a notched bill in some other falcons which are known to use their bill in cracking the neck of their prey.

The presence of posteriorly directed spines on the palate is a common feature of all the birds studied here. In male Shikra, they are more abundantly represented. It may be stated here that insects form a major part of the diet of this bird. Quite often, an entire insect is gulped and an abundance of spines serves as a useful device in preventing the escape of the insect.

The tongue is highly protrusible and roughly rectangular to lanceolate in shape. The epidermal pads are very thick. Toward its posterior side, the tongue bears a row of spines of which the outer most on either side is very big and thick. These outer spines form a well developed postero-lateral appendage of the tongue. The protrusible tongue with a well developed postero-lateral appendage facilitates swallowing of large pieces of flesh.
b) **Foot:**

The carnivorous animals are also subjected to an attack by their own victim. A snake, a lizard or any sharp-clawed mammal is likely to inflict a heavy injury to the predator. It would therefore serve as an advantage if it is provided with a suitable protective device against such attacks. Thick scutes are known to provide such a protection. It is significant to note that the epidermal covering of the feet is highly scutellate. A thick scutellate covering, forming plates, has been described in the secretary birds by Grossman et al., (1965). Well developed are formed by thick epidermal pads and absorb the mechanical shock which arises from the impact of the fast diving bird with a prey, thus, protecting the skeletal and other elements of the legs from the hazards arising out of striking of the bird with the prey. Further, the denticles, which are present on the bumps, provide a rough surface and thereby ensure a firm grip over the object. The hooked claws form the main weapon to paralyse the prey.

**BONY COMPONENTS**

A. **Skull:**

The skull of all the birds studied here is bulbous with a wide and high cranium. The temporal depression is, however,
shallow resulting in the reduction of the area for muscle attachments. But this loss is compensated by a greater width of the cranium. Fisher (1944) made similar observations in the skull of vultures and Goodman & Fisher (1962) also noted this feature in merganser which feeds on fishes. Besides, a wide cranium would facilitate for the development of large pharyngeal cavity. This confers an advantage in swallowing large pices of flesh. Goodman & Fisher (1962) have also pointed out a correlation between a wide cranium and swallowing of large fishes which form the main diet of merganser. As mentioned earlier, the surface of the cranium provides the area for the muscle attachment. Higher the cranium, the larger is the area available for the attachment of the neck muscles. This has resulted in the shifting of the foramen magnum toward the ventral side of the cranium. The surface of the cranium is thus much larger providing a great surface area for the attachment of the neck muscles. This arrangement has resulted in the increased mobility of the head about its pivot on the atlas. A high mobility of the head and more dorsal attachment of the neck muscles on the head, facilitate application of a strong dorsal pull in tearing operations. The width of the supraorbital isthmus shows a narrow range of variations and the ratio of this width to the cranial length varies from a minimum of 25.26% in the Shikra to a maximum of 30.12% in the Kestrel. As a result of the presence of the broad isthmus, the eyes shift more toward the lateral side enabling the predator to scan out a
wide hunting ground.

A broad fronto-nasal hinge adds to the strength of the beak. All the birds studied here have a broad hinge. The breadth of the hinge is especially noteworthy in the Laggar Falcon which hunts animals of a large size. A wide fronto-nasal hinge is also a characteristic of woodpeckers which pound heavily on the treetrunk (Richardson, 1942).

In all the four birds, the lacrimals are well developed and their descending processes meet the jugal bar almost vertically. This arrangement prevents an upward deflection of the jugal strut when a hard diet is being cut (Cracraft, 1968). Moreover, the lacrimals medially extend upto the ectethmoid forming a lacrimal-ectethmoid complex. This complex keeps, within safe limits, the protractory movements of the upper beak.

Earlier, while dealing with the epidermal structures of the Kestrel, a mention was made of the presence of the mandibular tooth. It may be added here that a corresponding projection of the premaxilla supports this tooth.

The pterygoids are long and the palatines are considerably broad toward their posterior end. An increase in the length of both these elements provides a large area for the attachment of the retractor muscles the significance of which will be discussed later.
The quadrate is more or less similar in all these birds and the orbital process is considerably long. The role of this process will be discussed while dealing with the mechanical advantage of the beak. It may, however, be mentioned here that, unlike in most other birds, the quadrate is placed obliquely. Such a position of the quadrate restricts an anterior swing of this bone and decreases the forward vector of force.

Disposition of the protractor muscle in these birds is such that by its contraction, the quadrate rotates medially and as a result, a forward rotational force of the quadrate is transmitted to the upper beak through the jugal strut. (Moller, 1931; Krip, 1933). The jugal strut is thick and suited to withstand a strong compression force.

The lower mandible is laterally compressed and the mandibular foramen is completely obliterated. The height of the mandible increases the strength of the ramus and provides a large area for the attachment of the adductor muscles. Further, the mandible is short and as will be seen later, this shortness contributes to increase the effective force applied at the bill tip. The interarticular process of the articular bone is long and it forms the secondary articulation of the lower jaw.

The postorbital ligament maintains a constant upward pull on the lower mandible keeping the quadrate-mandible articulation
intact. During the present study, it was observed that the removal of this ligament resulted in the increase of the angel of protraction and thereby, the kinesis.

B. Cervical Vertebrae:

All the sections of the cervical vertebrae show dorsal flexion, whereas, only the first and the second sections show downward flexion. The dorsal process of the vertebrae show an enormous development providing a large area for the attachment of the dorsal flexors of the head and the neck. In tearing operations, the dorsal flexors of the neck play an important role and the neck vertebrae are well suited to provide the surface for the attachment of these muscles.

When the neck is flexed upward, the neural arches are subjected to compression stress and the centra, to the tensile stress. On the contrary, the centra are subjected to the compression stress and the neural arches, to the tensile stress, when the neck flexes downward (Rockwell et al., 1932). However, since the second section does not show downward flexion, the neural arches in this section are subjected to the least tensile stress. Thick ligaments between the adjacent vertebrae help to nullify these stresses. It is noteworthy that the ligaments, which connect the neural
arches of the neighbouring vertebrae and also those which connect the centra of these vertebrae, are thick and broad. The ligaments, being inextensible and flexible, allow movements between the articulating surfaces and at the same time prevent movements of various parts beyond a critical point.

C. **Bones of the Hind Limbs:**

All the bones of the hind limbs are sturdy and the tarsus is short and broad. In the Kestrel and in the Laggar Falcon, the tarsus is even shorter than the femur. Further, the keellike hypotarsus in the former bird, gives an additional rigidity to this element. Thus, the bones of the hind limbs are well suited to withstand the impact of the forceful striking of the predator with a prey.

As seen from the tables 18, 20, 22, 24, the percent ratios obtained for the length of all the toes to the tarsus \( l \) are the highest in the Kestrel and the female Shikra. As mentioned earlier, these predators even hunt birds of their own size, and long toes would confer an advantage in ensuring a firm grip over the prey. On the other hand, these ratios are low in the Laggar Falcon. This bird depends more on the rodents for its diet. Obviously, small size of the toes of the Laggar Falcon are capable enough to grip these
animals. Further, the ratios of the absolute length to the functional length of the digits were the highest in the Laggar Falcon indicating the sturdiness and flexibility of the toes. This enables the bird to withstand an impact of the force when the bird strikes the prey on the ground.

The terminal phalanx of all the digits is hooklike and forms a support for the hooked claw. The ventral tubercle is prominent on the ventral side of the proximal end of the terminal phalanx. This tubercle provides the seat for the attachment of the tendons of the flexor muscles. Besides, it increases the leverage of the terminal phalanx making the toe an efficient raptorial tool.

MUSCLES OF THE FEEDING APPARATUS

A. Jaw Muscles:

The feeding behaviour of these birds involves an active participation of the talons. Consequently, the prey is firmly clenched by strongly flexed toes. The jaw muscles are generally brought into operation only after the food is held by the raptorial toes. An important role of the jaw muscles is to accomplish the task of thrusting the hooked beak into the body of the prey and holding a part of flesh firmly and then tear it to pieces. Since the prey is held firm by the toes, quickness in feeding assumes secondary importance. The tearing of flesh requires strong actions of
the jaws. In tearing operations, a strong upward pull is exerted on the upper beak by flesh. To nullify the effect of the external force and avoid danger of breaking the beak at the frontonasal hinge, the strong retractors are required to maintain the kinetic movements of the upper beak to the minimum. Therefore, the retractive action becomes one of the major functions of the jaw muscles and conversely, since the food is partly responsible for the protraction of the upper jaw, the avoidance of the protractory movements or keeping the movements to the minimum, becomes an asset.

(i) Abduction of the lower jaw:

For all practical purposes, the M. depressor mandibulae is the abductor of the lower jaw. In a majority of birds, opening of the beak is a simple function brought about by contraction of the M. depressor mandibulae. The predatory birds studied are no exception and this muscle shows a moderate development with a mainly fleshy and weak pinnate structure.

(ii) Adduction of the lower jaw:

The main adductors of the lower jaw are attached to the lateral wall of the cranium on one hand and to the
lower jaw on the other. Development of the M.A.M. externus shows a great deal of variations among the different members of the avifauna. This difference reflects upon the specific feeding behaviour of the bird concerned. While working on the feeding behaviour of Rynchops nigra, Zusi (1962) noted that the M.A.M. externus series showed a hypertrophy and he correlated it with the skimming habit of the bird. On the other hand, birds such as the Green Bee-easter and the Jungle Babler, which thrive on a soft diet mostly in form of insects, possess weak muscles adapted for quick action (Dubale, 1968). A poor development of this series of muscles, in the Blue-Rock-Pigeon and in the House Swift, is also correlated by the same author, with the fact that these birds simply pick up an object and gulp it. Goodman & Fisher (1962) also have reported a poor development of the adductors in the strainers, viz., Mallard and Muscovy duck, which feed on plankton from aquatic habitats.

The M.A.M. externus shows a complex multipinnate fiber arrangement and the seat of origin covers the entire temporal region of the skull. Further, all the slips of the muscle share their tendinous structures with one another. The M.A.M. externus is, therefore, suited for slow but strong actions to provide a firm grip over the prey.
Of the adductor series of muscles, the M.A.M. medius shows little variations in its structure and disposition in majority of birds. In all the predatory birds studied here, the muscle shows a simple structure with a weakly pinnate fiber arrangement. This muscle assists the externus series of the adductor muscles in lifting the lower mandible.

The M.A.M. posterior and the M. pseudotemporalis play a dual role. On one hand, these muscles assist the main adductors and on the other hand, they also serve to retract the upper beak. These muscles are mainly fleshy and weakly pinnate.

(iii) Retraction of the upper beak:

As has been already noticed, the food is often quite hard. In piercing operation, the nail of the upper beak is thrust into the body of the prey and for this, the beak has to exert a great pressure. Besides, during tearing operations, flesh of the cadaver creates a considerable upward force on the upper beak. To establish a stability of the upper beak against the external force, a powerful retractor is inevitable for these birds. The main retractor muscle in these animals is M.A.M. internus. This muscle is composed of three slips, viz., the M.A.M. internus ventralis anterior, the M.A.M. internus ventralis
posterior and the M.A.M. internus dorsalis. Of these, the first two slips show enormous development with a highly multipinnate fiber arrangement. The tendons of insertion are considerably thick and broad to provide a large area for the attachment of the muscle fibers. All the slips of the internus muscle are provided with a complicated type of fiber arrangement and the tendons add to the tenacity of the muscle. Being tendinous, no doubt, the action is slow but is strong enough to bring about retractive movement of the upper beak.

(iv) Protraction of the upper beak:

The M. spheno-pterygo-quadratus functions as the protractor of the upper beak. It is poorly developed and the muscle fibers show a parallel arrangement. Thus, the avoidance of the protractory movement of the upper beak is reflected in the poor development of this muscle.

Muscles of the Tongue:

Unlike in mammals, where the tongue plays a significant role in food manipulation, in birds, it generally plays a minor role in directing the food material toward the glottis. The movements of the tongue are much restricted and consequently, muscles of the tongue show a simple
structure. However, for the sake of mentioning, it may be added here that the tongue which plays a special role has been discussed in parrots by Mudge (1903), in New Zealand birds by McCann (1963, 1964) and in humming birds by Weymouth et al., (1964). In majority of birds, the tongue muscles are mostly fleshy or weakly pinnate. In the predatory birds also, the pattern is more or less similar, except a few modifications.

The tongue is highly protrusible to facilitate gulping of large pieces of flesh, and the extensor of the tongue, namely, the M. branchiomandibularis, shows a massive structure with a parallel type of fiber. Withdrawal of the tongue is affected by combined action of the M. gularis anterior, the M. sternohyoideus, the M. cricohyoideus and the M. thyroglossus. Of all these, the M. gularis anterior possesses a strong tendon of insertion and functions as the main retractor of the tongue.

B. Cervical Muscles:

As has been noted earlier, the birds studied here are predators which feed primarily by breaking or by piercing the beak through the body of the prey and tear its flesh. Piering of the beak through the body of the cadaver, and holding the food tightly and tearing the flesh to pieces,
are primarily brought about by the actions of the jaw muscles and their role has already been discussed in details. For efficient operation of the jaw apparatus, co-ordinated movements of the head are absolutely essential. These movements of the head on the atlas are mainly in the vertical plane and to a certain extent rotational. When the prey offers resistance, on account of its counter attack, the predator gives strong jerks by violent sideward movements of the head. These movements of the head are brought about primarily by the neck muscles which enable the head to carry out various functions such as piercing, tearing, etc., as a part of the feeding operation. The flexible intervertebral articulations further contribute to the mobility of the head.

A downward flexion of the neck and the head, is essential to reach the food held by the toes. The ventral set of muscles of the neck is employed in the movement. Of these, the M. flexor colli ventralis which extends ventrally from 17 through 3 plays a major role here. By its contraction, the muscle flexes down both the first and the third sections of the neck. Besides, it also lowers the sections I, II, and III on the sections II, III and the thoracic region respectively. Long hypapophyses of 16 and 17 increase the angle of attachment of the muscle bellies going to the anterior vertebrae and thus enable the muscle to exert a greater force.
In the kite which relishes food even while soaring, a downward flexion of the neck has to be brought about against the wind action. A strong muscle, therefore, required to overcome the wind action and flex the neck down. In this bird, the bellies of the M. flexor colli ventralis are relatively well developed with massive slips and thick tendons than in other three birds.

When the downward flexion of the neck is at maximum, the head reaches the food which is held firm by the toes. The hook of the beak is then thrust into the body of the prey by a sudden contraction of the ventral cranio-cervical muscles, viz., the M. rectus capitis ventralis. It may be noted here that the M. rectus capitis ventralis is a massive muscle formed of two parts. The tendon of origin provides a large area for the attachment of the muscles fibers. These structures enable the bird to thrust the beak into the body of the prey. Besides, the action of this muscle is further supplemented by that of the M. flexor colli profundus. The latter muscles shows a pinnate type of fiber arrangement. Both these muscles together lower the head and also flex down the first section of the neck to bring about the thrusting of the beak into the body of the victim. If the prey offers a counter attack or is struggling hard to escape, a heavy injury is further inflicted by the violent sideward movements of the head. To make the prey
ineffectual, quite often, these movements are carried out for a long duration. The M. splenius capitis, the M. rectus capitis superior and the M. rectus capitis lateralis play a major role in bringing about these actions. The muscles exhibit a pinnate type of fiber arrangement with thick tendons at either end. Further, the M. splenius capitis shows enormous development and anteriorly it attaches on the most of the occipital region above the foramen magnum. The insertion of this muscle extends upto the origin of M. depressor mandibulae. The M. rectus capitis superior has a strong tendinous attachment on the cranium. The action of these muscles is further strengthened by the action of the M. rectus capitis lateralis. The muscle has a fleshy insertion on the cranium and extends dorsally upto the insertion of the M. complexus. Such a disposition of the muscle is thus suited to bring about an efficient rotational and the sideward movement of the head. By its contraction, the M. intertransversarii also brings about lateral movement of the neck and assists the above mentioned muscles. These muscles show a multipinnate type of fiber arrangement as an adaptation to exert a strong action for loosenimg the body parts of the cadaver.

The antagonistic muscles which are primarily concerned with the raising of the head and of the neck, play an important role during feeding. It is a common knowledge
that flesh of the victim offers a great resistance before
torn to pieces and tearing of flesh requires a powerful
action of the muscles. The muscles of the dorsal set are
the M. complexus, the M. biventer cervicis, the M. splenius
capitis, the M. spinalis cervicis, the M. splenius colli
and the M. ascendentes cervicis. Of these, except the
M. biventer cervicis, all the muscles possess more than one
slip and have tendons at one or both the ends. A great
number of slips increases the resultant force of these muscles
to enable the bird, with enough strength, to tear flesh of its
victim. The M. complexus, the M. biventer cervicis and the
M. splenius capitis directly operate the head and raise it
on the first section. The M. spinalis cervicis, the
M. splenius colli and the M. ascendentes cervis on the other
hand operate the neck and indirectly assist the former
muscles to bring about dorsal, lateral and rotational
movements of the head. The M. spinalis cervicis flexes the
neck dorsally and M. biventer cervicis raises the head and
at the same time flexes the neck dorsally. Combined actions
of both of these muscles bring about a strong dorsal
flexion of the neck to facilitate tearing of flesh. Thick
tendons and massive bellies of these muscles in the kite
enable the bird to flex the neck dorsally against the wind
action especially when the bird tears flesh while soaring.
Zusi (1962) has also reported thick tendinous structures and massive bellies of the muscles of the dorsal set in Rynchops nigra which maintains its neck straight against the water currents while skimming.

C. Muscles Operating the Digits:

It is a common knowledge that the raptorial toes serve as the deadly weapons to the birds of prey in attacking their victims. To bring the victim under a firm grip, the digits are required to be extended to their full capacity. The main extensor muscles which bring about this action are the M. extensor digitorum longus and the M. extensor hallucis longus. They are quite massive and exhibit a pinnate fiber arrangement. Further, both these muscles are provided with long tendons of insertion. These tendons are attached on the anterior sides of the phalanges of all the digits.

The flexion of the digits forms an important function in providing a firm grip over the prey. A flexion of the digits is accomplished by the contraction of the M. flexor digitorum longus, and the other flexors going to the individual digits. All these muscles are extremely well developed and exhibit a pinnate type of fiber arrangement. Each of the muscles possesses a strong tendon of insertion. Besides, the presence of the vinculum between the tendon of
the M. flexor hallucis longus and that of the M. flexor digitorum longus, establishes a co-ordination in the movements of the digits. Contraction of any one of these muscles results in the flexion of all the digits and that of both these muscles at a time, further, increases the firmness of the grip over a prey.

OPERATIVE EFFICIENCY OF THE FEEDING APPARATUS

1) Kinesis:

As has already been stated, all these birds tear flesh of their victim and in tearing action, the flesh of the victim exerts a strong upward force on the upper beak. Under these circumstances, a great kinetic angle would be a disadvantage to these predators. It may be interesting to mention here that the angle of kinesis is small in these birds and it ranges from a minimum of $10^\circ$ in the kite to a maximum of $15^\circ$ in the Kestrel. In the Shikra, it is intermediate ($13^\circ$). A slightly higher angle of kinesis of the upper beak in the Kestrel is an advantage since it facilitates a wide opening of the beak to ensure a proper grip over the neck of the victim. Birds such as parrots, which rotate fruits between their bill arms, have a high kinetic angle. Beak of the parrot (Psittacula) is capable exerting a high force to break open hard pericarp of fruits.
(Dubale & Rawal, 1965). In both the above birds, the beak is strengthened by a broad fronto-nasal hinge.

ii) **Levers of the Feeding Apparatus and the Quantitative Myology:**

The lower mandible, the quadrate, the upper beak and the pelvic girdle form important levers of the feeding apparatus. The mass and fiber arrangement of the muscle no doubt play an important role in determining the potential force of the muscle. None the less, the structural peculiarities and the biochemical properties of the components of the lever are also equally important factors which finally contribute to its mechanical advantage.

During adduction, the lower mandible works as a third-class-lever and during abduction, as a first-class lever. As stated earlier, the fibers and various slips of the jaw muscles of the birds studied here show a similar pattern. It may be mentioned here that these animals are primarily predators, with different diet, strength of muscles, which are called upon to operate the bill, also varies. Birds which break or pierce the beak through the body of the prey, require adductors and retractor. As the prey is generally held under the firm grip of the toes, a great force of the associated muscles is more important rather than speed of their action.
The Kestrel which cracks the neck of its victim, has a total effective force of adduction 0.0755 gm. The Laggar Falcon and the kite which thrust their beak into the body of the prey possess a higher total effective force of adduction viz., 0.1013 gm and 0.884 gm respectively. On the other hand, the Shikra which feeds largely on insects, does not require powerful adductors and the total effective force of these muscles is much reduced, being as low as 0.0353 gm (Table 33). Goodman & Fisher (1962) have correlated large total effective force in grazers which feed on hard plant matter. These authors have also reported the least potential ability to adduct the lower jaw in a shoveler which strains plankton from the water.

In these and many other birds in general, abduction of the lower mandible is a simple action, not involving use of a great force. In the birds studied here, compared with the adductors, the abductor muscle is less developed and shows a low value of the effective force. It ranges from a minimum of 0.001 gm in the Shikra to a maximum of 0.008 gm in the kite. Slightly higher value in the kite enables the bird to increase the gap when the bird gulps large pieces of meat. The Laggar Falcon, the Kestrel and female Shikra are in the descending order, the effective force of abduction being 0.0068 gm, 0.0049 gm and 0.0033 gm respectively (Table 34).
In tearing operations, flesh of the victim exerts a strong upward pull on the upper arm of the beak and to counteract the external force, a large retraction force is required. In this relation, it may be noted here that the potential ability of the muscles to retract the upper beak is high in all the birds studied. The kite which pierces its beak through the body of the prey, has a large effective force of retraction (0.2340 gm). The Kestrel, the Laggar Falcon and female Shikra, which feed on birds and rodents, have more or less similar values for the total effective force of retraction, 0.1574 gm, 0.1393 gm and 0.1253 gm respectively. Whereas, in male Shikra which depends largely on inset diet and does not require powerful retractors, the potential ability of these muscles is low 0.0724 gm.

That a great protraction becomes disadvantageous to these birds has been discussed often. In this context, it may be noted here that the total effective of protraction exerted by the M. spheno-pterigo-quadratus, is quite low as compared to the total effective force of retraction. The total effective force of protraction is the highest in the kite (0.0219 gm) and is the lowest in the Shikra (0.005 gm). The corresponding figures for Laggar Falcon and the Kestrel are in the descending order, 0.039 gm and 0.008 gm respectively.
The osteological elements have not been studied in details as far as the pelvic girdle is concerned. None the less, it serves as a seat for the attachment for the muscles. The pubis is ventrally curved and the ischium is long. The former increases the angle of attachment of the postacetabular muscles and long ischium increases the length of the effort arm. As Fisher (1946) states, "Greater posterior extent of this bone permits more posterior origin of the muscles, which in turn increases their vector of effective pull by directing their force more nearly at right angles to the femur." The postacetabular muscles assist dorsal flexors of the neck during tearing operation. The total effective force of abduction exerted by the postacetabular muscles is very high in the kite (0.6763 gm) and in the Kestrel it is 0.6117 gm, indicating a greater capacity to tear flesh of their victim. In male Shikra which feeds largely on insects does not require greater capacity for tearing and it may be noted that the total effective force exerted by the postacetabular muscles is very low (0.1223 gm).

iii) Skull Architecture:

It is a common knowledge that in birds, there is a tendency toward lessening the weight of the body without losing the efficiency of the organ. This phenomenon is well exhibited in the internal structure of the skull parts.
The core of the beak is hollow and the pattern of trabeculae conform that of the trajectories. Such an internal structure increases the strength of the beak. Further, compact arrangement of the trabeculae in the nail region prevent bending of the nail when it pierces through any hard object. Besides, the trabecular extensions in the interorbital septum provide a firm attachment to the beak on the cranium. Such an arrangement in the cardinal skull has been reported by Bock (1966). Most of these trabeculae, in the interorbital septum, extend toward the base of the cranium.

Analysis of the external forces reveals that the hooked bill is so designed that with the minimum force applied at the bill tip, the nail of the beak pierces through the body of the prey and that the shear component contributes largely to biting force (Plate XXIX).

**Bone-muscle complex:**

Significance of structural modifications of various bones of the skull has already been noted. The surface area and various processes of a bone are dependent form their normal expression upon the functioning muscle (Scott, 1957). The effect of muscle functioning on the bone mass has been noted by Doyle et al., (1970). In this context, it would be
worth while to understand how far muscle function has affected the internal architecture of the associated bones in birds. In the cranium of various birds studied here, it was observed that the adductor muscles which exert large forces, had thick bony seats. For instance, the kite and the Laggar Falcon, in which the adductors exert a large force, had thick seats. On the other hand, birds which do not have powerful adductors, the bony seats of these muscles were thin. Even in the kite only, the externus series of adductor muscles, which exerts a sum of the effective force of 0.0635 gm, has thick and ossified bony seats. Whereas, the medius muscle, which exerts a small force (0.0065 gm) has a thin seat. This shows that the muscle functioning has a major role in determining structure of a bone.

D. Mechanical Advantage:

All the birds under discussion have a short hooked bill and a high angle of commissure. As Beecher (1962) emphasises, the angulated commissure increases the speed of the bill tip in terms of mechanical advantage. Moreover, a long orbital process of the quadrate increases the mechanical advantage. High values for the mechanical advantage in these birds show a powerful grasping capacity of the bill. The mechanical advantage ranges from a maximum of 0.51 in the kite to a minimum of 0.26 in the Kestrel. The Laggar Falcon is next
highest (0.47). Both female and male Shikra have roughly similar values, 0.37 and 0.36 respectively. (Table 46).
High values for the mechanical advantage have also been described in Lanius, a predator (Order: Passeriformes), by Malhotra (1967).

HISTOCHEMICAL OBSERVATIONS

In all the birds studied here, the adduction and the retraction involve slow and sustained actions by the concerned muscles. The adduction is brought about mainly by the M.A.M. externus series and the retraction is brought about by the M.A.M. internus series. In both these series, the muscles possess a higher percentage of the Type I fibers (Table 47) which are loaded with fat and are responsible for a slow and sustained activity (Padykula, 1952; Dubowitz & Padykula, 1958; George & Naik, 1959; George & Berger, 1966; Dubale & Murlidharan, 1970). Besides, except the M. depressor mandibulae, the rest of the jaw muscles show a greater number of the Type I fibers than the Type II fibers, showing their capacity to exert a slow and sustained action. A low number of Type I fibers in the M. depressor mandibulae shows that this muscle is not capable of showing a slow and sustained activity.
Except the M. flexor colli ventralis, the rest of the muscles of the neck and those associated with the digits, show more or less equal distribution of both the types of fibers.