On the Comparative powers of Reproduction possessed by the tissues of Man and the lower Animals

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The subject of which I have undertaken briefly to treat, is one of very great importance to the student or practitioner, either of Medicine or Surgery.

The conscientious, and proper discharge, of the duties, incumbent, especially on the latter branch of the profession, demands an acquaintance, with the processes and conditions, by and under which the loss of living texture is supplied, or compensated for. At least, so far as the repeated and careful investigations, both of older and later observers, have succeeded in bringing

them to light. –

Without this knowledge, our treatment must be necessarily empirical, and our practice consequently uncertain. –

It is unnecessary for me to dwell long on the important position, which this subject holds in the animal economy, since not only is it noticed, after every serious disorganization of a portion of the living being, or extensive loss of tissue, either intentional or accidental, but also in the more minute, and apparently trifling accidents of every day occurrence, by which breaches of continuity are effected, and loss of structure however small sustained. – How important then, that he who takes on him the responsibility of practising the healing art, should by a knowledge of its principles, be duly qualified to perform his part, in furthering Nature in her obedience to them. More than this, is not his province. to reproduce, or heal ~~it~~ lost or wounded ~~part~~ texture, is beyond his power; but it is his duty, by due appliances and proper

means

means, to assist Nature in her work, and to take care that no obstacle is presented in her way. -

If we examine the form and structure of an animal, we cannot help noticing, how admirably arranged and happily harmonious are its varied parts, each part, not being an isolated mass of matter, but dependant in some measure for its welbeing, on the due action of the rest and contributing its share to the stability and welfare of the whole. This is observable, even in Animals lowest in the scale of existence, and as we ascend to those higher in the grade of being, and of more perfect development, the multiplicity of parts, and complication of structures, render it the more surprising. If these then, are our ideas when beholding the working of the perfect individual, our admiration does not cease, but becomes intensified, when, that perfection being lost, we see the wonderful methods adopted for again attaining it -

There is in all organised healthy beings

a tendency to arrive, from a state of imperfection, to one of maturity or ~~not~~ specific perfection, to maintain itself, in that condition for a given time, after which its vital powers flag, its energies weaken, and it gradually relapses into a state of decrepitude and decay, which is so properly termed in man "Second Childhood" only that it possesses the feebleness, without the energy, the innocence without the buoyancy, and the helplessness without the freshness and latent force of youth. It is in the first of these stages, viz before arriving at maturity, that the power of repairing, and reproducing, wounded or lost parts exists in the highest degree: Wounds heal and lost parts are reproduced with greater quickness, and more certainty of endurance, than in after life whilst after the specific perfection has been attained, this power exists inversely to the protraction of duration of the being's life.

The capability of atoning in some way, for the deficiency of structure which casualties may occasion, is not confined to living organisms, but it is to these that we must at present direct our attention, and we find

that

that in them, this is effected, either by the lost part being replaced by another of the same definite form and structure, or by as near an approach to it as is possible under all the circumstances of the case - I have however at present not so much to do with the different methods and conditions of Repair, as with the Reproduction of lost parts, and with the Comparative powers or capabilities for this, possessed by the different tissues of Man and the lower animals.

It is difficult to lay down any rule or general law, which shall be universally applicable to the capabilities of reproduction of lost parts, in different classes of Animals. It is obvious that some possess the power to an enormous extent, whilst others comparatively slightly - Some have attempted to prove that it exists in the highest degree in those animals, which are lowest in the scale of being, and decreases in exact proportion upon as we ascend that scale; but although the first position may be correct yet the latter inference will not stand the light of investigation, and I think it will be seen as we

advance

advance, that the general rule which admits of the most universal application, seems most in accordance with fact, and is most satisfactory to reason, is, that the power is most in force in those animals, in whom the "germ power" is the least distributed, or in other words — where the component parts of the structure of the animal, are most similar to those of the germ, and consequently the "germ power" is the least exerted, in bringing the animal to a state of perfection —

In treating of this subject I propose

I. Briefly to consider the power or force, in virtue of which, all lost textures capable of regeneration, seems to be reproduced

II. To notice those tissues in the Human body, which admit of this reproduction, and to compare their capabilities for it

III To examine into the extent of this power, in the tissues and organs of the lower animals.

IV To draw some general conclusions

I. First then let us briefly consider the power or force in virtue of which all lost textures capable of regeneration, seems to be reproduced.

Physiological research seems to warrant the conclusion on the point, that each tissue of the body, or rather the ultimate components of each tissue, have the property of selecting their own proper nourishment, from the circulating fluid, and appropriating it as their food, thereby assimilating it to their condition, and moulding or building it up into their own form and structure; or that while these structural elements are undergoing a higher development, they give off germs or cytoblasts, which shall eventually in like manner be developed, and fill their place when their office in the economy of nature is fulfilled.

This will not however serve our present purpose. for, although this general law may be to a great degree satisfactory, to account for the maintenance of the body in a state of health, for the continued supply of new texture, to fill the place of that which is gradually wasting at all times of a being's life, yet since it always presupposes a model to exist after which the new structure is to be built and fashioned, it seems to be quite insufficient to account for the reproduction of parts, such as an entire limb where all preexisting models are destroyed, and no mould or type left in conformity, to which the new structure may be formed

We look however in vain, for any other force or impressed law, in virtue of which this can take place, except by referring to that one, which admits of universal application, and is of most persistent power, viz that principle of development, impressed upon the germ, from the commencement of its existence by its great Author, and which may be fairly supposed to continue in operation, not merely during the Embryonic stage, but (although

* Paget "Lectures on Processes of Repair and Reproduction after injuries". London Med Gazette 1849.

in a continually diminishing extent) throughout the entire life of the individual; that power, which disposes the apparently exactly similar constituents of the germ cell, to assume totally different forms, and to develop themselves into perfectly dissimilar structures, all harmonizing to produce specific perfection.

The force which Mr Paget has styled the "power of the germ or germ-power" since it is "in the germ that it has its apparent origin and incessant action" * is doubtless dispersed through every part of the organism, and pervades every structure, which it has been effectual in forming, thus endowing them with its own power, though to a limited extent.

Of what this vital force, or ~~germ~~ germ-power consists, however we can form no conception. It is of too ethereal an essence, and of too spiritual a nature, for our understandings to comprehend — Let it suffice us to know, that such does Exist, that every living impregnated germ, will when placed in favourable circumstances, select and dispose external matter, so that in due time for it

it, its own organism, will be constructed, precisely similar elements, with the developed into totally dissimilar organs, and in such admirable order and arrangement, as to meet all the requirements of the perfect being. Baird

The true searcher after truth should not lose himself, in a fruitless search after the solution of the Question "What is life?" but should heed its manifestations, wherever they come under his notice, and are capable of being comprehended by him.

Features distinctive and characteristic of this germ-power, have been adduced to prove that it is the same which is operative in the reproduction of lost parts, such as "its being limited to the attainment and maintenance of the perfection of the specific form, and to certain rules of time and space and mode of progress" — "its diffusion through various parts, which concur in the attainment of the design and destiny of the whole," * and the non existence of any model in the germ, either before, or after impregnation, according to which it could develope itself.; but it will be quite evident

* Page op cit

evident, that these characters, although unquestionably answering the purpose of showing that a similar power is in operation in the reproduction of lost parts, and that the theory of assimilation is inapplicable to it, yet leave us as much as ever in ignorance, as to the nature of the force, and enlighten us merely as to some of the limits, or extent of its operation.

Another interesting and conclusive evidence, which has been adduced of the working of this power in supplying the place of lost parts, is that the part reproduced, for instance a leg or foot, is not an embryonic leg or foot, but one suitable in every way, for the stage of the Animal's existence, in which it is re-formed it being produced, in exact accordance with the state of the limb, which the parents had, at that portion of their existence — And here the question suggests itself — Does this germ-power lie so to speak dormant, after the specific perfection of the Animal has been obtained, and give place to another force, viz that of assimilation, only to be called into action, when circumstances require it? or is it always in active operation throughout

throughout the entire life of the individual?
Since it is acknowledged to be more difficult
to attain to than to maintain perfection, Why
should not the force which is equal to the greater
be sufficient for the less? The discussion
of this deeply interesting topic, however would
lead us away from our subject, and perhaps
be of little practical benefit and I therefore
hasten in the second place

II To notice those tissues in the Human
body, which admit of being reproduced,
and to compare their capabilities for it.

From some interesting observations,
made by Prof. Simpson, which were commun-
icated to the obstetric Society of this city, and
published in the "Monthly Medical Journal" for June
1848, it would appear that in the human
embryo, a power of reproducing lost parts of
limbs exists. - In a girl 11 years of age
"who had been born wanting the left up-
per extremity, from a short way below the
elbow joint" the stump was perfectly skinned
over, with the exception of two spots of cicatri-

Zation

over the extremities, of the amputated bones of the forearm "a little in front of these two points, was a raised cutaneous tubercle, divided on the surface, into five minute nodules, on two of which small points of nail could be detected ..... This projection Prof. Simpson stated various reasons for believing to indicate an effort of nature to replace the lost portion of the limb; he considered it in fact to be a rudimentary hand, and a curious illustration of the power of regeneration of even compound parts in the Embryo and fetus in utero" In a series of casts also exhibited to the Society, by the Professor., all tended to prove the same fact, and a very singular circumstance connected with them was., that amputation seemed to have been produced in all, at the same spot.

We must therefore conclude, that in the human Embryo and fetus in utero, a power of reproducing at least parts of limbs, exists in common with some of the lower animals, in an adult state but after having passed through the Embryonic condition, the human body no longer possesses this power, and true regeneration, is confined

to some

of the textures composing it, and of them by no means the whole.

They are divided by Mr Paget* (whose arrangement I shall follow in this paper) into three classes of parts.

"First. Those which are formed entirely by nutritive repetition, such as the blood and epithelium"

"Secondly Those which are of lowest organization, and (which seem of most importance) of lowest chemical character" as the gelatinous tissues — the cellular and tendinous and the bones"

"Thirdly Those which are inserted into other tissues, not as essential to their structure, but as accessories, as connecting or incorporating them with the other structures of vegetative or animal life, such as nerve fibres and blood-vessels" —

The first of the Constituents that we have to consider is Blood, and, although it cannot with propriety be termed a texture, it yet requires our attention — Little however need be said as indeed

X Lectures on Surgical pathology - Lect VII

indeed little can be with certainty, as to the method of its reproduction after loss.

The almost immediate effect of any considerable loss of blood, is to render the circulating fluid thinner than before, in consequence of the fluid part being quickly restored, whilst the corpuscles require a longer time, for their reappearance. It is also highly probable that they are being constantly removed from the system, but neither the method of their removal, nor of their reproduction is well ascertained.

The idea which seems most prevalent, is that the corpuscles of the chyle and lymph, after their entrance into the blood, become the colourless corpuscles, and then by losing their nuclei, acquiring colouring matter, and becoming flattened, undergo a transformation into the red corpuscles.

Dr. Addison however supposes, that the pale corpuscles may be formed in the vessels, independantly of those derived from the chyle and lymph, and another view, is that the coloured corpuscles multiply by fission. The first theory seems to be the most plausible, with the exception, that in some animals, the red and pale

corpuscles

have very great inequality, with regard to size.

The Epithelial or Cuticular tissue which as cuticle covers the skin, and as Epithelium lines all the cavities which communicate with the exterior of the body, as well as the free surface of serous and synovial membranes, and also the inner surface of the bloodvessels and lymphatics, is from its nature and office, so subject to change, that a constant demand for it is kept up by the continual wear and tear, to which it is exposed.

The unceasing abrasions to which it is subject, render the work of reproduction, a never ending operation — whether it exist as scaly — columnar — spheroidal or ciliated it is composed Essentially of nucleated cells, which are formed into a continuous tissue, by the admixture of an intercellular matter — It possesses no bloodvessels, but in some kinds certainly in the scaly, new cells are formed in the deepest part of the structure, in ablastema thrown out by vessels of neighbouring parts.

These cells, at first round and nucleated

gradually

Valentin's "Text book of Physiology" p 309

gradually become changed in shape, and size, as they approach the surface; and after fulfilling their duty fall off, and give place to a repetition of the same process, in later formed cells.

Valentin supposes × Valentin supposes that this occurs also in the ciliated kind, and on good grounds — This tissue is capable of great regeneration, both from the simplicity of its structure, and the important part which it has to serve, as being the protective covering of all cicatrizations, of whatever extent, which may have been formed on the surface of the body.

It is almost superfluous to treat of the Nails and hair, since they are mere growths from the Epidermis or Epidermal appendages. Suffice it to say that provided the matrix or portion of the Corium, to which the nail is attached, and by which it is secreted is preserved, however large a portion of the nail is destroyed, it is wholly reproduced, and the like also obtains with the hair so long as the follicle remains, which is naturally effected in Animals when they cast their hair.

The Gelatinous tissues next come

under consideration and

First. The cellular or fibro cellular tissue, which occupies all the interstices of the body, and serves to bind together its different parts, hence called "connecting tissue" is next to Epithelium, the tissue more capable of reproduction, than any other in the body - It composes the substance or material of granulations, and also of inflammatory indurations, and is the bond of union in almost every repair of solution of continuity, on the surface of the body. - Its reproduction is effected in two ways - that which is produced for the supplying of lost substance, on the surface of the body, as in granulations is developed from nucleated cells; whilst that which serves the purpose of healing subcutaneous wounds, is found to be most generally developed through the medium of a nucleated blastema. According to Schwann & others the cells first formed resemble much the pale blood corpuscles, with the exception that in these the nucleus presents a well marked wall, and cell contents; whilst in the blood corpuscles, there is no such

distinction

distinction of wall or contents - In development the nucleus becomes clear and tense, and nucleoli are perceived in it, the cell also elongates considerably, splits at the end, and becomes filamentous - On the other hand the fibro-cellular or fibrous tissue, which is intended for the production of ligament or tendon, is developed through the medium of a nucleated blastema, although both these methods are no doubt much blended, and often coexist as in subcutaneous wounds and injuries - In the inflammatory product first effused, nucleated cells are organized, but these at a later period give place to the more perfect form of repair, and a nucleated blastema is developed, from which the tissue is built up.

The cellular and white fibrous tissue are so nearly allied and sometimes run so completely into each other, that the description of the reproduction of one serves for that of the other - The method of reproduction of Fibrous tissue, is best observed in the healing of subcutaneously divided tendons, & this has been seen to be performed through the medium of a nucleated

blastema

The greater facility with which new structure is produced in subcutaneous than open wounds, needs no comment from me, Daily observation renders the fact quite familiar although the greatest difference in this respect is seen, in those cases where the open wound remains so for some considerable time after the infliction of the injury - From the careful investigations of Mr Paget on this subject it appears that the first occurrence which takes place in the space, existing between the divided ends of a tendon, after the escape of a small quantity of blood, is the appearance of exudation cells - organized from a semifluid inflammatory effusion, which fills up the gap and renders the part in a condition apparently an asarcous. These cells undergo to a certain extent, changes as in granulations, and the vessels near the divided ends also appear increased in size, and gorged with blood. - So far however, the true reproductive process has not begun - The exudation soon ceases, and the cells do not develop themselves into cellular or fibrous tissue - Shortly after this

a fibrinous blastema, or molecular substance, is deposited in the fibro cellular tissue that surrounds and lies between the cut ends, This gradually acquires firmness and consistency, and nuclei are found in it, which appear to be formed from collected masses of granules and are firmly imbedded in the blastema. As development proceeds the material changes from a moist soft substance with a ruddy tinge, to be firm and tough, and the red colour disappears from the circumference to the centre, leaving externally, a well defined fibrous and vascular cord, connecting the divided ends. As this approaches perfection the inflammatory infiltration around the part is cleared away and the blood vessels attain the ordinary size *

The rapidity with which the new structure is formed, may be judged from the fact, that the half section of a chord which joined the retracted ends of an Achilles tendon of a rabbit, which had been divided only 6 days previously, sustained gradually increasing weights up to 6 lbs when it gave way, and in another rabbit but a little more than a pound in weight, about

of an

* For an elaborate description of these two methods of the development of fibro cellular tissue see "Paget's lectures on Surgical Pathology" Lect VIII

Achilles tendon, which had been but 10 days in formation, and which was not more than 2 lines in diameter, bore successively 20 – 30 – 40 and 60 lbs and was eventually torn with 56 lbs – This also will illustrate the intimate connection which exists between the old and new tendon

The new tissue never attains however to the perfection of ordinary tendon – The arrangement of the fibres is not so uniform, and it does not consequently possess the glistening appearance of tendon – Cases however have occurred, where in the human body, close examination after death has not been able to discover the slightest difference between the old and new structures – Such cases however are of rare occurrence –

Fibrous tissue constitutes the bond of union, between all ruptured parts in the human body which are incapable of regeneration, and its presence is also discernible in the reproduction of lost bone, which naturally leads us to treat of

Osseous tissue –

This texture holds a very prominent position among the animal structures,

when we

consider its capacity for reproduction after loss by disease or injury, indeed. Stanley goes so far as to say "that nowhere else in the Animal body does so perfect an instance of reproduction occur, as in certain cases of necrosis, where the shaft of a bone, with its compact walls, cancellous texture, medullary tube, membrane and medulla, are all reproduced with every essential feature of their original organization"

So much light has not been thrown on the repro process, by which bone is reproduced in man, by experiments on the lower animals, as might have been expected. There exist much greater capacities for development, in the lower animals in general than in man, as will be afterwards shewn, and especially in bone, where casualties accidentally occurring in man, are so different from injuries intentionally inflicted on Animals, (the condition of the soft parts being so different, both before and during necrosis in man, to those where a bone of an Animal is intentionally destroyed) that the process in one cannot with certainty be taken for that in the other

* Stanley on diseases of the bones - Introduction

Numerous have been the investigations made, in order to ascertain the methods, which Nature employs, in the reproduction of bone.

Observations were made by Hunter and more lately by many modern observers, and having a more specific purpose, to ascertain what part of the structure takes the most active part in this regeneration, the result of which go far to prove, that the periosteum, is not only of great service in supplying nourishment to the newly forming bone but also actually produces it. The apparently conclusive experiments of Prof.r Syme are well known *. Two experiments made on dogs. by removing a large portion of the radius in one, together with the periosteum, and in others leaving the periosteum, and finding that in those cases where the periosteum was left complete reproduction had taken place at the end of six weeks - whilst in the other cases, there was no corresponding development, and also from observations on the human subject. Prof.r Syme came to the conclusion, that the periosteum possesses

* Edin Med & Surg Journal / 269

the power of forming new bone, independantly of any assistance from the bone itself -

Others however, amongst whom are Kuoy-Miller and Prof. Goodsir, maintain that the periosteum alone, is not capable of producing new bone, but that in all cases where reproduction has been supposed to arise from this source, there have been Prof Goodsir avers that there must have been small detached pieces of the bone, connected with the periosteum, which have served as centres of growth, from which the new bone has been formed. He conceives it impossible to remove the periosteum especially in the way in which it must be performed in the living animal, without removing as well, strips of osseous substance - Moreover in all bones where portions of the entire shaft or the external lamellæ have died and been replaced by new bone, there are always to be discerned roughened spots or marks of previous ulceration, by which previous to the death of the shaft, small portions had been detached from its surface, and remained connected with the periosteum - Now it is an interesting fact, and

one which

one which lends considerable weight to this view of the case, that it is opposite these roughened portions of the shaft, that the earliest and most extensive development of new bone occurs, and that the Cloacæ, or openings in the case are invariably situated opposite the parts of the dead shaft, which are perfectly smooth, and afford no marks of ulceration having taken place

Cases of necrosis of the entire shaft of a bone, do however occasionally occur of which Mr Stanley mentions one in the museum of St Bartholemew's Hospital where to all outward appearance, the dead shaft presents a perfectly smooth surface, at least to a great extent, and yet in this case, complete reproduction had taken place +

In such cases it would certainly seem to be reproduced ~~from the periosteum~~ principally by the unaided action of the periosteum + but of course if it is to be taken for granted that a bone is never deprived of its periosteum, whether intentionally or by disease without some shreds or particles of osseous substance being removed with it, however minute and unobservable to the naked eye, then it is but natural to suppose

* Stanley Op cit

that these particles, may take at least an active part in the production of new bone

In the 5th Volume of the "Memories de l'Academie Royale de Chirurgie" for 1774. there is a passage bearing so directly on this subject, by a Mr Lamblot whilst explaining the reproduction of some bone which came under his notice, that I take the liberty of transcribing it

"On a mit ces cas dans la classe de caries; il faut d'abord admettre" dit Mr Lamblot" que ces os, reproduits et régénéré, n'étoient pas si entierement cariés, qu'il ne restat à chacun d'eux, quelques petites portions exemptes de la carie, et par conséquent aussi intactes aussi saines et aussi vives que les parties molles le sont sous une escarre gangréneuse sèche

2° Que le périoste de ces mêmes os. ayant échappé au moins dans une certaine étendue à l'action morbifique, a servi de trame de plancher et de moule, de concert avec les autres parties environnantes, tant au développement et à l'expansion, des vaisseaux

des extrémités osseuses, qu'à la condensation de la lymphe nourricière, ou au cassifique, qui exudoit de l'extrémité de ces mêmes vaisseaux" Mem. de l'Acad Roy. de Chirurgie Tome 5me p. 362

Whether the periosteum without any portion of bone possesses the power of reproducing a lost portion of the shaft or not, its importance as a requisite structure is by no means diminished since it is by it that the minute shoots if they do exist must be nourished. But there are other sources, from which bone has been supposed to be reproduced viz from the articular extremities and the surrounding textures. It is probable however that the articular extremities, do not possess the power in the slightest degree, and all those supposed examples of their effect are in reality illustrations of development from ends or portions of old bone attached to them & to use Prof Goodsir's word "An epiphysis is a distinct part, and has no greater tendency to supply the losses of the principal mass of the bone to which it belongs, than the femur, fibula or astragalus to supply the loss of a tibia"

It has been a matter of dispute whether

* Goodsirs pathological Obs. p 70

the surrounding textures are able or not to produce bone independantly of the periosteum, and adhering shoes of bony substance - By some it is supposed that under certain circumstances they are, and that these favourable circumstances are, that around the dead bone, there should be a thick stratum of soft parts, and that the inflammation in them consequent on the death of the bone, should have been so mild, as to terminate in the effusion of serum, or fibrin, rather than in inflammation. Much doubt however still remains on this point. and as the parts immediately around the bone in cases of fracture, become condensed, and ultimately take on much the same action, as the periosteum, it is likely that in some cases at least they aid in regeneration.

And now with reference to the material from which new bone is developed - Dr Robt Nesbitt in 1731. first described the ossification of some of the bones in the skull as taking place in membrane and not in cartilage as was formerly supposed. but until lately this doctrine has not been generally received - Dr Sharpey

has however recently discovered, that the method of ossification in the long bones by which they increase in diameter, is not through cartilage but through a fibrous structure, in which are imbedded stellate cells or corpuscles, so that increase takes place, by intramembranous ossification - Köllikers investigations would also seem to prove that this holds good not only in the long bones, but in all the other bones in the human skeleton, that are formed from cartilage, with the exception of the bones of the ear, so that the cartilage serves only as the mould, in which the bone is first laid, after which when it acquires solidity, additions are made through fibrous and cellular substance only

- A similar method is found to obtain in the reproduction of bone, which may take place through fibrous tissue, either in the rudimentary or the perfect condition, or cartilage may be formed - In the first of these conditions whether the rudimentary fibrous tissue exist as nucleated cells - or a nucleated blastema, ossification takes place, before the mature development of the fibrous tissue has been arrived at,

It is supposed probable that it is through nucleated blastema that union takes place in quickly and well repaired fractures in the long bones.

That ossification may be effected through fibrous tissue appears likely from the fact, that in cases of fracture of the long bones, where from undue mobility or other causes, what are termed false joints are produced, the substance connecting the broken ends is fibrous, which we may fairly judge to have been arrested at this step of its development. But the process is between often fractures of the cranial bones, and it is also evident in the ossification of interosseous membranes contiguous to sites of fracture in the long bones. Perfect Cartilage, as a reproducing agent or medium of bone although produced largely in Animals is seldom if ever found in Man. Near approaches to it however we may conceive likely to be made in the child and when mingled with fibres so as to form fibro cartilage it is not so rare. A combination of the three methods just named may doubtless be in discernible progress in the dance growth —

same growth - The extent to which bone may be reproduced, is in some cases really astonishing - The most favourable cases for it, are those where the bone has become suddenly necrosed, and where no great injury has been done to the surrounding texture.

The superior maxilla holds a high position in this respect - Dr Carpenter mentions a case which came to his knowledge, from good and creditable authority, of a young girl who lost the whole of one ramus of the lower jaw by disease, and yet complete regeneration was effected not only of the ramus but of teeth also which occupied the usual situations in it (1)

Prof. Syme also mentions a case in his Clinical report where the jaw recovered all its functions, and normal shape, after removal of the ramus and entire condyle (2) - A similar case is mentioned by Desault (3) and also mention is also made of one in the Memoires de l'Academie Royale de Chirurgie (4) & the same work is also reported the entire reproduction of the Clavicle. Weidmann relates a case of regeneration of the scapula (5) and this occurrence in the long bones

(1) Carpenters principles of Physiol Gen & Comp. p 872

(2) Edin Med & Surg Journal

(3) Chirurgical Journal. vol IV

(4) Mem. de l'Acad. Royale de Chirurgie 1774

5 Wiedemann de Necrosi p 28.

to a great extent is too frequently observable to require comment

We next come to treat of those parts which may be considered as accessory to other structures, as tending to incorporate them with the rest –

The first of these is

Nervous tissue If a nerve be divided in any part of its course, the cut ends retract by their own elasticity, In process of time a structure similar to that thrown out for the repair of other soft parts, is produced between the extremities, which connects them, and in this structure new nerve fibres are at length formed, so that the nerve is able again to perform its functions. It rarely however happens that all the fibres of the proximal end are joined to those of the peripheral segment; so that the last part of the nerve becomes less in size, and is also of a whiter colour than the other part. – Considerable portions of nerve are in this way capable of being reproduced, when cut out, but the amount formed depends on circumstances – From some of Dr Brown's experiments

experiments it seems to be best effected, when there is a constant irritation kept up near the seat of injury - We found that so much as an inch had thus been reproduced, in a horse's foot, but this is very rarely the case and was most likely caused by the existence of a carious bone near, which acted as a constant source of irritation +. When however the two ends of a nerve have failed to be thus united the parts beyond have been found to be connected to the nervous centre, by means of distinct branches of nerves, from the upper segment which had evidently been produced after the nerve had been divided - I need not mention the important bearing which this has on the practice of dividing nerves for the relief of neuralgic affections or the benefit which in some cases might ensue, if it could be ascertained, how much of a nerve it would be sufficient to remove to prevent reproduction. For the proper development of these new fibres, the cut extremities must be so situated as to be directly opposed to each other - The ganglionic corpuscles are found also to be capable of reproduction

The Arterial tissue next demands

* Strain on Nerves 18th Experiment

consideration and although when an artery is divided or a portion cut out of it, it cannot be joined or replaced, in the same manner as we have seen nervous or areolar tissue do as completely to restore the continuity of the structure, yet it is capable to a certain extent of regeneration.

In every case of a wound which does not heal by primary adhesion, but in which granulations are formed, we see that new arteries are produced which although for the most part are only temporary, still afford most admirable examples of the formative force of nature - Instead however of being formed from nucleated cells as in the embryo which send off prolongations of their walls in an irregularly stellate manner, which uniting with those from neighbouring cells become enlarged and permeable to blood, another method is adopted in these cases which has been termed a "species of outgrowth" or development from the walls of pre-existing vessels - If the plan of procedure be watched, a prominence in the wall of a vessel nearest the surface is found to extend itself gradually among the granulation cells - Contemporary with this, another prominence at a short distance

will be

will be perceived on the same vessell, and these two outgrowths, or so to speak blind tubes, which are open at the end towards the vessel gradually and by a definite course, incline to each other till their extremities meet and coalesce thus forming an arch through which circulation may be carried on - The growth of these little vessels is at times very rapid, and bears of course proportion to the amount and vascularity of the granulations. But wonderous as this process is and explicable I may add by no laws of assimilation, we yet see more perfect attempts made to regain the continuity of large arteries, from which portions even have been removed - What I have hitherto said refers only to the production or growth of vessels in new structure, but from Dr Parry's experiments made in 1819 it would appear that in some cases, when an artery is tied in its course or a portion removed new connections are formed between the ends which assist in restoring the circulation - Before he wrote it was the received opinion that this was never effected as in his work he thus quotes from Bichat "Quant aux artères il ne s'en forme jamais de nouvelles" and also at the present

* Parry on the Arteries p 35

present day as far as I am aware this opinion is generally held; but from Dr Parry's experiments it ~~would seem~~ which were performed principally on the carotids of dogs, it seems to be proved that the divided extremities of an artery, do not always dwindle or become ligamentous, or absorbed, but that when such a portion was removed, new connecting tubes were formed, between the divided ends, and so placed directly between the ends, as to leave no doubt in his mind, of their being new formations and not the enlargement of small pre-existing anastomosing branches - The principal growth of the tube seemed to be, from that side farthest away from the heart, and from the detail which he gives of one of his experiments it would appear that a fibrous cord is formed similar to that which fills the gap in a divided tendon - in or on which the new vessels are formed. "Condensed cellular substance" says he "was interposed between the two stumps, and supplied a bed for new arteries, which were now connecting the ends of the vessels and had re-established the circulation"* These observations however require corroboration, and would repay careful repetition

We thus find that the tissues of the Human body taken in the order of their capacity for reproduction are.

1 The Epithelial 2 The cellular or areolar and Fibrous 3 The osseous 4. The Nervous and lastly we may include the Arterial

Time will not allow me to notice those structures such as the ducts of glands &c which exhibit the power in a remarkable degree

Besides the tissues above named and treated of none are capable of being regenerated, in the true sense of the word, and injuries or loss are atoned for only by the production of some tissue lower in the scale of organization which may generally be said to be the fibro cellular.

Thus if a muscle be cut across, the ends of course retract by their own contractility, no new muscular fibres are reproduced to fill the gap, but the retracted portions first form new attachments to the subjacent fascia or bone, which in process of time a tough fibrous band joins the ends, and by subsequent contraction, restores to a great extent the usefulness of the muscle.

Skin however presents a nearer approach to a

true reproduction, than any of the other tissues
When we consider its Complex structure, we shall
not be surprised to find that it is not in all
its parts regenerated - So far as has been
ascertained neither the Sebaceous nor sudorife
rous glands are produced in the Cicatrix,
nor the muscular fibres, which are said by some
to exist in the Skin; but all its other structures
including its papillæ, and the pigment cells,
which in the Negro are developed between the Epi
dermis and the Corium, are present, The elastic
fibres however, require a prolonged period, for
their new development -

There are no grounds for the belief, that Cartilage
when lost is ever restored - Experiments on the
articular Cartilages of the lower animals and in-
vestigations into the appearance of the Thyroid
Cartilage when it has been divided in cut throat,
and the patient has lived long afterward, prove
to the contrary - In some cases as in the last
mentioned, the repair is by dense fibrous tissue,
- in others bone may be formed. - but this very pro
bably only occurs in those parts, in which the ossi
fic deposit naturally takes place in old age,
and

* Regeneration of Animal substances by Chas. Watt
Esq F R S &c

And in articular cartilages, a substitute is provided by what is termed the "Porcellanous Deposit"

As illustrative of the tendency to return, which sometimes abnormalities even present, the following case is interesting - In a paper published by Charles White Esq FRS Lond in 1782 - he states that he delivered a lady of rank of a fine boy who had two thumbs upon one hand or rather a thumb, double from the first joint on each of which there was a perfect nail - the outer one being however smaller than the other, The supernumerary one was removed by Mr White when the boy was three year old - but strange to say it grew again, having also a nail upon it - It was afterwards removed by William Broomfield Esq Surgeon to the Queens Household when on the supposition that the former operation had not been sufficiently extensive, the ball was turned fairly out of the socket and the growth entirely taken away - In spite however of this complete excision it grew again and a perfect nail was produced - No further interference was made †

Having briefly noticed those tissues in the human body which admit of regeneration, and compared their capacity for it; it now remains to consider the extent of this power in the lower animals. It has been already said that they possess it in a much higher degree, and to a far greater extent than man, as is easily perceivable in the case with which for instance whole limbs are reproduced, in some as in the Crustacea, the whole digestive apparatus in the others as in the Holothuriadæ, and a perfect body formed from a shapeless segment as in the Hydra, but leaving for a time these animals very low in the scale of being, we find that a great difference as to this power exists between the higher vertebrata and man. for although a greater number of tissues may not be reproduced - yet in these the process is much more rapid, and a greater amount of new texture is formed. We see this to be very markedly the case in the production of new bone, in fractures, for in animals there is a great amount of temporary callus, thrown out between and around the fractured ends, whilst in man it is a matter of some doubt whether

whether this ever occurs in ordinary repair of fractures, and certainly in many cases does not exist at all — Whilst however doubtless the true plan upon which nature works, in these instances, is to do nothing unnecessarily and provided there be no movement between the ends not to form a natural splint by throwing out some temporary callus.; yet if necessary in consequence of mobility of the broken fragments I can see no reason why this callus should not be formed and notwithstanding Mr Paget's opinion to the contrary and with all due deference to them, I can believe that it frequently is the case. In the lower animals we know there is a great amount of mobility, which combines with their increased vital power to produce the callus but even here, provided there be perfect rest maintained it is a great question whether this temporary callus would be formed —

The rapidity with which this formation takes place is also striking — Experiments on rabbits have shewn, that in them a perfect cartilaginous callus is formed in less time, than any perceptible growth occurs, between the opposed ends of a bone

in man since in the latter case, a period of inactivity of from 6 to 10 days is found to elapse after injury — In the healing of divided tendons and the production of other lost tissues, the same remark holds good, for although the process is to all intents the same, still in man a longer period is taken both for the production of the material, and its more perfect development and organization; and this is one chief objection against drawing too hasty conclusions, with reference to this power in the human body, from experiments on the lower animals —

The succession of molar teeth in the Elephant is also another example of this exalted power — They are changed from 6 to 8 times — each succeeding tooth being larger and containing a greater number of vertical plates than its predecessor — The principal wear of the tooth is in front, whilst the reproduction takes place from behind, and thus the new one continually presses forward the old, until it comes to occupy its place — Among the cold blooded vertebrata also we find, that the teeth are capable of being frequently reproduced — In reptiles and fishes

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*Carpenter op cit p 463

‡ " " p 871

and fishes this succession of teeth is remarkable, & reptiles they arise as offsets from the follicles of preceding teeth whilst "in by far the larger proportion of fishes this successional development, takes place from new and independant papillae, the germs of the replacing teeth being produced from the free surface of the buccal membrane, and advancing in their regular course of development, in proportion as the teeth previously formed are excavated or torn away or worn down in the predatory operations of the Animal" *

Amongst the cold blooded vertebrata, the regenerative power exists strongest in the Batrachians or reptiles, which undergo a metamorphosis, before arriving at their perfect condition. - In the Salamander for instance and even in young frogs, and toads, entire limbs are reproduced, being in every way perfect, the tail of the tadpole also grows again after amputation, and it is recorded that a perfect eye has replaced one which had been removed from the orbit. †

The only parts which have been observed to be truly reproduced in fishes are portions

of the fins which have been lost - but it may
not be fairly asked, whether this apparently
diminished reparative power may not arise
from the fact that the fins of fishes are the only
analogous parts to the extremities of other Animals,
and consequently observations on them are necessarily more limited in extent?

In the Articulata the power is
possessed to a considerable degree, even
amongst the higher members of the group -
New limbs are reproduced in the group Arachnida
which includes Spiders - Scorpions &c but not until
the moult subsequent to the infliction of the injury.
It is worthy of observation also that the repro-
duction takes place from the proximal articu-
lation, whether the whole of the limb has been
primarily lost or not -

In the Crustacea also the same thing
takes place - In a series of observations, made
by H. D. S. Goodsir Esq. - he found that whenever
one or more of the distal phalanges of the Common
crab are removed, or seriously injured, the
Animal immediately throws off, the remaining
parts of the limb, close to the body - This is done
in order

† For further particulars with regard to these interesting observations vide "Goodwin's Pathol. Obstr." p. 77

both to stay hæmorrhage, and in all probability to expose the part from which the new limb is to be developed — When healthy, the Animal is able voluntarily to throw off its limbs when seized by them, but if weak and unhealthy, when serious injury of a limb takes place it is not capable of casting it at the usual spot & consequently very soon dies from hæmorrhage. At this spot near the base of the first phalanx, there is a constriction for the length of half an inch or more, which "is filled with a fibrous glutinous glandular looking mass" the organ which Dr Goodsir supposed to supply the germ for future limbs —

This power seems to be more extended in the lower crustaceans as parts of limbs broken off at any of their articulations may be reproduced without the whole limb being thrown off —

The Myriapoda and Insecta also exhibit a great reparative power — In the higher apoda, the Antennæ with the legs are capable of being reproduced provided the Animal has not arrived at the adult stage — not having passed through its last moult. The young

the

* Transactions of Royal Society of London 1844

the individuals experimented on the more satisfactory are the results, and although the limbs usually present themselves at the moult directly succeeding the injury, yet they undergo improvement after each successive change of skin until no difference in size is perceived between the new and the old limbs - It seems however that though the full size of the parts, may be arrived at in the reproduced limbs, they yet do not attain to the full development of all the normal structures, an instance of which * Mr Newport mentions "in the development of the spines with which the basal joints of the posterior legs of the Scolopendrae are armed" and which furnish Zoological specific characters

In those Insects also which go through a complete metamorphosis, before arriving at the adult state this same power exists. If in the caterpillar condition one of their true legs be removed, the casting of their larva skin and change into the pupa state will be retarded, although not prevented - New limbs sometimes appear after the first change of skin, whilst in some cases not until the individual has arrived at its perfect

* Phenomena of Planaria

its perfect state

In some species of Lumbricus and Nais, as well as the true Annelida, there is an extraordinary tendency to reproduce lost parts & also each part, when severed has the power of forming a perfect body – Some of these Animals are noticed to divide spontaneously, when each part becomes an entire Animal

From Sir I. G. Dalyells interesting investigations on the Planariae* it is found that they also are capable of reproducing segments of the body, – he even succeeded in producing two heads, to one body by noticing the great tendency to regeneration of the head when cut off, Instead however of entirely removing it he made an incision near it from which in two or three instances an additional head was developed.

In the Cestoid Entozoa as the Taenia or tapeworm so long as the anterior portion of the Animal is intact, there seems to be no limit to the replacement of segments of the body, which have been cast off – In these however it cannot be called ~~a true~~ reproduction, since it seems to

be only

be only the natural growth of the animals - the additions taking place from the anterior portions of the body -

Among the Mollusca - the Lamellibranchiata groups are said to be able to reproduce the entire head with tentacles and eyes.

In the Radiata - the Holothuroidea according to Sir J. Dalyell reproduce as a new mouth the whole of their viscera which they eject when captured - The true Starfishes also are capable of replacing the rays which may have been lost, although no instance has yet been known of the rays producing the disc -

The Ophiuroidea pinnas the arm from and on account of their great brittleness when in danger of being taken, they divide spontaneously into segments - thus apparently destroying themselves although if the body remains the arm may again produced -

But the most wonderful instances of the reproduction of lost parts, is found in the lower forms of Zoophytes, as in the Actinoida Hydroida and in order to gain a good idea of the extent of this power, and the diffusion through all parts of

the organism

* Payt Op cit p 157

the organism I cannot do better than quote Mr Paget's graphic description. He says "Trembley cut a hydra into four pieces - each became a perfect hydra, and while they were growing he cut each of these four into two or three, these fractions of the quarters being on their way to become perfect, he again divided them and thus he went on till from the one hydra he obtained forty, all these became perfect - He kept many of them for more than two years and they multiplied by their natural generation just as much as others that had never been divided, Again he cut similar polyps longitudinally and in an hour or less, each half had rolled itself and seamed up its cut edges, so as to be a perfect hydra - He slit one into seven pieces leaving them all connected by the tail and the hydra became seven headed; He cut off the seven heads and hydra like they sprang forth again, and even the fabulist dared not invent such a prodigy as the naturalist now saw - The heads of the Lernean hydra perished after excision; the head of this hydra grew for themselves bodies, and multiplied with as much vigour as their parent trunk *

I regret that I have been only able to take a very cursory glance at the different types and classes of animals which possess the regenerative power - Enough has however been said I trust to make good the general principle with which we started

First We have seen that this regenerative power is possessed most extensively by those tissues whose organization and development is most simple and uncomplicated

Secondly That it is of greater force in young than old animals

Thirdly That it is generally most effective in those animals that have undergone the least change in their growth from the Embryonic to the adult state for if the metamorphosis has been extensive as in insects which pass through their larva and pupa condition before attaining specific perfection the power of reproducing parts such as antennæ or legs does not exist in the perfect animal

Fourthly That those animals which multiply by gemmation as the Hydra &c and whose adult state consists merely of a repetition of the original germ cells, and also in some of the Annellata in which

which increase, by the addition of rings, alone possess the power of developing fragments of the body into perfect animals

From these considerations then we deem it just to conclude

I. That the power of reproducing lost parts exists in an inverse ratio to the degree of their development.

II That the same power is active for the regeneration of lost parts, as was first of all effective in their formation.

Samuel P. Hazlett

Edinburgh March 1836