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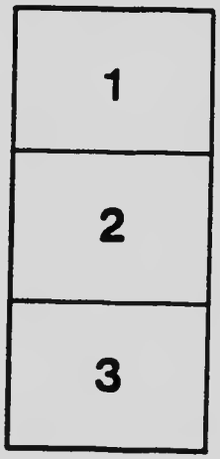

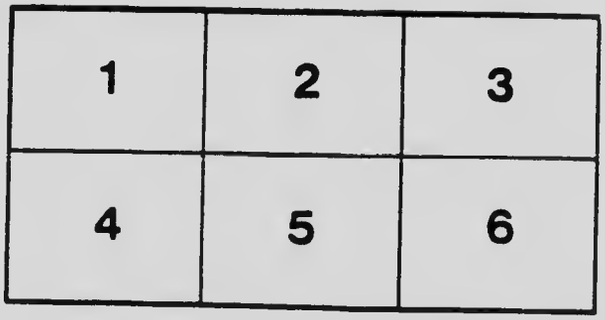

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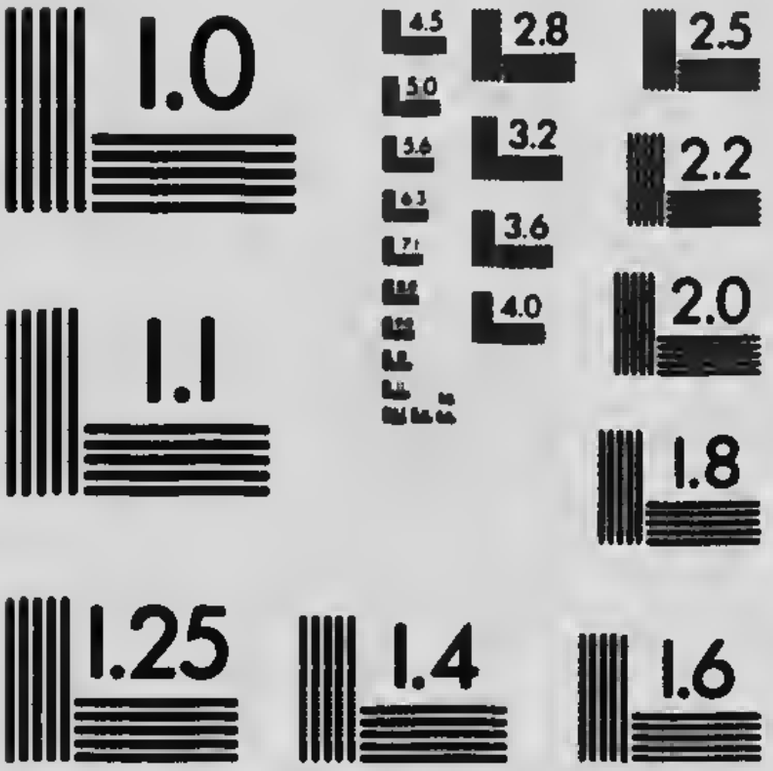

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The Finer Histological Changes in the Traumatic Degenerations of the Spinal Cord, following Bullet Wounds of the Cord Substance, or Shock to the Vertebral Column

BY

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WITH TWO PLATES

Reprinted from *Review of Neurology and Psychiatry*, October 1916.

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THE FINER HISTOLOGICAL CHANGES IN THE TRAUMATIC DEGENERATIONS OF THE SPINAL CORD, FOLLOWING BULLET WOUNDS OF THE CORD SUBSTANCE, OR SHOCK TO THE VERTEBRAL COLUMN.

By AUBREY MUSSEN, M.D. (McGill).

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(With Two Plates.)

BEFORE considering the degenerations found in these conditions, it may be advisable to briefly review the relations between the spinal cord and the vertebral column. For a severe shock to the column, without directly involving the cord, may produce profound disturbances in the spinal medulla. And when the cord itself is directly affected, these same relations bear an important part in transmitting to distant regions the effects of the concussion.

The spinal cord lies loosely within the vertebral canal. It is surrounded by fluid and protected by membranes. The outer of these membranes, the theca, forms a wide dense fibrous sheath which is separated from the wall of the canal by a narrow interval containing fatty tissue. The pia mater, a thin fibrous membrane, closely invests the cord. The space between these is filled with fluid in which the cord is supported by the ligamenta denticulata

These broad and firm bands arise from the pia on the lateral surfaces of the spinal medulla, and are attached to the dura. From the deep surface of the pia numerous septa penetrate into the cord substance. The most important of these are the posterior median septum which connects with the posterior commissure, and the lateral septa which, after passing through the white substance, end by uniting with the neuroglial fibres of the lateral horns. These septa, which assist in attaching the pia firmly to the cord, are closely connected with the supporting glia structure of the white and grey matter. And this structure forms a sheath to the myelin and is intimately associated with the axis cylinders. We thus see that any severe shock to the spinal column could be transmitted through these membranes directly into the substance of the cord.

Having recalled these facts, we will appreciate more clearly why a heavy blow to the spinal column, as when a bullet embeds itself in the body of a vertebra without injuring the cord, can produce such profound disturbances, and why also the fracture of a spinous or transverse process will sometimes cause such serious results.

The cases available for this research comprise—bullet injuries of the brain, with secondary effects on the spinal cord; bullet wounds involving the cord directly; fracture of the laminæ with injury to the cord substance; wounds involving the transverse process of a vertebra; and bullets embedded in the body of a vertebra without direct injury to the spinal medulla—a sufficient variety of cases from which to form some definite conclusions.

As the duration of the illnesses varied, the material investigated represented degenerations of 10 hours, 24 hours, 48 hours, 60 hours, 1 week, 11 days, 7 weeks, 2 months, 4 months.

The methods employed were as follows :—

(*a*) Bielschowsky's silver impregnation method, to determine the changes in the axis cylinders.

(*b*) Mallory's frozen section method, to show the alterations in the myelin sheaths (yellow); axis cylinders (blue); neuroglia cells (blue); neuroglia fibres (violet).

(*c*) Marchi method, for the degeneration of the myelin.

(*d*) Herxheimer's Scharlach R. method, to examine for the earliest traces of fat degeneration, and to study their relations to the nerve fibres, glia cells, and blood vessels

(*e*) Marchi counterstained by Mallory, to facilitate the investigations of the changes in the later stages of the degenerative process, for the tissue mistained by the osmic acid is beautifully differentiated by the Mallory.

Case I. (10 *hours*).—*Captain A. Stokes, No. I. Lab. B.E.F.*

The soldier was wounded by a hand grenade. One piece entered the right frontal lobe of the brain: there was no great haemorrhage, though sufficient to fill the region of the pons with clot. A second piece entered the neck, divided the right vagus, opened the jugular, and went on and bared the transverse process of the fifth or sixth cervical vertebra. It did not penetrate into the canal. He lived about ten hours. The post mortem showed that the cord was apparently uninjured.

Bielschowsky preparations from the cervical region show that the axis cylinders throughout the greater portion of the longitudinal section are normal. Their course across the whole field is straight; the fibres, which are of an equal size throughout, show a slight waviness, but there are no sharp twists. In another region of the same section the axis cylinders are suddenly bent at regular intervals, but there is no swelling or breaking of the fibre.

Mallory sections show the twisting of the axis cylinder as well as a distinct globular swelling of the myelin sheath, which also presents in some fibres a granulated appearance. Some fibres show a distinct swelling of the axis cylinders at regular intervals. This is generally associated with fibrillation, and occasionally with partial rupture; no changes were observed in the neuroglia cells.

The Marchi method shows here and there, extended along some nerve fibre, a few small dark staining balls of myelin. From their small size and the fact that the Scharlach R. shows no fat reaction it is evident that they are the Elzholz bodies, symbolic of the normal metabolism of the central nervous system.

Case II. (24 *hours*).—*Captain Stokes.*

This was only a portion of a cord. It showed a complete transverse division about the level of the first dorsal segment from a rifle bullet. Death occurred twenty-four hours after the injury. Sections stained by the Bielschowsky method show that the fibres are swollen, and in many instances broken. Many fibres are thrown into kinks and twists, which are sometimes so marked that complete loops are formed. The large majority of the fibres, though, in this section are normal.

Mallory.—A transverse section near to the lesion shows that in both lateral regions considerable disturbance has taken place with destruction of tissue. This is more marked on one side than on the other. On the least affected side one sees that a lateral septum, where it comes into relation with a vessel some distance from the surface, is torn, and the surrounding tissue shows a small hæmorrhagic infiltration. There is some swelling of the nerve fibres with vacuolation. On the opposite side the disturbance involves a much larger area. Several of the septa are torn, and in each case there is an infiltration of blood cells with disturbance of the surrounding nervous tissue. An illustration of the peculiar distribution of the shock effects is well shown here. One of the main lateral septa has evidently felt the force of the disturbance particularly, for along its course, where it comes in contact with a small vessel, the tissue is lacerated, a small hæmorrhage resulting. During its further course through the fibres of the white matter the tissue is quite normal, but when the septum reaches the grey matter of the lateral horn the structure is again torn, and three small hæmorrhages are observed. Around one of the branches from this septum a small localised area is affected. Two nerve fibres are involved.

The surrounding tissue is torn and infiltrated. The nerve fibres are swollen, particularly one of them, to about six times the size of those in the neighbourhood. The swelling almost entirely affects the axis cylinder, which is markedly œdematous. It shows a finely granulated appearance, the fibrillæ, which are irregularly separated by the œdema. Many fibres in this region are similarly affected, and a considerable degree of vacuolation is to be observed.

In longitudinal section numerous small infiltrations are found

scattered along the course of the nerve fibres. In one instance a fibre which runs parallel to one of these can be observed from before the hæmorrhage commences till after it has ceased. In the first part of its course the axis cylinder is normal in appearance, then it is seen to become sharply wavy for a short interval; after this it becomes normal, but opposite the greatest extent of the infiltration it is again thrown into sharp waves and kinks which are larger than in the first instance, and involve a longer portion of the fibre. After a short interval in which it is normal, the axis cylinder is again thrown into waves in a manner similar in extent and character to the first instance. It then resumes its normal state and disappears from the field.

In another part of the section marked swellings are to be observed along the course of the nerve fibres at irregular intervals. In these enlarged spaces the axis cylinder is found to be kinked up, sometimes swollen, and often broken. One sees, in fact, the first stage in the formation of the myelin balls, which will be referred to later.

A particularly interesting condition is found in another region. The myelin sheath of a fibre is swollen and fragmented, and the axis cylinder shows three distinct enlargements at intervals along its course. The condition, though similar to that just described, is more pronounced, for the axis cylinder is in this instance formed into distinct loops, and the twists are more marked. Besides this, each swelling of the axis cylinder is surrounded by a pale membrane. Sometimes this assumes the form of an evenly distended tissue, or the contour of the membrane may be broken. It stains similarly to the glia tissue, and appears in fact to form a fine glia sheath around the axis cylinder.

As regards the glia elements, a decided increase of one form of the cells is noticed in the neighbourhood of the degenerating fibres. In this, as well as other sections, three forms of glia cells are to be distinguished. First, those which appear to be fixed in the tissue. They are frequently larger than the others, the cell is round, stains more deeply, and the chromatin bodies are generally very prominent. It is surrounded by a large mass of protoplasm from which numerous fibres are given off to form the supporting structure of the surrounding tissue. Second, a cell very similar to the first; it is also fixed in the tissue by a few fibres which are given off from the protoplasmic body, but neither the fibres nor

the protoplasm surrounding the cell are so well developed as in the first instance. The third form appears to lie free among the fibres. It is not surrounded by protoplasm, and no fibres are given off from it. It does not stain so deeply as the others, and the chromatin granules are not so evident. It is this form which shows an increase about the degenerated fibres. As will be shown later, this is due to the amœboid-like activity of these cells.

Marchi preparations show as in the previous case the Elzholz bodies, but no proper reaction to the osmic acid.

By the Scharlach R. method no traces of fat are to be found.

Case III. (about 48 hours).—Captain Stokes.

This patient arrived at the hospital moribund, and died without recovering consciousness. He had been wounded by a rifle bullet which fractured the first dorsal spine as well as the laminæ on both sides. The body and pedicles were not injured. The notes state that death occurred between twenty-four and forty-eight hours.

At the post mortem, when the laminæ were removed, the theca appeared to be quite normal. On cutting the cord there was an extensive haemorrhage in the central grey matter three segments from the lesion. The portion of the cord forwarded for examination included from the fifth cervical segment to the fourth dorsal segment.

Captain Stokes calls attention in the notes (29th October 1915) to the fact that he had seen three cords in which there was an extensive microscopic injury, though there had been no direct contact of the projectile with the cord. He mentions that the remote effects of bullet injuries is not sufficiently recognised, which probably accounts for a great deal of the sepsis and delayed repair. This remark is based on his observations on the muscles, kidney, and liver, and he thinks that the three cases mentioned bear it out as regards the nervous system.

When the cord was examined at the laboratory, small scattered haemorrhages were seen throughout the white and grey matter. These involved the whole portion of cord obtained, and were most marked in the upper region.

Bielschowsky preparations show the bead-like swellings sometimes found along the nerve fibres. In a small area of one section

all the fibres show this condition. The swellings, which vary in size, occur at more or less regular intervals. The myelin sheath is distended by the changes in the axis cylinder. This is seen to be bent and twisted, sometimes forming corkscrews, occasionally complete loops. In no case was the fibre broken, and between these swellings it was quite normal in appearance.

Mallory.—In an area infiltrated by a localised hæmorrhage which has spread along between the fibres, a very marked state of degeneration is to be observed. The nerve fibres show globular distensions which are more or less separated from each other by glia structure. These are filled with broken-up axis cylinders—blue, and portions of myelin-yellow. The axis cylinder pieces show a swollen and granulated appearance. The whole mass is surrounded by a glia ring—violet, and represents the early stage in the formation of the myeloclast.

Marchi.—Beside the Elzholz bodies, which are again observed, there are numerous other round masses which stain darkly, and are strongly suggestive of a true scattered Marchi degeneration. But the Scharlach R. still shows no sign of fat.

From the condition of the nerve fibres in this case I have considered it to be one of about forty-eight hours.

Case IV. (60 *hours*).—*Captain Stokes.*

A portion of a spinal cord from a case wounded by a rifle shot. The bullet passed through the first two rings of the trachea, which were fractured, and the œsophagus, and embedded itself in the body of the first dorsal vertebra. Tracheotomy was performed, but the man expired sixty hours after the injury. After hardening the cord was cut, when an extensive syringo-myelia was found to exist. The notes state that the sergeant had been doing his duty up to the time of his wound, and there was nothing to show that he had ever suffered any inconvenience. Sections made from the cord several segments above and below the lesion showed the following changes:—

Bielschowsky.—In various regions numerous axis cylinders are seen to be affected. They are bent, twisted, and frequently broken. The peripheral fibres are more affected than the central ones, and the vacuolation is more marked at the circumference.

Mallory.—Broken up masses of myelin are shown to be rolled

up into balls and surrounded by glia structure. Broken axis cylinders are found twisted up in the bead-like swellings of the sheath. Myeloclasts are numerous, that is, myelin debris and portions of axis cylinders rolled up into a ball, and surrounded by the processes of a neighbouring glia cell. Long lengths of fibres are seen in which portions of the axis cylinders are thrown into kinks and corkscrew twists.

Marchi.—Scattered throughout these sections numerous dark staining rounded masses are found along the course of the fibres. They are larger than the Elzholz bodies and much more numerous. Short portions of single fibres are found in which these changes can be observed. As has just been shown in the Mallory preparations, these rounded masses are myeloclasts containing fragments of myelin and axis cylinder. The function of these myeloclasts is to convert the myelin into fat at the place where the degeneration takes place, so that the products of the degeneration can be later carried off to the blood vessels. In the Marchi sections we find in many of these myeloclasts that the osmic acid has stained some of the debris black. In addition to this we find in the walls of some of the vessels minute black granules which are gathered together into isolated groups. These are exactly similar in appearance and distribution to the fat globules contained in the adventitial cells.

Herxheimer's Scharlach R. Method.—In these preparations we find scattered throughout the tissue minute fat globules lying along the course of the degenerated fibre. They are also to be observed lying free in the tissue. Sometimes they are gathered together into clumps when a confluence occurs, and large globules are formed. Glia cells, without any protoplasm surrounding them, are generally found in the vicinity. Sometimes their amœboid character is illustrated by the method in which they take up the fat. After the globules have become attached to the cell, protoplasmic processes are given off which surround them, and the fat is then gradually absorbed. In another area we will see these cells loaded with fat in the vicinity of the vessels. One vessel in particular is very instructive. Lying within its sheath is a glia cell, which is crammed full of fat globules both large and small. In one end of the cell the globules are crowded together forming a rounded mass, while towards the other end they taper off to a single cell. The rounded end of this cell is

in proximity to the ends of two adventitial cells. The adjacent ends of these cells, instead of tapering off to a point as the other cells in the vessel wall do, are broadened and rounded off as if suggesting a receptive condition, and between the cell loaded with fat and the adventitial cells some minute fat globules are to be observed. The whole condition indicates that the cell through its amœboid action has penetrated into the sheath of the vessel, and is in the process of giving off the fat globules to the adventitial cells. In other portions of the vessel endothelial cells are shown full of fat globules, and some globules appear to be free in the vessel wall.

Description of the Syringomyelia as shown in a Mallory Section from the Sixth Cervical Segment.

The cavity involves the central region of the cord, and is almost entirely surrounded by a thick sclerosis. In the grey matter we find that the commissure is about completely sclerosed, and there is a well-marked increase of neuroglia tissue throughout the lateral horns. The various cell groups, as well as can be observed by this method, appear normal. Several of the anterior root fibres can be observed passing through the white substance, and in both axis cylinder and myelin sheath there are no changes.

White Substance—Left Side.—The pia throughout is much thickened, but particularly on this side. The septa are greatly increased in size, and the neuroglia tissue of the antero-lateral regions shows a marked proliferation. There is a considerable scattered degeneration throughout these regions, but the majority of the fibres are normal. On the right side the fibres of the antero-lateral and lateral regions are normal.

Posterior Columns.—Roughly speaking, the central half of these columns has been destroyed. In the remaining portions there is a well-marked increase of neuroglia tissue. While many fibres have undoubtedly perished, there is only a scattered degeneration in this region, for throughout the thickened neuroglia fibres blue axis cylinders surrounded by the yellow sheath are everywhere to be seen. On the inner surface of the sclerosis a few ependymal cells were observed in this and other sections.

The degeneration resulting from this enormous cavity, which

could contain an ordinary pencil, are briefly as follows:—(1) The total destruction of the central half of the posterior columns on the left side, and a scattered degeneration throughout the remaining portion. (2) The central half of the posterior columns on the right side, excepting a small zone in the lateral region, are completely gone, and there is a scattered degeneration among the remaining fibres. (3) A slight scattered degeneration in the left antero-lateral regions from the neuroglia proliferations.

Case V. (*7 days*).—*Dr Kidd, London General Hospital.*

Extensive bullet wound of the head involving the left parietal and occipital regions. Death occurred one week after the injury. The investigation of the brain was not completed, but that of the cervical and dorsal regions of the cord is as follows:—

The Pal Weigert and Marchi methods in transverse section show no changes.

Bielschowsky.—Shows whole fields in which the fibres are undergoing degenerative changes. These are represented by long rows of swellings in which the broken-up axis cylinder is frequently seen. Numerous fibres in this area show marked kinking and twisting. In another section the normal condition of the fibres is to be seen. Some which stretch across the field show only a slight waviness of the axis cylinder. None of them show the kinks and twists to which attention has been called in the early cases. But again in this same section, at the circumference, a similar condition to the above, viz., a swelling of the fibre, is to be observed.

Mallory.—Sections show portions of the nerve fibre to be in the early stage of degeneration. The myelin is broken up and formed into balls which are surrounded by glia fibres. Sometimes a blue fragment of axis cylinder is also enclosed. These myelin balls form long rows along the course of the fibre. In some instances glia cells are to be observed in the neighbourhood. A cell which is near to the degenerating zone but still free in the tissue appears in its normal round form. Not infrequently a cell is found between the balls of myelin; it is then elongated and somewhat triangular, suggesting that it has reached its position by an amœboid-like action. More rarely still the glia cell is to be observed in close contact with and adapting itself to the rolled-

up fragments of myelin which in some instances it has enclosed within protoplasmic processes.

Scharlach R. preparations were not completed.

These sections from a case of one week show practically the same conditions as were found in the previous case of sixty hours. The explanation of the difference in the time taken to produce a similar stage of degeneration is, that in the case of sixty hours the injury involved the spinal column, while in this case it involved the brain.

Case VI. (11 *days*).—*Captain Stokes.*

The injury was caused by a bullet which penetrated the spinal canal at the level of the seventh cervical segment. The patient survived for eleven days. At autopsy it was found that half of the cord at the level of the lesion had been destroyed, and that the bullet had embedded itself in the spinal column.

A few sections stained by the Pal Weigert eosin method were forwarded to the laboratory for examination. The conditions found in these sections are as follows:—

At the level of the lesion, the seventh or eighth cervical segment, practically one-half of the cord was destroyed. What remains of the anterior horn of the grey matter is greatly disorganised. The vessels are congested, and there is a diffuse hæmorrhagic infiltration. The posterior horn is absent. In the white substance only a small region lying in front of the anterior cornu remains normal. The anterior root zone shows marked degeneration, but the fibres of the direct pyramidal tract are less affected. There is no trace of the lateral column. In the posterior columns the lateral is completely destroyed, but some portions of the median, which is extensively degenerated, remain.

In the other half of the section both the membranes and the roots are intact. In the grey matter very little pathological change is to be observed, excepting a small hæmorrhage at the base of the anterior horn. Of the motor cells only the antero-internal group is affected, due probably to the degeneration of the commissural fibres from the opposite horn. The anterior commissure shows a large number of healthy fibres, but in the posterior commissure there is extensive degeneration. The posterior horn is normal. In the white matter the root zone is

normal, but between the direct pyramidal tract and the grey matter there is an area of degeneration. There is also some scattered degeneration throughout the anterior and lateral columns. The posterior columns show a hæmorrhage near to the commissure which involves the neighbouring fibres. Many of the endogenous fibres lying in contact with the horn are degenerated, and there is an extensive scattered degeneration throughout both the internal and external columns.

Transverse section of the fifth cervical, two segments above the lesion. In the pia surrounding the cord, in the fibrous prolongations into the white substance, and scattered throughout the white substance, are many small hæmorrhages. On the right side, in the antero-lateral and in the dorso-cerebellar regions, they are very distinct. Hæmorrhages are also present in the posterior columns.

Throughout the white substance at the periphery there are numerous patches of degeneration. On the right side the areas are rather large, and occupy the antero-lateral and posterior cerebellar regions. The regions of the direct and crossed pyramidal, and the anterior cerebellar tracts are fairly free, though in these areas also many fibres have degenerated. On the left side, at the periphery, a few small areas of degeneration are to be observed in the cerebellar region. For convenience the degenerations are described as being located in the various tracts, though they are in no sense typical of tract degenerations. In the posterior columns the fibres are considerably affected. This is principally confined to the median, and like the others is most marked at the periphery. Scattered throughout the white matter generally are numerous swollen fibres, and as many of these have fallen out, the section presents a distinctly vacuolated appearance.

Grey Substance (side on which most degeneration is seen).—In the anterior horn there is extensive degeneration and some small hæmorrhages. The cells are diminished in number and somewhat pale. In the lateral horn the cells of the external and posterior groups are healthy looking. Of the anterior root fibres one bundle appears to be completely degenerated, and another group is partly so. The posterior horn and roots are not affected. On the opposite side the anterior root fibres are pale, but there is no definite degeneration; the posterior roots are normal. In the posterior commissure there is considerable

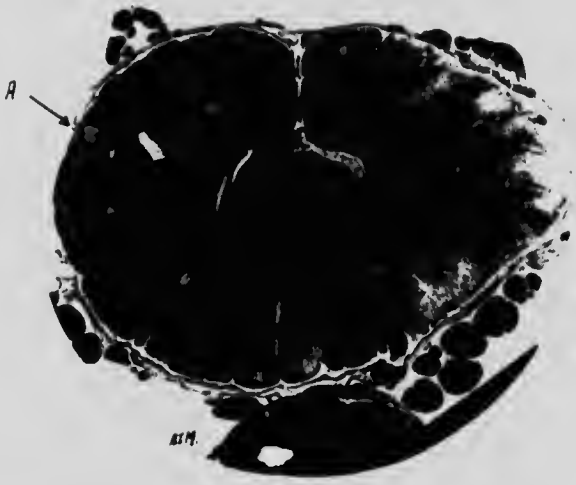

FIG. 1. FIFTH CERVICAL, TWO SEGMENTS ABOVE THE INJURY.

Areas of degeneration around the periphery of the cord, principally in the lateral regions, and usually in connection with the septa. Tearing of the tissue along the septa is to be observed. Both in the white matter and in the grey the destruction of tissue is associated with haemorrhages.

FIG. 2.

Enlarged from A in Fig. 1. The situation of a degenerated area on either side of a septum is shown. There is thickening of the pia, and proliferation of the glia cells. There is marked swelling of the fibres associated with distension of the neuroglia sheaths.

destruction from hæmorrhage and tearing, and this extends down into the posterior horn.

A closer examination of these degenerated areas (Fig. 1) reveals the fact that they are situated in particular around the septa which run from the pia into the cord substance. And that in addition to these a distinct tearing of the tissue along the course of the septa has occurred, associated with minute and localised hæmorrhages. A marked laceration of the grey matter including the commissure and both horns has also resulted. In the right half of the cord, internal to the posterior roots, we find the dura thickened and infiltrated with blood. Internal to this, in the region of the direct cerebellar tract, there is a focus of necrosis. Scattered throughout this area are numerous minute hæmorrhages. The nerve fibres are swollen, and a faintly staining sheath often alone remains. Many of the fibres have dropped out giving to the section a vacuolated appearance.

On the opposite side a small localised disturbance situated on either side of a septum shows in a remarkable manner the effects of the concussion. (Fig. 2 enlarged from A in Fig. 1.) Nerve fibres in various stages of degeneration are shown. In some instances the axis cylinders are only slightly swollen, and fill up completely their place in the sheath. In others they are larger and show minute deeply staining granules, and between the axis cylinder and the sheath there is frequently a large clear space due partly to the œdema, but principally to the falling out of the disintegrated myelin. In Fig. 3 one very large fibre is shown (300 diameters). In the centre of the fibre is the swollen axis cylinder, and this is surrounded by the degenerating myelin. Some debris partly fills the space around this mass. The whole is enclosed by glia structure, which is thicker than normal, and is broken in several places. Lying in the centre of the mass over the axis cylinder is a glia cell. The dark staining granules are probably fat. This condition of the fibre represents one of the stages in the formation of the myeloclast.

Besides these changes in the fibres the glia also shows some interesting developments. As has already been mentioned there are numerous open spaces scattered through the section where the nerve fibre has fallen out. These spaces are surrounded by a glia structure which had previously formed the sheath of the nerve. Within this glia ring which is generally thickened fine fibres are

frequently observed. These usually make their first appearance at the circumference where they form a network which gradually extends until the space becomes filled up. Sometimes, though, one or more fibres will bridge across the opening, and from these others will be formed till a firm interlacing structure fills the space. A similar condition is also to be observed where the neuroglia has been torn. Through this neuroglia proliferation the damaged structure of the cord is bound together with a firm tissue which will eventually develop into a sclerotic mass. These changes are of particular interest in that they have been observed in a case of eleven days. It is, though, only another of the many evidences which show that the stages of degeneration in these traumatic cases vary greatly from the usual type.

In the section from the first dorsal level (Fig. 4) there is some congestion of the vessels of the pia and septa. In the white matter there is a small localised area of degeneration in the region of the anterior cerebellar tract. In the posterior columns a small area is affected amongst the endogenous fibres caused by a hæmorrhage extending from the posterior commissure. Throughout the white matter a number of degenerated fibres are to be seen. These are more numerous in the columns of Goll and Burdach, and many of them have fallen out.

The Grey Matter on the Side of the Degeneration.—In the anterior horn the cells appear normal, excepting those of the antero-lateral group which show considerable degeneration. The anterior root fibres are also affected. The posterior horn is normal and the fibres of the root zone are healthy. In the lateral region of the grey matter a few small hæmorrhages are to be seen, and there is some degeneration of the cells. On the opposite side the grey substance appears healthy throughout; the cells and nerve fibres are normal. In the posterior commissure there is a small hæmorrhage which extends towards the post horn, and into the posterior columns where it has produced a small area of degeneration on either side of the median fissure.

A Section from the Third Dorsal Segment.—There are many small hæmorrhages in the pia and septa. The superficial neuroglia is increased, and there is a distinct proliferation of the cells. The white matter shows in the anterior and lateral columns some scattered degeneration. In the posterior columns the degeneration is more marked, and the vacuolation more evident. There are no

FIG. 3.

Fig. 3 enlarged 300 diameters. Enormous swelling of the fibres. In some the myelin has dropped out, leaving a space about the swollen and degenerating axis cylinder. The large fibre on the right shows the axone, greatly increased in size, surrounded by the thickened myelin sheath. About this some debris is to be observed in the space between the fibre and the neuroglia sheath. Lying on the axis cylinder in the centre [redacted] is a glia cell the two rings of the axone and the cell being clearly shown. The surrounding dark pigm[illegible]obably fat.

FIG. 4.—FIRST DORSAL LEVEL—ONE SEGMENT BELOW THE LESION.

A localised area of degeneration at the circumference is to be observed. It is connected with many of the smaller septa and one large one. There are also several small patches of degeneration in the antero-lateral region about the septa. Degenerations in the right anterior roots. Hæmorrhages in the grey matter.

definite areas of degeneration, but the periphery is stained paler than the central regions, suggesting a slight degree of annular sclerosis.

The Grey Matter.—In the left anterior horn there are some small hæmorrhages, and the cells of the anterior groups and their nerve roots show degeneration. The lateral group of cells and fibres are also affected. The vessels throughout are congested, and there is considerable infiltration of the tissue with blood cells. Around Clarke's column the vessels are particularly congested and the cells are degenerated. There is a marked proliferation of the glia cells. In the posterior horn the fibres and the root zones appear normal. In the anterior cornu the anterior, mesial and lateral groups of cells and some of the root fibres show degeneration. The commissure and the posterior horn are torn, and there is considerable destruction of tissue with infiltration of blood.

Section from the Sixth Dorsal Segment.—The staining is faint, neither the fibres nor the cells show up well. Throughout the grey matter in scattered areas a number of large and small fibres have fallen out. crossed pyramidal tracts and the posterior columns are particularly affected, though in the latter the periphery is almost free. In the grey matter the cells of the right anterior horn are faintly stained and there is considerable degeneration in the anterior root fibres. On the left side the cells and root fibres are normal. In another section from the same level, two small hæmorrhages are found in the central portion of the posterior column.

Section from the Seventh Dorsal Level.—There is a slight scattered degeneration of the fibres in the posterior columns. The area involved is almost limited to the central region, the fibres near to the commissure, in the root zones, and on the periphery being almost free. In other respects the section is normal.

Sections from the eighth and ninth dorsal segment show practically a normal condition.

Case VII. (*7 weeks*).—*Dr Head, London General Hospital.*

Bullet wound of the spinal column at the level of the twelfth dorsal vertebra. The skiagraph showed twelve large fragments and several small ones in this region. After an illness of several weeks, during which septicæmia and broncho-pneumonia

developed, death occurred. The post mortem showed a chronic purulent inflammation within the spinal canal. On opening the thickened dura there was much congestion of the surface of the cord and among the roots descending into the lumbar plexus. The greatest thickening was over the third, fourth, and fifth lumbar and first sacral segments. The cord was firm and on section showed no areas of softening to the naked eye.

Pal Weigert.—Second lumbar, complete degeneration of both posterior columns. Sixth dorsal and third cervical, complete degeneration of the posterior columns, and slight in the cerebellar tracts.

Bielschowsky.—Shows large areas in which the majority of the fibres are completely degenerated. The myelin and axis cylinders are broken up and formed into balls which extend in long rows along the course of the fibres. In others the axis cylinders are slightly swollen and twisted. Among these a few fibres are always to be observed which are still quite normal in appearance.

Mallory.—This section shows the various stages of degeneration from the earliest to those well advanced. Many of the fibres are quite normal, and can be observed pursuing a straight course across the field. In the degenerated areas we find the axis cylinders twisted, thrown into kinks, and broken. The myelin is generally broken up and formed into irregular masses, which are distributed along the course of the fibres. In other areas, where the condition is more advanced, the myelin is rolled up into balls, which sometimes include the broken axis cylinder. These are enclosed by a glia ring. We will also find that this mass will become surrounded by the processes from a glia cell, or a glia cell will find its way into it, and the myeloclast thus formed is then ready to begin its function of converting the myelin into fat. The final stage to be observed in this section is the formation of the myelophagocyte. This second form of scavenger cell is developed from the glia cell, with a rich protoplasmic body surrounding it. When one of these cells comes into relation with a myeloclast it gradually encloses it by means of processes given off from the protoplasm, and the whole myeloclast, including the myelin, axis cylinder, and glia cell, is taken into the larger cell. In other instances some of these myelophagocytes will surround four or five myeloclasts. Processes are then given off which find their way in and around the degenerating material until it is all

enclosed. In the later stages we will see how these cells act on these disintegrating masses.

The multiplication of the glia cell by a process of mitosis is also to be observed in this case in different stages of its development. The earliest stage found shows an elongated protoplasmic body containing two glia cells at opposite poles. Both cells and protoplasm stain faintly, and the chromatin granules are very indistinct. Later we find that the protoplasm is beginning to divide, though it is still united by a narrow portion. Across the interval, which partially separates the protoplasm, are stretched a few fine threads. A still later stage shows that the division of the protoplasm has been completed. The adjacent walls of the protoplasm are parallel to each other and separated by a narrow space. Finally we can observe the cells completely separated and enclosed in a rounded-off body of protoplasm. Throughout the whole condition both the protoplasm and the cell stain faintly.

Marchi in Transverse Section.—The picture is similar to the Pal Weigert. In longitudinal section the nerve fibres are completely broken up, the debris being rolled up into balls which extend along the course of the fibres. The masses of the degenerating material vary greatly in size. Some are very large and contain several myelin fragments in various stages of degeneration, as shown by their black or brown staining, others are quite small. Numerous spaces are seen where the large scavenger cells, the myeloclasts, and the myelophagocytes have fallen out.

Case VIII. (2 *months*).—*Dr Feiling, 13th General Hospital.*

In this case the wound was from a shrapnel bullet which struck the vertebral column, just below the spine of the left scapula. There was immediate loss of power in the arms and legs, associated with retention of urine. Sensation was lost up to the fourth cervical segment. X-rays showed the bullet to be lodged in the canal just to the right of the spinous process of the sixth cervical vertebra. A laminectomy of the fifth, sixth, and seventh cervical was performed a few days later and the bullet removed. It was found within the spinal canal, lying to the right of the theca which appeared uninjured. After two months' illness, during which his condition got steadily worse, he died from respiratory failure. At the level of the injury, which

involved the fifth and sixth cervical segments, the dura was strongly adherent to the pia, and the substance of the cord at this point was much damaged. On section gross macroscopic changes, softened areas, were observed extending upwards to the fourth cervical segment and downwards to the third dorsal. In the left posterior horn, extending from the second to the fifth dorsal segments, a small localised patch of necrosis was observed.

Mallory—Transverse Section from the Third Dorsal Segment.—There is marked degeneration of the pyramidal tracts as well as the posterior columns. Fibres in all the early stages of degeneration are to be seen scattered throughout the section, myelin balls, myeloclasts, myelophagocytes. In the left horn there is a large necrotic area, which is surrounded by a narrow margin of grey matter. Its probable origin was a haemorrhage. The vessels throughout the grey matter are markedly congested.

Marchi Counterstained by Mallory.—In this section one can still see the axis cylinders to be broken and twisted and surrounded by degenerating myelin; also yellow or yellow-brown Marchi balls forming rows along the course of the fibres. In some cases, even at this stage, the remains of the axis cylinder in the rolled-up balls of myelin are still visible. Myelophagocytes are also present and are seen to contain partially-converted myelin, as shown by its yellow-brown colour, and myelin that is completely degenerated and is stained black.

In another section, through a degenerated area, a great increase in the glia structure is seen. This ramifies throughout the whole region, surrounding and binding together the spaces left by the disintegrating fibres. The course of these fibres is marked by swellings containing large masses of black staining degeneration products, broken-up axis cylinders, myeloclasts, myelophagocytes, and here and there a granular cell. This later development of the scavenger cell is found in this and other sections in various stages of activity. In the early stage it is somewhat irregular in form, contains a single deep blue staining nucleus, and its body is filled with a fine net-like pale blue structure. Yellow staining myelin in the process of conversion, and sometimes long rolled-up bits of blue axis cylinder, are to be observed within the meshes of the cell. In a later stage we find that in the network of the cell numerous large and small vacuoles have developed which contain large dark staining masses of degenerated myelin. No axis

cylinders are to be observed in the cell at this stage. The cell may contain two or more nuclei according to the manner in which it has been formed. Still later we see some of these cells in a degenerating condition. The nucleus has lost its full rounded form and may appear shrunken or distorted, it stains poorly sometimes a blue-brown, and the chromatin granules are not now recognisable. Many of the vacuoles among the meshes of the cells are empty, and the black staining degenerating products may be observed protruding from the cell wall, lying in close contact with the outer margin of the cell, and also as free masses in the immediate vicinity.

Some myelophagocytes are still to be observed which contain the yellow myelin and the blue axis cylinder fragments, indicating that in those regions the process of degeneration is in an early stage. Throughout the degenerating areas, where the fibres have completely disappeared, we find that the spaces have become filled with a homogeneous substance. In some cases this shows signs of breaking up, and fine fibres are beginning to make their appearance at the circumference. This change indicates that already at two months the beginning of the final stage has in certain areas begun, and that by the gradual increase of these fibres the process will be continued until the region is converted into a firm sclerotic mass.

Case IX. (4 *months*).—*Dr Head.*

The injury was caused by a rifle bullet which traversed the back of the neck, fracturing in its course the spinous processes of the sixth and seventh cervical vertebræ. Immediately following the injury he was paralysed from the waist down, but could move his hands and arms. After an illness that lasted for four months, which was complicated by incontinence of urine and fæces, the development of severe trophic disturbances, abscesses over the hip, and a large abscess in the abdomen, death occurred. At the post mortem it was found that the greater part of the seventh spine had been shot away, and that the caudal half of the sixth and the laminæ of the seventh were soft and friable. An irregular transverse fracture was visible across the laminæ of the sixth, with crushing on either side of it. The bodies and transverse processes of these vertebræ were not affected. From

the second dorsal segment to the sixth cervical the cord looked bruised. Below and above this area it appeared quite normal.

Tolnidin blue sections from the fifth and eighth cervical; second and sixth dorsal; and second lumbar were examined. The condition in all was practically the same. The cells stained faintly, in many cases they were distinctly swollen, and the tigroid bodies which were very pale frequently showed granulation. As the cells throughout the whole cord showed distinct chromatolysis, the condition was evidently the result of the general septic state.

Pal Weigert.—Section from the fifth cervical, three segments above the lesion. There is complete degeneration of the posterior median columns, a marked degeneration of the direct cerebellar tract, and in the antero-lateral regions the fibres show a very pale staining. At the level of the lesion, which involved principally the second and third and to a less extent the first and fourth dorsal segments, there was a laceration involving the central region of the cord, which had resulted in the formation of a cavity. The degeneration due to the pressure and to the disturbance from the shock resembled a condition of almost complete transverse myelitis. The posterior and the right lateral columns were quite gone. The left lateral takes a very pale staining, as do also the antero-lateral regions. In the seventh dorsal segment there is complete degeneration of the crossed pyramidal and the direct cerebellar tracts as well as in the marginal zone of Lissauer. Anteriorly in the direct pyramidal tracts and throughout the antero-lateral region there is a well-marked degeneration. In the second lumbar segment the degeneration involves the crossed pyramidal and the direct cerebellar. And extending along the border of the anterior regions a number of degenerated fibres are also seen.

Mallory—Transverse Section from the Fifth Cervical Segment.—In the lateral column the degeneration in some of its early stages is still to be seen. Many of the fibres are enlarged, the myelin is swollen and fragmented, and the axis cylinders are greatly increased in size and often broken. There is also a marked increase in the glia cells. In some instances the glia cell is seen to have found its way into the degenerating fibre and is to be found with the axis cylinder occupying the centre of the myelin.

The posterior median columns show complete degeneration.

There is an enormous increase in both the neuroglia tissue and the cells. The fibre spaces are filled with granule cells and surrounded by thick masses of glia structure. In longitudinal section the condition of the neuroglia fibres is particularly well shown, and it is seen that the greatest increase is in the fibres which run parallel to the nerves, but crossing these in all directions are numerous fibres which give to the structure a web-like appearance. Myelophagocytes are also to be found. In some instances they have not yet completed their function, and we find in their meshes some remains of yellow staining myelin substance. In the granule cells which have completed their activities we find that the web-like structure has given place to a homogeneous mass, and that the nucleus has disappeared. Later it begins to shrink and in the space between the degenerating cell and the enclosing glia structure fine fibres make their appearance. This condition, which has already been observed in the second month, progresses until the space is filled. This stage in the general process of repair is much further advanced than in the previous section. In some areas the broken-up appearance of the degenerating mass has already given place to a regular fibrous condition from which all debris has been removed and which is now in a state that will gradually develop into a firm sclerosis.

Summary of the Changes Observed in the Previous Cases.

Case I. (10 *hours*).—While the majority of the fibres throughout the section are normal, some areas have been distinctly affected. The axis cylinders show sharp bends and twists. Swellings at regular intervals have also been observed generally associated with fibrillation and occasionally with rupture.

Case II. (24 *hours*).—Axis cylinders show twists, kinks, and complete loop formations. Swelling and œdema are also present. The myelin sheath may be distended, due to the kinking and breaking up of the axis cylinders. Peculiar vibration effect on a nerve fibre from the shock of the concussion is shown. Opposite a hæmorrhagic infiltration, which is surrounded outside of the affected zone by normal tissue, an axone has been thrown into short sharp waves. These are greatest in the centre of the disturbed portion of the fibre and gradually subside in both directions till they disappear entirely. On each side of the

central disturbance the axis cylinder is normal for a short distance. The fibre is then again disturbed on both sides of, and at an equal distance from, the first portion affected. These last two wave-like conditions are similar to each other but are shorter and less marked than in the first case. A long length of fibre can be followed on either side of these, but nothing further is to be observed. On some of the affected axis cylinders a sheath-like structure is apparent.

Case III. (48 *hours*).—The axis cylinders are bent, twisted, show corkscrew formations, and complete loops, also swelling and fragmentation. The myelin is swollen and broken up into globular masses which include bits of axis cylinder. The whole mass is surrounded by a glia ring forming the myelin ball.

Case IV. (60 *hours*).—The axis cylinders are broken and the myelin is fragmented. Numerous myelin balls are to be observed. Myeloclasts, the first form of the scavenger cells, are now found. These are seen to be formed by glia cells which have surrounded with protoplasmic processes the myelin balls. First traces of Marchi degeneration found in the myeloclasts. Fat is also found in these cells; free in the tissue, in the glia cells, and in the vessel walls. The presence of the fat in these advanced stages will be considered later.

Case V. (7 *days*).—Myelin balls form long rows along the fibres. Formation of the myeloclast is to be observed as well as the amœboid-like activity of the glia cells. The condition in this case is not quite so advanced as in the previous one. This is due to the fact that in Case IV. the injury involved the spinal column while in this instance it involved the brain.

Case VI. (11 *days*).—As there were only a few sections stained by Pal Weigert available, it is impossible to describe the changes minutely. The photographs show marked swelling of the axis cylinders and vacuolation of the fibres. The large fibre in Fig. 3 appears to contain a glia cell directly over the axis cylinder. Such a condition is frequently found in the early stages of the degeneration, and the granules observed in the central area resemble more in size the chromatin granules of an active glia cell than the cut ends of the fibrillæ. In addition to this, two distinct rings are to be seen even in the picture. By this method, though, none of the finer details can be studied.

Case VII. (7 *weeks*).—All the early stages of the degenerative

process are represented from the first disturbances of the axis cylinder and myelin sheath, to the myelin balls and myeloclasts. In addition to this we find the second form of scavenger cell present. This is seen in the stage of its formation when a glia cell rich in protoplasm surrounds a myeloclast, or where several glia cells each surrounded by a protoplasmic body enclose within their processes several myeloclasts. Some of these myelophagocytes have evidently been active for some time, as the myelin has been broken up into small masses which are sometimes shown as bright yellow balls within the blue protoplasm of the cell, or in the Marchi preparations as black fragments. Proliferation of the glia cell by mitosis is also to be observed in this section.

Case VIII. (*2 months*).—In all these later stages the early conditions are always to be found at the margin of the degenerating area. Thus we see again the axis cylinder and myelin sheath in various conditions, the myeloclast, and the early myelophagocyte which may still show within the enclosed myelin some axis cylinder fragments. In the later stages of the activity of this cell the axone has disappeared. The original irregular outline of the cell has now given place to a more or less rounded form. The homogeneous mass of protoplasm has also changed, fibres have been developed which have divided still finer the enclosed myelin masses, and the cell body shows a granular appearance. In this manner the granular cell is formed. Marchi preparations show the black staining degenerated myelin within these cells. In a few instances granular cells are found which are apparently undergoing degeneration. The cell body has lost its granular appearance. It has begun to shrink, and in the space thus left between the cell and its greatly thickened surrounding structure of neuroglia tissue, fine fibres begin to make their appearance. These develop in the form of a network around the circumference. This represents the earliest manifestation of the final stage.

Case II. (*4 months*).—The conditions observed here differ from the previous case only in the more advanced state of the degeneration. The degenerated area is occupied by a mass of granular cells. In some regions the debris has all been removed, and the irregular broken-up condition of the disintegrated mass has given place to an ordered state in which there is a great proliferation of fibrous tissue. From this time on a regular progress will be made until the affected area has become completely sclerosed.

In regard to the changes observed in the cases of 10, 24, 48, and 60 hours, which are probably the earliest of this nature reported upon that have been carefully examined, attention is drawn to the fact that in these injuries the disturbances described have been directly caused by the shock of the traumatism, and are not in the earliest stages secondary degenerations in the usual meaning of that term. And this gives rise to the question whether it would not be advisable to call the changes resulting from injury associated with severe shock "traumatic degenerations" so as to make a distinction between them and the usual secondary form.

As long ago as 1876, when Schiefferdecker studied the finer histology of secondary degeneration in the Goltz spinal dogs, he distinguished between the ordinary type of degeneration and the traumatic form. Since then no particular distinction has been made. In civil life these cases occur so seldom, and the difficulties of obtaining the material are so great, that it is practically impossible to collect a series; and with operated animals, whether the cord is partially divided by section or injured by a blow from a small weight attached to a metal arm 12 to 18 in. in length, as is usually done, the result is practically the same. Though in one case the cord has been crushed and in the other it has been cut, the degenerations that will result will be of the usual secondary type. But in injuries due to bullet wounds the concussion caused by the impact of the bullet, which at 200 yds. would strike the body a terrific blow in a $\frac{1}{3000}$th of a second, produces a tremendous vibration, the effects of which are transmitted through the dura to the spinal fluid, ligaments, pia, and septa into the cord substance: and wherever the final effects of these vibrations are felt there we find a laceration of the supporting structure, hæmorrhages, and injuries of the nerve fibres. These lesions are actually the expression of the effects of the traumatism. The character of these changes differ, both in regard to the localisation of the lesions and the manner in which the tissue and fibres are affected, from that of the usual type of secondary degeneration. In the first instance the areas involved are scattered, and have no relation in regard to their situation to primary lesions above or below them. The lateral regions of the cord are most frequently involved, though disturbances are also found elsewhere throughout the cord substance, and generally along the course of the septa. In no case was any

disturbance of the spinal medulla associated with the anterior or the posterior roots. Besides this, localised destruction of the cord substance is always to be observed—if carefully looked for by modern methods—in regions many segments removed from the seat of the injury. Again, the progress of the degeneration is much more rapid in the traumatic cases, especially in the early stages, so that at 60 hours we find a Marchi degeneration and the presence of fat in the tissues, while in the usual type of secondary degeneration these are not found till after the fourth or fifth day. Taking into consideration all these facts, it has been considered advisable to classify these cases under the term "traumatic."

That doubt still exists as to these early changes is shown by a statement that has recently been made in regard to a case, that as death had taken place 48 hours after the injury there was no time for degenerative changes to have occurred in the white matter. As has been shown in the first three cases of this series, viz., 10 hours, 24 hours, 48 hours, a whole sequence of events has taken place during this time. The axone has been bent, twisted, and broken up into short lengths; the myelin sheaths have been ruptured, and single portions, sometimes including bits of axis cylinder, have been rolled up to form the myelin balls. That these changes form part of the degenerative process, if any doubt remains, is proven by the next case of 60 hours, that is, 12 hours later.

In Case IV., 60 hours, we find that the myelin balls have become surrounded by the processes of the glia cells, and the myeloclasts thus formed have already converted some of their contents into fat. This is shown by the definite Marchi reaction, and the demonstration of fat by the Scharlach R. method in these cells and free in the tissue.

In the notes of the case reference was made to the condition of syringomyelia that was found to exist. It formed a large central cavity capable of containing a pencil, and extended through several segments in the lower cervical and upper dorsal regions. The man, a sergeant, had been performing his duties quite normally up to the time of his injury. Unfortunately the presence of this condition confuses the findings, and one naturally asks whether the early Marchi degenerations observed, and the presence of fat in the cells and the tissue, are not due to the

degeneration resulting from the syringomyelia rather than to the disturbance produced by the injury to the spinal column. A point of considerable importance was the finding of some ependymal cells lining the cavity, for the opinion has been advanced by Schlesinger, that when a median cavity is lined by these cells the syringomyelia could probably be attributed to developmental origin. If that is so, then the condition is more easily understood. For the fact that the man was apparently quite normal shows that there could not have been much disturbance from this cause, which would be accounted for by the condition progressing so slowly, involving only individual fibres, so that it was possible for other fibres to take on the function of those destroyed.

From the Mallory sections we learned that some tearing of the tissue had occurred along the paths of the septa; that myelin balls had been formed of the broken-up sheaths and the axis cylinders, and that these had been surrounded by the protoplasmic processes from the glia cells. That, in fact, the stage of the myeloclast had been reached, the function of which is to convert into fat the broken-up myelin. The axis cylinder dissolves up and is absorbed from the tissues. From this we see that the stage was set for the production of the fat. And the time, 60 hours, is sufficient for the degeneration of the myelin to have occurred. Jakob found it in the rabbit 55 hours after hemisection of the cord, and Doinikow 48 hours after dividing the peripheral nerves. From this it would appear safe to say that the fat globules found in the myeloclasts, or free in the tissue, or surrounding or in a glia cell, could be from the degeneration produced by the injury. The question of the origin of the fat globules contained within the cells found within the vessel sheath presents a more difficult point to determine. Unfortunately no material was available to confirm or disprove it. Neither has reference to the literature given much satisfaction. It has been shown that 24 hours after section of a peripheral nerve fragmentation of the myelin, with swelling and kinking of the axis cylinder, was observed: after 48 hours myelin balls were formed, there was a granular disintegration of the myelin, and the appearance of fat droplets in the plasma of the cells of Schwann; at 96 hours fat was found in the fixed tissue cells of the endoneurium. In spinal cases we learn that when 96 hours have elapsed after a hemisection of the cord there is fragmentation of the axis cylinder,

breaking up of the sheath, the formation of myeloclasts and myelophagocytes; Marchi degeneration is also found, accompanied by fat drops in the myeloclasts and myelophagocytes, free in the tissues and collected in groups around the glia cells. From this we see that the changes in the peripheral nerves have progressed more quickly than in the spinal cord, and also that they correspond practically with the changes observed in this series. Also the traumatic influence in our cases would cause the changes to develop more rapidly, so that we might compare the results at 60 hours with those of Jakob's at 96 hours. On the other hand, if one takes the stand that the fat globules in the cells and in the sheaths of the vessels are due to the degenerations resulting from the syringomyelia, then it presupposes that the secondary changes are of long duration. If that was so, one would expect to find evidences of it in the way of a more pronounced Marchi degeneration, granular cells, &c. As these were not observed as the cavity was almost completely surrounded by a sclerotic band, and as no symptoms were present during life, it would appear that the degenerations reported were the result of the injury, and had no connection with the syringomyelia.

It is a point of some importance whether such advanced changes can occur in so short a time. But as it cannot be decided by discussion, it must be left to some future investigator to determine.

In Case II. mention has been made of a pale membrane which forms a sheath-like structure about the axone. This condition has been observed in several instances where the early breaking up of the fibre occurs. In these cases, when the axis cylinder is bent, twisted, or formed into loops, the disturbed portion is seen to be surrounded by a faintly staining membrane. This is sometimes quite even in outline, but occasionally its contour is broken and the ruptured ends are curled up. Paladino showed that in man the glia structure could be followed to the axis cylinder, around which it formed a sheath-like structure, and Held has confirmed these observations. Jakob has also shown such a sheath to be present.

Regarding these injuries to the central nervous system from the shock of concussion, one sometimes wonders what it actually means to be struck by a bullet at 100 or 200 yds., for the bullet of the service rifle has a very high velocity, and the shock of the impact must be enormous. On making inquiries I was

referred to the Shooting Editor of the *Field*, who very kindly has written me on the subject under date of 2nd May, as follows:—

"In confirmation of the promise made by me per telephone, I submit the following values relating to the ·303 Mark VII. service bullet weighing 174 grains.

Range.	Velocity.	Striking Energy.
Muzzle	2,450 ft. per sec.	1,490 ft.-lbs.
50 yards.	2,339 „ „	1,360 „
100 „	2,231 „ „	1,240 „
150 „	2,126 „ „	1,120 „
200 „	2,020 „ „	1,010 „
250 „	1,920 „ „	916 „

"The foot-pounds unit of energy is the accepted method of expressing the striking power of projectiles of diverse weight and velocity. Just as falling bodies may have any weight, and may fall from any height, and yet be reducible to the common denominator derived from multip' ng the two together the product being an exact quantity of work, so projectiles are reduced to the same measure. The basis of calculation is the height from which a bullet would have to fall in vacuum to strike earth at the velocity in question. When so reduced to gravity condit. s, the complex idea of diverse heights and weights is converted into foot-pounds.

"The actual force denoted by any given foot-pounds energy depends on the resistance offered. Thus, assuming that a bullet strikes the body at 200 yds. with 1,000 foot-lbs. energy, and is pulled up in 3 in. by the skin, muscles, and spinal column, the resistance offered by the tissues is on the average 1,000 divided by ·25 (viz., the fraction 3 in. is of a foot) equals 4,000 lbs. This 4,000 lbs. being the resistance offered by the tissues, it may be regarded as the static pressure of the bullet acting against the tissues. This would only be the mean resistance over the 3 in., since the opposing force would be greater during the early stages when the velocity was high than during the later ones when it had diminished. When bullets are directed against water containing mediums they set up a hydraulic force which acts radially

throughout the mass. At velocities exceeding 2,000 ft. per second this tendency has been found to be very much more pronounced than below that limit, so much so that the term 'explosive' has been adopted to express the idea of the suddenly applied hydraulic force.

"When the older type of comparatively blunt-nose bullet gave place to the pointed form, big game shooters, in their endeavour to account for the large area of the wounds produced, jumped to the conclusion that the bullet must turn and travel sideways, that is, rotating around its shorter axis. Personally I did not accept this view for two reasons:—First, the as-a-rule lighter weight and better ranging properties of the pointed form of bullet, increased the proportion of shots hitting above the 'explosion' level of velocity; second, the wedge shape of the pointed form would be more likely than the punch shape of the older type to set up a movement in the tissues radially to the path of the bullet. Motion so set up would be continued by inertia after the bullet had gone by, and the tissues so set in motion would drive against other tissues adjoining, and so greatly increase the area of the contusion as compared with the actual cross section of the true line of passage of the bullet. This idea has, I think, been accepted as a result of war experience.

"*P.S.*—The Mauser bullet is a little lighter than the ·303 Mark VII., it has a higher velocity, and would produce a more serious wound."

It is not surprising, therefore, that the impact of such a force produces tremendous disturbances, and also that these so frequently occur at regions remote from the seat of the injury. In this respect the letter supports the idea that shock effects can be transmitted to the spinal fluid where "they set up a hydraulic force which acts radially." And this force, by vibrating the cord, would cause it to pull on its attachments to the ligaments, which would result in the tearing of the tissue in the lateral regions and along the septa.

In this connection it would be of interest to examine the spinal cords, and especially the medullary regions, in cases of sudden death from concussion, produced by the explosion of a shell without causing direct injury. For, from the results of the investigations in these cases, it would appear not improbable that another form of concussion might produce similar disturbances,

and as the cervical region would in these cases probably feel the effect of the shock most, so we might find areas of localised destruction of tissue involving the vital centres.

In conclusion, I wish to express my appreciation to those whose efforts to obtain material have made this research possible. And I want to thank Captain Adrian Stokes particularly for the trouble he has taken to collect the valuable specimens which he so kindly forwarded, without which it would have been impossible to complete the splendid series that has formed the subject of this investigation.

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