STUDY OF GRIP MECHANISM BASED ON BIONICS

PRODUCT DESIGN
SPECIAL PROJECT

Rupesh Nath. U
0 5 6 1 3 0 1 0

Guide: Prof. **V. P. Bapat**

Submitted in the partial fulfillment of the requirements of the degree of

Masters of Design
In
Industrial Design

Industrial Design Center
Indian Institute of Technology Bombay

March 2007

APPROVAL SHEET

The Product Design Special Project titled " **Study of Grip Mechanism based on Bionics"** by **Rupesh Nath.U , 0 5 6 1 3 0 1 0** is approved as a partial fulfillment of the requirements for Post Graduate Degree in Industrial Design.

Project Guide :____

Date :____

ACKNOWLEGMENT

With a sense of achievement and satisfaction, as I reflect upon my project activity, I filled with a deep sense of gratitute towards the important few whose help and support was instrumental in the com pletion of my project.

I wish to express my greatfulness to my guide Prof. V. P. Bapat who encouraged and inspired me in undertaking this project. I thank him for his gruidance, cooperation and valuable advice throughtout the course of my project.

I thank my department Industrial Design Center for providing me with wonderful facilities during the course of my project development.

CONTENTS

Bionics (also known as biomimetics, biognosis, biomimicry, or bionical creativity engineering) is the application of methods and systems found in nature to the study and design of engineering systems and modern technology.

It is a multi-disciplinary subject involving a wide diversity of other domains like electronics, informatics, medicine, biology, chemistry, physics, mathematics, and many others. This discipline has already shown the way to number of innovations and improvements in space engineering.

Often, the study of bionics emphasizes imitation of a biological structure rather than just an implementation of its function. For example, in computer science, cybernetics tries to model actual organic structures that make humans intelligent, while artificial intelligence tries to model the intelligent function regardless of the particular way it can be achieved.

The conscious copying of examples and mechanisms from natural organisms and ecologies is a form of applied case-based reasoning, treating nature itself as a database of solutions that already work. Proponents argue that the selective pressure placed on all natural life forms minimizes and removes failures.

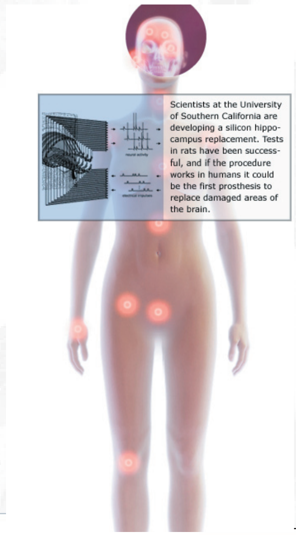
Although almost all engineering could be said to be a form of biomimicry, the modern origins of this field are usually attributed to Buckminster Fuller and its later codification as a field of study to Janine Benyus.

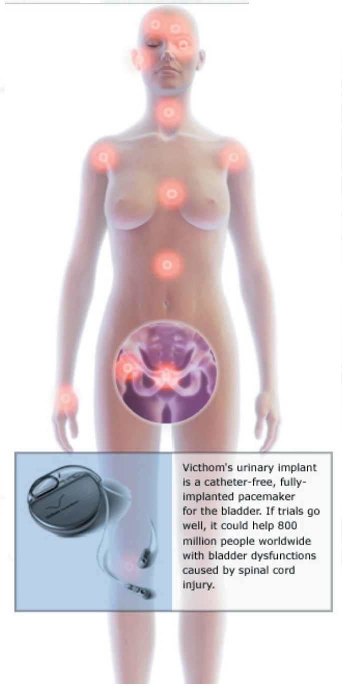
Roughly, we can distinguish three biological levels in biology after which technology can be modelled:

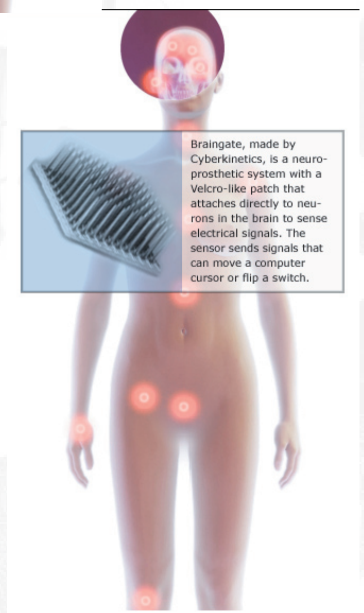
- Mimicking natural methods of manufacture of chemical compounds to create new ones
- Imitating mechanisms found in nature (velcro)
- Studying organizational principles from social behaviour of organisms, such as the flocking behaviour of birds or the emergent behaviour of bees and ants.

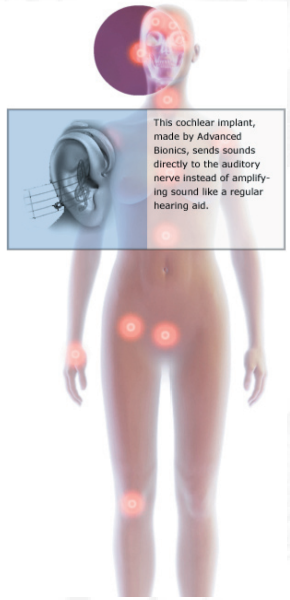
Designs in nature must be examined not with the idea of duplication, but rather, one must determine the objective behind the form.

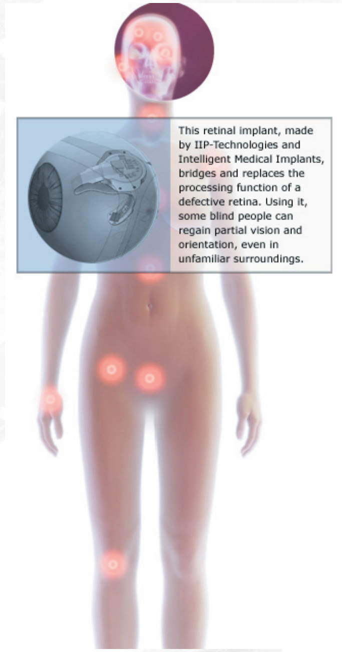
There are limitations to copying nature. One need only glance at human technology to find basic devices that have no natural ananlogues. Direct imitation of nature is often difficult and can lead to misleading results. Natural designs are almost all multifunctional, for example, a feather acts not just as the surface element of an airfoil but also as a component of a bird's thermal insulation. Hence it would be foolish to simply copy the shape of a feather when designing of wings of an aeroplane.

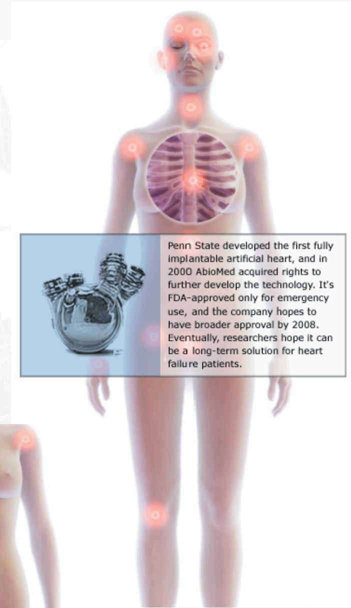


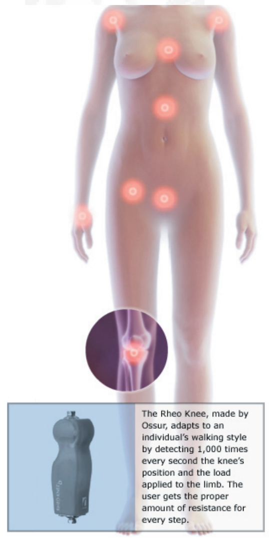












Study of the various grip mechanisms in different species for an application in future based upon bionic priciples.

The proposed project aims on the study of grip mechanism based on the bionics, the process goes with the data collection of the various grip mechanisms adopted by different species. The study further proceeds with study of mechanisms and acting forces on and by the bones, muscles and tendons. Also the types of joints, leverage and mechanical advantages, etc are studied. With these inputs or inferences some concepts may be developed for some suitable applications.

There are many applications of bionics are done and still researches are going on. Grip mechanism is one of the area in which researchers are doing intense research and also succeeded in some areas of application like grabing of an item with the help of leverage, example is plier.

The study in the paper is focused on identifying different grip mechanisms adopted by different animals like Primate, Bat, Crab and Bird.

To understand it one has to understand the principle of levers and kinematic chains.

In technical words these are the materialistic elements, which actually transfer force from source to application with predetermined ratio, but in biological world it is done with bones and muscles.

The Methodology followed during the study

- Study of different types of grips
- Arrangement of muscles and their mechanisms
- Kinematic chains
- Analysis

Pic. 1

Mainly there are five types of grips are used by the human hand

- Power Grip
- Pinch Grip
- Oblique Grip
- Hook Grip
- Palm Up, Palm Down Grip

Power Grip

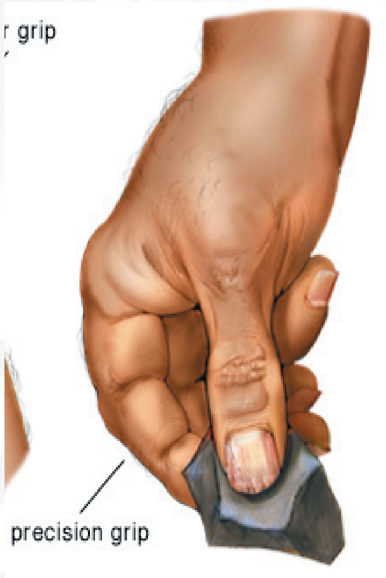
This is the most common/natural grip as shown in picture 01. The fingers are wrapped around the barbell with the thumb positioned along side the index finger, the grip remains like this for the remainder of the exercise. While under low loads this remains an effective grip, when the athlete begins to perform near maximal lifts the grip strength will generally fail before the muscles in the or back are fatigued.

Power Grip (Cylindrical grip) is the maximum gripping force that can be generated by the hand

- Two factors affect the ability to generate force with a power grip

    -- Wrist orientation : Deviations from a normal posture reduce the maximum grip force
    -- Grip span – Spans that are too small or large will reduce grip strength

- Optimal Grip span of the hand is around 2”



Pic. 2

Pinch Grip

In a pinch grip, the fingers are on one side of an object, and the thumb is on the other. Typically, an object lifted in a pinch grip does not touch the palm. This is generally considered a weaker grip position. The pinch grip is used when grabbing something like a weight plate or lifting a sheet of plywood by the top edge.

- Characterized by opposition of the thumb and distal joints of the fingers
- Pinch grip has almost equal to 25% maximum power grip strength
- Pinch grip strength decreases rapidly at spans < 1” or > 3”

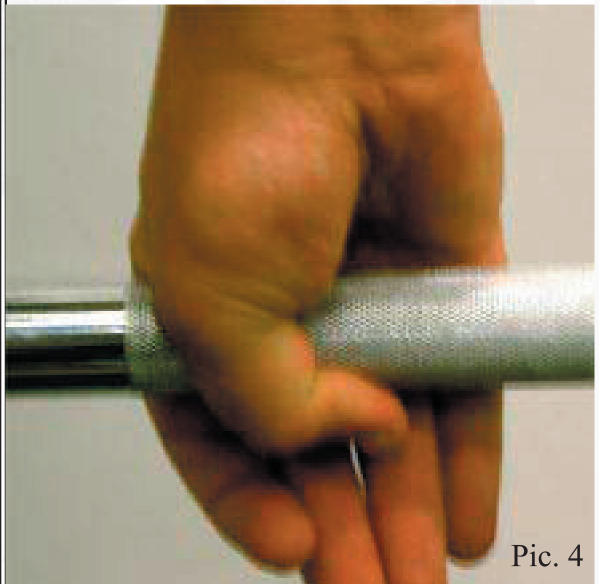
Two types of grips

Internal – Tool handle is internal to the hand e.g. knife
External – tool handle is external to the hand e.g. pen

Pic. 3

Oblique Grip

- It is a variation of Power Grip
- Gripping across rectangular surface causes this kind of grip
- Oblique grip is almost equal to 65% of power grip strength
- Oblique grip is strongly affected by grip span
- Grip is mainly depends upon shape and size


Pic. 4


Pic. 5

Hook Grip

In weightlifting (clean and jerk/snatch) the athletes are taught to use the hook grip when lifting. The thumbs wrap around the barbell first, picture 04 and then the fingers wrap over the top of the thumb and barbell, as shown in picture 05. This means that the thumb is applying pressure to the barbell and fingers are also applying pressure to the thumb and barbell.

Use of this grip can lift heavier than athletes who use the closed grip. Therefore for the long-term development of the athlete if they begin using the hook grip when training then their grip strength will be stronger.

The negative side to the hook grip is the soreness to the thumb and thumbnail when first using the grip. Athletes will experience soreness to the thumbnail due to the applied pressure to the nail of the thumb when exercising. However, generally this will reduce within 6-8 training sessions and the body adapts to the effects of the grip.

• Flat hand, curled fingers, thumb as stabilizer, fingers support load
• Hook grip strength is almost equal to power grip for 2” span
• The narrow or wide sections of handles, or poor contours will decrease the grip strength. Load may exceed 22lbs/inch maximum skin pressure

Palm Up and Palm Down Grip

The alternated grip is predominately used by powerlifters (Bench press, squat and deadlift) in the deadlift. One palm faces towards the body and the other faces away from the body as shown in Picture 04. The athlete can use either the hook or closed grip.

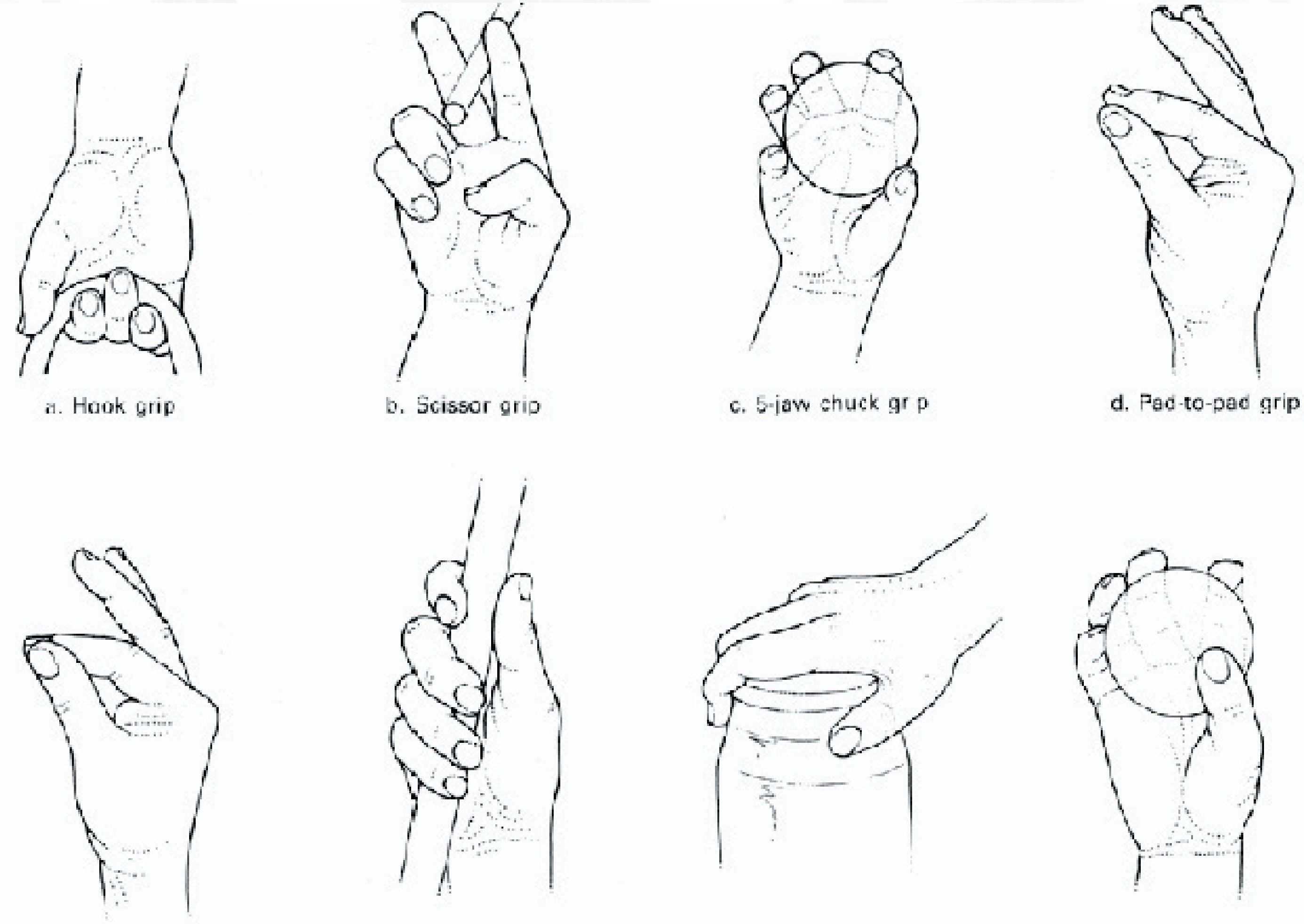
The grip allows the athlete to pull on the barbell when deadlifting and results in greater use of the biceps during the lift. Generally this is stronger than a closed grip and similar to a hook grip in terms of amount of load that can be lifted before grip failure. The drawback of this grip is it can only be used.

Palm Up Grip

- Grip strength depends upon arm strength and grip span
- It is difficult to perform when the height of the object being lifted exceeds elbow height (~35" above floor level)

Palm Down Grip

- This kind grip is primarily used for precision activities
- Druing palm down grip activity the arms are sub-optimally positioned
- Once the load weight exceed 0.5kg (1lb) griping efficiency reduces
- Gripping strength also effected by span of the grip



a. Hook grip
b. Scissor grip
c. 5-jaw chuck grip
d. Pad-to-pad grip
e. Pad-to-side grip
f. Squeeze grip
g. Disc grip
h. Spherical grip

CASE STUDY 1

PRIMATE

AND

HUMAN HAND

The general shape of the hand is highly variable among primates. In particular the hands of Lorises (e.g. Nycticebus) have one or more reduced fingers so that they can use a side-to-side pincer grip when holding branches. This grip is extremely strong as anyone who has tried to pry a loris off a branch can attest to.

One important peculiarity seen in some non-human primates are hand adaptations associated with terrestrial locomotion (Figure 1). Digitigrade walking is commonly seen in terrestrial walkers since it acts to elongate the limb and reduce the weight of the distal extremity (similar adaptations are seen in quadrupedal carnivores). Knuckle-walking is uniquely found
in chimpanzees and gorillas and involves flexion rather than hyperextension of the finger joints but is otherwise likely to have the same adaptive use.

Some of the observations listed below about adoptation of primate parts

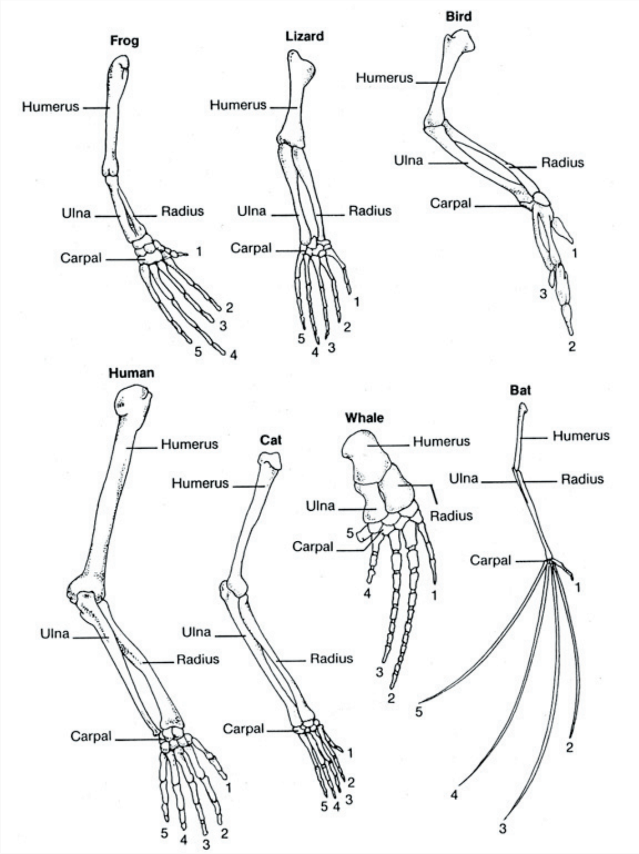
1. Preservation of generalised limb structure with primitive pentadactyly.
2. Enhancement of free mobility of the digits, especially of the pollux and hallux (both used for grasping).
3. Replacement of sharp, compressed claws by flat nails; development of very sensitive tactile pads on the digits.

Diagram of the forelimb of a variety of tetrapods showing how the primate has retained the primitive pentadactyly limb (3 girdle bones; 1 upper limb bone; 2 lower limb bones; carpals/tarsals; meta-carpals/tarsals; phalanges) whereas various other mammalian orders have lost various bones

The increased lengths of the orang-utan and gibbon forelimbs is almost certainly due to their suspensory lifestyle which is extreme in the case of the gibbon.

All, though to different degrees, possess prehensile (grasping) hands and all (except humans) prehensile feet. The hands of catarrhines show a greater range of precise manipulative activity than those of other primates. Lemurs, for example, lack the functional duality of the hands of most apes and Old World monkeys (catarrhines). Duality in hand function has been described in terms of precision and power grips. The power grip of lemurs and lorises is very well developed, but the precision grip is lacking. The New World monkeys show a considerable advance over primitive primates in tactile sensitivity, but they possess less functionally effective hands in prehensile terms than Old World monkeys.

As you can see from figure 3 the primates have retained a limb bone structure that is very similar to that of the primitive tetrapod, whereas the other mammals shown have considerably reduced bone numbers. Enhancement of free mobility of the digits, especially of the pollux and hallux (both used for grasping). Figure 3 also shows how the primate hand and foot has long, mobile digits compared to some other mammals. Coupled with this, primates can use a variety of power and precision grips to manipulate objects.



Comparison of primate hands

Primate hands vary in their structure and manipulative ability.

Tarsier has an opposable thumb and slender fingers with adhesive pads adapted for grasping preys or objects.

Orangutans are adapted for swinging from branch to branch; the fingers serve mainly as hooks for hanging on branches and the thumb is short so as not to get in the way.

Gorilla has a longer, more opposable thumb than the orangutan, and the fingers are shorter, so they can hit hard.

Human hand has the most manipulative ability; the long thumb is more opposable and the fingers more dexterous and capable of free movements.

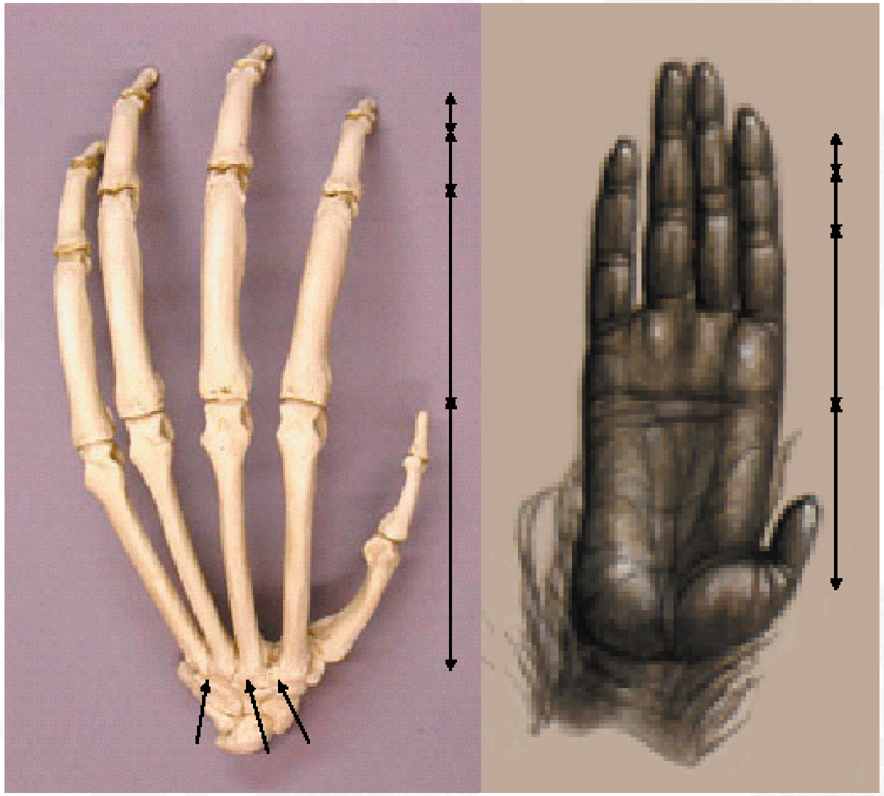
Human hand and primate hand mostly adopts opposition grip, larger thumb and opposition grip gives greater dexterity and this allows more effective tool use.

Gripping Behaviour

For many activities like lifting, lowering, carrying, pushing and pulling the type of grip is the interface between the person's hand and the object handled.

The type of grip affects the force that is generated on an object and also affects the risk of injury.

Next page bone structure of orangatan is shown. Its its long curved bone structure gives an advantage of wraping around the branches of tree and hang for long time. All the pressure is taken up by fingers only.



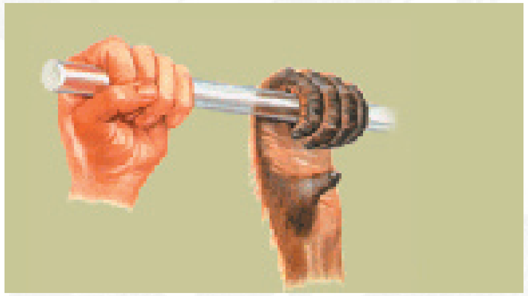
Three joint surfaces are oriented as like humans and they are oriented in different directions and that will allow a little rotation and helps to grasp round and bigger objects

Inferences

• Due to long curved bone structure in the hands grabing around the tree branches is easy.

• Opposition grip is week even it is used for holding a branch or object, so the forefingers will wrap and almost touch the palm end.

• The profile of the palm will be just like hook.



CASE STUDY 2

CHIROPTERAN

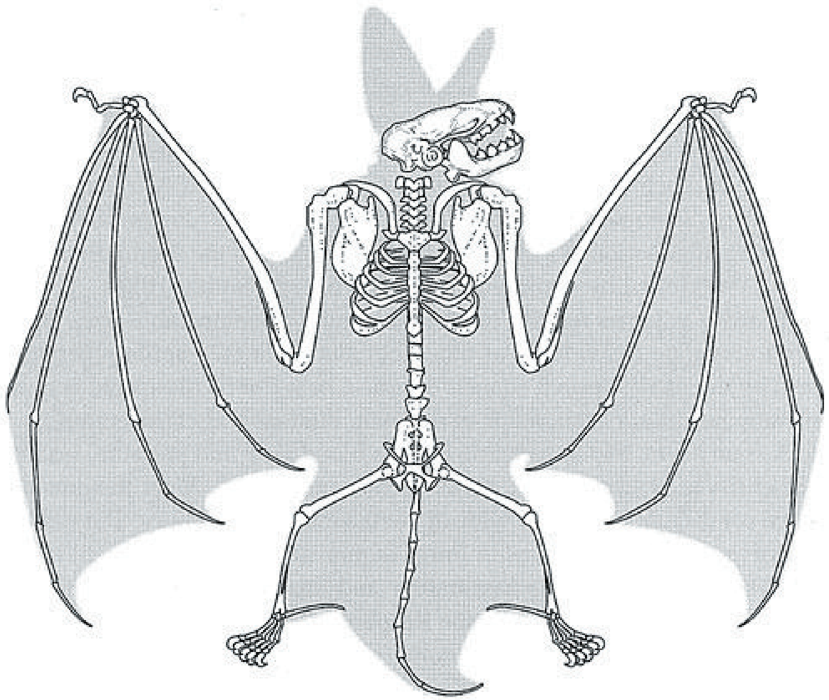
Bats are mammals. Bats are not rodents, although many people think of them as mice with wings, and indeed, the members of the genus Myotis (including the common Little Brown Bat, Myotis lucifugus) are called mouse-eared bats. But they only have one pup per year (a few have twins or up to four), and live twelve toothirty or more years, depending on the species. Bats are so unique that they have been placed in their own order, Order Chiroptera, meaning “hand-wing”. As the name implies, their wing consists of an arm that ends in a wrist with a thumb and four separate fingers which are webbed with skin, and form the ribs of the wing. By contrast, a bird’s wing possesses a greatly-reduced number of “finger” bones. When bats aren’t flying they fold their fingers back along their forearms out of the way. While the thumbs of most insect-eating bats who catch their prey on the wing are small and weak, the big fruit-eating bats called flying foxes (because of their fox-like or dog-like face) have very long and strong thumbs with curved “thumbnails” like claws, which they use for climbing around in trees and gripping fruit.

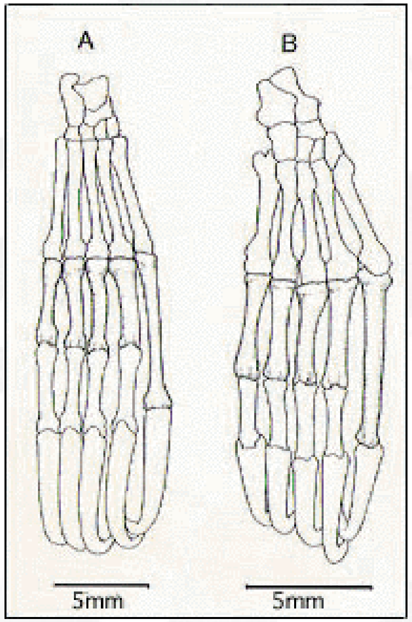
Bat fingers have the same number of bones ours do, but they are proportionately much longer. The last bone of the “middle” finger of the Rodrigues bat (Pteropus rodricencis), for example, is actually folded behind the elbow when at rest. Look at your fingers and forearm; try to fold your fingers down against your arm, and try to imagine your fingers extending past your elbow. But don’t forget to leave your thumb extending forward for gripping and climbing. Then there is the webbing that connects all the fingers except the thumb, and extends all the way along the arm and body to the ankle, and in most species continues to envelop all or part of the tail. When bats extend their fingers and arms, their wings are ready for flight. By shaping their “hands” they control the shape of their wings. Slow-motion photography (National Geographic Video) has actually shown insect bats scooping up insects in their wings and tail membranes, transferring them to their mouths in mid-flight. Truly they are unique mammals.

The order is broken down into two sub-orders, Megachiroptera, the “big bats”, and Microchiroptera, the “little bats”. All the insect bats are microbats; the old-world fruit bats, the flying foxes, are megabats. All the rest are in one or the other, mainly according to their size. The system breaks down, however, since some micros, like the little Jamaican fruit bat (Artibeus jamaicencis), eat fruit, and one flying fox, the Queensland blossom bat (Syconycteris australis), weighs only half an ounce.

Bats, like cars and planes, are the product of very careful, intelligent design; all the varied shapes and features equip different bats to function in different ecological niches. All the anatomical details necessary to fly and to hang upside down have been thought of and "programmed" into the genetic code. Bat feet are totally relaxed when they are hanging (Dr. Blair Csuti, personal communication, October 17,1998), requiring effort to let go; how did that "evolve"?

Bat Skeleton





Dorsal View of the foot

A) Micro chiropteran

B) Mega chiropteran

Like humans, bats have four fingers and a thumb on each hand, but the fingers are very long--each about as long as the body--and very thin. The thumb is relatively small and has a claw that is used for gripping when the bat is at rest, whereas the fingers have lost their claws (except in many fruit bats of the Old World, which have a claw on their second finger).

The bones of the arm and four of the fingers are light, slender, and lengthened to support, spread, and manipulate the membrane. The thumb, usually with a sharp claw, is not attached but remains free for clinging to various surfaces. Unlike other mammals, the hind limbs are positioned so that the knees, when bent, point backward while the bottom of the feet face forward. The toes have claws which help in gripping and in hanging head down, the normal bat resting position. A long spur, the calcar, extends from one of the ankle bones and helps spread the interfemoral membrane, that part of the wing membrane between the tail and the hind legs.

A few species of bats are carnivorous, eating small frogs, lizards, and birds. Other species are known for their fish-eating habits and are usually specialized by having huge hind feet and claws.

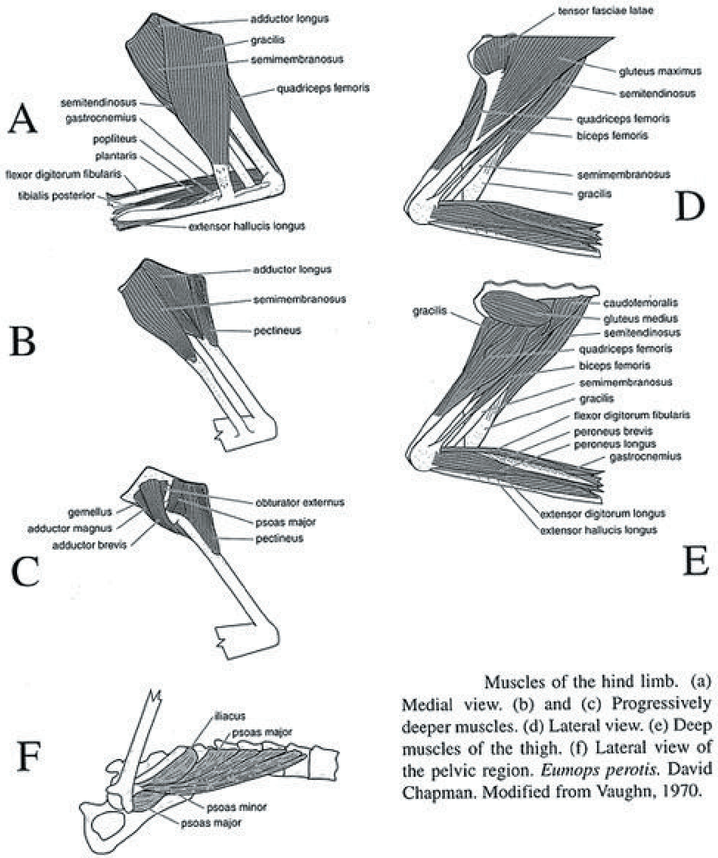
More or less linear increase in the dimension of the bat would not suffice to support greater increase in the body mass there slender legs are unable to tolerate any compressive loading hence it is advantageous for the bats to suspend their weight by hanging tension loading is independent of the length since there is a little tendency of bending as shearing and in bats ligaments and tendons in the foot and leg share the load an dmake the reptilian angulation of the legs of crawling bats servers to reduce compression stress on their shoulder bones so does there usual behaviour of crawling backwards when grounded or ascending a wall. Backward locomotion pulls the weight rather pushing it.

The bats femur have unusual rectangular cross section this provides stronger structure to tolerate greater stress and also resistance to bending stresses. Resistance to bending stress afforded by this shape is likely improtant to these animals where lateral jumping is common behaviour.

So the main inferences are

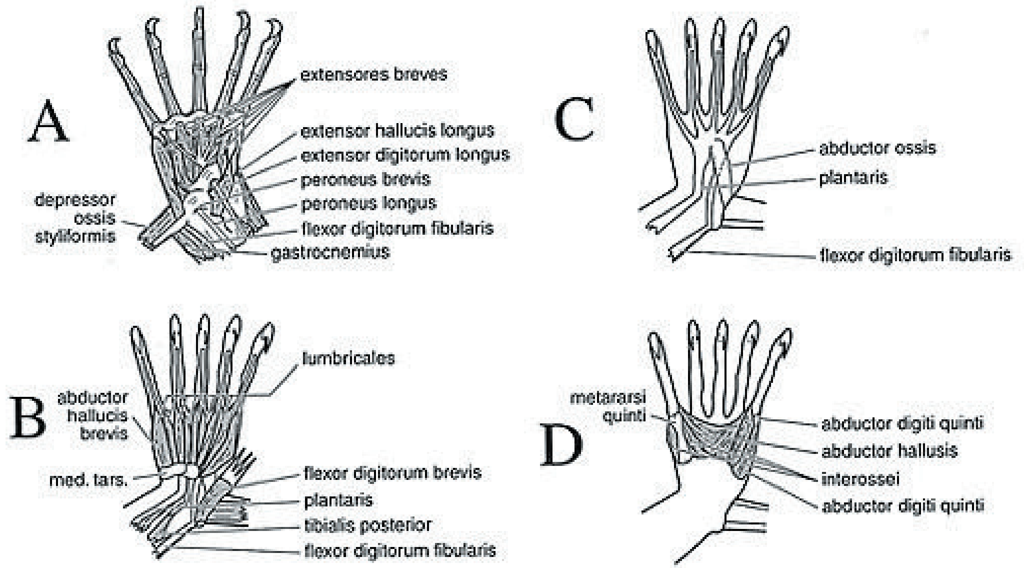
• Easy to fly by reducing there weight by having thin legs, which can't take compressive loads so hanging is very advantageous.
• Protection from predators.
• Facilitisation of flight take off.

LEG MUSCLES



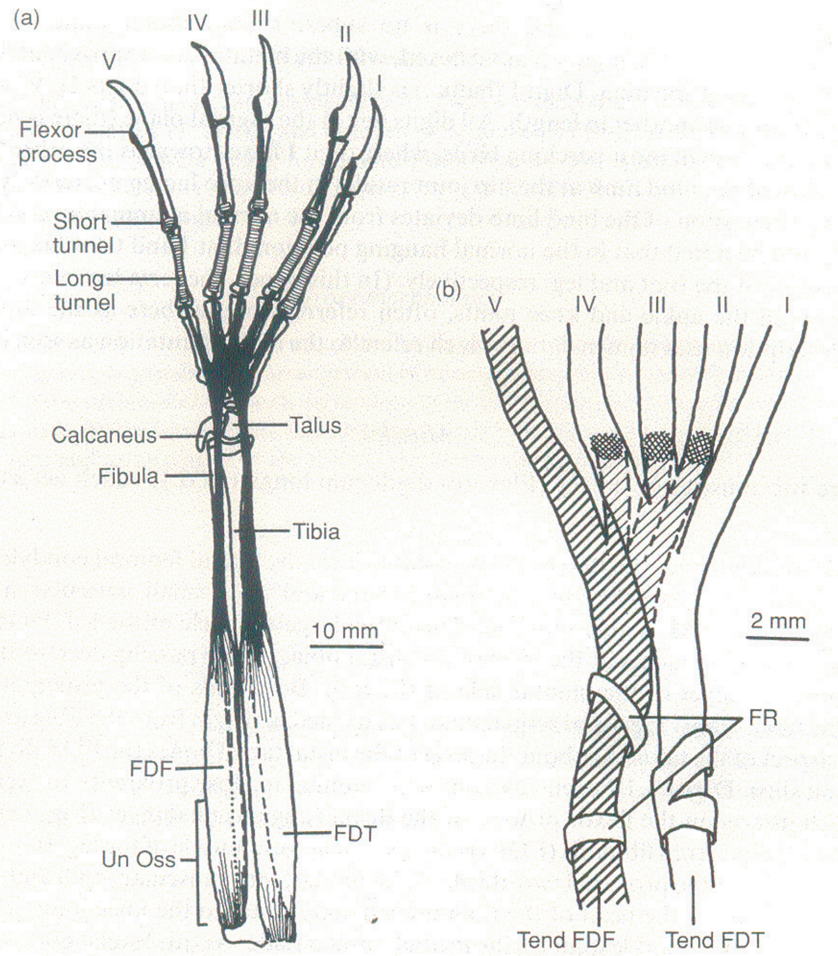
Muscles of the hind limb. (a) Medial view. (b) and (c) Progressively deeper muscles. (d) Lateral view. (e) Deep muscles of the thigh. (f) Lateral view of the pelvic region. *Eumops perotis*. David Chapman. Modified from Vaughn, 1970.

MUSCLES OF THE LEFT FOOT



(a) Dorsal view of the left foot. (b) Dorsal view of progressively deeper muscles. (c). Ventral view. (d) Ventral view of progressively deeper muscles. *Eumops perotis*. David Chapman. Modified from Vaughn, 1970.

Bats have tendinous arrangement in the hind limbs, which acts as an automatic digital flexor mechanism(Borelli, 1680; Watson, 1869; Bock, 1965; King and McLelland, 1984). A mechanism by which the tendons of the deep digital flexor muslces (M.Flexor digitorum longus and M.Flexor hallucis longus) are able to lock the digits in a flexed position has been described. Locking of digits is achieved by virtue of rough patches on the plantar surfaces of the tndons engaging with corrugation of the flexor tendon sheath.



Upon contact of the hind limb claws with the substrate, contraction of the digital muscle pulls the distal portion of the flexor tendons proximally, through a series of tendon sheath, which contains thickened section called retinacula.

When the roughened sections of tendon are positioned benath the corrugated retinacula, there s engagement between the scales of tubercles on the tendon surface and the transversely arranged, rib-like plicae that invest the inner walls of the retinaculum. In theory, igital flexion is maintained without coninued contractile activity of the digital flexor muscles, and the energetic cost of hanging is lowered.

FDT (Flexores Digitorum Tibialis) is the largest muscle

FDF (Flexores Digitorum Fibularis) is the second largest muscle

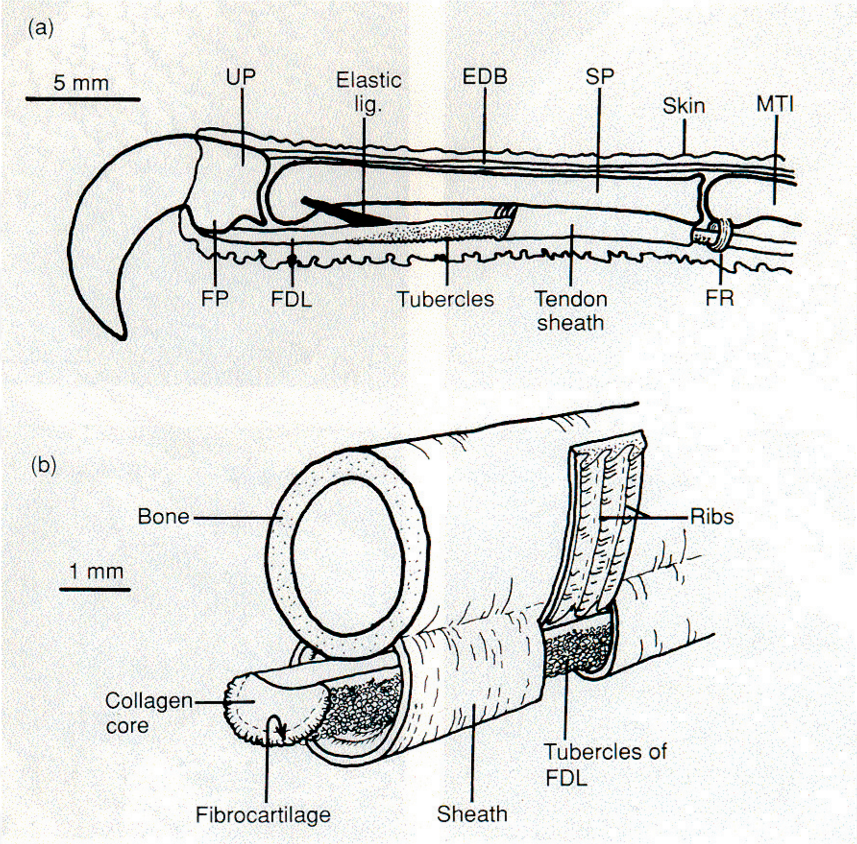
Only II, III, IV are the one which interlocks during hanging. The interlocking details is explained in the next page.

All species of bats exhibit morphological specialization similar to those in the avian foot, and referred as Tendon Locking Mechanism (TLM). Locking mechanism were found in all the digits of the hind limb and in the thumb of bat forelimb.

In the Fig: FR, Flexor retinacula. Cross-hatched region represents the insertion sites of tend FDF on to the deep aspect of tend FDT.

Rather than the usual mammalian scheme in which tendon and sheath surfaces provide as little friction as possible, the tendons and sheaths of many bats have a locking segment on the manual and pedal flexor tendon complex. This tendon locking mechanism (TLM) exists opposite the proximal phalanges of each toe and pollex of many bats. Its structure, similar to a ratchet mechanism, assists bats in hanging with little muscular effort. The third digit of the pelvic limb and the pollex of species representing 15 chiropteran families were studied to determine the presence or absence, morphology, and function of the TLM. Most of the species studied have a TLM consisting of a patch of tubercles on the ventral surface of the flexor tendon associated with the proximal phalanx of each pollex or toe. The sheath adjacent to this portion of the flexor tendon has a series of transverse folds or ridges, which, when engaged with the tubercles on the tendon, lock the tendon in place. The TLM is similar in megachiropterans and microchiropterans possessing it. The TLM is absent, however, in some of the microchiropterans studied, most notably in the phyllostomids. Since many birds have a TLM similar to that of bats, it is an excellent example of the convergent evolution of a feature brought about by similar functional pressures on birds and bats.

The hindlimbs are rotated through 180º, thus when a bat walks on the ground its knees stick up into the air. The lower section of the hindlimb is composed almost entirely of the tibia, the fibula is vestigial, like the ulna in the forelimb only more so, and fused tto the tibia. The whole limb can rotate through a wide angle allowing a hanging bat to swivel its body through a complete circle. The toes of the hindlimbs all have strong, laterally compressed, claws and an automatic locking system involving a tendon that passes through a sheath of cartilaginous rings attached to the phalange that constrain its movement. This tendon is so attached that it is the bat's own weight that keeps it taught. This allows the bat to sleep without falling from its roost. Birds also have a locking mechanism on their claws to stop thm from falling off their perch, but their system is quite different.

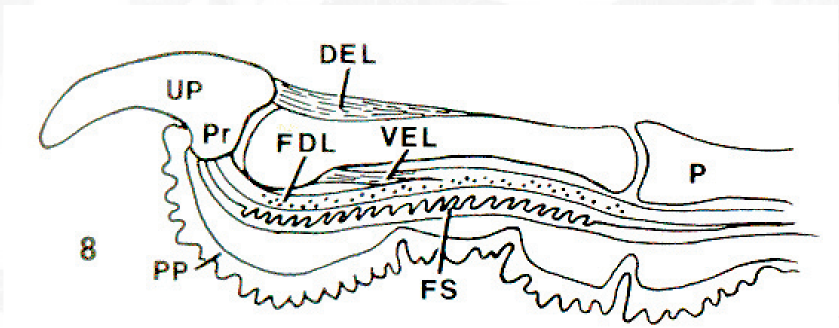


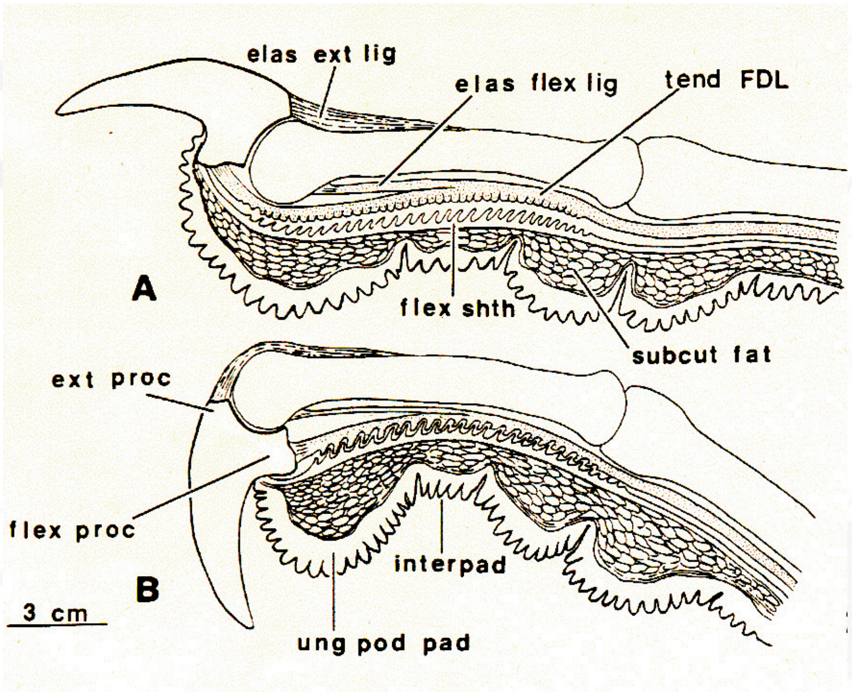
In the Fig.

UP - Ungual Phalanx
FP - Flexor Process
FDL - Tendon of M. FDL
EDB - Tendon of M. extensor digitorum brevis
SP - subterminal Phalanx
FR - Flexor retinaculum
MT1 - Metatarsal 1

Initially the FP is rotated due to force applied by SP and MTI respectively. Due to this movement tendon sheath, ribs and tubercles of FDL gets interlocked.

This mechanism is clearly described in the next with figures.





The locking of two main components of the TLM in hanging posture occurs in two ways.

• The digits are curled around a support then it is possible that the tendon sheath and the tendon be compressed between bone and structure. The tendon must initially pulled around the flexor. As the digits curl, the motion carries the line of action of the flexor tendon farther away from the axis of rotation of the distal phalanx joint. The moment arm is therefore increase with the simultaneous increasse in torque at the distal phalanx joint. Since a force will produce a greater torque when moment arm is large, it appears that flexion of the distal phalanx joint is powerful in bats. The grip established on the substrate by this forceful initial flexion of the ungula phalanx is maintained by locking the tendon in place with TLM.

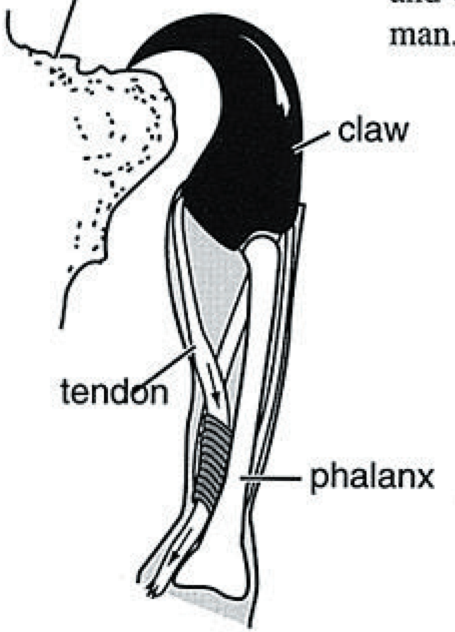
• Only point of contact with the support is made by the distal phalanx, the tendon will be forced against the restraining tendon sheath. This occurs, as there is a component of force acting perpendicular to the long axis of tendon. Thus the line of action of tendon is changed and the components of TLM are engaged.

UNLOCKING MECHANISM

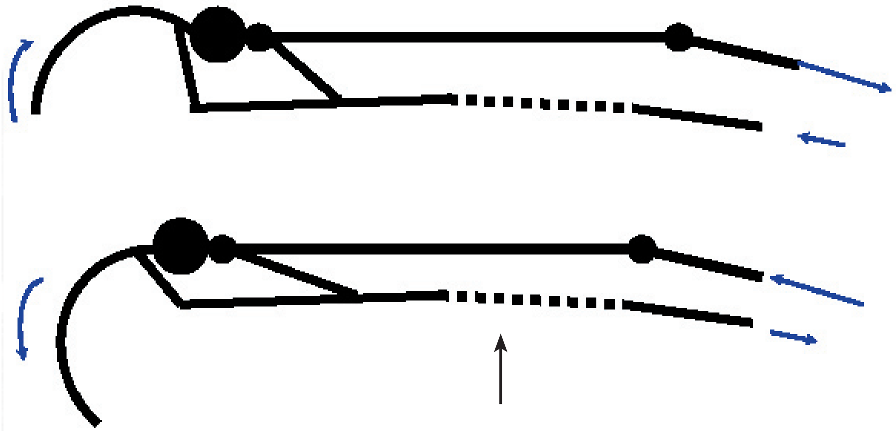
The actual method of unlocking of tendon has not been determined so far. But it is probable that relaxation of two muscles (FDF and FDT), coupled with the effect of gravity and contraction of EDL and EDB is sufficient to bring to extend the digit. Once the tendon disengages from the tunnel ridges it will be pulled distally and towards the phalangeal bone i.e., away from the ridges, by action of flexor elastic ligaments.

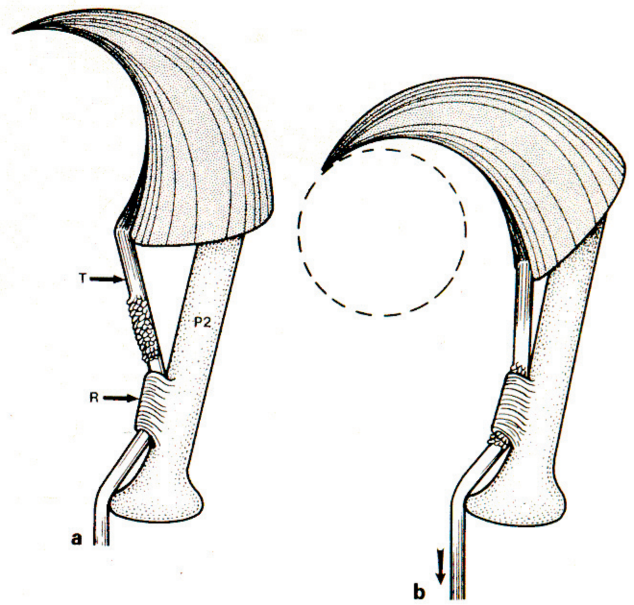
The researches has not done much in finding the unlocking mechanism as per my knowledge.

TENDONS OF THE CLAW



The organization of tendons in the legs and feet are such that the weight of a hanging bat causes the toes and claws to grip the roost. David Chapman. Modified from Hill and Smith, 1984.



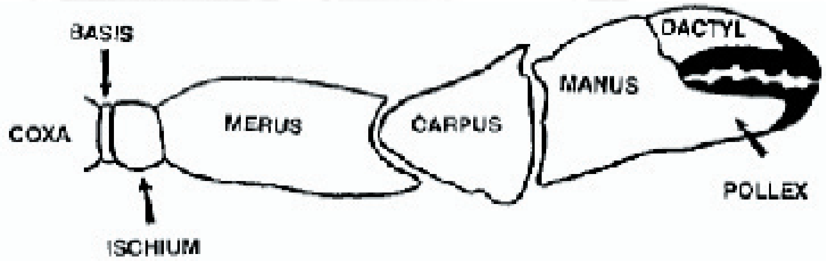


Hooking around a circular surface

CASE STUDY 3


CRAB CLAW

CRAB CLAW

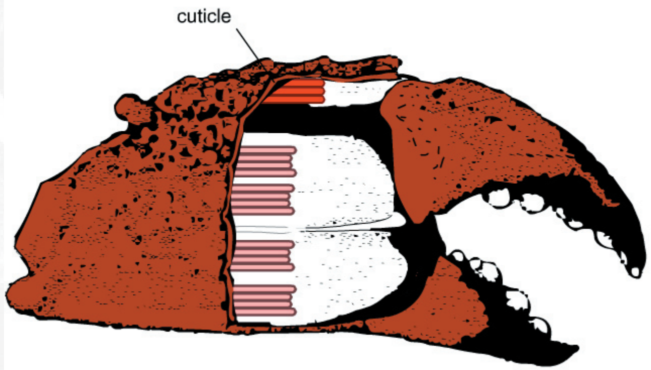


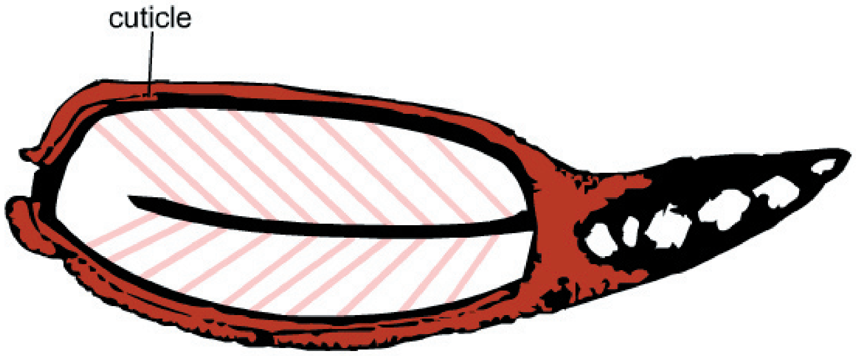
Crabs are well know as pedators of shelled molluscs. While most species which include molluscs as food have very generalised diets, the intensity of their predation is in many cases sufficient to influence the local distribution of prey species.

Claw Labels

Cuticle

Like all arthropods, the flesh of a crustacean is enclosed by a tough, often mineralized cuticle that must be molted to grow. The cuticle serves as an exoskeleton that suppots the body and provides a rigid surface for muscles to attach. It also gives rise to apodemes, which are just an arthropod version of a tendon. Muscles that attach to these apodemes open and close the claw.

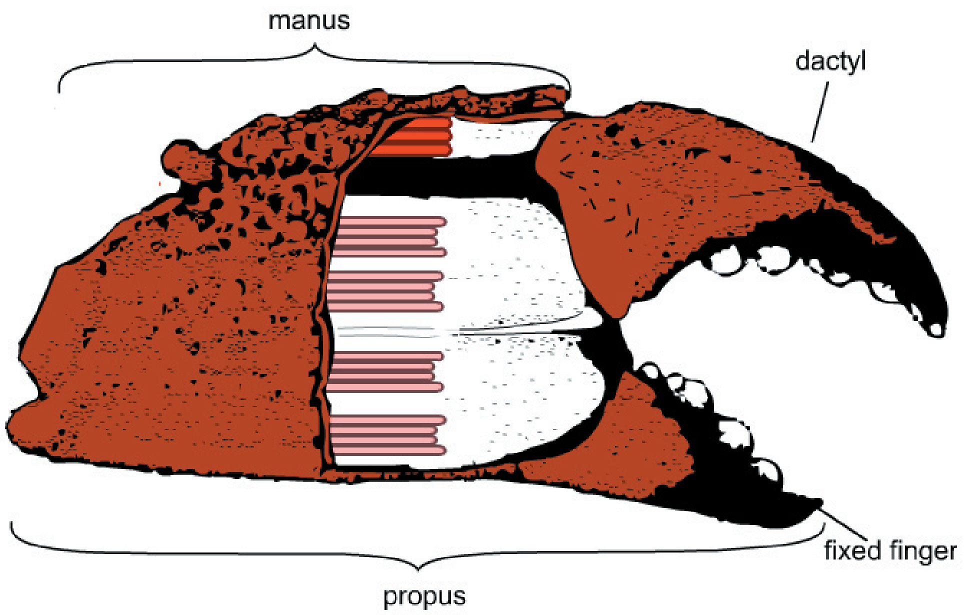




Crustaceans limb muscles differ greatly from those of vertebrates. Instead of a single linear muscle, crustaceans have bipinnate muscles where two sets of muscles exten from opposite sides of the apodeme and attach to the outer cuticle. Therefore, compared to vertebrates, crustaceans can generate twice the force with the same volume of muscle because twice as many muscle fibers can pull at the same time. Notice how the muscle angles change as the muscles contract.

Propus

The propus, or next-to last segment of a decaped leg, is the larges part of a claw. It houses the opener and closer muscles in the manus (hand portion). Note that the fixed finger isn't a finger at all. It is just an outgrowth of the propus. In some crustaceans no fixed finger exists at all, and the dactyl simply squeezes up against the blunt end of the propus.

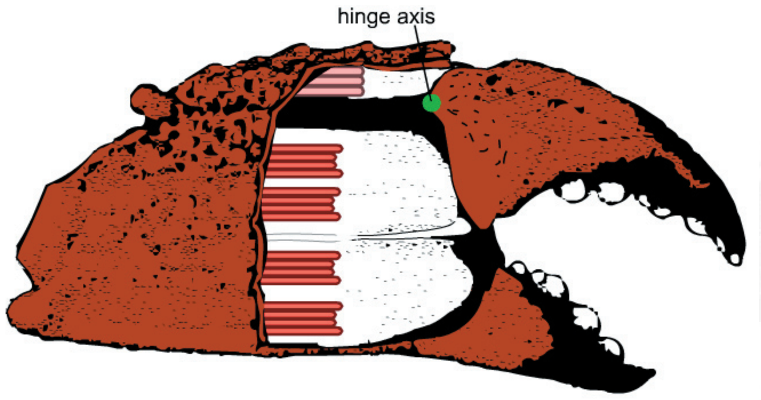


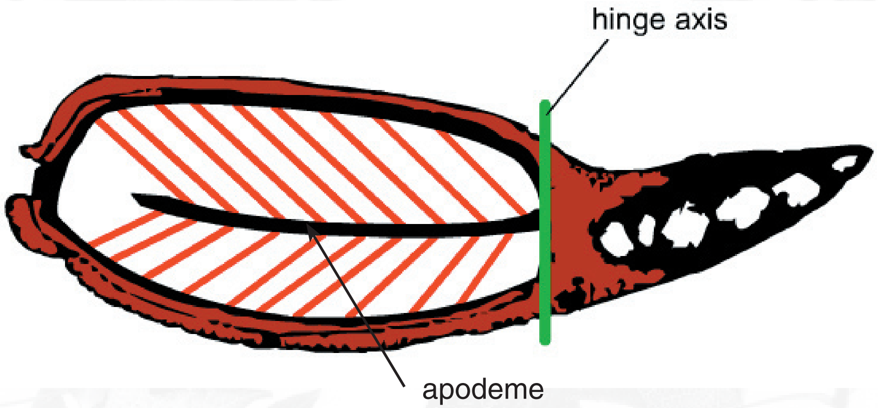
Dactyl

The dactyl, or moveable finger of a claw, is simply the terminal segment of a decapod leg. It rotates about a hinge axis so that the lip presses up against a rigid outgrowth of the propus or next-to-last segment of the leg. For mechanical reasons a stout claw like this one is better for crushing hand-shelled prey, but one with long with lng slender fingers is better at grasping fast-moving prey.

Hinge Axis

The dactly, or moveable finger, rotates back and forth around a fixed hinge axis. At opposite ends of this axis two ball and socket joints holds the dactly firmly in place in the propus. As a consequence, the dactyl can only move up and down within a single plane. Interestingly, the hinge axes of adjacent limb joints are at right angles to each other to allow maximum versatility of movement of the whole leg.



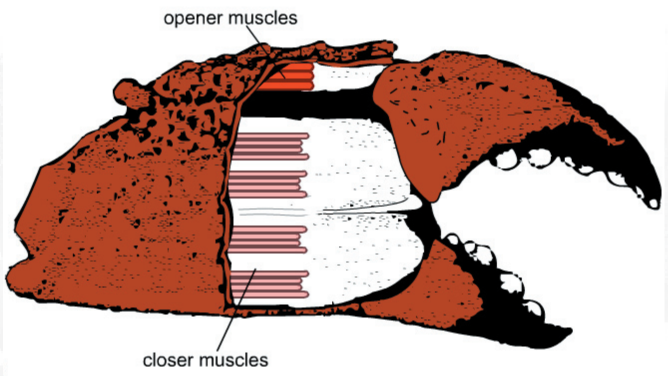


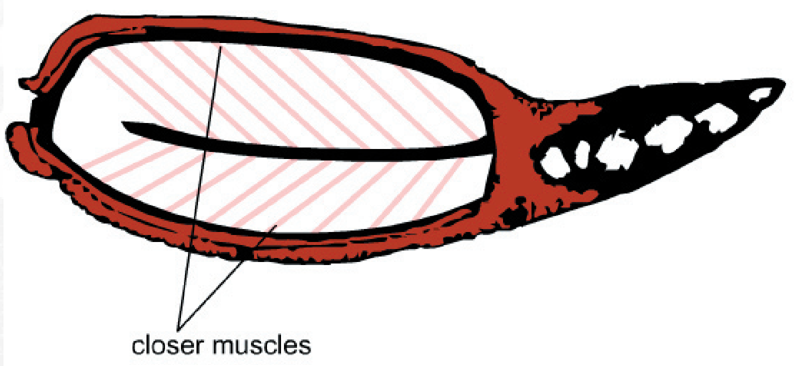
Apodemes

To work properly, crusiacean muscles, like vertebrate muscles, must attach to something at both ends. One end attaches to the rigid outer circle, whereas the other end attaches to a moveable tendon (apodeme). When muscles contract, they move the apodeme relative to the outer cuticle. In walking legs, two apodemes always exist in each segment: one to extend the segment (opener) and one to retract it (closer).

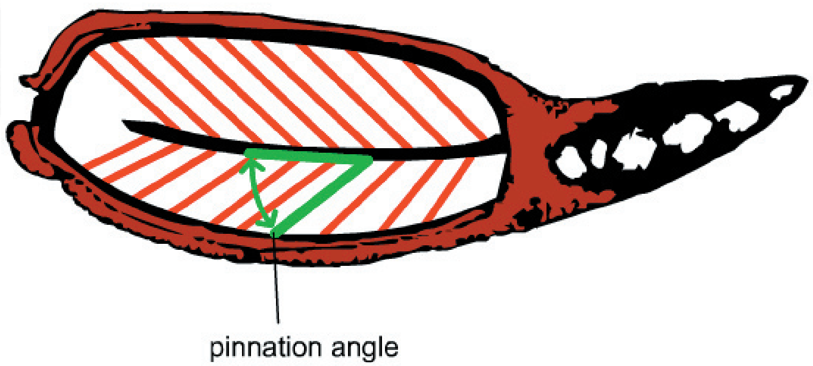
Muslces

Curiously, the muscles that move the dactyl up ad down do not lie within the dactyl, but lie in the next limb segment closer to the body (the propus). This is true of the moveable segments of all cruslacean walking legs. On e set of muscles pulls the opener apodeme, another much larger set pulls the closer apodeme. Unlike in vertebrates, however, the muscles extend from both sides of the tendon (apodeme).





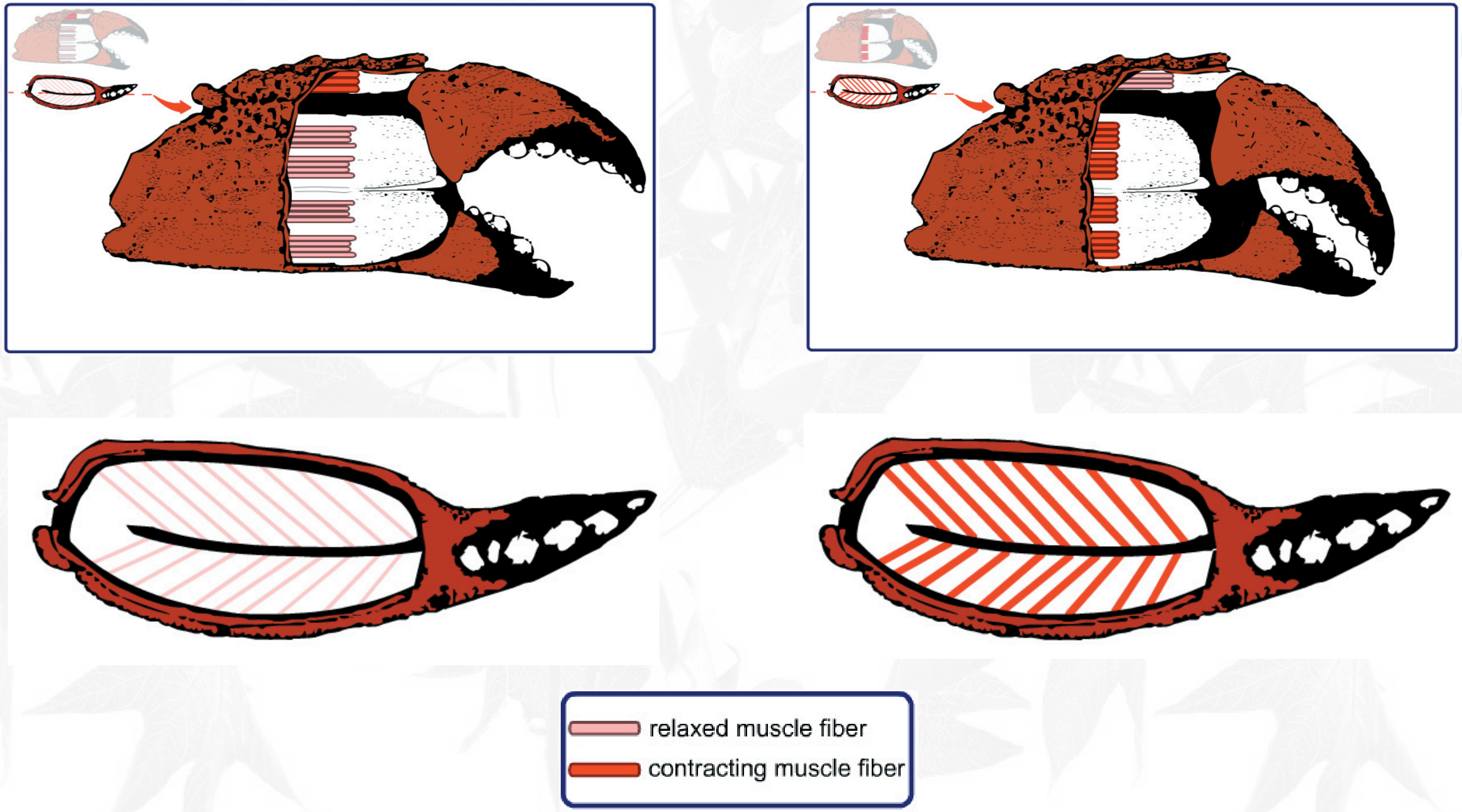
Opener Muscles attached to the opener apodeme extend the tip of the leg or open the claw. Notice how the opener and closer muscles are more similar in size in a walking leg than in a fully chelate leg. In a claw, the opener, apodeme and muscles are relatively much smaller. In a subchelate leg, this difference is not as great.



Closer Muscles attached to the closer apodeme retract the tip of the leg or close the claw. Notice how the closer muscles and apodeme are much larger in a fully chelate leg than in a walking leg.

Claw Motion

Claws have evolved independently in a remarkable number of arthropod groups. Although they may look like complex structures, they are actually very simple pinching or grasping machines that have only one moving part (the dactyl with its attached tendons, the apodemes). Because they are so distinctive, it is easy to forget that a claw is just a specilisation of the last two segments of a normal crustacean leg: dactyl and propus.



Claw Evolution

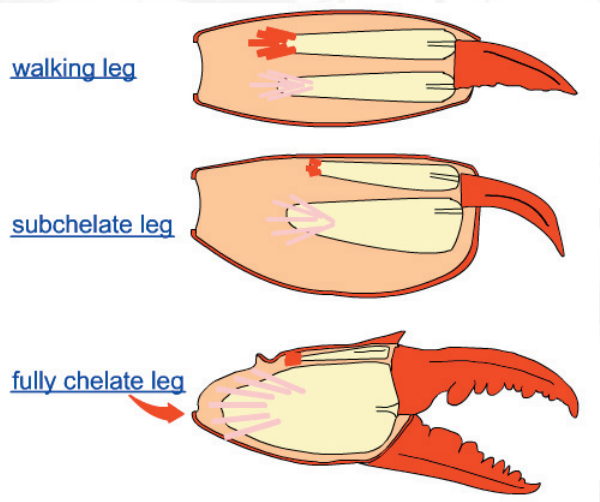
From leg to Claw : Believe it or not, claws are nothing more than specialised ends of walking legs. The fully chelate form evolved from a normal walking leg by way of a sub-chelate intermediate form. Many living crustaceans still possess sub-chelate legs.

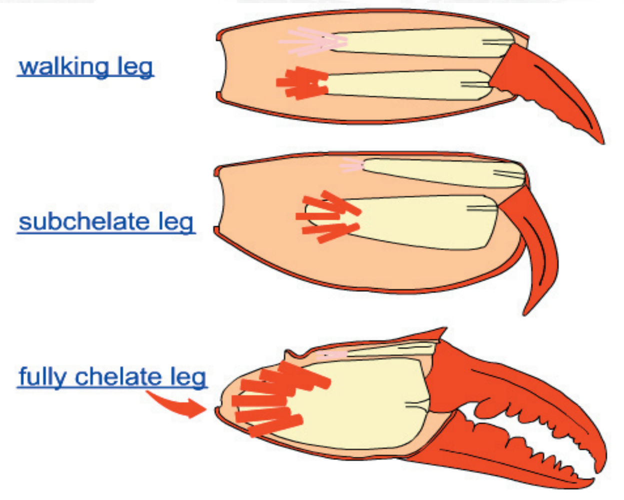
Evolution Stages:

Walking Leg: In normal crustaceans walking legs, the terminal dactyl segment is typically small and positioned in the middle of the end of the propus, and the two apodemes, and their association muscles are similar in size. The propus dactyl allow crustaceans to have a better hold to the substratum.

Subchelate Leg: In a subchelate leg, the distal end of propus is inflated and blunt, the dactyl sits to one side of this blunt end, and the apodemes are different size (the closer or larger). Notice, though, that the fixed finger is absent. This subchelate form still works efficiently to grasp and hold objects between the dactyl and the lower blunt margin of the propus.

Fully Chelate Leg: A leg becomes fully chelate when, instead of having a blunt lower margin, the propus develops a rigid, elongated projection called the fixed finger. Here the dactyl closes against the fixed finger, like a true pincer, instead against the blunt end of the propus. Notice too how the closer apodeme becomes much larger than opener apodeme.





Comparing the Parts :

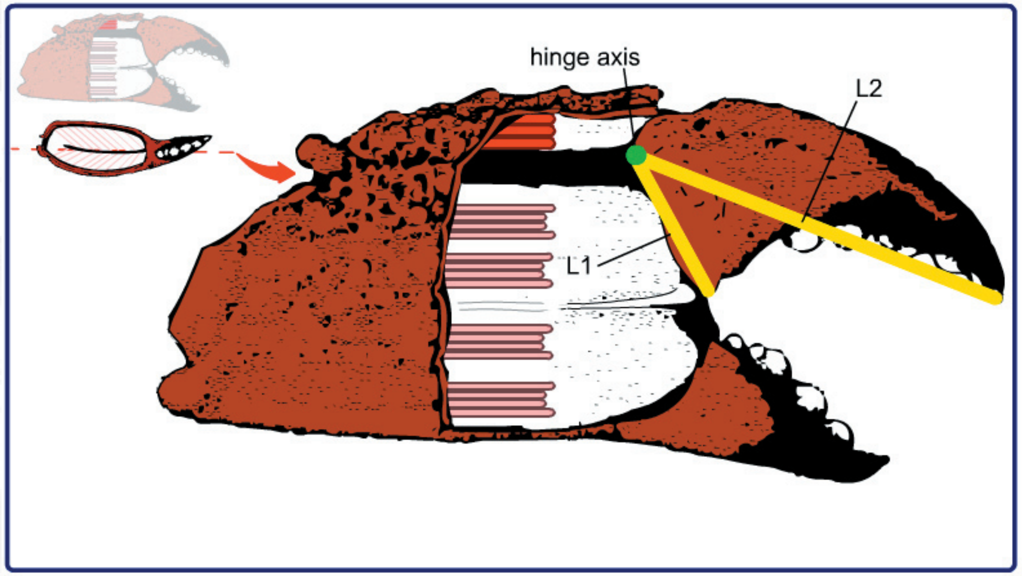
Dactyl: The dactyl is the terminal segment of the crustacean leg. In a fully chelateleg, or claw, it becomes more moveable finger.

Propus: The propus is sub-terminal segment of the crustacean leg. It houses the muscles that will move the dactyl. The fixed finger of a fully chelate is an out growth of the propus.

Fixed Finger: A fully chelate leg appear to have two fingers, but notice that only one can move. The fixed finger is just an elongated projection from the lower margin of the propus against which the movable finger may press. In a sub chelate leg, the movable finger simply presses against blunt lower margin of the propus.

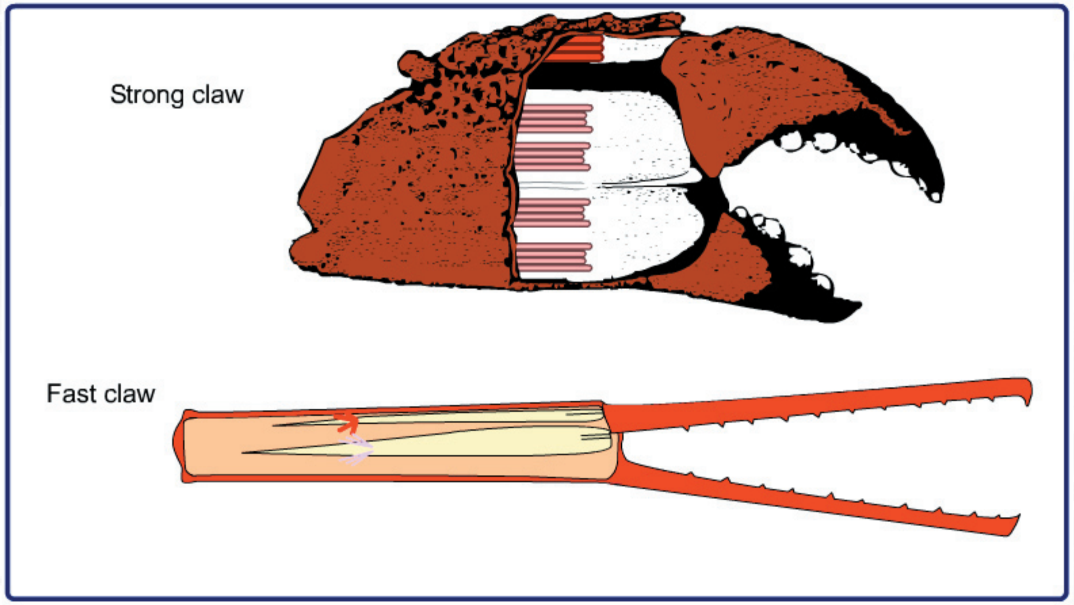
Claw Mechanics

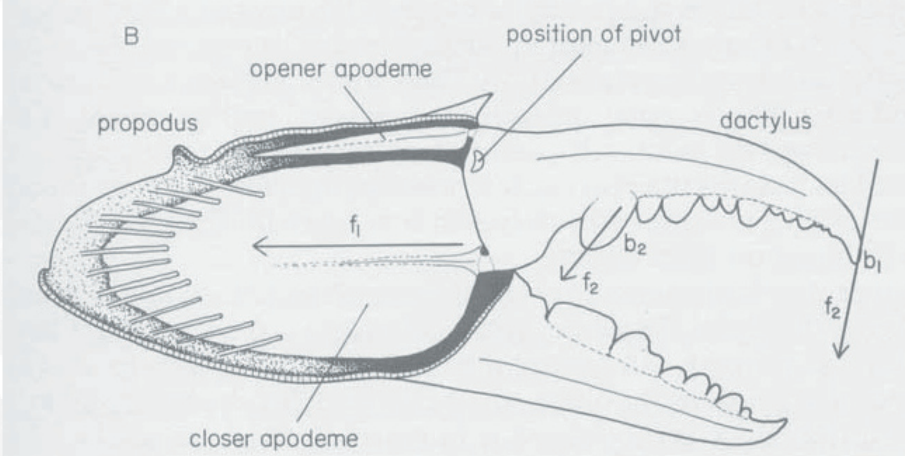
A claw is wonderfully simple lever system. Large muscles apply a force to one lever (L1) transmitted to the tip of the dactyl by a second lever (L2) as the dactyl rotates about the hinge axis. Among claws of different shape, as L1 gets longer, or L2 gets shorter, the dactyl tip applies more force but **moves more slowly.**



The ration **L1/L2** is the **mechanical advantage** of the claw.

Can you see why a claw cannot be simultaneously 'strong' (generate high force at the tip) and move 'fast' (move quickly at the tip)? Some more explainations on this you can see in the next page.





Crab claws come in a remarkable variety of forms. Some are considered strong claws because they have a higher mechanical advantage and can generate higher crushing forces for attacking hard-shelled prey. ‘Strong claws also have blunt, molar like teeth. Others are considered fast claws because, although they have lower mechanical advantage, the tip of the dactyl can close more quickly to better catch the fast-moving prey with their pointed teeth.

Closing Force proportional to musle cross section area (MCA) and also it is also a function of Mechanical Advantage (MA).

Some of the researches specified that about 256 Newtons of force is produced by a single crusher chelae.

CASE STUDY 4

BIRD FEET

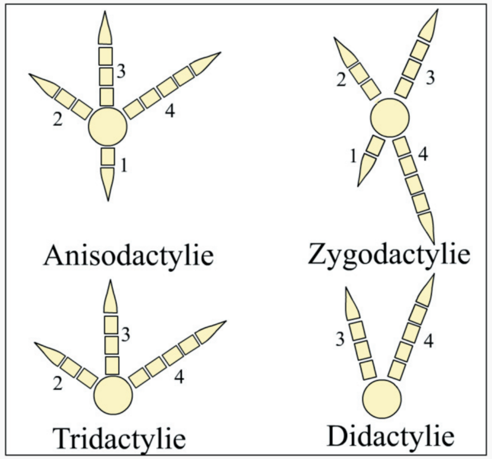
The use of the term “feet” is actually a bit misleading. What we commonly think of as a bird’s foot is actually just its toes. The remainder of its anatomical “foot” actually extends one bone further up its leg, so birds essentially spend their lives on their toes. In any case, birds use these appendages for a variety of activities including perching, running, wading, swimming and adjusting their eggs in their nest.

Bird feet have four toes usually tipped with claws, but the position of the toes varies. Most birds have three toes forward and one backward, which is helpful in perching and holding a bird in place while it sleeps. (When a bird rests, its body slumps and tightens a tendon behind its heel that pulls the bird’s toes together, clamping its foot to its roost). Woodpeckers, on the other hand (or should that be foot?), usually have two toes forward and two back. This helps them to hold onto the bark as they move up and down a tree.

Birds of prey, or raptors, such as hawks, eagles and owls, have long, curved sharp claws called talons that help them catch and kill their prey. The feet of these aerial hunters also possess a ratchet-like locking system of muscles and tendons that prevents their grip from slipping. Many owls have another special adaptation, feathered feet that baffle sound, allowing them to silently approach their quarry. And osprey have spiked, scaly pads on the bottoms of their feet that enable them to grip slippery fish with greater ease.

Meanwhile, shorebirds have long, thin toes that eqully distribute their weight across a greater surface area. This prevents them from sinking into the soft, mucky surfaces upon which they walk in much the same way that snowshoes prevent people from breaking through the snow. As with many other water birds, shorebirds’ hind toes are often significantl smaller than the other three and join the leg at a higher point so that they do not make contact with the ground.

Anisodactyly



Anisodactyly is the commonest arrangement of digits in birds, with three toes forward and one back. This is common in songbirds and other perching birds, as well as hunting birds like eagles, hawks, and falcons.

Syndactyly (birds)

Syndactyly in birds is like anisodactyly, except that the third and fourth toes (the outer and middle forward-pointing toes), or three toes, are fused together, as in the Belted Kingfisher Ceryle alcyon. This is characteristic of Coraciiformes (Kingfishers, Bee-eaters, Rollers, and relatives).

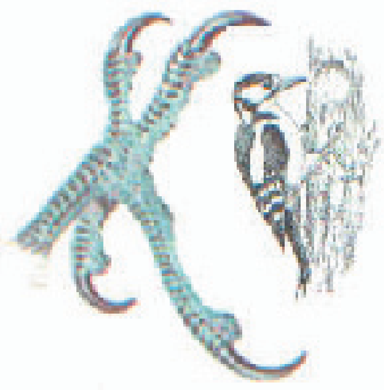
Zygodactyly

Zygodactyly is an arrangement of digits in birds, with two toes facing forward (digits 2 and 3) and two back (digits 1 and 4). This arrangement is most common in arboreal species, particularly those that climb tree trunks or clamber through foliage. Zygodactyly occurs in the woodpeckers, including flickers, nuthatches, and parrots.

Heterodactyly

Heterodactyly is like zygodactyly, except that digits 3 and 4 point forward and digits 1 and 2 point back. This is only found in trogons.

Special Feet of Wood pecker :

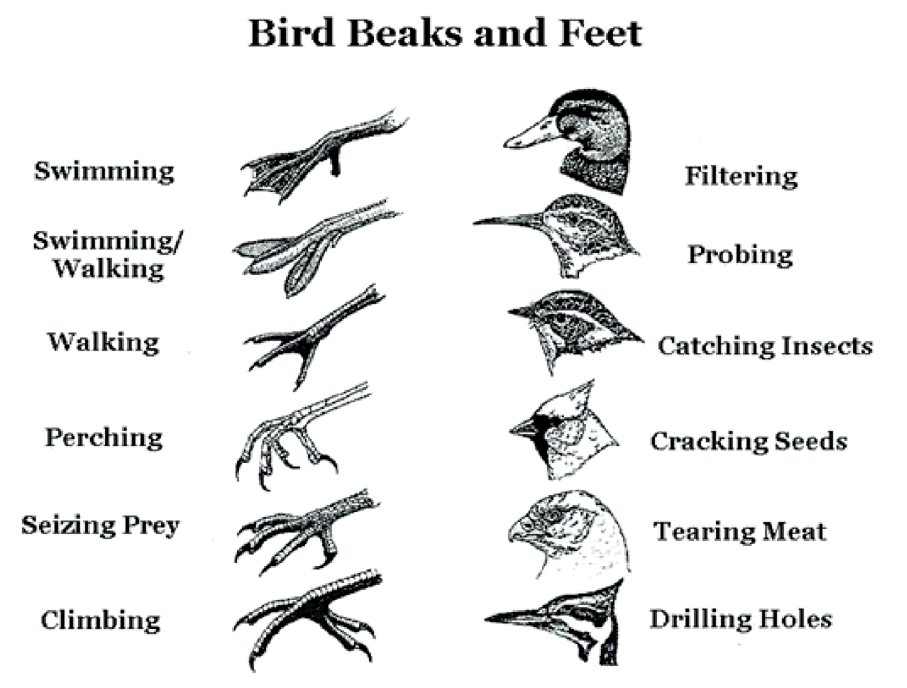


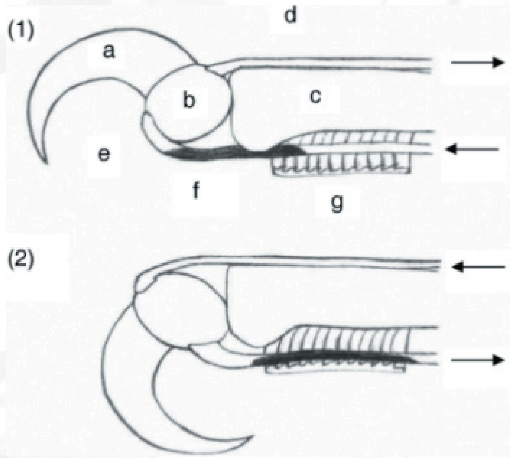
Woodpecker's feet have adapted to climbing and gripping tree bark. Having two toes facing forward and two facing back is called zygodactylous.

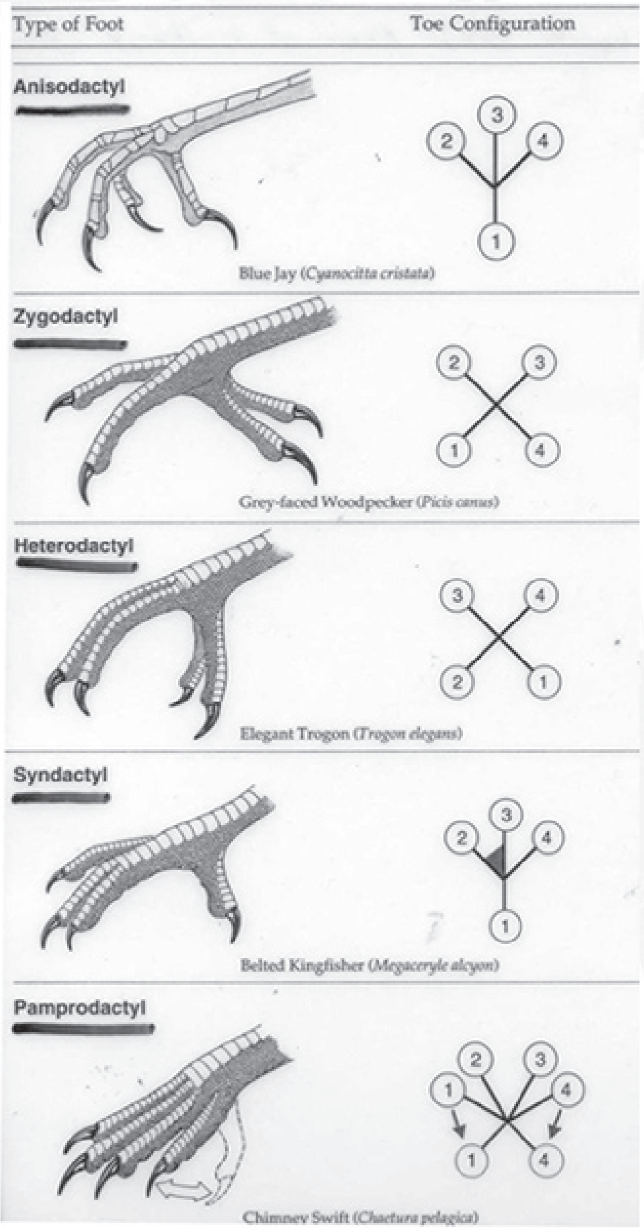
Woodpeckers also have strong tail feathers which they use to brace themselves on trees while pecking for insects.

Thailand has 36 species of woodpecker. It's easy to pick out woodpeckers in flight. They fly in a pulsing movement. Meaning, they'll flap for a bit, then glide with their wings closed.

Digital tendons form a mechanical-locking mechanism in many birds that must maintain a degree of grip force, including perching, hanging, tree-climbing, and raptorial species. In raptors, powerful hindlimb muscles produce a strong grasp, and a tendon locking mechanism (TLM) helps sustain grip force. The components of the digital TLM include a 'textured' pad on the ventral surface of each flexor tendon that contains thousands of minute, rigid, well-defined projections called tubercles (see figure below). The neighboring portion of the surrounding tendon sheath contains a series of transversely running plicae (folds) that often have a proximal slant (i.e. towards the base of the toe). When the flexor tendons are pulled taut, and the digits flexed, the tubercle pad moves proximally over the stationary plicae on the sheath. When resistance to digital flexion is met, the locking elements intermesh and engage and the friction produced prevents slippage of the tendons. This permits digital flexion to be maintained with little or no muscular involvement (Einoder and Richardson 2006).







Topography of Foot - Toe Arrangements

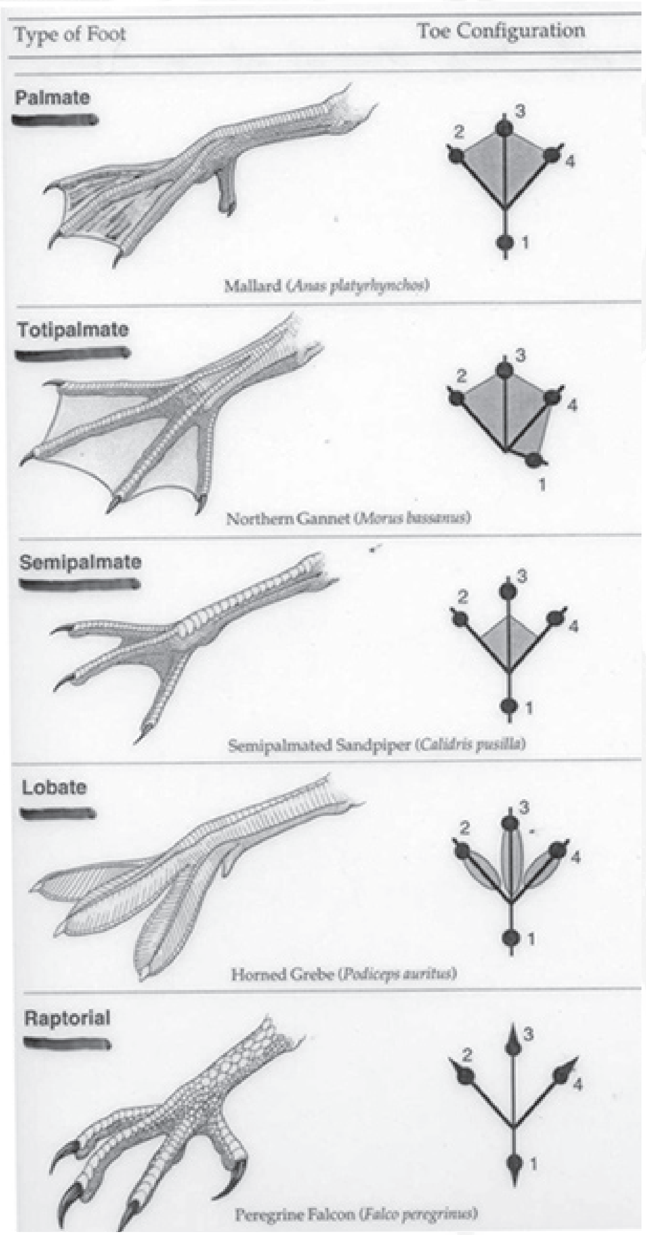
The anisodactyl foot is most common arrangement of the avian toe. Song birds and most other perching birds have this feet.

The zygodactyl foot is other most common toe arrangement in perching birds. It is found in the Osprey, most woodpeckers, owl, cuckoos, most parrots

The heterodactyl foot closely resembles zygodactyl foot, but in heterodactyl the second toe is reversed, to aid the short, weak first digit in gripping branches. Heterodactyl foot is found in the Tragons.

In the syndactyl foot the second and third digits are fused for much of their lenght. This food is common in Order Coraciiformes, kingfisher, hornbills.

In the pamprodactyl foot the first and fourth digits pivot freely forward and backard. Some swifts have pamprodactyl feet. They often rotate all four toes forward and use their tiny feet as hooks to hang while roosting on the walls of chimneys, caves or hollow trees.



Topography of Foot - Toe Arrangements

In the palmate foot only the anterior digits (2,3 and 4) are included within the webbing. This is the most common type of webbing and is found in ducks, gease, swans, etc.

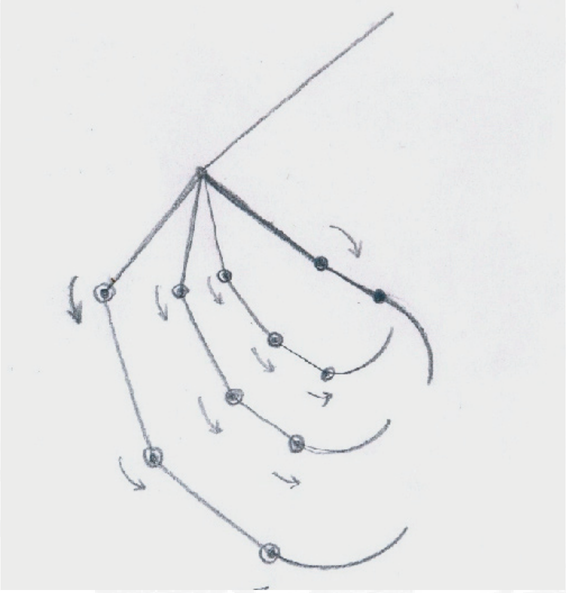
In Totipalmate all the four digits are included within the webbing. Totipalmate feet are found in gannets and boobies, cormorants and pelicans, all highly acqatic group.

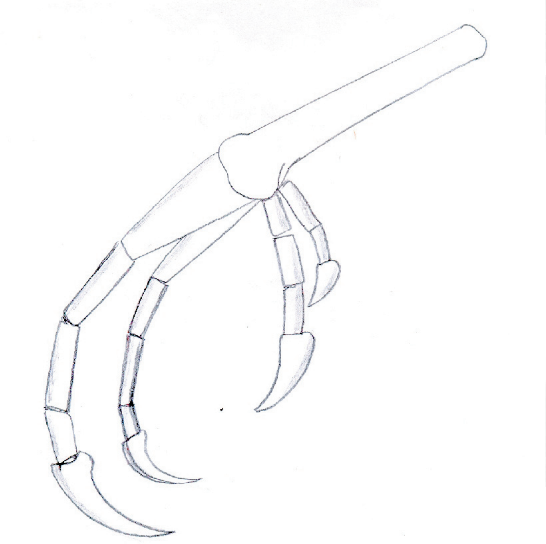
Semipalmate means small web is present between anterior digits (2,3 and 4). Semipalmate feet are found in some sandpiper and plovers, all grouse and some domestic breeds of chicken.

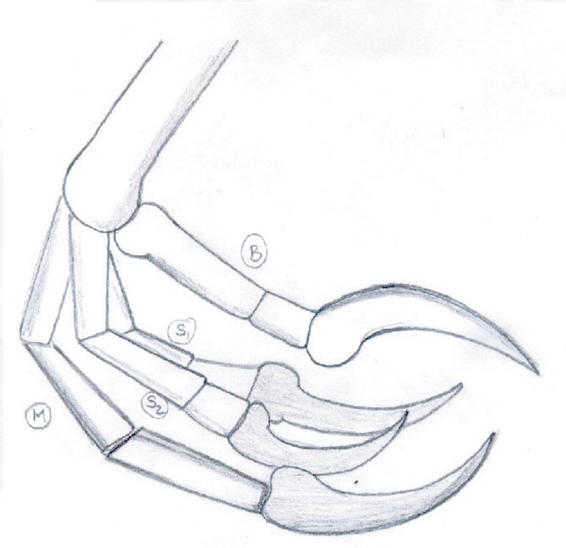
In the lobate foot the anterior digits (2,3 and 4) are edges with lobes of skin that expand or contract as the bird swims. Lobate feet are found in the grebes, though some palmate footed ducks have lobes of skin on the hallux.

The Raptorial foot is charecterised by long, strong digits armed with heavy claws for catching, holding and kiling preys animals. Raptorial feet are found in kites, hawks, eagles and falcons.

The images in this page shows the skeletal views of the bird foot.







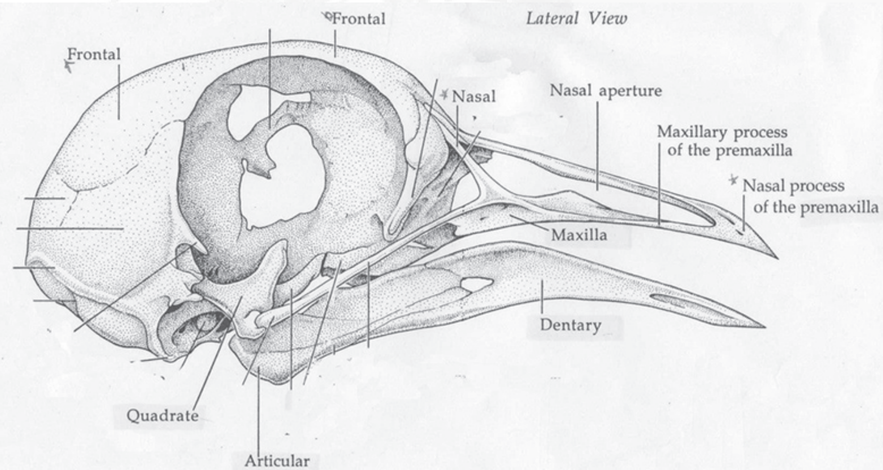
CASE STUDY 5

BIRD BEAK

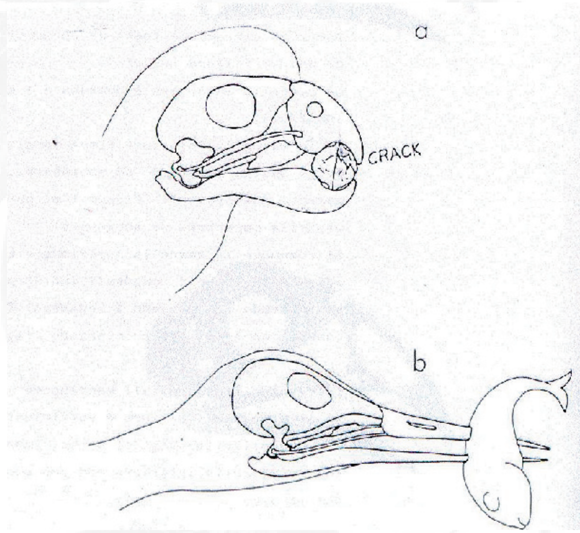
A skull is a machine — one designed by nature nearly 500 million years ago to protect the brain and sensory organs in vertebrate animals. A model of mechanical efficiency, each of the skull's features is built to support specific functions, including food procurement and processing, optimal sensory intake, and impact absorption. Based on the architecture of an animal's skull, scientists can deduce many of its dietary and social patterns.

The skull of bird exhibits tremondous diversity in the form and function. Some of this diversity reflects the multiple roles played by the skull: feeding, housing of sense organs, protecting the central nervous system, and in some cases, functioning of locomotion or social display. Much of the diversity reflects features related to feeding. As a feeding organ the skull is important in obtaining, processing, and ingesting food. It is therefore subject to a number of special mechanical requirements, and all vertebrates exhit some adaptations to meet the requirements, and all vertebrates exhibit some adaptations to meet the requirements of feeding. On the other hand, the skull exhibits a common basic patter across all terrestrial vertebrates. The tetrapod skulll in early development is remarkably similar, and the same majore bone, muscle and nerve groups are present in all groups. The similarity is often attributed to common developmental patterns.

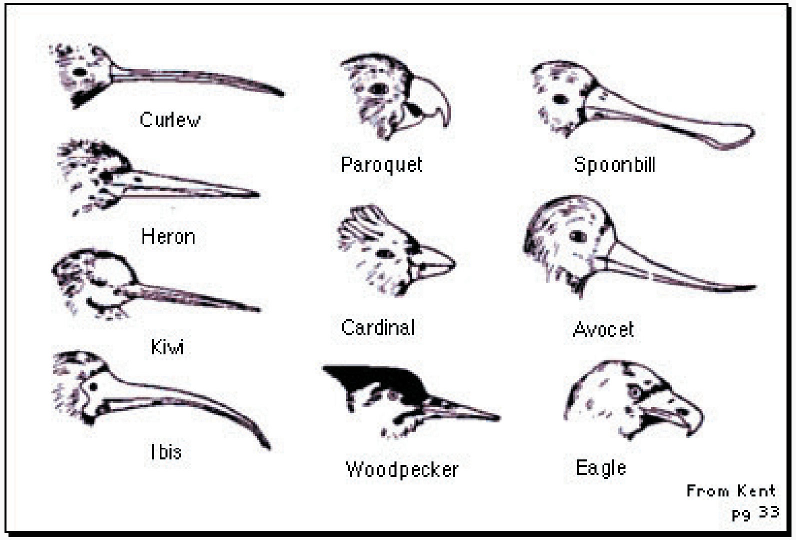
The bird skull, like the skull in snakes and lizards, includes regions of intracranial mobility. Like snakes, but unlike lizards, it is well established that intracranial movements are an integral part of

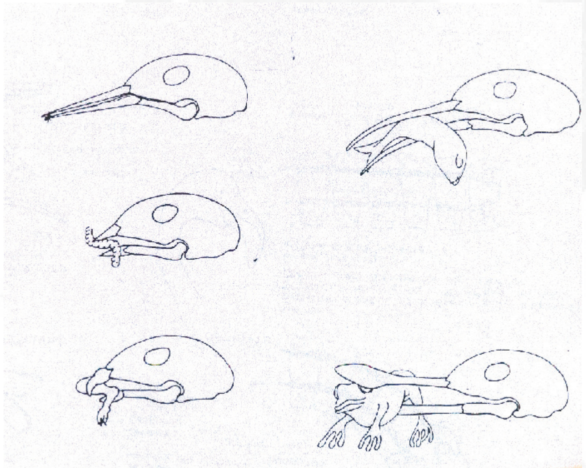


The basic patternn of the avian skull has been summarised by Bock (1964), who presents a detailed mechanical analysis, and Buhler (1981) and Zusi (1993) who present reviews of the functional diversity. Avian kinesis involves anterior sliding of a palatal unit, composed of the palatovomero complex and juga, pterygoid, and quadrate bones, relative to a solid braincase as shown in figure.



According to habitat birds have adopted different shapes of the bird beak. The images shows some of the variety of birds with different beaks according to their eating habits.

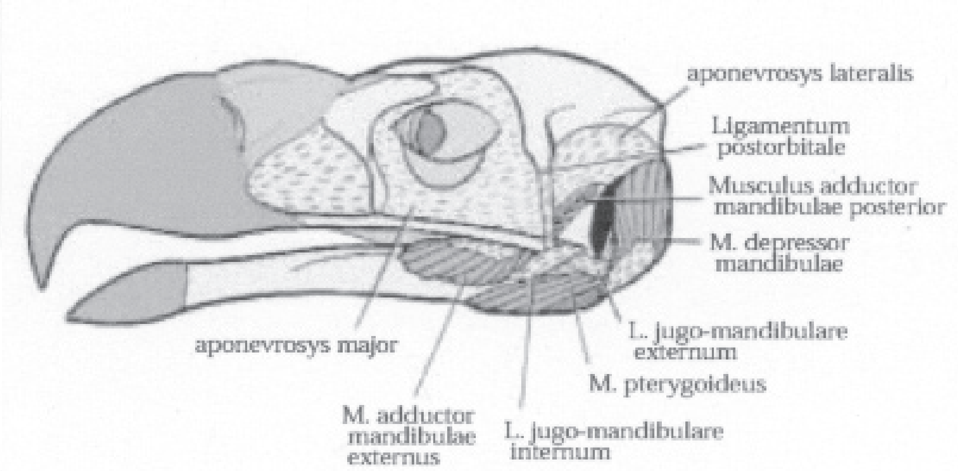




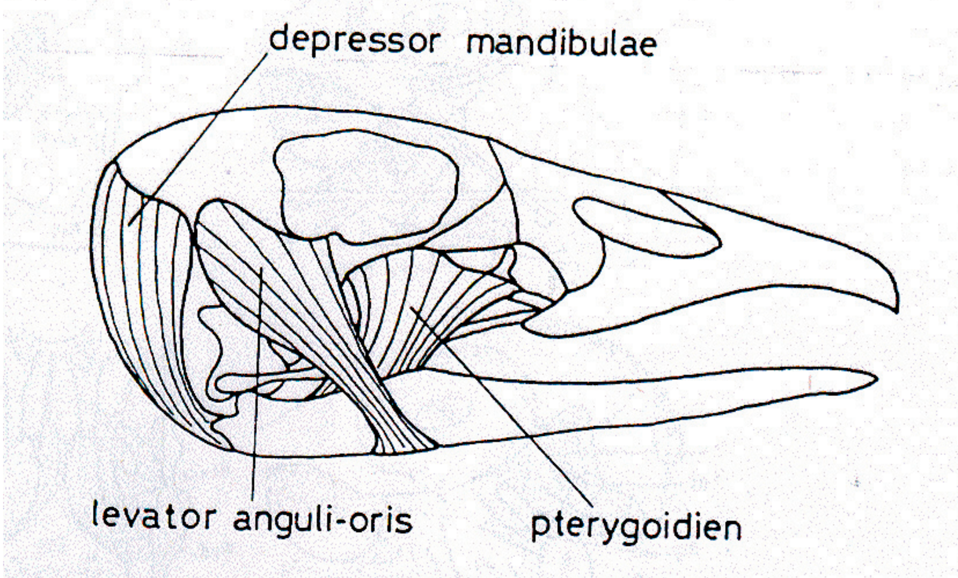
Instead of being fused to the skull, some bird beaks are connected to the skull with ligaments, so both the top and bottom portions can move. This adaptation helps predatory birds avoid beak breakage while holding wriggling prey in their mouths. It also allows macaws to crack open nuts without transferring that pressure to the skull.

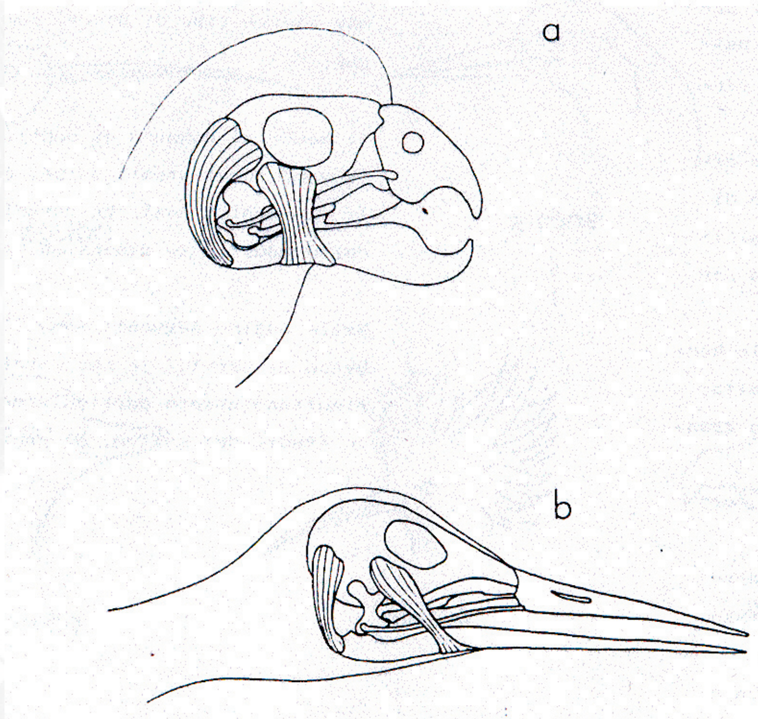
The movement for cranial kinesis is generated by a complex mechanism in the skull. This mechanism includes the quadrates, pterygoids, palatines, jugal bars and all associated muscles and ligaments. The closely associated pterygoids, palatines and vomer will be referred to as the pterygoid–palatine complex (PPC; Gussekloo and Zweers, 1999). Bock (Bock, 1964) has described the kinematics of the quadrate and PPC in cranial kinesis for a neognathous prokinetic bird as follows: rostro-dorsal rotation of the quadrate results in a rostral movement of the pterygoids, which transfers the movement onto the palatine, vomer, maxilla and premaxilla, resulting in elevation of the upper bill. A caudo-ventral rotation of the quadrate, and a subsequent caudal movement of the pterygoid, palatine, vomer, premaxilla and maxilla, achieves depression of the upper bill.

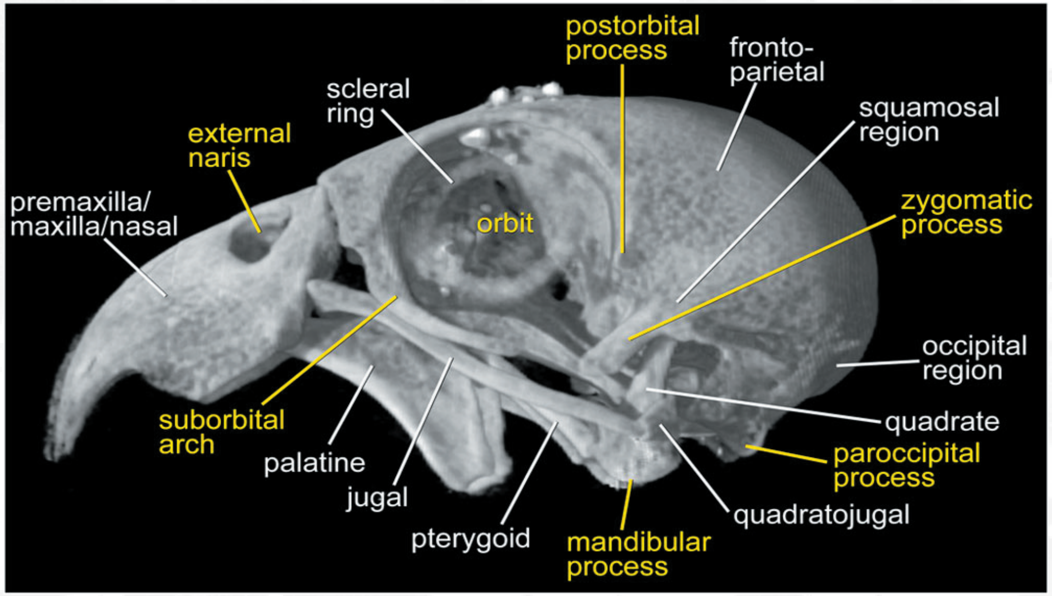
Muscular System in a Bird Skull

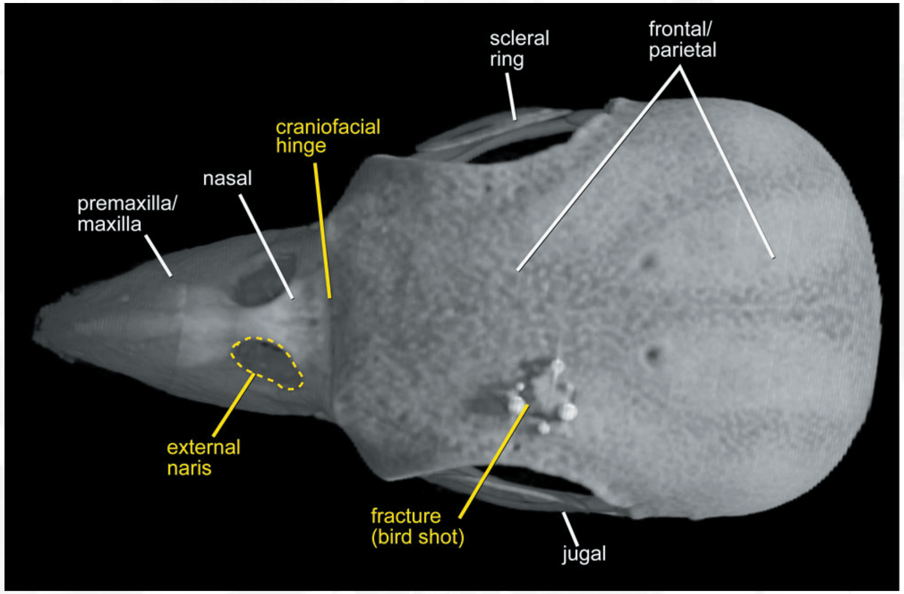


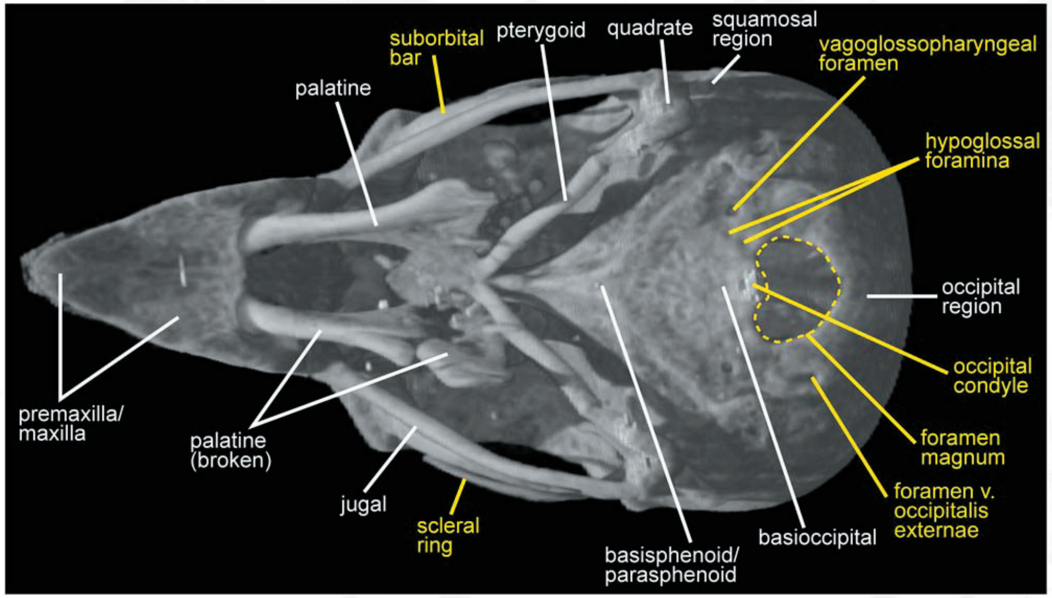
Muscles, situated at the back of the head, generate crushing forces that are transferred to food by means of the upper and lower beak.



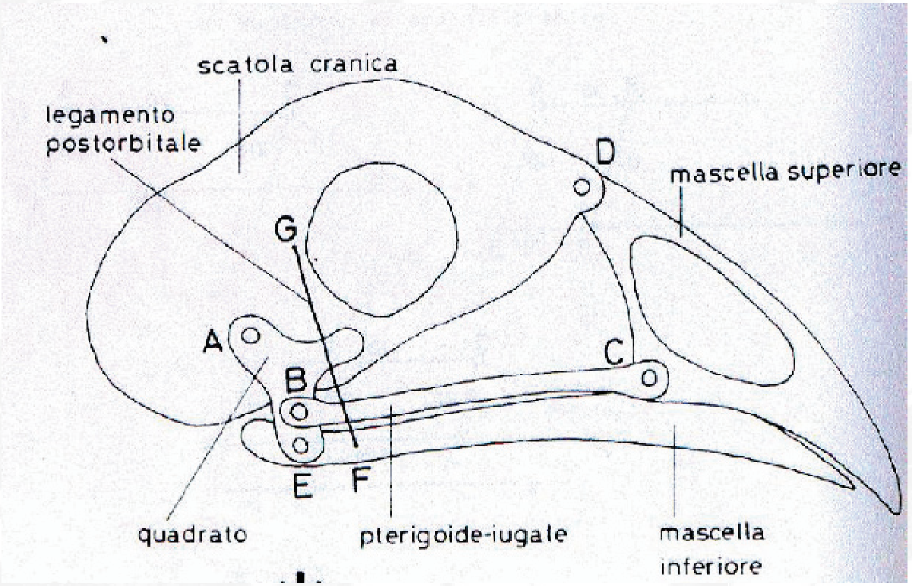



postorbital process
fronto-parietal
scleral ring
squamosal region
external naris
premaxilla/ maxilla/nasal
orbit
zygomatic process
occipital region
quadrate
suborbital arch
palatine
paroccipital process
jugal
quadratojugal
pterygoid
mandibular process


scleral ring
frontal/ parietal
craniofacial hinge
nasal
premaxilla/ maxilla
external naris
fracture (bird shot)
jugal


suborbital bar
pterygoid
quadrate
squamosal region
vagoglossopharyngeal foramen
palatine
hypoglossal foramina
occipital region
occipital condyle
premaxilla/ maxilla
palatine (broken)
foramen magnum
jugal
scleral ring
foramen v. occipitalis externae
basisphenoid/ parasphenoid
basioccipital


Copyright Bone Clones® 2004

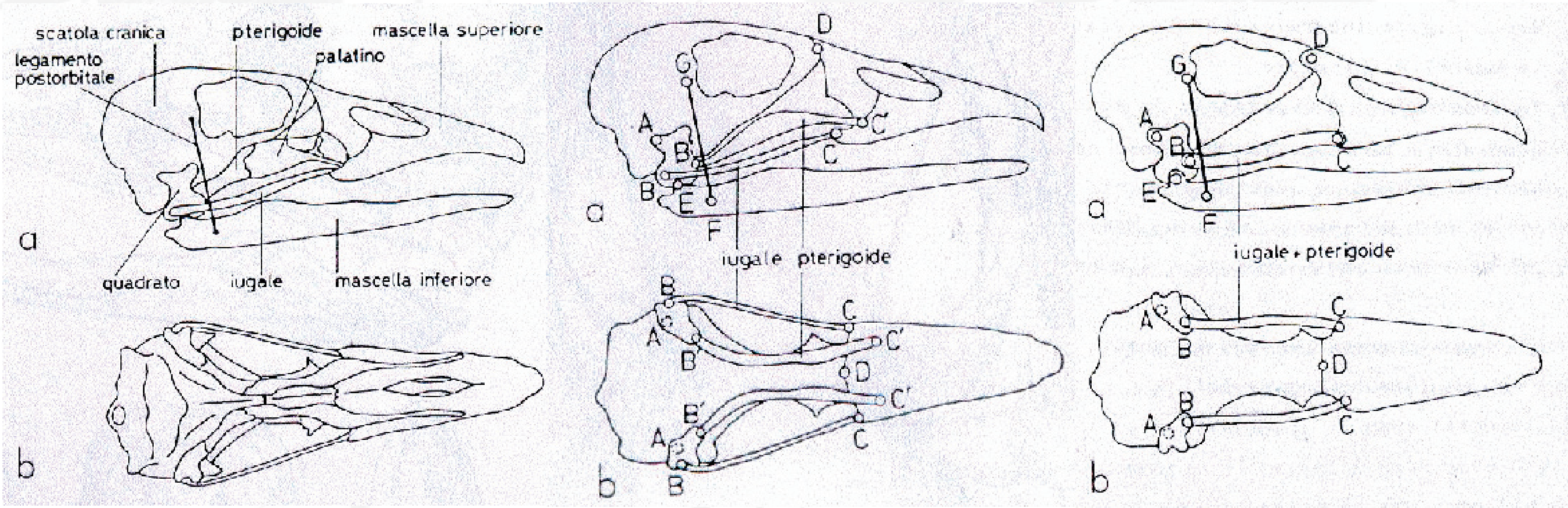


Outline sketches of the bird skull, below three figures shows (from left hand side)

1. Sketch represents all bones in a bird skull

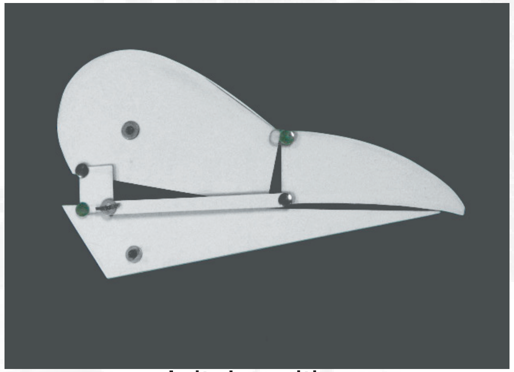
2. Sketch represents side links and bottom links of the skull

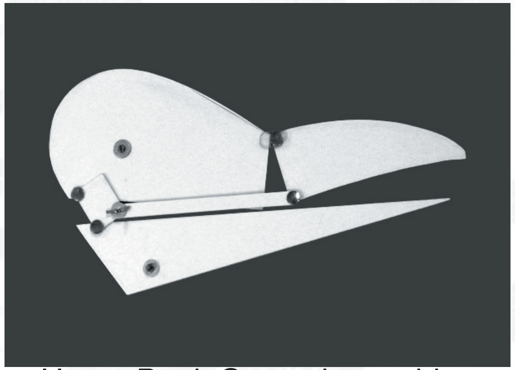
3. Sketch represents side links

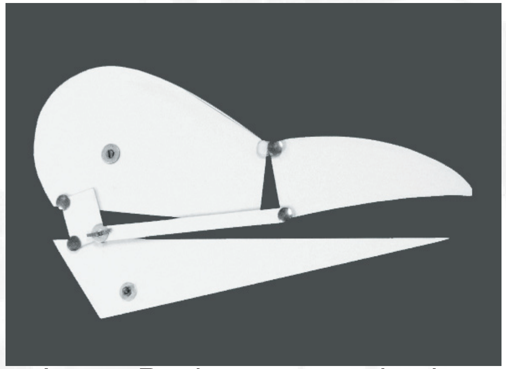


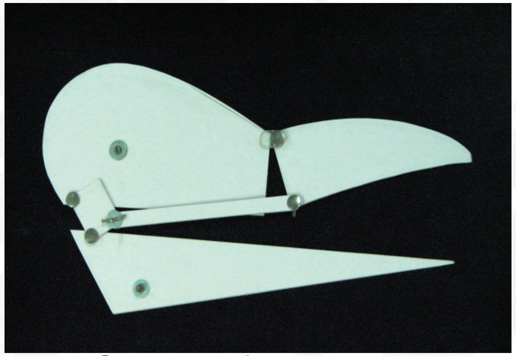
Analysis

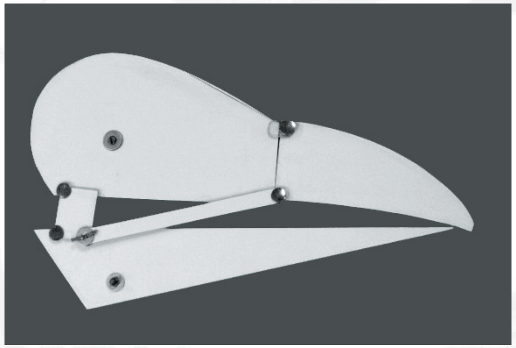
Each element of the skull is studied and a 2D model is made to study further the exact movements of all parts.

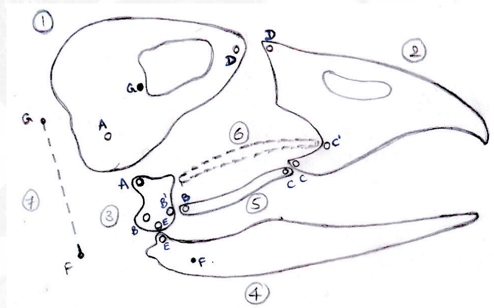

Inital position

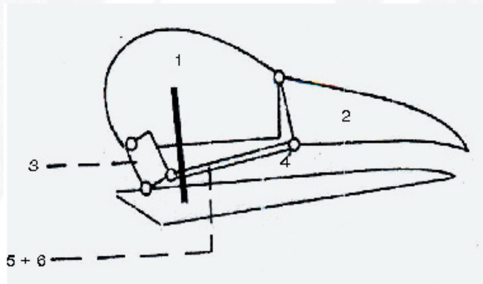

Upper Beak Opens by pushing


Lower Beak starts opening by Lower muscle


Opening of Lower Beak


Closing of Lower and Upper beak

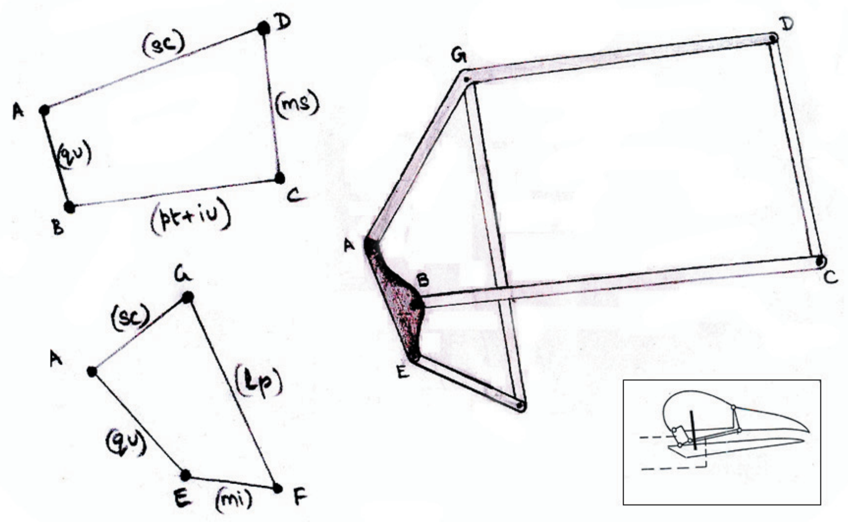


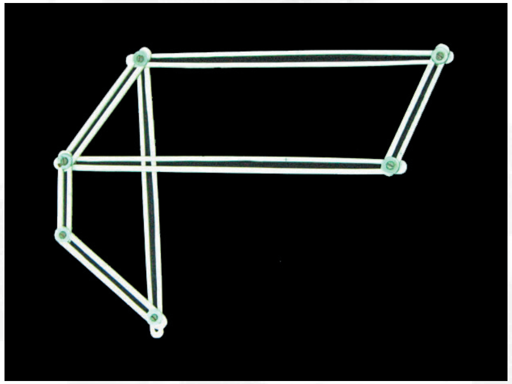


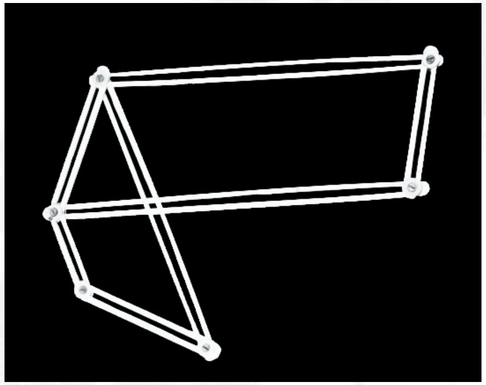
1. Brain Case
2. Upper Jaw
3. Quadrate
4. Lower Jaw
5. Jugal
6. Ptregoid
7. Post orbital Ligament

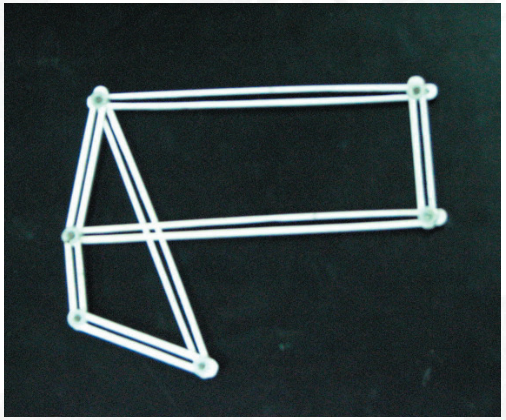
Analysis

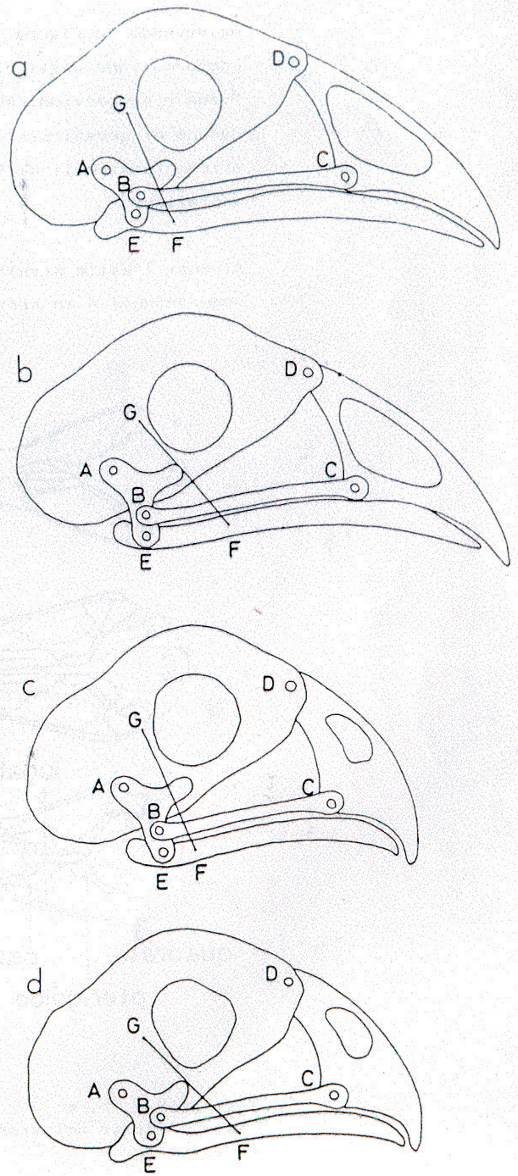
To further simplify the 2D elements converted into links.











Mechanisms of jaw function in birds and study of the complex patterns of motion during feeding have been the focus of numerous studies investigating the functional morphology of feeding. The functional diversity of bird skulls is largely a result of the fact that birds possess cranial kinesis, in which the upper bill can move relative to the braincase.

Most birds have a prokinetic skull in which the upper jaw pivots around the nasal-frontal hinge (Bock, '64). This hinge occurs in an area of lattening of bone where the nasal and premaxillary bones meet (Fisher, '55; Zusi, '84). Other species exhibit rhynchokinesis in which mobility occurs within the nasal bone. These regions of intracranial mobility allow the complex opening, closing, and grasping motions of the beaks of birds.

Bock ('64) proposed a mechanism for kinesis in which the upper and lower jaws are mechanically coupled. By this model, the motions of upper and lower jaw are dependent on one another. In addition, the lacrimo-mandibular ligament may also physically couple the upper and lower jaws (Bock, '64; Zweers, '74). The physical linkage through the postorbital ligament is thought to operate in the following manner (Bock, '64): when the mandible is depressed, the mandibular attachment of the ligament tends to move away from the attachment on the brain case; this puts the postorbital ligament into tension. The inextensible ligament prevents this movement. Consequently its mandibular attachment becomes the fulcrum of a lever system. This results in the swinging forward of the quadrate, which raises the upper jaw. The mandible can be depressed only as the quadrate swings forward. The upper jaw can be elevated without a correlated depression of the mandible, but the mandible cannot be depressed without the upper jaw being raised. By this model, the postorbital ligament must be placed into tension before the upper and lower jaw can be physically linked during jaw opening. The postorbital ligament does not transmit forces during jaw closing.

In this report, we propose a model of kinesis that is founded on principles of linkage mechanics and the cranial morphology of the avian skull. Jaw morphology in birds suggests that a double fourbar linkage physically connects the upper and lower bills. If a double four-bar linkage is present, then movements of upper and lower bills will be correlated during jaw opening. The arrangement of bones and ligaments of the skull forms the basis for quantitative modeling of jaw function. The models are generally applicable to the possible types of cranial kinesis found in birds, and they allow simulations of jaw movements under four sets of assumptions, including both coupled and uncoupled kinesis with force transmitted through either the jugal or pterygoid bones. Predictions of jaw movement are simulated through the use of a computer animation, the basis for which is provided by morphometrics of cranial anatomy. To test the accuracy of the model, quantitative predictions then are compared with kinematic observations of jaw movement.

The mechanics of jaw opening in white-throated sparrows were modeled using two major models: a coupled mechanism in which the postorbital ligament functions to link upper and lower jaw motions, and an uncoupled model in which upper and lower jaw movements are independent.

Both the coupled and uncoupled models were tested under two assumptions:

(1) the jugal transmits force from the quadrate to the upper jaw, or
(2) the pterygoid transmits force from the quadrate to the upper jaw.

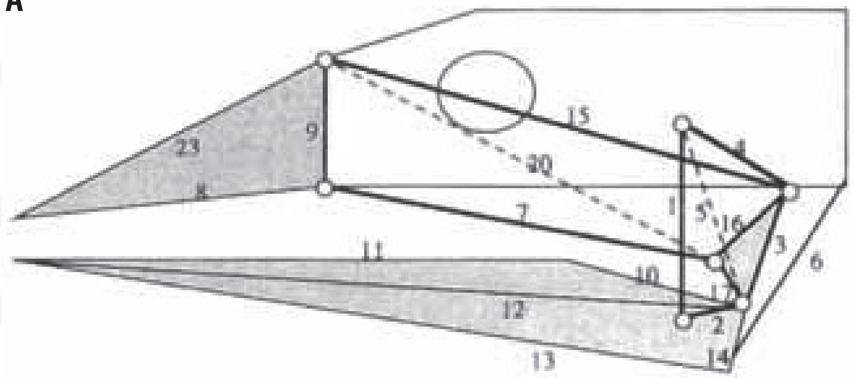
Thus four models were generated (coupled-jugal, coupled-pterygoid, uncoupledjugal, uncoupled-pterygoid).

All models tested here use four-bar linkage theory from mechanical engineering. A four-bar linkage is a mechanism composed of four co-planar links connected by joints to form a closed rhombohedron.

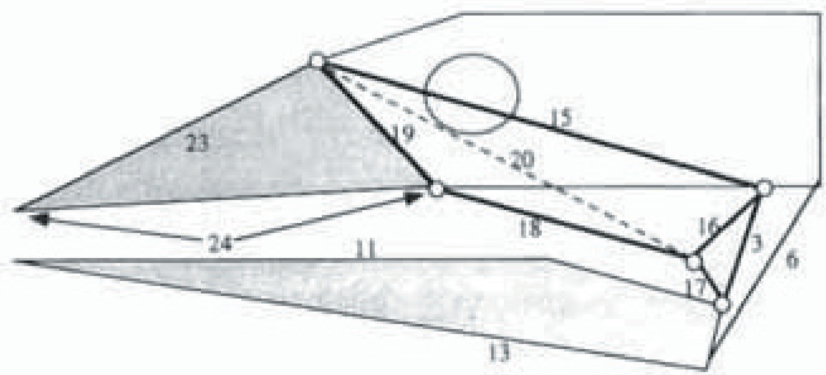
Analysis

It is found that the functioning of the skull happens with two mechanisms
A. Coupled Four Bar Mechanism
B. Un-Coupled Four Bar Mechanism

A

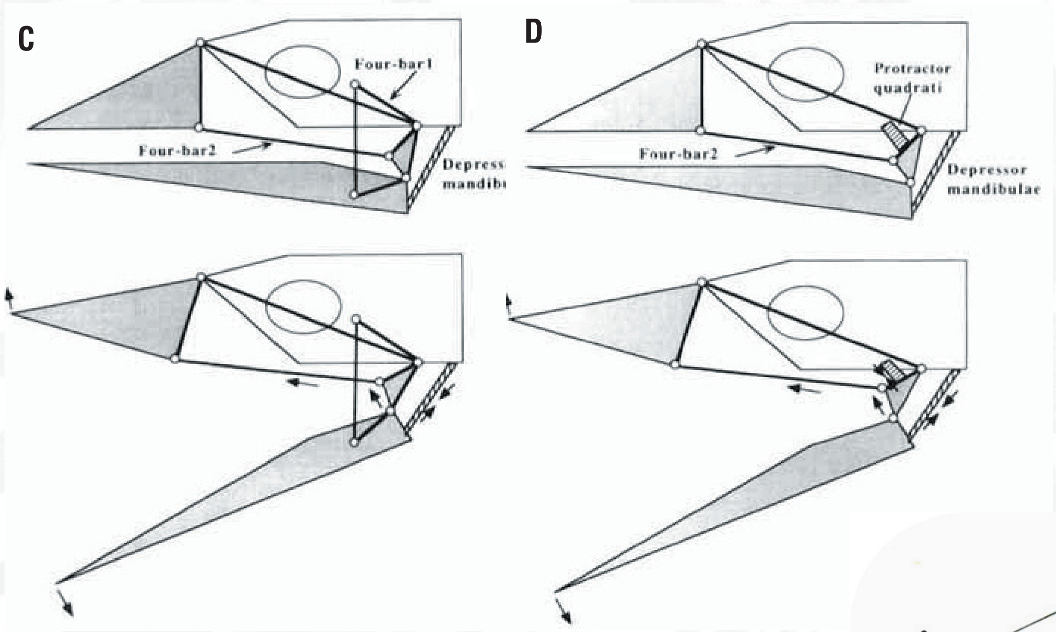


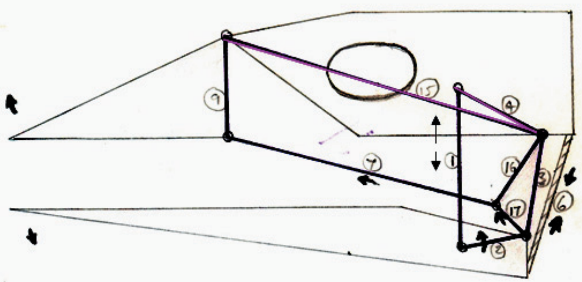
B



A. Mechanical diagram of the coupled mechanism under assumption that the jugal transmits force from quadrate rotation to the upper jaw. Links (1,2,3, and 4) include the quadrate rotation linkage through the postorbital ligament, lower jaw, quadrate posterior edge, and a fixed link from quadrate to postorbital ligament origin. Links (7,9,15, and 16) involve the jugal, posterior edge of the upper jaw, a fixed link from the quadrate to the dorsal flexion zone, and the quadrate anterior edge.

B. Mechanical diagram of the jaws linkage mechanism under assumption that the pterygoid transmits force from quadrate rotation to the upperjaw. Quadrate rotation linkage (not shown) is the same as in B; force transmission through the pterygoid include links (15, 16, 18, and 19) involving the fixed link from the quadrate to the dorsal flexion zone, quadrate anterior edge, pterygoid, and posterior edge of the upper jaw. See Table 1 for morphological measurements corresponding to all linkage numbers in B and C. Scale bar = 10 mm.





Coupled Mechnism

(Two Four Bar Mechanisms)

Number of Inputs Required : 2

Number of Muscles : 2

Degrees of Freedom = 3 (n-1) - 2j - h

n = Number of Links in the mechanism

j = Number of Lower pairs (Surface contacts)

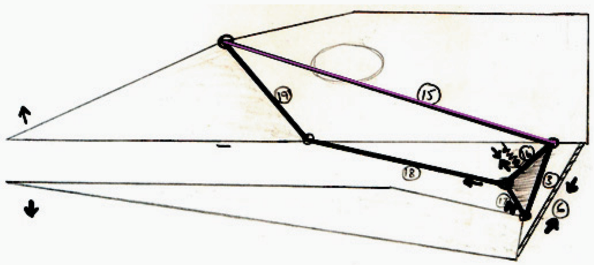
h = Number of Higher pairs (Point/line/curve contacts)

UnCoupled Mechnism

(One Four Bar Mechanisms)

Number of Inputs Requred : 1

Number of Muscles : 2



* Links 4 and15 are fixed

Coupled Model

The coupled models combine two integrated four-bar linkages for jaw opening and an additional linkage involved in jaw closing. The first linkage (Fig. A in next page) is the quadrate rotation linkage that involves the postorbital ligament (Fig. A, link 11, the lower jaw (link 2), the quadrate (link 31, and a fixed link from quadrate to postorbital ligament origin (link 4). The second linkage (Fig. A) is the upper jaw rotation linkage that involves the quadrate anterior edge (Fig. A, link 16)' the jugal (link 7), the posterior edge of the upper jaw (link 9), and a fixed link from quadrate to the dorsal flexion zone of the upper jaw (link 15). An alternative geometry of the second linkage for the coupled model, shown in Figure IC, substitutes the pterygoid (link 18) for the jugal as the force transmitter from the quadrate. This variation also involves a different geometry of the posterior upper jaw (Fig. B, link 19). In the coupled model, a linkage was also identified for jaw closing that includes the adductor mandibulae muscle, the lower jaw, the quadrate, and a fixed link. This closing linkage was not evaluated in the current study.

The mechanism of beak opening in the coupled linkage (Fig. C and D) is driven by contraction of the depressor mandibulae muscle, which rotates the lower jaw into an open position. If the postorbital ligament is in tension, then the posterior portion of the lower jaw rotates dorsally. This forces the quadrate to rotate dorsally and anteriorly. Quadrate rotation is the output motion of the first linkage (Fig. C). Quadrate motion then functions as the input motion of the second linkage, in which motion is transferred through the jugal (or pterygoid) to the upper jaw.))Dorsal rotation of the upper jaw is the output motion of the second linkage (Fig. C).

Uncoupled model

The uncoupled models (Fig. D) are similar to the coupled models, but assume that the postorbital ligament does not function to transfer lower jaw rotation to quadrate rotation (i.e., the first linkage does not function). Instead, lower jaw rotation is modeled according to depressor mandibulae contraction, and is considered independent of quadrate motion. Quadrate rotation is determined by the action of the protractor quadrati muscle (Fig. D). The transmission of quadrate motion to the upper jaw is modeled by the same fourbar linkage in the coupled model. Thus, in the uncoupled models, the timing of motion and the degree of rotation of upper and lower jaws are determined by different muscle actions, and are not linked by the postorbital ligament.

Evaluation

The **coupled** model of jaw function predicts that lower jaw rotation should be tightly coupled to upper jaw rotation. the coupled model does not accurately predict cranial kinematics. For a given jaw rotation that is within the expected range of values for a frequency sweep during song (0-30”), the predicted rotation of the quadrate (up to 30 degrees) is surprisingly high and probably not within physiological limits. Manual manipulations of the quadrate of a fresh specimen suggest that only a 5-10” rotation is likely for the quadrate.

The coupled model shows a linear relationship between the input motion of lower jaw rotation and the output motion of quadrate rotation, but exhibits nonlinear behavior for the second linkage in transfer of motion from quadrate to upper jaw. This nonlinearity is notable because most previously modeled four-bar linkages are linear within their working ranges (Westneat, ‘94). Four-bar linkages in engineering are often nonlinear (Hrones and Nelson, ‘51), but the only previously identified nonlinear output of a biological four-bar linkage is the behavior of the hyoid linkage in fishes (Westneat, ‘90). A potential functional role for a nonlinearity is to maximize displacement amplitude in the initial phases of linkage motion.

Jaw morphology in birds suggests that a double four-bar linkage physically connects the upper and lower bills. If a double four-bar linkage is present, then movements of upper and lower bills will be correlated during jaw opening. The arrangement of bones and ligaments of the skull forms the basis for quantitative modeling of jaw function. The models are generally applicable to the possible types of cranial kinesis found in birds, and they allow simulations of jaw movements under four sets of assumptions, including both coupled and uncoupled kinesis with force transmitted through either the jugal or pterygoid bones.

The coupled model differs in its behavior according to assumptions of transfer of force and motion via the jugal or the pterygoid. The jugal mechanism results in a considerably higher rotation of the upper jaw for a given lower jaw rotation than does the pterygoid mechanism. Although neither model is accurate overall, the pterygoid model is closer to the actual kinematic values for upper jaw rotation. It is curious to note these differences in upper jaw rotation when the actual gape distance that was produced is similar between the two models; a small rotation of the upper bill results in a large displacement of the upper bill tip under the pterygoid model due to its relatively long output lever arm.

The key morphological element of the coupled model of cranial kinesis is the postorbital ligament. If a robust postorbital ligament were present to connect the two fourbar linkages, the model predicts that lower jaw depression necessitates a corresponding elevation of the upper jaw.

A major feature of the **incoupled** models of kinesis is that upper and lower jaw motions are biomechanically independent of one another. The level of correlation in timing of upper and lower jaw motions is thus dependent upon relative timing of contraction of the protractor quadrati and depressor mandibulae muscles. To test fully an independent four-bar linkage model of upper jaw kinesis would require measurement of the input rotation of the quadrate in order to compare predicted kinematics with actual motions. Additionally, knowledge of the motor pattern and contraction physiology of the depressor mandibulae and protractor quadrati muscles would aid in resolution of timing features of the two mechanical units.

Upper jaw movement varies in timing and magnitude of rotation relative to lower jaw depression. This pattern would be expected if jaw motions were uncoupled. Under a model of simultaneous contraction of the depressor mandibulae and protractor quadrati muscles, the ranges of motion predicted by the uncoupled model are similar to the actual ranges of motion seen during song. For example, given a muscle contraction of 20% of resting length, the uncoupled model predicts a peak upper jaw rotation of around 6”, maximum lower jaw rotation of about 25”, and a peak gape (for simultaneous muscle contractions) of 1 cm.

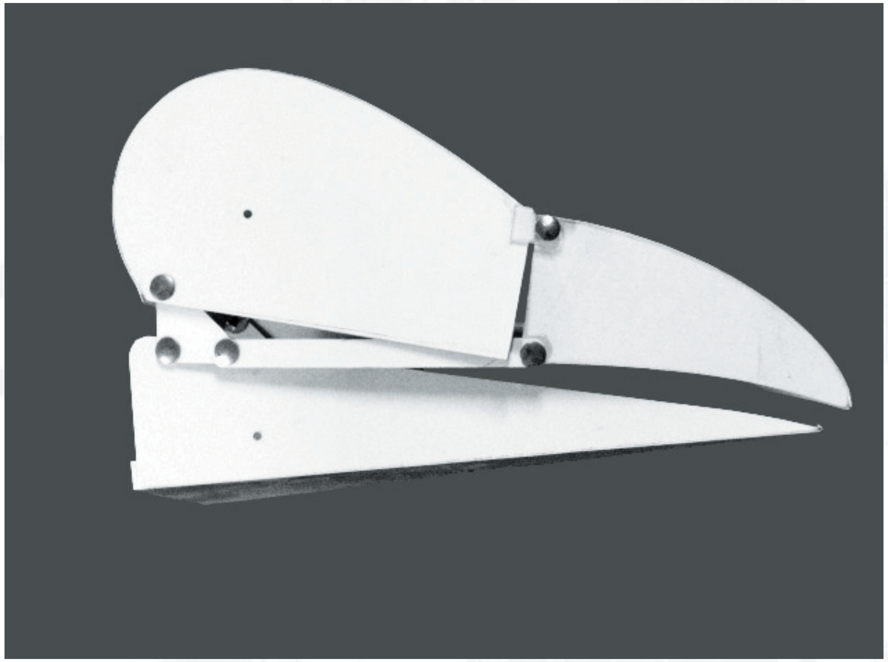
Differences in the timing and pattern of muscular contraction controlling the opening of the jaws might produce a wide range of
potential kinematic output. Simulations of simultaneous contraction of muscles from the two systems is thus only one of numerous potential patterns. However, simultaneous activity in the depressor mandibulae and protractor quadrati muscles might be expected due to correlated nervous control.

1. Postorbital ligament length	7.1
2. Jaw joint-PO ligament insertion	3.4
3. Quadrate length	4.6
4. Quadrate joint with neurocranium-PO ligament	4.5
5. Linkage diagonal 1	7.4
6. Depressor mandibulae muscle length	5.4
7. Jugal length	13.1
8. Jugal joint with upper jaw-upper jaw tip	11.0
9. Jugal joint with upper jaw4orsal flexion point	5.5
10. Jaw joint-Adductor mandibulae insertion	5.2
11. Adductor mandibulae insertion-lower jaw tip	20.5
12. Lower jaw total length	24.8
13. Lower jaw ventral edge length	23.3
14. Lower jaw posterior edge length	2.5
15. Quadrateineurocranium jointdorsal flexion pt	15.2
16. Quadrate anterior edge length	4.7
17. Quadrate ventral edge length	2.8
18. Pterygoid length	8.5
19. Pterygoidiupper jaw joint4orsal flexion pt	7.1
20. Linkage diagonal 3	12.9
21. Protractor quadrati muscle length	3.3
22. Protractor quadrati origin-quadrateineurocran	4.3
23. Dorsal flexion point-upper jaw tip	14.3
24. Ventral flexion point-upper jaw tip	15.9

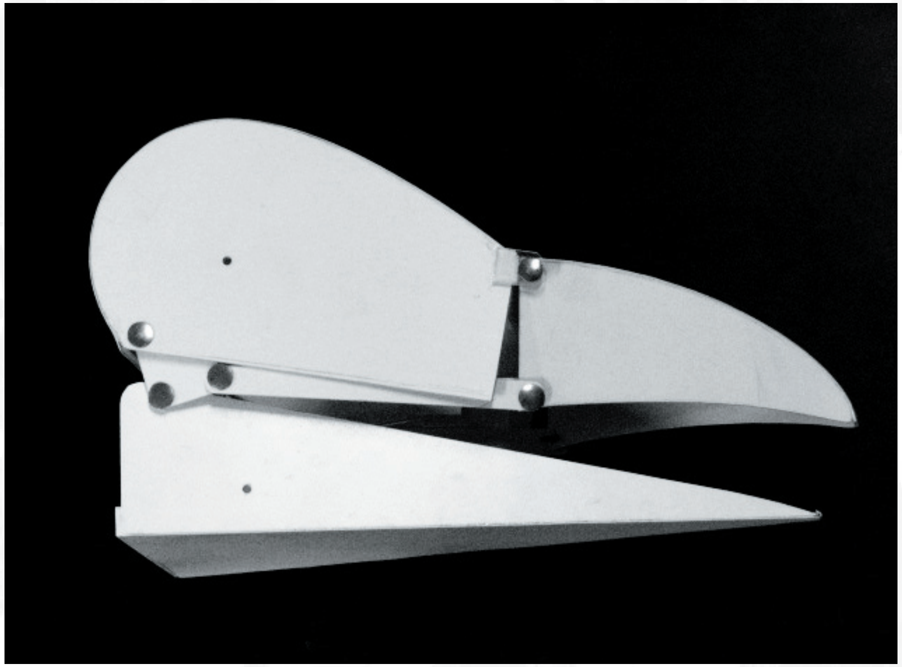
All measurements are in mm.

According the above data a 5:1 model and animated simulation of the links are done, which shows all the linkages by which in future anyone can understand and further continue with the research.

3D Model



Opening of Upper Jaw



Opening of Upper and Lower Jaw

The beak is a primary tool that birds use for interacting with the world. The jaw functions in a multitude of different behaviors including feeding, singing, nest building, defense, and preening. Because the jaw is a complex system with multiple demands on performance, there are likely to be competing demands on underlying morphology (Nowicki et al., '93). For example, functional requirements of jaw movements associated with feeding may be radically different from those associated with gripping and crushing. The degree to which jaw motions are coupled or retain independent motion may play an important role in the Performance of varied behaviors associated with the jaws. Future work using

Force Analysis

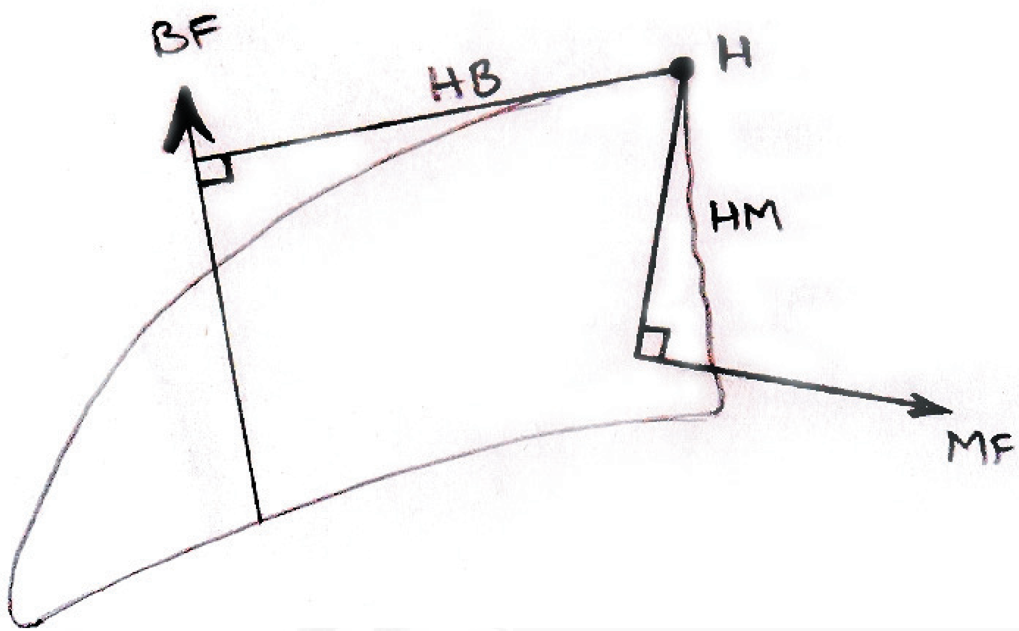
There are several assumptions that are to be made while in which most important assumption is the beam is a rigid unit. That is, the upper jaw must not undergo significant deformation typical loading. It is also assumed that "the mechanical system is completely determined and all force vectors and all moving parts are known exactly." This assumption is invalid in biological systems. Another assumption is all the friction forces are neglected at the hinges.

When a bird in this case addusts its upper jaw as in biting, there are two major forces involved : an adductor muscle force (MF) and the bite force (BF). In birds, the adductor muscle force comes from the pterygoideus musculature, which attaches to the mandible and basicranium caudally and palatal skeleton rostrally. Contraction of muscle pterygoideus retracts the palatal skeleton, depressing the upper jaw, which rotates about the craniofacial hinge (H). The moment arm (HM) of the pterygoideus muscle force is the perpendicular distance from the axis of rotation (H) to the muscle force vector (MF). Thus, the pterygoideus muscles generate a moment, which is the product of the force (MF) and the distance (HM) over which it acts. Adduction of the upper jaw produces a bite force on a food item held in the jaws. Again following Bock (1966), we view this as the equal and opposite reaction force (BF) of the food on the jaw acting perpendicular to the tomial edge. The corresponding moment is the product of BF and HB. When the jaw apparatus is not moving, we assume static rotational equillibrium. As a convention, counterclockwise moments, are considered positive in sign, and clockwise moments negative. If a system is in static equillibrium, then the sum of all moments about the axis of rotation must be zero.

(MF) (HM) - (BF) (HB) = 0

or BF = (MF) (HM) / (HB)

The above equation shows Biting force, which can be increased by (1) increase the pterygoideus muscle force (MF), (2) increase the moment arm of the pterygoideus (HM), and (3) decrease the moment arm at which the bite force is applied. Pterygoideus muscles force (MF) could be increased by changing muscle architecture. or by increasing muscle mass.(MF) could be increased by changing muscle architecture. or by increasing muscle mass. The moment arm of the pterygoideus (HM) can be increased by increasing the height of the upper jaw. Finally, the moment armof the bite force (HB) can be decreaed by initiating the bite in a more caudal position. The actual lenght of the moment arm of the bite force (HB) depends mostly on the behaviour of the animal and thus remains unknown.



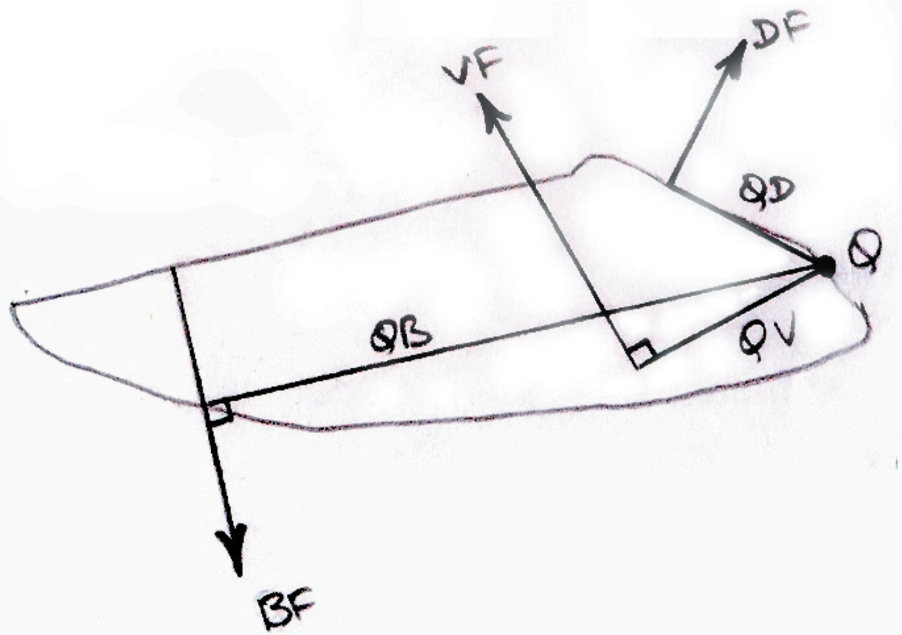
The same way as the upper jaw, and we apply this model here to lower jaw. Whereas in the upper jaw only one major muscle adducted the jaw, two complex sets of muscles adduct the lower jaw: the pterygoideus musculature (VF) and a suite of muscles termed the “dorsal adductors” (DF) by Bock (1966). The bite force (BF) is as before. The axis of rotation (Q) is the quadratomandibular articulation. The moment arms to the various force vectors (QV, QD, QB) again are perpendicular distances drawn from the jaw joint (Q). If the jaw is in static equilibrium, the sum of the moments equals zero.

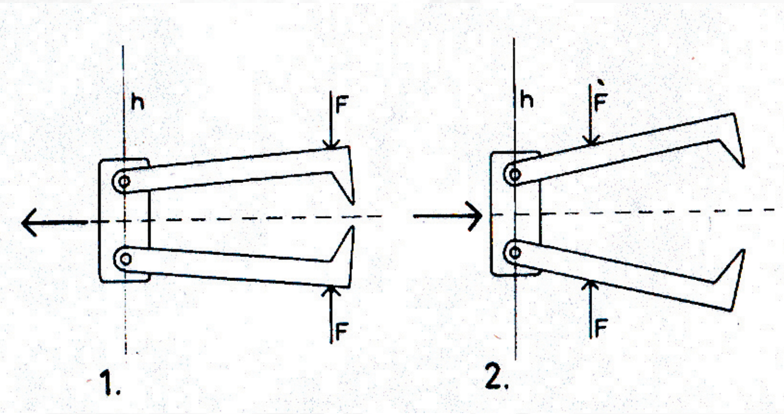
$$(DF)\ (QD) + (VF)\ (QV) - (BF)\ (QB) = 0$$

or

$$BF = [\ (DF)\ (QD) + (VF)\ (QV)\ ]\ /\ (QB)$$

Implies of previous equation are similar. Increasing the force of the adductor muscles (DF and VF), increasing the lenght of their moment arms (QD and QV, respectively), and / or decreasing the moment arm of the bite force (i.e., initiate the bite at a more caudal position on the mandible) all have the effect of increasing bite force (BF).

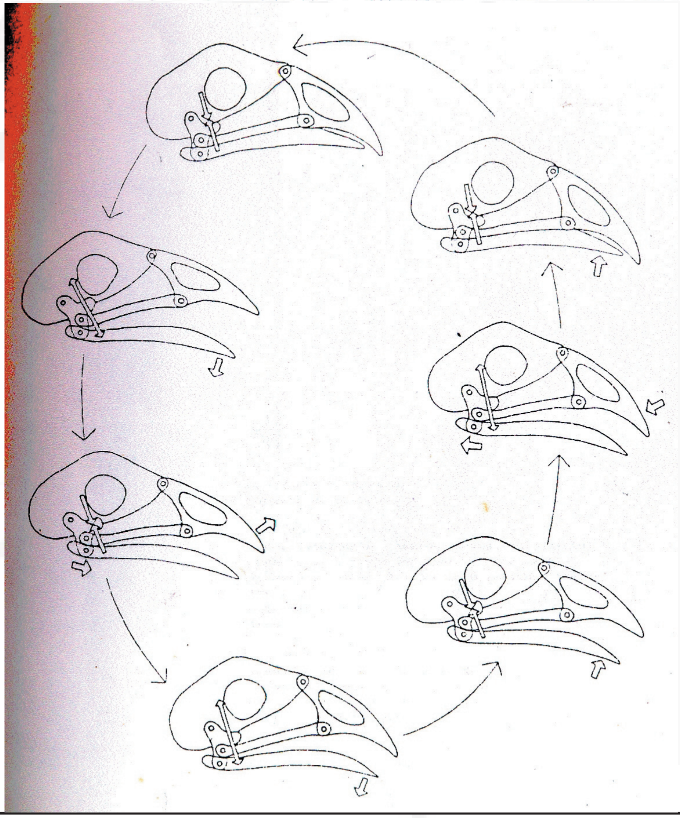




The Moment of Force is depend on the Biting Force applied “F”.
Which again depends on lenght of the beak and force applied by the muscles.

Some researches has experimented and found that a 35mm skull bird in length can break a Ovile Pit which is almost equal to 470 to 700 Newtons of force.

As shown in the figure the F in second figure shows optimum distance of application of force get maximum efficiency for griping and crushing any object and also speed of closing will be maximum due to leverage when force is applied as shown in 1.



Below figure shows the patten in which movements of the bird skull parts when a bird opens and closed the mouth.

So according to above analysis further applications can be developed by increasing or decreasing the scale factor of the lengths. The above analysis will not give exact values exerted by the bird when taken 1:1 and forces. It is a modification of the same mechanism but with some assumptions as state previously.

A CD with all the data collection during the reasearh, papers, pictures, photographs documentations and animation of the links is encolsed with this report for future reference.

REFERENCES AND BIBLIOGRAPHY

Primate

http://blog.wired.com/images/bionicanimation.html
httphomepage.mac.comwisPersonallecturesevolutionary-anatomyPostcranial%20Skeleton.pdf
httphomepage.mac.comwisPersonallecturesevolutionary-anatomyPrimate%20Taxonomy.pdf
httpwww.hopkinsmedicine.orgFAECBR2002AJPA.pdf

Bat or Chiropteran

http://www.earthlife.net/mammals/bat-anatomy.html
http://www.nhm.ac.uk/nature-online/life/mammals/fathomseminar-bats/session2/no-mamm-fathomseminar-bats-session2.html
http://www.batworld.org/main/photoinfo.html
http://www.batworld.org/book/anatomy.html
http://www.si.edu/Encyclopedia_SI/nmnh/batfacts.htm
http://www.nhm.ac.uk/nature-online/life/mammals/fathomseminar-bats/session2/no-mamm-fathomseminar-bats-session2.html
http://www.batworld.org/bat_problems/bat_problems.html
http://www.earthlife.net/mammals/bat-anatomy.html

Crab

http://www.biology.ualberta.ca/courses.hp/zool250/animations/CrabClaw.swf
httpweb.media.mit.edu~adollarbuggrasp.pdf
httpwww.jstor.orgcgi-binjstorprintpage09628452di01547701p0166q0.pdfbackcontext=page&dowhat=Acrobat&config=jstor&userID=3ba31930@iitb.ac.in01cce4405f00501b72b94&0.pdf

Bird

http://www.biology.eku.edu/RITCHISO/birddigestion.html
http://www.calacademy.org/exhibits/skulls/structure_and_function.html
http://www.1911encyclopedia.org/Bird
http://www.arclab.org/node_pages/400.html
http://www.fi.edu/wright/again/wings.avkids.com/wings.avkids.com/Book/Animals/instructor/birds-01.html
http://www.biology.eku.edu/RITCHISO/birddigestion.html
http://www.nhm.org/birds/home.html
http://www.nature.com/nature/journal/v409/n6817/full/409185A0.html (on bird songs)
httpjeb.biologists.orgcgireprint204101735.pdf
httphome.uchicago.edu~awardPublic_filesWard%20et%20al.%202002.pdf

General Search engines : www.google.com ; www.wikipedia.org ; www.answers.com, www. springer.com; www. library.iitb.ac.in; www.altavista.com