Ms. A. J. Mackay

Thesis

Animal Mechanics
"There is scarcely a part of the animal body, or an action which it performs, or an accident which can stop it, or a piece of professional assistance which can be rendered it, that does not furnish illustration of some truth of Natural Philosophy."

(Annette Physics)
The animal body bears a relation to the earth we inhabit, and is subject to the laws which operate on matter. Cohesion and gravitation act upon it, the one conferring solidity, the other weight and consequently a power of resistance. The solidity of the body I shall have occasion to notice hereafter; but in the meantime it is curious to observe the relation that the different actions and postures of animals bear to their centre of gravity.

We know that any structure is stable or tottering in proportion to its altitude and breadth of base. In this fact we have an explanation of the circumstance that infant take ten or twelve months, or even more, to learn to support themselves steadily on their legs, for they acquire this faculty slowly and with difficulty on account of the comparative narrowness of their back; whereas the young of quadrupeds can stand and move about from the very birth.
birth, the breadth of their base enabling them
to do so with leg exertion. He naturally supposes
that this supporting base is only the space occupied by
the foot, but it also includes the vacant space be-
tween them; and it is necessary to remember this
to understand the advantage we derive from turn-
ing out the toes. By doing so we kindly diminish
the length of the base at all, while we add
considerably to its breadth. It is interesting to
observe that in naturally & instinctively, place
our foot in precisely that position which can be
fixed mathematically with the best. The put
are so disposed, that the distance A.B.
between the outside points of the heel,
exactly equals the length of the foot,
and they are turned at an inclination
of 60° to each other, so that the lines C.A. &
D.B. when prolongs meet at E and form an
equilateral triangle A.B.E.

The difficulty of walking on a narrow
base is well exemplified by ladies or others
who have had both lower extremities amputated,
and who consequently are obliged to put up
with the crude substitute of wooden legs.
In addition to these wooden legs they use extensors, the heads of which, being inserted into the arm-slit, increase the breadth of the base, and enable them to move about, though certainly in a very unsatisfactory manner.

The force of custom, however, is seen here as in everything else. Many people, but especially the inhabitants of the Vendée, in the South-West of France, by constant practice acquire the power of walking upon stilts, which double the length of the natural limbs, without increasing, or indeed, if anything, rather diminishing the breadth of the base.

We generally find that the various positions a man assumes are for the purpose of keeping the centre of gravity above the base. Thus a person carrying a weight on the top of his head, stands straight and upright: if he is very fat, or carries a weight in front, he leans backwards; if he suspends a weight on one side, he leans to the other. In walking, but particularly in running, this is an inclination of the body forwards; and according as this inclination is great or small, the pace at
Arnott's Physics - Vol I. page 141.
at which the individual progresses is slow or fast, for he is obliged constantly to keep advancing his feet to prevent him from falling. Thus, walking has been fitly denominated 'a succession of falls'. For the same purpose, to bring the centre of gravity over the base, an individual, on rising from the sitting posture, draws back his feet or bends forwards his body before he attempts to move, because if he did not he would fall back again the moment he rose. A very good illustration of this is given by Dr. Arnot in his work on Physics. He says, "A man standing with his back close to a perpendicular wall, cannot, without falling, bend forward sufficiently to pick up any object which lies before him on the ground; because the wall prevents him throwing part of his body backward, to counterbalance the head and arms which must project forwards. A person little versed in such matters, might agree to give ten guineas for permission to possess himself of the cash, or a purse of twenty lads, before him on the ground — he, of course would lose his stake."
The mechanical contrivances in the human body are perfectly adapted to the ends to be accomplished, and afford safety in the exercise of the natural actions of the body. But we are not to suppose that an entire security against all accidents should be afforded. In all grades of classes of animals we find, that to procure anything some action must be performed. Nothing, I only do believe, is done by Nature more than can be helped. In this respect man stands on a level with the lower animals. The organs necessary for the different functions, as for instance, for Digestion, are given, but the food must be sought for and obtained by the animal itself, and without exciting itself so as to produce this aliment the animal must perish. Hunger, in this case, seems the animal of the necessity of obtaining nourishment. And so in regard to the strictly mechanical contrivances in the body. As I said above, they are quite sufficient for performing the natural actions, although they do not afford protection against all injury. Consequently a man must use precautions, must not trust the mechanism too much.
Sir Charles Bell "on the Hand"
true pain stops in and consumes us to the 
upon our guard lest we overtread and injure 
ourselves. The two cases are perfectly analogous, 
and we cannot say that the mechanism of 
the body is imperfect because it does not 
protect us from all injury, any more than we 
can say that the organs of digestion are im-
perfect because food is not supplied without 
leptition on our part. And without this 
liability to accident, many of the faculties of 
the mind would remain undeveloped and undevel-
oped. "Where" asks Sir Charles Bell, "where 
else would come courage, resolution, and all 
the manly virtues? Take away the influence 
of the uncertain duration of life, and we 
must suppose also a change in the whole 
mental constitution of man."

In the mechanism of the body the skeleton 
occupies a conspicuous place, as that part which 
gives support and firmness to the various organs, 
affords attachment to muscles, and enables us to 
perform the various movements of locomotion. 
Phrenesia, R. T. Bone is composed of two 
substance
substances, animal matter & mineral matter, the one conferring solidity, the other elasticity. It is of great importance that the proper proportion of these substances should be maintained: for if there were an excess of mineral matter the bones would lose their elasticity, become brittle, and be liable to be cracked and fractured by any sudden twisting or torsion—this is often the case in old age. On the other hand, there were a deficiency of mineral matter, the solidity would be lost, the bone would be unable to support the weight of the body, and distortion would occur in every action of the muscles—this state we observe in Rickets. Thus, the mechanical structure of bone corresponds exactly to what is required of it in the animal body—solidity & elasticity.

I must pass to consider the mechanism of the different bones, and

I. First of the Skull—now we always find that the structure and arrangement of parts correspond to the functions they have to perform. What, then, is the purpose the skull has to serve? To preserve the Brain; and...
to understand how it does so, we must first as-certain how the Brain may be injured. This may happen in two ways, by a foreign body directly acting on it and causing a lesion in its structure, or by a foreign body acting on its case and indirectly causing concussion. To prevent the first cause of injury the brain-case must be hard and capable of resisting penetration, but it must not be of glassy hardness or else it would be liable to be chipped - to resist external blows properly it must be both tough and hard. The outer table of the Skull is admirably qualified to serve this purpose. The use of the inner table is not so obvious, but I think we may safely declare its function to be, the prevention of the second cause of injury. It seems to serve a similar purpose to the plastic on a room, it deadens the sound and lessens the violence of the vibration. In this it is assisted by the Pura Mater which lines it and the Diploe between it and the External Table. It is evident that it cannot possibly be of any service in the way of defence, for being hard and vitreous it is easily penetrated. In no case in which the outer table is broken do we find the
Sir Charles Bell.
the inner one whole, and, in opening the head
for examination after death, we have to saw
through the outer table while the inner one is broken
by the blow of a chisel. As, then, it can be of no use
as a means of defence against penetration, it is just
to consider it as having for its function to lessen
the danger of Concussion. The hair, too, which
covers the scalp, acts in a similar way by deaden-
ing the force of a blow and lessening the vibrations.
Thus, we may compare the Brain-case, as a
whole, to the helmet of a dragoon, which is formed
of three substance—a hard substance to resist
penetration, lined with leather and covered with
hair to lessen the danger of Concussion.

Looking now at the connection between
the different bones of the Skull, we find that
the sutures of the External table are minutely
described, small processes from one bone
interdigitating with similar processes from
another. The sutures of the internal table, again,
do not interlace, the edges of the bones are thrown
plated in opposition to one to the other. Now
why is this? I shall not examine how it
happens, but merely what purpose does this
arrangement
arrangement serve. In this inquiring analogy is of great use to us. Take, for example, a wooden box and you will find that the different pieces of which it is composed are joined together by regular indentations, because the wood, being tough, admits of such an adjustment. This wooden box, with its minute dovetailing, corresponds to the tough external table of the skull. Take now a box of glass and you will find that the edges of the different pieces are closely placed in apposition, because if indented the small processes would chip off on the slightest vibration. This corresponds to the vitreous inner table. So, the one being tough, is dovetailed; the other, being glassy, is not.

Here is one further, however in, the external table, in which the bones do not interlace — the squamous, the temporal and sphenoid bones overlap the parietal. The use of this arrangement is evident. The lower edges of the parietal bones (A, C) being the points from which the arch of the skull springs require to be secured; for, if they were not, a weight upon the top of the head...
head (at 0) would press out these edges, and the bones would assume the position of the dotted line (A, B, Z). The temporal bones (4, 4) and the Sphenoid bone (O) prevent any such displacement. These bones here act like the tie-beams and wall-slates in the roof of a tunnel.

But not only might the bones be drawn out (as at D and Z), they might also be pressed together by a force acting upon the sides, and assume the position of the dotted line (D, Z) in the second figure, were it not for the Sphenoid bone (O) here acting as a restraining piece.

We find, too, on looking at the skull as a whole, that those parts of it which are most exposed to injury are thicker and stronger; the points from which ossification proceeds, viz., the lateral parts of the Frontal and Parietal Bones, and the central part of the Occipital, resisting the injuries by which means perfect their work.

Spinal Column

Here.
Spinal Column.

Here, again, we ask, what are the offices the Spine has to perform? These are three: to present the Spinal Column, to support the head and trunk, and to serve as a connecting medium between the various parts of the body. To answer the first, it must be a continuous tube; to answer the second, it must be firm; to answer the third, it must be flexible and admit of motion. But this motion must be of such a kind as not to injure the delicate nervous matter it contains. To prevent any such injury as considerable bending can be permitted at only one place, consequently we have the column composed of 24 pieces, each joint admitting of but a slight movement, while the motion of the whole column is great. These separate pieces gradually increase in size from above downwards in strict proportion to the additional weight they have to sustain. The continuity of the tube is preserved by the different formulae being placed directly the one above the other. To prevent the jar which would otherwise be transmitted to the Brain in many of
Sir Charles Bell's treatise on 'Animal Mechanics' in the Library of Useful Knowledge.
the movements of the body, in walking for instance, there is interposed between each of the vertebral a fibro-cartilaginous substance, and the whole column is bent somewhat like the italic letters S. The inter-articular fibro-cartilages also serve an important purpose in the movements of the column, for, by being compressible and elastic they adapt themselves to the different positions the vertebra may assume, and thus prevent the gaping which would otherwise result from the slightest movement and which would destroy the continuity of the tube. The two bends in the column likewise facilitate its movements.

If the Spine were straight it would yield with very great difficulty in any direction from the pressure being equally balanced on all sides, and, the instant the motive power was withdrawn, it would recover its straight position with a jerk. This, of course, would materially damage the head; but, by being bent "it is prepared to yield in the direction of its curve, and its elasticity is immediately in operation without any jerk."

The Vertebral Column, taken as a
whole, is an example of a lever of the third kind, that, namely, in which the power is exerted between the weight and the fulcrum. The articulation with the Sacrum constitutes the fulcrum, the resistance to be overcome lies in the weight of the head and trunk, and the power is exerted by the muscles which are inserted into the column along its course.

Pelvis.
The most striking peculiarity in the mechanism of the Pelvis is its inclined position, and the oblique direction of the Sacrum which runs downwards and backwards from the Spinal Column. The inclined position of the pelvis diminishes the force of concussion transmitted from below; and the obliquity of the Sacrum, together with the curvature of the lower part of the Vertebral Column, causes the weight of the body in leaping to be thrown upon the surface of the Sacro-Iliac articulation, and thence transmitted to the heads of the thigh bones, instead of multiplying the ligaments, which would result from a horizontal arrangement.
of the joint. There is also a peculiar arrange-ment in the structure of the iliac bine on each side, for transmitting this weight of the body more directly to the heads of the femora. This consists in a prismatic thick-en ing of the substance of the 12th Ilium extending from the Sacr.-Iliac symphysis to the top of the acetabulum. Between these two bony columns lies the Sacrum, which they, as it were, support; and their office is rendered very evident by observing the comparative thinness of the Ilium in their immediate neighborhood. These groinings, and inclined articulations, which occur in the Pelvis, along the line of transmission of force, furnish a good illustration of the two prin-cipal laws which prevail throughout the structure of the Skeleton, viz., first, that accumulation of osseous matter indicates, and is proportionate to, pressure to be sustained. Secondly, that frequency, and obliquity, of joints, indicates, and are proportionate to, concession to be distributed. 

The only other circumstance ev.
connected with the mechanism of the Pelvis which I have to notice, is the double wedge-like shape of the Sacrum; but this has been so much insisted on by all anatomists that I need only mention, that its form has the effect of preventing its displacement by any force acting either from above downward, from before backward, or from behind forward.

The Mechanism of the Thorax.

I pass over here, as I shall have occasion to allude to it in the second part of my theory, when describing the mechanical arrangements by which the principal functions of the body are carried on. I proceed therefore to a short consideration of the Extremities.

The Superior Extremity.

The Scapula. There is one point in relation to the Mechanism of the Scapula which has been overlooked by almost all anatomists. Indeed I know only of one (Mr. Ward) who has directed attention to it at all, and he has described it so admirably that I shall not hesitate to quote largely from his
his work. I refer to what he has called the "Sub-scapular angle." It is a retiring angle in the subscapular fossa corresponding to the Spine. He also explains the circumstance that this angle having escaped notice in this way. He says: "The reason why this angle has hitherto escaped notice appears to be, that it is filled up and in great measure obliterated, as it approaches the border of the Scapula, by the thickening of the bone towards the head, on one hand, and at the Vertebal costa on the other. This sort of shelving away on each side, deceives the eye as to the real abruptness of the bend in the middle of the fossa." In the first place to prove the existence of such an angle, he has given a diagram which I have here copied.

This diagram represents a longitudinal section of the Scapula 'about midway between the Vertebal and axillary borders.' A C is the Spine, B C the Supraspinous portion of the Alae, C A the Infraspinous portion of the Alae. There are here then three angles. a, e, b = the Supraspinous, a, e, d = the Infraspinous, and b, e, a = the
the Subscapular angle. The different dotted line, a e, c d & e l represent the general direction of the spine, the infraspinous portion of the ala & supraspinous portion of the ala respectively. Round the point c (where these three lines meet) as a centre, is described a circle f. e.g. - the size of the different angle is thus obtained. The numbers are seen in the diagram opposite each angle. I tried and made several measurements, the mean of which he thus give.

Subscapular angle = 129 1/4°
Infraspinous = 132 3/4°
Supraspinous = 98 1/2°.

From these measurements he draws the very just conclusion 'that the Subscapular angle is much too considerable a bend in the ala to be without a purpose. Now what is this purpose? The point C) at which the three dotted line meet is directly opposite the glenoid cavity. It is situated in the centre of a triangular thickening running from the base of the scapula to the glenoid cavity, and corresponding to the prismatic
column in the thigh, which I described above as passing from the sacro-iliac symphysis to the acetabulum. It is evident, then, that the muscles which pass from the different fossae to the humerus, and whose function is to draw the head of that bone towards and maintain it in close connection with the glenoid cavity, will be more efficient the nearer they lie to this prismatic axis, because then only can they act upon the humerus in a direction parallel to the line of motion required. Hence for the most advantageous disposition of the muscles in question, it is requisite that each fossa should have considerable depth in this part.

If there was an infraspinular angle, then the infraspinatus muscle would be lodged in a disadvantageous position, but as it is, each fossa has its greatest depth opposite the point C, and consequently the thickest part of each muscle lies in that precise position in which it can operate most effectively on the head of the humerus.

As there is little to be said about the mechanism of the shoulder-joint.
upper arm, I proceed, that of the fore arm—Here we have to notice two relations, first those which exist between the Humerus and ulna, secondly between the Radius and ulna.

The principal requisite in a joint, like the elbow joint, (for by that I mean the relation between the Humerus and ulna, the Radius forming no important part of the articulation), are great strength with great motility in a single plane.

Let us see how these essentials are provided for. The strength depends on the firm grasp the ulna takes of the Humerus between the Humeron behind and the Coracoid process in front; the motility depends on the muscles which act upon the forearm being inserted so near the fulcrum, by means of which the force of those muscles at the elbow is converted into velocity at the distal extremity of the limb; and its limitation to one plane depends on the longitudinal position of the Ferullea and greater Sigmoid cavity.

The hand, in flexion of the Elbow joint, is not raised vertically to the Shoulder, but passes somewhat towards the middle line. This is caused by the prominence of the inner margin.
Sir Charles Bell on the Hand.

Cuvier's 'Anatomie Descriptive,' tom. 1, p. 421

"le rayon de l'arc de cercle qu'il décrit autour du culitus."

March's 'Osteology'. 
of the elbow, which produces an obliquity of about 10° from the perpendicular line of the humerus, in the direction of the plane in which the ulna moves.

Relation between Radius and Ulna. The Radius forms with the ulna two joints, a superior and inferior. In the superior, the convex head of the Radius rolls in a cavity in the ulna; in the inferior, a cavity in the Radius glides round a convexity in the ulna. By this arrangement the Radius rotates so as to perform the actions of pronation and supination. The axis round which the Radius turns does not seem to be well understood, at least there is a good deal of difference among anatomists upon the point. Sir Charles Bell declares that it rotates upon its own axis: Cruveilhier states that the transverse diameter of its lower extremity is the radius of the curve which it describes round the ulna; while Mr. Wundt expresses its relation thus: "The head of the Radius is so disposed, in relation to the sigmoid cavity of the lower extremity, that the axis of the former, if prolonged downward, falls upon the centre of the circle, of which the latter
is a segment;" and to prove his statement he gives this diagram. A cone is described, having for its apex, $e$, and for its base $c d$. The line $a b$ represents the axis of the cone—the one extremity of it ($a$) corresponds with the centre of the head of the radius, the other extremity ($b$) corresponds with the centre of the circle of which the sphenoid cavity is a segment. The portion of the line, $a b$, evidently corresponds to the axis of the head, and the remaining portion, $b c$, is its imaginary prolongation downwards. The result of having this axis is, that no thing-like motion takes place in the superior radioulnar articulation, as has been supposed; as the brand expresses it the movements of its lower extremity are performed without disturbance to the parallelism of its superior joint.

Hand.

Carpus. The office of the seemingly complex and numerous small bones of the Carpus, is to distribute, and consequently lessen, the force of, carry the force of concussion transmitted from the Metacarpus to the bone of the fore-arm. The accompanying diagram...
will show how this office is performed. I represent the three last meta-carpal bone & three bones of the Carpus upon which they act.

Any force transmitted upward, in the direction of the arrows, by the 4th or 5th meta-carpal bone will fall upon the Metaform (g) which will distribute it in the manner shown by the small arrows, part to the 5th Magnum (f), part to the Cuneiform (c), and part to the Semilunar (b). While any force acting through the 8 1/2 meta-carpal bone will be divided by the 5th Magnum between the Scaphoid (a) and the Semilunar (b).

The arrangement by which the thumb is rendered elastic is shown in figure 2, where the Scaphoid, Trapeziun, and first Meta-carpal bone are represented. The axis of the Scaphoid (a b) forms with that of the Trapeziun (a c) an obtuse angle, and this again forms an obtuse angle with the axis of the first Meta-carpal bone. During the transmission of a concussion these angles are rendered more acute, the bone being slightly moved from their position, and by this mechanism the shock is divided & distributed over the bones themselves, the neighbouring bones, & the Carpal ligaments.
Sir Charles Bell treatise on Animal Mechanic in Library of useful knowledge.
Lower Extremity.

Thigh. The only circumstance calling for notice in relation to the Femur is its double obliquity.

Sir Charles Bell explains this obliquity of the neck of the thigh-bone by comparing it to the mechanism of a wheel. He says, that when a cart rests equally on both wheels, the spokes are oblique to the line of pressure, but that when one wheel is raised, say by a step, then the spokes of the other become parallel to the line of pressure in which position they are better fitted to support the increased weight. Similarly, he declares, the necks of the thigh-bone oblique when we rest equally upon both legs, and similarly does the neck of the femur, when we stand upon one leg, become vertical. Better able to sustain the weight of the trunk. This opinion of Sir C. Bell has been shown to be erroneous by Mr. Ward. As I have no space for his argument, I must refer to his work. Page 376. His explanation, however, I will give shortly.

The advantage of this obliquity is, that when the lower end of the femur is advanced, the head and neck of the bone turn on a horizontal axis.
that is to say, the angular motion of the shaft is converted into a rotary movement at the hip. Another advantage of this form is, that by it flexion is greatly increased. The angular motion of such a joint as the hip would soon be stopped by the femur coming in contact with the margin of the acetabulum, whereas by the present mechanism such an occurrence is altogether avoided. In his words: "Three principal advantages appear to result —
1st. enlargement of the space for the adductor muscle between the thigh-bones. 2nd. Equalisation of the extent of bearing surface in the hip-joint throughout its passage from extreme flexion to extreme extension, or the reverse. 3rd. Increase of the range of the thigh in flexion."

The mechanism of the foot is so similar to that of the knee that I shall pass it over without remark.

Before leaving the subject of the skeleton, there are two points of a general nature of which I must speak — viz. The cylindrical form.
form of most of the long bones, together with the uses of the Spine, we find running along their course, and a consideration of the joints and ties of the body.

First, then, I have to inquire, why most of the long bones are cylindrical, & what are the uses of the Spine we find running along their course. All through the body, away, in all the works of nature, we invariably find that every thing is done with as few material as possible. There is no superfluity, nothing over and above, but every work is conducted at the least possible expense, that is to say, the least possible expense compatible with security. This we observe to hold true with regard to the construction of most of the long bones—they are hollow cylinders. Now, of what advantage is this form? In the first place, the bones are rendered lighter than they would be if solid. This, of itself, is a great advantage! Every one knows how much more easily walking, running, or any other exercise is performed by having on, say, light shoes, and what an additional amount of power must
must be exerted, to move about in the usual way, if we are encumbered with much additional weight. From this we may understand what would be the effect of the body being solid. Our present muscular system would never suffice in that case; we would require larger and more powerful muscles to move the bone with the same force and rapidity we do now; to keep up the symmetry of the frame, an increase in length would be requisite in proportion to this increase in bulk, and thus an immense loss of material would ensue.

Again, by being cylindrical, the bones are increased in strength. A cylinder which has to support a weight, may be divided into three parts: an upper one (A) which does so by its 'solidity and resistance to compression', a lower one (C) which does so by its 'toughness or adhesive quality', and a middle one (B) which may be taken away without materially weakening the bone. Now, this central part which is of no use where it is, may with advantage be removed and added to either of
Sir Charles Bell in the Hand page 248.
the other. Sir Charles Bell mentions an ex-
periment which demonstrates this very clearly,
and I shall give it in his own words. He says,
"If a portion, amounting to nearly a third
part, of a beam be cut away, and a harder
piece of wood be nicely let into the space, the
strength will be increased, because the hard-
ness of this piece of wood resists compression.
This experiment, he continues, I like the better
because it explains a very interesting peculiar-
ity in the different densities of the different
parts in side of the bones. The deviations
from the cylindrical forms are not irregular-
ities; and if we take that bone which
deviates furthest from the cylindrical shape,
the Tibia, we shall have demonstration of the
correspondence between the shape of the bone
and the force which it has to sustain.
If we consider the direction of the force in
walking, running, or spring leaping, and in all the powerful exertions while the weight
of the body is thrown forwards or the ball
of the piston, it will appear that the
pressure against the skin-bone is chiefly
in the anterior part: And there is no doubt that if the tibia were a perfect cylinder, it would be subject to fracture from the mere free of the body itself being thrown upon it. We readily perceive now an anterior spine should be thrown out: And, if we attend to the internal structure of that spine, we shall find that it is much denser & stronger than the rest of the bone. This perfectly corresponds to the experiment of our hemp which we have described, while the dense piece of stout wood, being let into the piece of timber was found to be a means of resisting transverse fracture.

This is also the case with the different bone of the skeleton, in all of them the position of the spine, being a relation to the direction in which the force, to which the bone is exposed, acts.

I have now to run over shortly & generally the joints and bones. The joints may be divided into two great classes, the ball & socket and the hinge joints. The ball & socket joints afford the greatest extent of motion.
and we consequently find that the Shoulder-joint (the most perfect example of this kind of articulation) is held out from the body, as it were, by the peculiar arrangement of the Clavicle and Scapula. In the Hip, again, where much a variety of movement is not required, this is not the case. The ends of the different bones, or those parts of them which enter into the formation of the articulation, are covered with Cartilage, which by its comparative softness and elasticity, permits the bone to play upon each other, and this is lined or covered by Synovial Membrane, so called from its secreting a fluid to lubricate the articulating surface. These surfaces are kept in apposition by ligaments passing from one bone to the other, surrounding the joints; but, independently of these ligaments, the bones are kept together by the pressure of the atmosphere. To demonstrate this plainly, it is only necessary to take a Hip-joint, when it will be found, that after all the ligaments and soft parts have been removed, the head of the Femur remains firmly lodged in the Acetabulum, and requires the exertion of considerable force to dislodge it.
In the knee, the constant pressure of the atmosphere amounts, according to Arrott, to upwards of fifty pounds; and he declares that while the capsule surrounding the knee joint remained air-tight, the broad surfaces of the bone could not be separated by a force of less than about a hundred pounds, while he adds "that in air being admitted into the articular cavity, the bones at once fell to a certain distance apart." He also declares it to be his opinion "that in all joints it is the atmospheric pressure which keeps the bones in such close contact that they move smoothly and without noise."

In considering the leverage power of the human body, it is not necessary for me to go over all the levers in the system; it is sufficient for any purpose to give an example of each kind.

1. The first kind of lever is that in which the fulcrum is between the power and the weight. Of this the Occipito-articular articulation is an example. In this instance, the fulcrum is at the joint between the
Occipital bone and the Atlas, the weight is in the front of the head, (as is seen by the tendency it has to fall forward when unsupported), and the power in the back of the head, where the muscles passing from the Spinal Column are inserted.

2. The second kind of lever is that in which the weight is between the power and the fulcrum. Of this the ankle joint is a good illustration. The fulcrum here is the ball of the toe resting on the ground, the weight (that of the body) rests on the astragulus, and the power (the tendo Achillis) acts on the 05 Calcius.

3. The third kind of lever is that in which the power acts between the weight and the fulcrum. I have already given an illustration of this in operating on the vertebral Column taken as a whole. The elbow joint and fore-arm is another example. But in my opinion, the best instance is to be found in the Lower-jaw. In fact, this is one of the best examples of lever age power in the whole body. The fulcrum

it
is at the articulation between the condyle of the jaw and the glenoid cavity of the temporal bone, the weight to be resisted by any substance placed between the teeth, and the power is exerted by the temporals and masseter muscles between the weight and the fulcrum. A great resistance has to be overcome, the power acts perpendicularly to the line of the jaw-bone, and, by thus acting at right angles to the weight, greater force is gained than in most of the other limbs in the body, as in the arm, where extent of motion is the principal object to be attained. The force, too, with which the power acts, is greater the further back or nearer the fulcrum the weight is placed — thus, breaking or tearing anything, as cracking nuts, is performed with greater ease of less exertion by the back than by the front teeth.

I pass next to a consideration of the organs of the senses, or rather, of those two of the organs of the senses which are strictly mechanical — the Ear and the Eye.
Paley's Natural Theology
The part of the Ear.

The labyrinth or internal Ear, being the sentient portion of the organ, is the mechanism of the outer two parts that I will speak. Paley says "that the communication within, formed by the small bones of the Ear, is, in some sense, more like what we are accustomed to call machinery than any thing I am acquainted with in animal bodies" and certainly the arrangement is the most mechanical that could be imagined.

What has to be done? The vibrating and modulation of the atmosphere have to be collected, concentrated, and increased in intensity and conveyed to the auditory nerve.

The outer ear serves the purpose of collecting the vibration of the atmosphere—iniquity, irregular, it acts like an ear trumpet, gathering together, as it were, the undulating and conveying them to the middle Ear. It is blank in the tympanum, that these sounds are increased in intensity. Now, what results have been deduced from experiment as regards the propagation of sounds?
Carpenter's Principle of Human Physiology
The following are taken from Carpenter's Physiology. I. "Vibratory undulations, in passing from air directly to water, suffer a considerable diminution in their strength. While, on the contrary, if a tense membrane exists between the air and the water, the vibratory undulations are communicated from the former to the latter medium with great intensity." The use of the tense membrane closing in the Fenestra Außentum, and separating the air contained in the Tympanum from the watery fluid contained in the Labyrinth, is now evident.

II. "A small solid body, fixed in an opening by a border of membrane is as to its exterior, communicates vibratory vibrations from air on one side, to water on the fluid of the Labyrinth on the other, much better than solid media not so constructed. But the propagation of sound to the fluid is rendered much more perfect, if the solid conductor, thus occupying the opening, is by its other end fixed to the middle of a tense membrane which has atmospheric air on both sides." Here we see the use of the chain of small long
which, attached at one end to the Membrana Tympani, stretches across the cavity of the Middle Ear to the Fenestra Ovalis.

But more particularly as to the office of the part contained in the Tympanum. The undulation of the air, collected in the Concha, and conveyed by the External Auditory canal, strike upon the Curved Surface of the Membrana Tympani, by which they are rendered deeper. The handle of the Malleus is attached to the Middle of this Membrane, and receiving from it the vibrations, to the end of this is attached the Incus, this again is articulated with the Stapes, which play upon the Fenestra Ovalis and is connected to it by an annular ligament. By means of these small bones, and in accordance with the Second Principle that I have mentioned, the undulations are condensed, and the sound is propagated to the Auditory Receptacle of the Inner Ear. Leading into this cavity of the Tympanum, we find a tube, the Eustachian Canal, conveying atmospheric air from the throat.
use of this seems to be "the maintenance of the equilibrium between the air within the tympanum and the atmospheric air; to prevent inordinate tension of the Membrana tympani, which would be produced by too great or too little pressure on either side, and the effect of which would be imperfectition of hearing." I think that it also directly conduces to hearing, for vibration conducted by it to the Tympanum would strike against the Membrane of the Fenestra Rotundum, and be by it conducted to the inner ear in accordance with the first principle laid down. He thus finds, that the mode by which sound is conveyed to the Auditory Nerve is perfectly Mechanical, and in accordance with known Mechanical laws.

The Eye.

Rays of light transmitted from a luminous body, on entering a medium of different density, are refracted. If the transition be from a denser into a denser medium, the
rays are bent towards the perpendicular to the surface at the point at which they enter; if from a denser into a rarer, the refraction is from that perpendicular.

Thus, if rays proceeding from any luminous body, fall upon a double convex lens (at B) they are bent or refracted toward the perpendicular, and are united at some point C, on the other side of the lens, which is called the focus.

If these rays fall upon a double concave lens, they are acted on in a directly opposite manner, they are refracted from the perpendicular. A double convex lens unites the rays which fall on it from every point of a luminous body into corresponding points in the other side, and thus forms true an image of the object. Now this is just what is done in the eye.

Suppose AB to represent the luminous body C and D the crystalline lens.

The rays passing from A are so refracted as to produce the distant counter part.
If $A$ at $A_1$, so with the rays passing from $B$ and $C$ with the rays from all the intermediate points.

But two circumstances interfere with the perfection of an image thus formed. The first is what is called spherical aberration. This consists in the fact that those rays which fall upon the margin of a lens, are brought to a focus nearer the lens than those which pass through its centre. This of course, must materially affect the distinctness of vision.

The second circumstance, which interferes with the perfection of an image, is chromatic aberration. This is caused by the unequal refrangibility of the different colored rays, so that the violet rays are brought to a focus at one point, the blue at another, the red at a third. In the eye, the first of these is obstructed by the stop, or diaphragm, of the pupil formed by the iris, which cuts off the marginal rays. The second is obstructed by having several lenses of different curvatures, and composed of different substances.
Substances, and whose dispersing power is consequently different.

There, in the preceding pages, goes over the general mechanism of the human frame; I pass now to consider the mechanical arrangement by which its great functions are carried on.

The Circulation of the Blood.

The circulation of the blood is carried on by a perfect piece of hydraulic mechanism, and can be explained entirely on mechanical principle. This I shall endeavour to show as I proceed. There can be no doubt that the great part of the moving power belongs to the heart, which corresponds to a central pump. It has been said that the heart could not propel the blood further than the Capillary vessels, and that it had nothing to do with the circulation in the veins. That this doctrine is erroneous is proved by various
circumstances, which does not here en-
umerate; suffice it to say, that the
heart has sufficient power to complete the
circle. But although the circle of the
blood may be thus completed by the
heart, yet, if the vis viva was the only
force, the motion of the blood would be
very slow and languid in the veins, and
great danger would consequently ensue.
This has been recognised by all physiolo-
gists, and various have been the theories
adopted as to how this central power is
supplemented. Now it is curious to
observe, that, not contented with explain-
ing the circulation in the veins, almost all
writers extend their theories to the arteries
and capillaries, and endeavour to es-
tablish the existence of some force there,
while no such force is required. I
shall endeavour here to prove, that no
such extra power resides in either ar-
teries or capillaries.

1. The first theory is that the arteries
have muscular coats.
Carpcnter's "Principles of Human Physiology".
physiologists who argue for the existence of muscular coats in the arteries, endeavour
to point out two distinct layers in the middle coat. As use Dr. Carpenter's word
"We find in this coat, a layer of annular fibre, possessing no small resemblance to
that of which the muscular coat of the alimentary canal is composed. On the
outside of this is a layer of yellow elastic tissue which is much thicker in the large
arteries, in proportion to their size than in
the smaller. So this last tissue is due
the simple elasticity of the arterial walls, which
is a physical property that exists after death;
whilst to the one first mentioned we are to
attribute the property which they unquestion-
ably possess - in common with proper mus-
cular tissue - of contracting or the applica-
tion of a stimulus, so long as their
vitality remains."

The arguments which they adduce
to prove the existence of muscular fibres are,
1. First. These have been seen, they
are discoverable by the microscope.
Now, instead of the microscope proving these fibers to be muscular, in my opinion it proves directly the contrary. If I were to ask any Physiologist — how many kinds of muscular fibers are there? — he would undoubtedly answer, 'two.' And if I asked still further for an example of each, he would most certainly refer to the Biceps R. as an example of the voluntary or striated, and to the muscular coat of the Intestine as an example of the involuntary or non-striated kind.

And if I pressed still further — said, 'Are you sure these are the only varieties of muscular fibers in the body?' — I should again (and again) be told, 'Yes, these are the only two kinds.'

I now turn to the so-called muscular coat of the arteries, and I ask the same Physiologist to which class, that belongs, and the only answer I get is, 'It bears no small resemblance to the muscular coat of the alimentary Canal.' It cannot be said to be exactly the same, but it
It bears no small resemblance to it. The microscope proves it not to be the same, but it is something like it, and upon this slight resemblance we are called upon to acknowledge as muscular a structure different from the only two kinds of muscle in the body.

2. The second argument made use of is, that the arteries possess irritability. Now, the way that and how lie, of course, with those who have put forward the theory of arterial muscularity. But as satisfactory evidence has yet been given. Even Dr. Carpenter himself allows that "Many experiments have failed in producing contractions of the tissue." He adds, however (and this is a mode of reasoning adopted by many) that "in a question of this kind the positive evidence must be held to outweigh the negative." In fact, as I have read it more boldly stated "The positive experiment is better than a dozen negative ones." Now, I certainly never could understand that mode of reasoning.
Probationary Essay on "The Forces Which Move the Blood." By W. Brown, F.R.C.S.E.
by which the exception is made the rule; the general idea is that exceptions only strengthen the rule, not only do away with it altogether. Consequently, I think that if the great majority of experiments fail, the theory must be given up.

And most unquestionably the majority have failed. I find stated by Mr. William Brown the fact which abundantly proves this. He says that of the original experiments of Verschueren "only one half succeeded"; and further that when Verschueren tried to repeat them in the presence of the professors of Edinburgh, his attempts failed, showing, not his want of veracity, but the uncertainty of the experiments and consequently the little dependence that is to be placed upon them." Mr. Brown also adduces the evidence of Dr. Dennison, a strong upholder of this doctrine, who "confesses that these experiments fail much more frequently than they succeed."

But besides all this, many of the experiments said to have succeeded have in
Brown on the power which move the Blood.

page 13.
fact failed; that is to say, they proved nothing. Such is the case with those experiments in which mineral acids have been applied to the arterial tunics. These, of course, have contracted, and this has been held up as a proof that the arteries are muscular. It is, however, very evident that no such deduction can justly be drawn. Apply the same mineral acid to any other texture of the body, or to a piece of Indian rubber, and the same result follows. There has, in fact, taken place "a chemical action between the stimulant employed and the arterial coats." When a concentrated acid is applied to an artery, it contracts; but this is not an animal reaction, it is merely a shrivelling or tanning of the coat, which Bichat calls "un racornissement," which takes place equally well on the dead body, is not a contraction followed by relaxation, and is not produced by alkalies, although substance equally stimulating.

B. A third argument used, and the only other one I will mention is, the toniccity
Carpenter's Physiology p. 567.
tonicity of the arteries, which Dr. Carpenter considers to be a manifestation of vital contractility. I shall only say upon this point, that, to my mind, this tonicity can be readily explained by the elasticity of the middle coat. This being always on the stretch, both laterally and longitudinally, of course contract and retract when cut across.

I hold, therefore, on these grounds, that the muscularity of the middle coat of the arteries has not been proved.

But even admitting that they may be muscular, I would ask—what purpose would it serve? It is perfectly plain that any marked general contraction of the arteries would not only not promote the circulation but would really retard it. Dr. Carpenter acknowledges this, but he says that possibly by "alternately contracting and relaxing they may supplement the heart's impulse." But this also is impossible. If there was only one wave (if I may so speak) of the blood circulating, then, just as in the esophagus..."
or Intestinal Canal, this alternate contraction and relaxation would assist its flow; but as part of the Arterial System is ever empty; so that a contraction of the vessels, however partial, must act upon the fluid in the arterial tubes both on the distal and Conduit side, hastening, of course, the flow of the former portion, but as evidently retarding that of the latter. It follows, that a marked contraction of the arterial wall, whether general or local, so far from being a necessary adjunct of the circulation, can not even be permitted.

The only other office which this muscularity of the arteries could perform is, "regulating the diameter of the tubes in accordance with the quantity of blood conducted through them to any part." As instances of this supposed regulating power Dr. Carpenter mentions - the enlargement of the Uterine and Mammary arteries at the epochs of Pregnancy and Lactation. the increased diameter of the Spermatic artery when the Testicle is greatly enlarged. Etc.
But surely, this is no evidence of the muscularity of the arteries: it is only an example of a law universal in the body—

that increase of function causes increase in bulk. During lactation the Rama has its functional activity increased, it increases in bulk; when one kidney is diseased the other has its functional activity exalted, it increases in bulk; when the parts which it supplies are enlarged, the functional activity of an artery is exalted, and it increases in bulk; and if the enlargement of an artery, when its function is exalted, is a proof of its muscularity, so also is the enlargement of the kidney, and 2 is the enlargement of the Rama.

The theory of arterial muscularity has been extended to the Capillaries, and the same arguments have been used to prove the existence of muscular fibres here as in the larger vessels. These of course are liable to the same objections in the one case as in the
the other. It has, however, been further 
argued, in reference to the Capillaries, that 
the effect of mental emotions on them proves 
their muscularity and dependance on the 
Nervous System. Blushing, for instance 
is said to depend on a relaxation of the 
minute vessels caused by the influence of 
the Nervous System on their muscular coat. 
Palor also is stated to be dependant on the 
same cause. Now, it appears very strange 
to me how two such opposite effects as 
Palor and Blushing could have so long 
been ascribed to one cause. The influence 
of the Mind causes the relaxation of the 
Muscular fibers, and consequently Blushing; and 
the same influence of the Mind causes the 
directly reverse state of Contraction of palor. 
This surely cannot be correct!

I think it may easily be demonstrated 
that Blushing at all events is not de- 
pendant on Muscular action. What is the 
effect of Nervous influence of all the other 
Muscular fibers in the body? It causes 
them to contract, and if they surround 

a tube (as in the intestine) to lessen its diameter. That is the result of nervous influence of the muscular fibre all over the body, and surely we are not to suppose that that law is directly reversed in the Capillaries. Blushing, therefore, cannot be dependant on muscular action; but, instead of being a proof of the muscularity of the Capillaries, it rather tends to disprove that theory. For, judging from the analogy of the alimentary canal, the influence of the mind, upon which local blushing is dependant, would, if the Capillaries were muscular, produce local palor, by inducing contraction of the annular fibres and thus lessening the diameter of the tube. Upon whatever local cause, therefore, blushing is dependant, it is not muscularity of the vessels. Palor, again, is most frequently general and not local; that is to say, it is produced by a depression of the heart action affecting the free circulation all over the body.

Dr. Carpenter
Dr. Carpenter has advanced another theory which I have now to notice shortly.
He says, that there exists in the Capillary vessel a force, which he calls 'Capillary power,' altogether distinct from 'mechanical propulsion,' and which he likens to the force by which the sap is made to circulate in plants. Now I do not think that such a power has much to do with the circulation in the natural state. Dr. Carpenter states, that, on looking at the web of a spider's foot, there are variations seen in the force and rapidity of the current of the blood, and that sometimes, this variation extends to the entire reversal, for a time, of the direction of the movement. He further states, that an entire stagnation of the current in some particular tube precedes the reversal of its direction. He, however, goes on to say, that irregularities of this kind are more frequent when the heart's action is partly or altogether impeded.
Draper on the forces which produce the organization of Plants
that is to say, these movements do not take place to such a degree as to be observable when the animal is in health; it is only when something unnatural occurs that they can be seen.

Another argument which he adduces to prove the existence of this "Capillary power" is the empty condition of the arteries after death. He supposes that this attractive power draws the blood from the arteries into the Capillaries. But, if this was the case, we would surely find an accumulation of Blood in these Capillaries, whereas the surface is pale, the minute vessels are contracted, and the most of the blood has passed on to the Veins.

The next argument he uses is that first brought forward by Prof. Draper. Prof. Draper says: "If two liquids communicate with one another in a Capillary tube, or in a porous vascular matrix, and have for that tube or structure different
"different Chemical affinities, movement will ensue, that liquid which has the most energetic affinity will move with the greatest expense velocity and may even drive the other liquid before it." Dr. Carpenter adopts this reasoning and says, "that arterial blood containing Oxygen with which it is ready to part, and being prepared to receive in exchange the Carbonic acid which the tissue set free must obviously have a greater affinity for these tissues than venous blood, in which both changes have been expected." From this he concludes "that on these physical grounds we must allow the existence of this Capillary power." But I would ask, how are we to reconcile this statement of his with a previous one which he makes, viz. "let it be clearly understood that this Capillary power is altogether distinct from Mechanical propulsion" Dr. Carpenter evidently contradicts himself.
himselves here. Which of these two statements are we to believe? I think our safest course is to believe neither.

The last argument he makes use of to prove the existence of some force in the Capillaries is, that the circulation is carried on in the cardiac arteries. But, when we turn to Dr. Marshall Hall, we find him using the same argument to establish the existence of some force in the arteries. He says, "The fact of a perfect circulation in the cardiac arteries, seems thoroughly to indicate an important influence in the arteries. It is difficult to conceive of this phenomenon as accomplished otherwise than by the agency of these vessels." Here, then, we have Dr. Carpenter (and Dr. Marshall Hall using the same argument to prove directly opposite things. What is our safest course here? Which are we to believe? As in the former case I think neither; we ought rather to agree with
Brown "on the powers which move the Blood"
with Mr. Brown that it is hardly fair to reason from a monster, a thing bearing in its front the acknowledgment of nature that it is something irregular, and that we ought not to draw from it general conclusions, upon the structure and functions of a being perfect in his organs and in their uses.

Another theory that the motion of the blood in the small vessels is influenced by the mechanical power of "capillary attraction," is refuted by merely observing, that tubules which are already full can exercise no "capillary attraction" and that consequent this power can not be expected in the minute vessels.

From all this I conclude, that the circulation through the arteries and capillaries is effected by the vis a tergo of the heart —
The circulation in the veins. Here still the vis-a-typ of the heart forms the principal motive power, but, as stated formerly, this of itself would not suffice to keep up the circulation in the veins at its proper rate; some other force must be added. One of the most powerful of these is the contraction of the muscles. When a muscle contracts, it, of course, compresses the veins in its neighbourhood, the blood they contain is prevented passing backwards by the valves, and is consequently of necessity forced onwards to the heart. That muscular movement plays an important part in carrying on the venous circulation, is seen by the effect of any violent exertion, the heart's action becomes very much accelerated, in consequence of the increased quantity of venous blood which is poured into it. Other forces have been supposed to influence this part of the circulation. Some, as Mr. Brown, 

"Authoritative"
They suppose that the heart is capable of dilating itself, and thus producing a vacuum into which the blood is forced by atmospheric pressure.

Mr. Brown attributes this dilating power to the Columnae Carnea and Musculi Postinato. It is doubtful whether they possess this power at all, but even admitting that they do, the dilatation consequent upon their contraction only affect the circulation very partially. For, from the peculiarity of the coats of the veins, the effect of suction would be destroyed at any considerable distance from the heart, by the flapping together of the coat walls of the vessels. This has been clearly demonstrated by Dr. Arnot.

The same objection applies to the Inspiring movement expressing any general or marked effect upon the Venous Circulation. It cer-
certainly has some influence upon the blood near the chest, but, for many reasons, and the one I have mentioned more particularly, it cannot be held of any material consequence.

Respiration.

In considering the mechanism of respiration it is not necessary for me to go over the structure and arrangement of the lungs, or, indeed, to touch at all upon the physiology of the process. I have only to examine the movements of the ribs and diaphragm by which a vacuum is produced. The diaphragm by contracting, from being highly arched becomes quite flat, and, of course, thus increases the longitudinal and diameter of the chest.

On looking at the skeleton, we observe that each loop of the ribs passes downwards and forwards, so that its sternal attachment is lower than its spiral; and further we observe...
observe, that the ribs on each side are inclined downwards and outwards, so that the middle of each is below the middle of a line connecting its extremities. Before the ribs, therefore, can be brought into a horizontal position, two movements are necessary, their sternal attachment must be raised to a level with their spinal attachment, and their centres must also be raised to a level with their extremities. By the first of these movements the antero-posterior diameter of the thorax is increased; by the second, the transverse.


Into a consideration of the other functions of the body, as digestion, absorption &c, I have not space to enter; nor can I, as I at first intended, enter upon the subject of Medical and Surgical Mechanics.
Suffice it now to say, that the further we advance, the more reason do we see for admitting the truth of the motto that I adopted, nay, even for extending it, and declaring — that there is NO part of the animal body, in health or disease, which does not furnish illustration of some truth of Natural Philosophy.

Fyris John Mackay

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