ON THE
REPARATIVE PROCESS
IN
HUMAN TENDONS
AFTER SUBCUTANEOUS DIVISION FOR THE CURE
OF DEFORMITIES,

ILLUSTRATED BY A SERIES OF SPECIMENS AND DRAWINGS FROM
FIFTEEN POST-MORTEM EXAMINATIONS.

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THE reparative process in human tendons after subcutaneous division has not, so far as I am aware, hitherto been investigated in its different stages; obviously from the following causes.

1st. A connected account of the process, from its earliest stages up to its completion, could only be based upon the examination of a large number of specimens; and,

2dly. The opportunities for pursuing this investigation must necessarily be extremely rare; since only those cases would be available for the purpose in which death occurred during the reparative process, from accidental circumstances, or from causes altogether unconnected with the operation, and also those cases in which amputation should be rendered necessary, as in one of the present instances, from

some cause also unconnected with the operation of tenotomy. The cases in which death has followed, or amputation been required, from extensive suppuration, sloughing, aneurism, &c., following tenotomy (and such cases have occurred, though very rarely), would be utterly useless for the purpose of this investigation, in consequence of the interference with the healthy process of reparation.

In the absence of observations on the human subject, the reparative process in tendons after division by subcutaneous and open wound has been carefully investigated by experiments on animals, performed by several distinguished Continental and English observers, more especially by Hunter¹ (1767 ?); Mayo² (1827); Von Ammon³ (1837); Pirogoff⁴ (1840); Paget⁵ (1849); Gerstaecker⁶ (1851); Thierfelder⁷ (1852); and Boner⁸ (1854).

The conclusions arrived at, however, by the above-mentioned authorities as to the nature of the reparative process,

¹ Probably about this date. In Ottley's life of Hunter (see 'The Works of John Hunter,' Palmer's edition, London, 1837), it is stated that, in the year 1767, Hunter ruptured his tendo Achillis whilst dancing, and that this accident led him to examine into the process by which divided tendons are reunited. His experiments on dogs by subcutaneous division of the tendons are then referred to. The Hunterian preparations in the College of Surgeons are from the ass and deer.

² 'Outlines of Pathology,' London, 1827, and the three subsequent editions, in which the same account is repeated.

³ 'De Tenotomiæ Physiologia, Experimentis Illustrata.' Dresdæ, 1837.

⁴ 'Ueber die Durchschneidung der Achillessehne, als operativ-orthopädisches Heilmittel von Nikolaus Pirogoff. Mit sieben Tafeln.' Dorpat, 1840. For an account of these experiments see also Gerstaecker's 'Diss.'

⁵ 'Med. Times and Gazette' for 1849; and also 'Lectures on Surgical Pathology,' vol. i, London, 1853.

⁶ 'Dissertatio de Regeneratione Tendinum post Tenotomiam,' Adolphus Gerstaecker. Berolini, 1851.

⁷ 'Diss. Histol. De Regeneratione Tendinum, F. F. Thierfelder, Micenæ, 1852.

⁸ 'Die Regeneration der Sehnen,' J. H. Boner; 'Archiv für Pathologische Anatomie und Physiologie und für Klinische Medicin,' R. Virchow. Berlin, 1854, p. 162.

and especially in reference to the influence of extravasated blood, inflammatory lymph, and the sheath of the tendon, were so widely different, that in the year 1855 I re-investigated the subject, in a series of experiments performed on sixteen rabbits; the parts removed from fourteen of which, illustrating the process from the second to the sixty-second day, were exhibited to the Pathological Society, and the results were published in the sixth volume of this Society's 'Transactions.'¹ Two other animals lived to the periods of six months, and a year.

I will here only observe, that my investigations generally confirmed the account of the process previously given by Mr. Paget, especially with regard to the influence of blood and the inflammatory process in interfering with, rather than assisting, the reparative effort; in this respect, therefore, they were at variance with the opinions of all the other authorities above mentioned. My investigations also confirmed Mr. Paget's observation, with regard to the development of the new connective tissue from a proper reparative material effused for this purpose, and described by Mr. Paget as "nucleated blastema," a material in which the cell-forms do not advance beyond the condition of nuclei, and thus differ from inflammatory lymph, in which fibro-cellular tissue is developed from nucleated cells. The most material point in which my observations differed from those of Mr. Paget was in reference to the influence of the sheath of the tendon, which I found not divided, and generally but very little injured, in the subcutaneous operations. It therefore appeared to me, that in the reparative process the sheath was of primary importance in maintaining a direct connexion between the divided extremities of the tendon. In my experiments, also, it appeared that the new reparative material was infiltrated between the fibrous elements of the sheath, which, therefore, at once formed the matrix for the newly formed tendon, and also determined its direction and definite form, as described by Thierfelder.

¹ 'Trans. Path. Soc. of London,' vol. vi, 1855.

Mr. Paget, on the other hand, completely ignores the influence of the sheath in the reparative process, and after describing the general infiltration and succulency of all the tissues surrounding the tendon, and the subsequent changes which occur in any inflammatory lymph and blood which may be effused, and the manner in which the development of the nucleated blastema laid down between the separated extremities of the divided tendon appears to proceed, observes that "a single well-designed and cord-like bond of union is thus gradually formed, where at first there had been an uniform, and seemingly purposeless, infiltration of the whole space left by the retraction of the tendon."¹ Mr. Paget also states that, in experiments in which the tendon was divided by an open wound, when the wound through the integuments healed quickly, the case proceeded like one in which the subcutaneous division had been made, and therefore he adduces this in proof "that it is unimportant for the healing of divided Achilles tendons, whether the cellular sheath or covering of the tendon be divided or not." The facts and observations which have led me to a different conclusion on this point, will be specially adverted to in the general description of the reparative process given below.

Valuable as such experiments performed on animals undoubtedly have been, the necessity of investigating the same process in the human subject still remained, and a connexion of more than eight years with the Royal Orthopædic Hospital has afforded me the opportunity of examining *post mortem* the reparative process in human tendons after subcutaneous division, in nine patients who had been operated upon by myself, one by Mr. Tamplin, and two by my late respected friend and colleague, Mr. Lonsdale. I have also examined after death one of my own cases in private practice. These patients all died from various causes unconnected with the operation, at periods varying from four days to three years after the division of the

¹ Op. cit., p. 269.

tendons. I am also indebted to Mr. Erichsen and Mr. Curling for the opportunity of examining two valuable cases, one after death, and the other after amputation. The details of Mr. Erichsen's case have already been published, together with a lithographed plate of the appearances presented, in the 'Transactions of the Pathological Society.'¹ I have therefore examined, in the recent state, fifteen cases in which subcutaneous tenotomy had been performed, at periods varying from four days to three years previously, and from twelve of these either the specimens or drawings—in ten cases the specimens—are presented to the Society. I have also examined several preparations preserved in spirits, in the possession of Mr. Tamplin and the late Mr. Lonsdale. In most of the cases above referred to, several tendons had been divided at different dates, thus multiplying the stages at which I have been enabled to investigate the reparative process; I have now, therefore, ventured to submit the results of my observations to the Fellows of this Society.

CASES AND POST-MORTEM EXAMINATIONS DESCRIBED IN ABSTRACT.

CASE 1.—*Four days after operation.*—Child, æt. 4 weeks. Severe congenital talipes varus. Tendo Achillis and tibialis anticus divided. Death from pneumonia.

Post-mortem examination.—Divided extremities of tendo Achillis three quarters of an inch apart, but connected by the cellular sheath of the tendon, which was vascular and succulent, and enclosed a small quantity of extravasated blood. Divided extremities of the tendon square, abrupt, and unaltered in appearance and texture.

Appearances of divided anterior tibial tendon similar, but the connexion by the cellular sheath less distinct, and separation greater—one inch.

CASE 2.—*Eleven days after operation.*—Child, æt. 8 weeks. Severe congenital talipes varus. Tendo Achillis,

¹ 'Trans. Path. Soc. of London,' vol. viii, London, 1857.

tibiales anticus and posticus, and flexor longus digitorum tendons divided. Death from diarrhœa.

Post-mortem examination.—Divided extremities of tendo Achillis seven eighths of an inch apart, but connected by a solid bond of union, of a soft and somewhat gelatinous consistence and blood-red colour; general vascularity. Divided extremities of the tendon slightly rounded, and a little softer than natural, but retaining their dead-white colour, and pretty firmly connected with the uniting bond of new material.

Tibialis posticus tendon.—Divided extremities seven eighths of an inch apart, and without any direct connexion. Connected with each of these divided extremities of the tendon was a portion of new material, a quarter of an inch in length, of firm consistence, translucent in appearance, and of a ruddy tinge. It seemed doubtful whether union would ever have taken place between these divided extremities, their permanent connexion with the sheath behind the malleolus, as in Case 12, appearing more probable.

Flexor longus digitorum.—Divided extremities half an inch apart, but directly connected by a thin band of fibrous tissue.

Microscopical examination.—The new connective tissue, formed between the divided extremities of the tendo Achillis, consisted of nucleated blastematous material, in which, after the addition of acetic acid, numerous small oval and rounded nuclei were apparent, irregularly scattered, and not arranged in linear series. The connective tissue had no disposition to split into fibres, but, whether teased with needles, or compressed with the glass, resembled at its edges torn membranous material. The portions of new tissue connected with the extremities of the posterior tibial tendon presented similar appearances, but with less intermixture of inflammatory effusion, and a much smaller quantity of molecular oil.

CASE 3.—*Sixteen, twenty-three, and thirty days after operation.*—Child, æt. 3 weeks. Severe congenital varus of both feet. The tibial tendons of both feet, and the tendo

Achillis of the right foot, were divided. Death from pneumonia.

Tendo Achillis, sixteen days after operation.—Divided extremities rather more than half an inch apart, but connected by a tough bond of new material, of a ruddy, blood-stained colour, equal in diameter and bulk to the tendon it served to connect. The divided extremities of the old tendon retained much of their abrupt and square outline, the margins only being a little rounded. They appeared not to have undergone any material change, though they were firmly connected with the new tissue by a very fine dovetailing arrangement, scarcely traceable by the naked eye.

Microscopically examined, the connective tissue between the divided extremities of the tendo Achillis appeared to consist of old fibro-cellular tissue, such as probably formed the sheath or fibro-cellular investment of the old tendon, intermixed with a large quantity of granular, nebulous material, studded with molecules and larger globules of oil, the latter probably derived from included portions of fat. After the addition of acetic acid, numerous small rounded and oval nuclei were brought into view. These nuclei had no disposition to a linear arrangement. At the junction of the new with the old tissue, a coarse separation of the structure of the old tendon into obtusely rounded bundles of fibres, between which the new material was inserted, was very evident; and the new tissue at this part was much clearer than towards its central portion, and, after the addition of acetic acid, was seen to be thickly studded with small oval and rounded nuclei, without any disposition to a linear arrangement.

Tibiales anticus and posticus tendons of left foot, twenty-three days after division.—Divided extremities of anterior tibial tendon three quarters of an inch apart, but connected by a firm cylindrical bond of new material, easily distinguished, by its ruddy tinge and appearance of vascularity, from the old tendon.

Divided extremities of posterior tibial tendon half an inch apart, but connected by a tough bond of new material, as

in the anterior tibial. The extremities of the old tendon retained their abrupt and square outline, but slightly rounded at the margin, without any bulbous enlargement or dovetailing visible to the naked eye.

Microscopically examined, the new material approached in its structural arrangement the characters of well-formed tendon sufficiently to justify its being described as newly formed tendinous structure. It had a distinctly fibrillated character, though pale and delicate when compared with old tendon, but yet its margins would not split or fray out into separable fibres or bundles of fibres. The addition of acetic acid exhibited an appearance of elongated nuclei, united by filaments in a linear arrangement, and running in parallel lines, with almost as much regularity as in the old tendon; but the nuclei, if they may be so considered, in the new tendon were dotted and more elongated than in the old tendon, in which the nuclei were clear and well defined. At the junction of the new with the old tendon, the structure was more translucent than at any other part, and there was an absence of the linear arrangement of elongated nuclei and of the fibrillated appearance of the new tissue; at this part only the smallest nuclei, generally of spherical or oval form, were clustered without any regularity. Numerous vessels existed in the new tendon, the larger trunks running transversely or obliquely across it, as if formed from the circumference towards the centre, and then dividing; the smaller branches were either continued obliquely, or ran in a longitudinal direction.

Tibiales anticus and posticus tendons of right foot, thirty days after division.—Divided extremities of anterior tibial tendon nearly three quarters of an inch apart, but connected by a firm bond of new material like that in the corresponding tendon of the opposite leg.

The posterior tibial tendon, a little above the inner malleolus, presented externally a ruddy tinge from blood-staining and vascularity of adjacent areolar tissue, resembling in some degree the appearances of the corresponding tendon of the opposite leg, but a longitudinal section and minute

examination showed that this tendon had not been divided. This specimen might have been considered by some as exhibiting a very perfect condition of repair, and as an example of a linear cicatrix, especially as the case had proceeded as favorably as if it had been divided.

CASE 4.—*Eighteen days after operation.*—Child, æt. 4 weeks. Severe congenital varus of right foot. Tibialis posticus and flexor longus digitorum divided. As it was supposed that the posterior tibial artery had been wounded, the other tendons were not divided. Death from diarrhœa. Instead of gradual extension being made, the foot was retained in the deformed position by a tin-splint, and pressure applied—the plan we adopt when the artery is supposed to have been wounded. This accounts for the unusually slight extent of the separation of the divided extremities of the posterior tibial tendon. The specimen, which is now in St. Bartholomew's Museum, was carefully examined by Mr. Paget, and the following is an abstract of the description written by him.

Divided extremities of *posterior tibial tendon* only one line apart; upper extremity grayish-looking, succulent, slightly swollen, and rounded or bulbous; lower extremity unchanged in texture, and free end rectilinear. Between the two, and attached especially to the end of the upper portion, was a firm, tough, elastic, grayish substance, apparently a connecting bond of reparative material, about a line in length, and less than half a line in width or thickness; smaller, therefore, than either portion of the tendon. This substance was united to the adjacent tissues, yet could be dissected from them. Portions of it, examined with a microscope, appeared to be composed of reparative material placed among the filaments of fibro-cellular tissue, such as might have collapsed into the space between the separated ends of the tendon. It contained abundant blood-vessels, but was essentially composed of compact, closely-wrinkled tissue, like that of new tendon in the rabbit, dotted with minute molecular matter. The addition of acetic acid made

it quite clear, and showed in it a few nuclei, besides those of the blood-vessels that traversed it.

The tendon of the flexor longus digitorum was divided somewhat obliquely. Both its portions were very slender, and the upper one was so wanting in firmness that it was difficult to trace its end; neither did there appear any distinct new-formed bond of union between them; they were held together by white tissue, apparently the fibro-cellular, which had invested the tendon, and to which the portions of the tibialis posticus and their uniting medium were adherent.

CASE 5.—*Five weeks and six weeks after operation.*—Child, æt. 6 weeks. Congenital talipes varus, not severe. Tibiales anticus and posticus, and flexor longus digitorum, divided six weeks, and the tendo Achillis five weeks, before death, which resulted from acute pneumonia.

Tibialis anticus.—Divided extremities nearly half an inch apart, but connected by a tough bond of new material, equal in thickness to the extremities of the tendon, and similar in appearance to the other specimens about this date.

Tibialis posticus and flexor longus tendons.—Divided extremities rather less than a quarter of an inch apart, but connected by new material of a firm, compact texture, and pale colour; grayish, with a light-ruddy tinge from vascularity. Both these tendons adherent to each other and to the adjacent bone-surface. The less separation of the tendons in this instance is explained by the case not being of a severe form.

Tendo Achillis.—Divided extremities a quarter of an inch apart, but firmly connected by a tough bond of new material, presenting on section a translucent appearance, and light-ruddy tinge from vascularity, readily distinguished from the opaque-white extremities of the old tendon. The junction of the old with the new tendon was indicated by a fine dovetailing process.

Microscopically examined, the new material exhibited a delicate, fibrillated appearance, but would not split or fray out into separable fibres. The addition of acetic

acid brought into view abundant nuclei, and an arrangement in parallel linear series was evident, so that a perfecting of the new connective tissue towards the characters of well-formed tendon was clearly traceable.

CASE 6.—*Six weeks after operation.*—Child, æt. 9 weeks. Severe congenital talipes varus. Tibiales anticus and posticus, and flexor longus digitorum, and tendo Achillis, divided at the same time by Mr. Tamplin, in whose possession the specimen now is. The post-mortem examination was made by me, and the specimen minutely examined at the time, and drawing made. Cause of death not recorded. Several muscular irregularities, with additional tendinous slips, passing between and connecting the various tendons around the ankle-joint and in the foot, existed in this case.

Tibialis posticus and flexor longus digitorum.—Divided extremities a quarter of an inch apart (or rather more), but connected by a tough bond of new material, of a grayish appearance, and with some vascularity. Both tendons were inseparably fused in this material, which was also closely and firmly adherent to the surface of the bone.

Tibialis anticus.—Divided extremities half an inch apart, but in consequence of the splitting of this tendon, and its connexion with the anterior annular ligament, its cylindrical form and definition were less distinct than usual. The connecting bond appeared to consist of old fibrous tissue, thickened by infiltration of new reparative material.

Tendo Achillis.—Divided extremities rather less than half an inch apart. The depression of the heel did not appear to be complete in this case. On section, the new material presented a grayish translucent appearance, so that it was readily distinguishable from the old tendon; its vascularity was evident. At the junction of the new with the old tendon the dovetailing process was very obvious, especially at the lower extremity, where this appearance was coarse, and the old tendon presented a slightly bulbous enlargement.

Microscopically examined, the new material in the several

tendons presented a delicate, fibrillated appearance, but would not fray out into separable fibres, except in some portions from the tendo Achillis, and in this situation some bands of old fibro-cellular tissue, blended with the new material, were probably examined. In all the tendons acetic acid, applied to the new material, brought into view a parallel arrangement of elongated nuclei, and at the junction of the old with the new tendinous material the latter was clearer than in its central portion, and studded with very small oval or rounded nuclei, irregularly scattered over the field.

CASE 7.—*Three months after operation.*—Girl, æt. 8 years. Talipes equinus of right foot, associated with partial paralysis of the muscles of the leg. Tendo Achillis divided. Death from sloughing sore-throat; scarlatina? Post-mortem examination made by Mr. Coghlan, of Notting Hill, and myself. The whole of the spinal cord was examined, with a view to the pathology of infantile paralysis, but no abnormal condition was detected in any part. All the muscles of the leg below the knee were in a more or less advanced state of fatty degeneration, but the muscular structure was not so completely destroyed as I have seen it in other cases. The form of the foot was natural, and without excessive depression of the os calcis.

Tendo Achillis.—The cylindrical form of the tendon was well defined on its superficial and lateral aspects, but the definition of its deep surface was obscured by adhesions. At the seat of division its surface was not so smooth and glistening as above and below this portion; from this part no loose, separable sheath could be dissected. A slight increase of vascularity also identified the seat of operation. On section, the divided extremities of the tendon were seen to be three quarters of an inch apart, but firmly connected by a tough and close-textured bond of new material, equal in bulk and thickness to the tendon it served to unite, and of a slightly striated or fibrous appearance, which was added to by a few injected vessels running longitudinally

through its texture. The junction of the new with the old tendon by a dovetailing process was very clear and distinct. The cut extremities of the old tendon were slightly puckered in at the exact line of junction, especially at the upper extremity, so that the new material for about one eighth of an inch ensheathed the extremity of the old tendon, but beyond this, especially at the lower extremity, a slight bulbous enlargement of the old tendon existed.

Microscopically examined, the structure of the new material, or new tendon, so closely resembled the structure of the old tendon, that careful observation was necessary to distinguish them. The new material presented a distinctly fibrous appearance, resembling that of the old tendon, more easily splitting into separable fibres than in any specimen I have examined at an earlier date. Acetic acid rendered the tissue translucent, and brought into view numerous elongated nuclei, arranged end to end in parallel linear series, an appearance also exhibited in the old tendon after the addition of acetic acid.

The reparative process by regeneration of tendinous structure between the divided extremities of the old tendon (the portion of new tendon being three quarters of an inch in length) was beautifully illustrated by this specimen, one half of which I have presented to the Royal College of Surgeons.

CASE 8.—*Three or four months after operation*.—A boy, æt. 16 years. Talipes equinus. Tendo Achillis divided by Mr. Tuson, of the Middlesex Hospital. Specimen formerly in the possession of my late colleague, Mr. Lonsdale, and now in St. Bartholomew's Hospital. Divided extremities of tendo Achillis one inch and a quarter apart, but connected by a tough bond of new material, equal in bulk to the thickness of the tendon. The dovetailing process of the new with the old tendon was obvious at the line of junction. Imbedded in the new connecting material were the remains of a rather large clot of blood, and the reparative process was imperfect at this part. The new material also presented

the appearance of a more irregular interlacement of fibres than usual. Altogether, there was more evidence of local disturbance at the seat of the operation, from extravasated blood and inflammatory effusion, than I have generally seen.

CASE 9.—*Seven months after operation.*—A boy, æt. 10 years. Congenital talipes varus. Operated upon by my late colleague, Mr. Lonsdale. Death from scarlet fever. Post-mortem examination made by me.

Tendo Achillis.—Divided extremities one inch apart, or rather more, but connected by a tough and very strong bond of new tendinous structure, equal in bulk and thickness to the extremities of the tendon it served to connect. The new material had a grayish translucent appearance, with very little evidence of vascularity to the naked eye, but with slight traces of a fibrous arrangement of its structure; some fibrous bands, approaching somewhat to the opaque pearly lustre of old tendon, passing obliquely through its substance. This appearance I have seen more marked in cases at a later date. The deep surface of the new tendon was somewhat ill defined, from its connexion with thickened bands of fibro-cellular tissue intersecting the adjacent fat.

Microscopically examined, the new material presented a distinctly fibrous character, and although not splitting easily into separable fibres, still the edges of any portion examined exhibited a tendency to such splitting, and in some parts would fray out into delicate fibres. Acetic acid rendered this structure transparent, and the arrangement of elongated nuclei in parallel linear series was distinct.

CASE 10.—*About one year after operation; and also at two subsequent periods, probably about seven and four months, but the precise dates uncertain.*—A girl, æt. 3 years. Congenital talipes varus. Operated upon by my late colleague, Mr. Lonsdale. The case was one of unusual severity, and the operation had to be repeated. Death from scarlet fever.

Tendo Achillis.—The appearances left after three divisions

of this tendon were clearly traceable. The divided extremities of the old tendon at their point of widest separation were one inch and a half apart, but within this space were two detached portions of old tendon, which together measured about half an inch in length, and these were firmly and intimately blended with the new tendinous structure, formed after the three divisions of the tendon. These detached portions of old tendon retained their opaque pearly lustre, and were thus readily distinguishable from the intermediate portions of new connective tissue, which presented a grayish, translucent appearance, as seen in all the other specimens some months after the operation. The junction of the old with the new tendon, by the process of dovetailing, was obvious, both in the detached portions, and at the extremities of the old tendon. The new tissue had but very slight traces of vascularity to the naked eye, and only slight indications of a fibrous arrangement of its structure.

Microscopically examined, the new tendinous structure had a distinctly fibrillated appearance, and, after the addition of acetic acid, exhibited the parallel linear arrangement of elongated nuclei previously described.

CASE 11.—*One year and a half after operation.*—A girl, æt. 9 years. Talipes equinus, coexisting with a recurrent fibroid tumour in the calf of the leg. After an incomplete removal of the tumour, the connexions of which were found to be too deep to admit of complete enucleation, Mr. Curling divided the tendo Achillis, and cured the deformity of the foot. The tumour returned, and then Mr. Curling amputated the leg.¹ For the opportunity of examining the leg I am indebted to Mr. Curling. It is important also to mention that the deformity had returned to an extreme degree previous to the amputation.

Tendo Achillis.—After exposing this tendon by dissec-

¹ 'Path. Soc. Trans.,' London, vol. vi, p. 345; and also vol. vii, p. 345.

tion, it might be said, from a rough external examination, that no traces existed of the tendon having been divided. Its external form and size were quite natural, without any irregularity of surface, which was readily defined by dissection, nor was there any increased vascularity; but a closer examination showed that through two inches and a quarter of the length of the tendon, its surface did not present such a smooth, glistening appearance as in the normal condition, and that in this portion we could not dissect from its surface the layer of loose-textured areolar tissue, which naturally surrounds the tendo Achillis, and is described as its cellular sheath.

After making a longitudinal section of the tendon, it was at once apparent that it had been divided, and that the divided extremities were separated to the distance of two inches and a quarter, but were firmly connected by a tough bond of new connective tissue, or new tendon, equal in bulk and thickness to the tendon it served to re-unite. The new tendinous structure presented a grayish, translucent appearance, contrasting very obviously with the opaque, white, pearly lustre of the old tendon above and below it, and exhibited only slight traces of vascularity. Its structure was homogeneous rather than fibrous in appearance; it had no longitudinal fibrous arrangement, but some opaque, white, glistening fibrous bands appeared to traverse its structure obliquely, and presented on the cut surface a somewhat feathered appearance. The junction of the new with the old tendon was very distinctly indicated by the process of dovetailing described in the other specimens, the new material, which preserved its translucent appearance, being inserted between the split fibres of the old tendon, which retained their opaque pearly lustre. This was equally distinct at the upper and lower extremities of the old tendon, in neither of which was there any appearance of bulbous enlargement.

Microscopically examined, the new connective tissue, or new tendon, so closely resembled the appearances presented by the old tendon, that it would certainly have been

difficult for any one, unaccustomed to examine these structures, to point out any characters by which they might be readily distinguished. The new tendinous tissue presented very distinctly the appearance of separable fibrous structure, differing only from the old tendon in being more delicate, and less readily separable, the margins only fraying out. The addition of acetic acid did not render the new tissue so clear and translucent as in the cases at an earlier date, nor was the arrangement of elongated nuclei in parallel series so distinct. The fibrous character of the new tissue remained faintly traceable long after the addition of acetic acid, and the appearance of elongated nuclei was obscure, so that the latter might well be supposed to be replaced by dark lines or spaces. The same might be said of the old tendon after the addition of acetic acid, faint tracings of fibres and indistinct elongated nuclei taking the place of complete translucency, and distinctly elongated nuclei arranged in parallel series, as seen in the specimens of new tendon at an earlier date, and also in the original tendinous structure in infants. The new tissue was studded with a small quantity of molecular oil.

Much of the interest which attaches to this case arises, not only from the circumstance that a portion of new tendon, two inches and a quarter in length, could be proved to exist between the divided extremities of the old tendon one year and a half after its division, but that, coexisting with this additional length of new tendon, the deformity, viz., talipes equinus, had returned in an extreme degree previous to amputation. It is, therefore, proved that in this case the relapse of the deformity was not due to the contraction and absorption of the new connective tissue, but depended upon changes taking place in the muscular structure. The same fact is also illustrated by the next case, but the pathological changes in the muscular structure were of a different nature.

CASE 12.—*Two years after the last operation, but a longer, though uncertain, period after the previous operations.*

—A man, æt. 37. Non-congenital equino-varus of paralytic origin. This specimen has already been described at great length, and figured in the 'Transactions of the Pathological Society of London,' vol. viii, 1857; and to this description I must refer the reader. It is here only alluded to as one of a series, and its place indicated in reference to the period of the reparative process.

CASE 13.—*Three years after operation.*—A lady, æt. 42. Equino-varus of one foot, and equino-valgus of the other, produced by infantile paralysis. Both Achilles-tendons divided. Death from phthisis.

Achilles-tendons.—The divided extremities of these tendons were found to be, one an inch and a quarter, and the other an inch and an eighth apart, but firmly connected by a strong bond of union, or new tendon, equal in bulk and thickness to the extremities of the tendons it served to unite, and presenting a grayish, translucent appearance, by which it was readily distinguishable from the old tendon. The new material had, in a more marked degree than I have seen in any other human specimen, a longitudinally striated appearance. The cut extremities of the old tendon were very distinct, from the contrast of colour above described, and the line of junction of the new with the old tendon was indicated by the dovetailing process described in the previous specimens. The new material extended at its circumference slightly beyond, and ensheathed the extremities of the old tendon.

Microscopically examined, the new connective tissue presented the appearance of well-formed tendon; and when portions of it were examined side by side with portions of the old tendon, the general resemblance was so close that, without the evidence presented by the recent section, it might very well have been said that no material differences of structure existed in any part; the presence of any new material might have been doubted, and an inference favorable to the *linear cicatrix theory* drawn. The new tendon presented a distinctly fibrous appearance, and

readily split into separable fibres, more delicate than the fibres of the old tendon, and dotted with minute molecules of oil. In the old tendon, however, molecular oil was very abundant, an appearance which I have not seen before in old tendon; and this, together with the increased separability of its fibrous structure, might, perhaps, be regarded as changes of degeneration, depending upon the long-standing paralytic affection. After the addition of acetic acid the appearances were very similar in the old and new tendon, viz., a shaded, nebulous appearance, with pale and indistinct traces of its fibrous structure, and dark crooked lines, as of the remains of elongated nuclei arranged in ill-defined parallel series.

This completes the series of thirteen cases, of the recent appearances of which, with one exception, I have been enabled to give a detailed account from my own dissection and microscopical examination; accompanied in every instance by a drawing.¹ In all these cases the reparative process has been observed in different stages between four days and three years after the subcutaneous division of the tendons.

I also possess short notes of three other post-mortem examinations, which have been made by me at periods between one and seven months after the operation; and from one of these cases I have preserved a portion of the foot, but have no detailed account of the post-mortem appearances, nor were any drawings made at the time. I am not, therefore, enabled to state the exact length of new material formed in these cases; but can, with confidence, assert that the general appearances of these three cases corresponded with the others above described of about the same periods after operation.

¹ From ten of the above cases the specimens were exhibited to the Society.

GENERAL SUMMARY OF THE REPARATIVE PROCESS.

The principal events in this process of development of new tendon after subcutaneous division, may, I believe, be described in a general summary, as follows. Let it be understood, however, that the description especially applies to the tendo Achillis. Essentially the reparative process is no doubt the same in all tendons; but as the anatomical conditions, under which tendons are placed in some situations, vary,—for instance, where tendons pass through dense tubular sheaths, as the tibialis posticus behind the inner malleolus, the flexor tendons along the fingers, &c., there is an absence of the investing cellular sheath, and of the fat and cellular tissue which surrounds the tendo Achillis and other tendons similarly placed,—and as these conditions sometimes interfere with the perfection of the reparative process, to which I will afterwards refer, it will be better to limit the general description to the process as it appears to me to occur in the tendo Achillis, which I prefer for illustration, though it would equally apply to other tendons placed under similar anatomical conditions. The process, it appears to me, may be best described under the four following heads, under which the principal events may be most conveniently grouped. They cannot be considered as so many different stages, because two or three of the processes described are always proceeding simultaneously.

1st. *Immediate results of the operation.*—After the subcutaneous division of the tendo Achillis in the human subject, separation of the divided extremities of the tendon takes place to a very variable extent. Under ordinary circumstances the separation of a divided tendo Achillis in an infant is about half an inch, and in the adult from one to two inches. This is produced in the following way: the upper portion of the divided tendon is drawn upwards by the contraction of the muscular fibres, and the lower portion is drawn downwards, in proportion as the foot is

restored to its natural position. The separation must, therefore, depend upon the capability of the muscular fibres to contract, and also upon the flexibility of the ankle-joint; and as in deformities the muscular structures are found in all conditions, from that of health to complete degeneration, and as the ankle-joint is also found in every degree of rigidity, from the adapted shortening of the ligamentous and other structures, &c., the separation of the divided tendon will vary in a proportionate degree. The circumstances which limit the separation of the divided extremities of the tendon are—1st, degeneration of the muscular tissue, as in non-congenital cases of deformity of long standing and of paralytic origin, &c.; 2dly, rigidity of the ankle-joint, produced by a variety of causes, but in congenital cases principally by the adapted shortening of the ligamentous structures, and in the non-congenital cases by old inflammatory infiltration of the structures surrounding the joint, &c.; 3dly, old adhesions in the neighbourhood of the tendon, such as result from a previous operation, or other causes. Frequently two, and sometimes all three, of these conditions coexist, and in such cases scarcely any separation of the divided extremities of the tendon will take place at the time of the operation, so that the surgeon may be led to doubt whether the tendon has been completely divided.

Influence of the sheath.—The separated extremities of the divided tendon still remain indirectly connected with each other through the medium of the cellular sheath of the tendon, by which I mean the loose-textured areolar tissue which closely invests and surrounds the tendo Achillis, and which is never divided, and often appears to be but very little injured, in a subcutaneous operation; it evidently yields before the knife as the latter passes through the tense tendon. Even if this cellular sheath should be completely divided as in an open wound, it would not retract with the tendon, in consequence of its connexion with the subcutaneous fat and cellular tissue in the human subject; and in rabbits, in which animals no subcutaneous fat exists in the neighbourhood of the tendo Achillis, it would not retract, in

consequence of its connexion with the deep fascia and sheaths of the deeper tendons. The influence of the sheath, therefore, which I hold to be of great importance, is not destroyed, as has been supposed by Mr. Paget, by the open wound, though it is certainly impaired; and the reparative process in these cases is proportionably less perfect, but not to an extent permanently to interfere with the formation of a sufficient quantity of new tendon. (See experiments on the reparative process after division by open wound, in the sixth volume of 'Path. Soc. Trans.'). This cellular investment of the tendo Achillis, which is scarcely demonstrable as a sheath in an anatomical dissection, becomes very easily demonstrable as such after the subcutaneous division of the tendon, because the loose-textured areolar tissue, of which the sheath is composed, is then put on the stretch, and being very little injured in the operation, as I have explained, from its yielding before the knife, presents the form of a tubular sheath passing between, and connecting indirectly the separated extremities of the divided tendon. This is very readily demonstrated in the rabbit (see experiments previously referred to, and the accompanying plate, in which this appearance is represented). I have also seen the same condition in the human subject.

A very small quantity of blood is generally effused at the time of the operation within the sheath, now of tubular form, and is seen adherent to the upper and lower extremities of the tendon, but principally to the upper extremity. In many of my experiments on rabbits, there was scarcely a trace of blood; and in two examinations in the human subject, a few days after the operation, I found only a very small coagulum, certainly not sufficient to take any important part by its organization (the possibility of such a process being admitted) in the formation of the large quantity of new tendon required to connect the separated extremities of the old tendon. If the effused blood should be sufficient to fill the sheath and infiltrate the surrounding tissues, the reparative process will be retarded and rendered proportionably less perfect. Such an event must be regarded as

an unfavorable accident of the operation, instead of an essential part of the process, as it has generally been regarded, especially by the French and German authorities. In such cases, the greater part of the blood will become absorbed, and the remaining and firmer portion of the clot will be found at a late period inclosed in the midst of the new tendon; this I have witnessed in several instances both in the human being and in the rabbit.

At the time of the operation, then, the separation of the divided extremities of the tendon, which remain connected by the sheath, which now assumes a tubular form, and the effusion of a small quantity of blood, are the ordinary occurrences.

2d. *Commencement and nature of the reparative process.*—

The true reparative process commences in the human subject by increased vascularity of all the structures at the seat of the operation, viz., the subcutaneous cellular tissue and fat, and the cellular sheath of the tendon, now of a tubular form, passing between and connecting the separated ends of the tendon. In the rabbit the increased vascularity is confined to the connecting tubular sheath. For this reason, then, I regard the increased vascularity of the sheath in the human subject as essentially the first step in the reparative process, the extension of the vascularity to the cellular tissue and fat being the necessary consequence of the existence of this tissue, but unimportant as regards the reparative process. Increased vascularity of the sheath is followed by infiltration of a blastematous material into its meshes, or spaces, between its fibrous elements, so that the sheath, now forming the matrix in which the reparative material is effused, presents a vascular and succulent appearance. In the human subject this effusion and succulency may sometimes extend to the surrounding cellular tissue and fat, especially in clumsily performed operations, which may be followed by inflammation; but essentially I do not believe it extends beyond the sheath, because in carefully performed operations, followed by appropriate treatment, viz., a compress and bandage applied immediately after the

operation, the gap between the divided extremities of the tendon remains as a depression for several days; it does not become filled up, as it would do if the tissues were at once infiltrated; and an external examination by the finger readily detects the square and abrupt extremities of the divided tendon freely moveable in the cellular tissue, which to the touch seems flaccid rather than distended by infiltration.

Development of the reparative material.—The blastematous material infiltrated into the meshes of the sheath increases in quantity, and, microscopically examined, exhibits the development of innumerable small oval nuclei. A few cells, of large size and irregular form, with granular contents, or perhaps with one or more nuclei, and studded with minute molecules of oil,—cells such as are met with in ordinary inflammatory effusions,—may also be found according to the extent of the inflammatory lymph which may be accidentally intermixed with the nucleated blastema,—so called by Mr. Paget, and described by him as the proper reparative material as distinguished from inflammatory lymph, in which development proceeds through nucleated cells, as in the ordinary exudation from a granulating surface. A blastematous material, then, in which the cell-forms do not pass in development beyond the stage of nuclei, appears to be the proper reparative material from which new tendon is developed, and any admixture of inflammatory lymph in which the ordinary inflammatory exudation-cells are developed, must be regarded as an accidental complication of the reparative process, instead of being an essential part of it, as is generally supposed.

The changes which subsequently occur in the nucleated blastema are—1st, the formation of capillary blood-vessels. In the specimen from a child, exhibiting the reparative process on the eighteenth day after division, above described, examined microscopically by Mr. Paget and myself, newly formed and forming capillary blood-vessels with their nucleated parietes were beautifully seen after the addition of acetic acid, and were very abundant. 2dly, the nuclei assume an elongated, spindle-, or oat-shaped form, and are

seen, after the addition of acetic acid, to be arranged in parallel linear series. Whether fibres are formed in this way, or in what manner the elongated nuclei are disposed of, may still be matter of opinion; but I am inclined to believe in the development of fibres from this process, after carefully examining numerous specimens, both in my experiments in rabbits, and in the specimens from the human being.

As a gradual change towards perfecting the new connective tissue in its structural characters and general resemblance to the old tendon, the divided extremities of which it serves to connect, a fibrillated appearance of the new tissue is traceable under the microscope, and, in the course of time, a more distinctly fibrous appearance, *i. e.* tissue capable of splitting into distinct fibres under the microscope, becomes developed. The fibrous tissue, however, always remains more delicate and less distinctly separable than in old tendon.

3d. *General appearance and structure of the newly formed connective tissue, or new tendon.*—By the development of the blastematous material above described, a solid bond of union is formed between the divided extremities of the tendon, of variable length, according to the distance between the divided extremities; and this appears to be generally from half an inch to an inch in children, and from one inch to an inch and a half or two inches in the adult; but it may occasionally exceed this, and yet retain its full strength and proportionate size to the extremities of the tendon it serves to connect. The greatest length I have witnessed in the human subject is two and a quarter inches, and this was in the tendo Achillis of an adult, a year and a half after the operation (Mr. Curling's case, above described).

This connecting bond of union, or new tendon, as it may with propriety be called, is of a very tough consistence, and appears to the naked eye to be homogeneous rather than fibrous. A small portion of it cannot be split into fibres, but when teased out with needles on a piece of glass for microscopical examination, it spreads out like a portion of

serous membrane, rather than splits into fibres, though its fibrous character is readily distinguishable under the microscope, as above described. There is, however, one very marked peculiarity of new tendon, even at a late period, viz., that, after the gradual subsidence of the vascular injection and consequent ruddy tinge of the new tendon, it presents to the naked eye a grayish translucent appearance, a peculiarity which it has retained up to the latest period I have had the opportunity of examining it in the human subject, viz., three years after operation; and in the rabbit, one year after operation. This grayish translucent appearance at once distinguishes the new from the old tendon in any specimen of which a section may be made in the recent state; but as the translucency is destroyed by spirit, which immediately renders the new tendinous tissue opaque, this indication is lost after the specimen has been put into spirit. Pure glycerine, or a solution of half glycerine and half water, preserves the appearance of translucency in the new tendon for a short time—a few weeks; but gradually this solution renders the old tendon translucent, and thus the contrast between the new and the old tendon is also lost. I am not aware of any fluid in which the appearance can be retained.

I would here observe that no section, in the recent state, had been made of the human tendons presented to the Royal College of Surgeons by Mr. Tamplin, upon the external appearances of which the theory of a *linear cicatrix*, supposed to result from the contraction and complete absorption of the new connective tissue, has been based. These tendons (the tendo Achillis, and tibial tendons of a child aged nineteen months, in whom these tendons had been divided nearly eighteen months previously¹) are said not to have presented externally any appearance of having been divided, and minute portions, taken by Mr. Quekett from different parts, exhibited the microscopic appearances of well-formed tendon. Hence it appears to have been

¹ 'Path. Catalogue of the Museum of the Royal Coll. of Surgeons,' vol. ii., Nos. 358, 359, and 360.

assumed by Mr. Tamplin that the new connective tissue had been completely absorbed, and that the divided extremities of the old tendon had again come into direct apposition, so that only a *linear cicatrix* remained. The fact that the new connective tissue, or new tendon, so closely resembles in structure the old tendon as to be scarcely distinguishable from it, had not at that time been demonstrated, and it is to be regretted that the recent section, the most important test, was not made. Sections of these tendons were made some months since by Mr. Quekett and myself, but from the effect of spirit in destroying the translucency of the new tendon (if such existed), it was impossible to say whether any new tendinous tissue existed or not. There did appear to me to be some indications of a portion of new tendon in the tendo Achillis, but the traces were obscure, and as the tendon of the opposite leg was not preserved, it is impossible to say whether any increased length of the tendon had been obtained.

4th. *Junction of the new with the old tendon.*—The divided extremities of the old tendon take no active part whatever in the reparative process during its earlier stages, and have but a slender connexion with the new material when first formed. A little later, certain changes are observed to occur in the divided extremities of the old tendon, and these commence earlier and proceed more rapidly in the upper than in the lower extremity of the tendon. These changes are—1st. The cut extremities of the tendon, with their square surfaces and sharp edges, become a little rounded, and their structure slightly softened. 2dly. They become slightly enlarged, and exhibit a disposition to split, and thin streaks of new material, of a grayish translucent appearance, are seen between the split fibres. This is the commencement of the junction between the old and the new tissues, and by the increase of new material between the split fibres of the old tendon, the extremity of the latter presents a slightly bulbous appearance. 3dly. At a later period this bulbous enlargement gradually diminishes, till the extremities of the old tendon again

assume their natural appearance, and the new and old tendon become of uniform diameter; but the appearance of a very fine dovetailing of the new material with the split fibres of the old tendon still remains, and in two cases above described was distinctly traceable in the recent section at intervals of a year and a half, and three years, after the division of the tendon.

This complete and firm junction of the new with the old tendon may be regarded as essentially the final stage of the reparative process; but proceeding simultaneously with it is a further perfecting of the structure of the new tendon, as to its density, the diminution of vascularity, general resemblance to the structure of healthy tendon, except in the translucency as above described, and in the external definition of form; but in all the specimens I have examined at late periods I have found a want of definition along the deep surface of the new tendon, arising from adhesions between this surface of the tendon and the deep fascia. In the human subject, the cellular tissue between the deep surface of the tendo Achillis and the deep fascia presents the appearance of having been infiltrated with lymph to a greater or less extent in different specimens, and its structure is proportionably increased in density and its fibrous septa thickened. It is no doubt this condition of deep-seated adhesions which limits the separation of the divided extremities of the tendon when subjected to a second operation, and hence arises the extreme importance of gaining sufficient length of new tendon after the first operation. When divided a second time, a tendon very rarely gives way with a *snap*, and the separation of its divided extremities is generally very slight. This I have found to be the case, even after an interval of ten years between the operations; but the adhesions would no doubt be much stronger when the first operation had been clumsily performed, and followed by an unnecessary amount of inflammation.

Amongst the changes which the new tendon undergoes in its gradual improvement at a late period, I have observed the more or less perfect reproduction of the sheath of the

tendon, which I described as forming in the first stage the matrix in which the reparative material is effused.

This process of re-formation of the cellular sheath on the surface of the new tendon is accomplished more perfectly, and is more easily traceable, in rabbits than in the human subject. In my experiments on rabbits I found a separable layer of areolar tissue formed on the surface of the new tendon through its entire length, between the second and third month after division; and above and below it was continuous with the cellular sheath surrounding the extremities of the old tendon, but it was neither so delicate nor so loose-textured as the cellular sheath of the old tendon; it adhered more closely to, and could not be so easily separated from, the surface of the new tendon. In dissecting from above downwards, or from below upwards, in either case from the old to the new tendon, and raising the investing cellular sheath, the line of junction of the new with the old tendon could be readily determined by this difference in the separability of the sheath, when no other indication was apparent.

In the human subject the same process takes place, but is not so easily demonstrated, owing to the existence of, and connexions of the sheath with the cellular tissue and fat in which the tendon is imbedded, and which is entirely absent in the rabbit.

CIRCUMSTANCES WHICH MAY INTERFERE WITH THE PERFECTION OF THE REPARATIVE PROCESS, OR ENTIRELY PREVENT IT, SO THAT NON-UNION OF THE DIVIDED TENDON MAY RESULT.

Having now described the reparative process, as it appears to take place under the ordinary circumstances of health in a divided tendo Achillis, I would observe, that the process appears to be precisely similar in all other tendons which possess a cellular sheath and are similarly situated with respect to the surrounding soft tissues, or

which possess a delicate membranous sheath, as the flexor tendons in front of the wrist-joint, and tendons in many other situations. These delicate thecal membranes appear to serve the purpose of connecting the divided extremities of the tendons after section, and, together with the loose-textured areolar tissue (imperfect cellular sheaths) in immediate contact with the surface of the tendons, no doubt materially assist in the reparative process.

But there are some circumstances under which the reparative process may be interfered with to a greater or less extent, so that union may take place through an imperfectly formed and attenuated uniting medium, or, it is said, that union of the divided extremities of the tendo Achillis may completely fail. I have never seen a case of complete non-union in the tendo Achillis, and should feel disposed to doubt its occurrence, in consequence of the uninterrupted connexion of the cut extremities, which continues to exist after division through the medium of the sheath, which is never completely divided, and is often but little injured in a subcutaneous division; and if it should be completely divided, as in an open wound, the sheath does not retract with the tendon, in consequence of its connexion with the surrounding tissues, as above described. In the posterior tibial tendon, however, complete non-union does occur, from the absence of a connecting cellular sheath, and is probably of more frequent occurrence than may be supposed: but of this I shall presently speak.

The circumstances under which the reparative process in the tendo Achillis may be interfered with, and the union remain imperfect, are—

1st. Some constitutional defect in the reparative powers of the patient, or depressed vital power in the limb from paralysis.

2d. Injudicious after-treatment from—(a), not sustaining the temperature of the limb, especially in paralytic cases during very cold weather; (b), too early and too rapid mechanical extension, restoring the form of the foot before there is any evidence of the reparative material being

thrown out, or of the commencement of the reparative process; (c), the mechanical treatment being altogether ignored, and the patient allowed to walk within two or three days of the operation, the surgeon relying upon the unassisted powers of nature in walking to restore the form and functions of the foot;¹ (d), discontinuing the mechanical treatment too early, and bringing the foot too quickly into use, by which the uniting medium may be elongated and weakened.

From any of these circumstances imperfect union of the divided tendo Achillis may take place, the uniting medium being imperfectly formed and attenuated, in some cases consisting of little more than the sheath of the tendon somewhat thickened. Of the very serious results arising from this failure of the reparative process, not only in interfering with the restoration of the functions of the muscles, but in the production of talipes calcaneus, essentially an incurable deformity, it is not my intention to speak. The practical deduction, however, seems to be, that the rate at which the separation of the divided extremities of the tendo Achillis is to be produced by mechanical extension in the cure of deformities must be regulated by the activity of the reparative process. Rapid extension would not, I believe, endanger the perfect union of the tendo Achillis in well-nourished infants and children, in cases in which there is no paralysis of the limb operated upon. But in non-congenital cases of deformity at all ages, when any paralysis exists, as it certainly does in a very large proportion of such cases, the extension must always be slow and proportionate to the rapidity of the reparative process, which is evidenced by the filling up of the gap between the divided and separated extremities of the old tendon, and can be felt by external examination and manipulation.

¹ See 'Lancet' of 17th March, 1855, where this plan of treatment is advocated, and several cases given, by Professor Syme, of Edinburgh, in illustration of its supposed merits. The patients were encouraged to walk on the third day after the operation. (See also observations on this subject by Mr. Adams, in 'Medical Times and Gazette,' April 28th, 1855.)

COMPLETE NON-UNION OF DIVIDED TENDONS.

When tendons, situated *in dense tubular sheaths*, are divided, the reparative process appears liable to be more seriously interfered with, and if the divided extremities of the tendon are much separated, union sometimes completely fails, and the extremities of the tendon become adherent to the internal surface of the dense tubular sheath. I found this to have occurred in the posterior tibial tendon in one case, which I dissected two years after the tendon had been divided, and the appearances are represented in plate x, vol. viii, of the 'Transactions of the Pathological Society,' London, 1857.

In another *post-mortem* examination, which I made eleven days after division of the posterior tibial tendon, No. 2 of the present series, there seemed to be very little prospect of union taking place; the small portions of new tendon connected with the divided extremities of the old tendon were half an inch apart, without any connecting tissue between them. I have also seen good reason to believe in the failure of union in this tendon in several instances during life, in which, after its division, the feet have become flat and everted, and exhibit a degree of weakness and peculiarity of form which I believe to result from this cause.

With respect to the cause and the condition which favour the non-union of the posterior tibial tendon, I would observe, if the posterior tibial tendon be examined carefully as it passes through the dense tubular sheath behind the inner malleolus, a small quantity of very loose-textured and delicate areolar tissue, in the meshes of which small particles of fat are entangled, will be seen on its surface, and the same appearance will be noticed in other tendons in their passage through dense tubular sheaths; sometimes there is also an imperfect layer of very delicate thecal membrane.

Now, it will be obvious, from this anatomical examination alone, that if the posterior tibial tendon, or any tendon

similarly placed, be divided in a dense tubular sheath, and if the divided extremities of the tendon should separate, as I have shown they generally do, to the distance of half an inch, and sometimes to nearly an inch, there would be no tissue capable of holding in connexion these separated extremities. The small quantity of areolar tissue above described is not disposed as a regular cellular sheath, as there is no necessity for such a provision, but if the separation of the divided extremities of the tendon should not exceed a quarter of an inch, I think the areolar tissue described would be sufficient to connect them, and play the part of the cellular sheath of the tendo Achillis in forming the matrix in which the new reparative material may be effused: if, moreover, in a sudden and wide separation of the divided extremities this areolar tissue should be torn across, so that the ends of the tendon cease to have even this slender connexion, it would appear, from my examination in the case, No. 2 of this series, that the portions of this areolar tissue which remain connected with each end of the tendon may still serve as the matrix for the development of a small portion of new tendon connected with each extremity of the old tendon, but their junction may not take place.

In the case adverted to, the ends of the old tendon were separated to the extent of seven eighths of an inch, and connected with each extremity was a small portion of newly formed tendon, about a quarter of an inch in length. As there was no direct continuity between these two portions of new tendon, which were nearly half an inch apart, it seemed that there would have been no prospect of their ever coming into contact, and the only result of which I could see a probability was that of adhesion to the sheath, as in the case above adverted to, and described in the 'Pathological Society's Transactions,' vol. viii, plate x. Now, the question which arose in my mind with respect to the appearances presented in case No. 2 was, how were these portions of new tendon formed in connexion with the divided and completely separated extremities of the old

tendon? To suppose that the new material had been effused from the divided extremities of the old tendon would be in opposition to all that I have seen in my experiments on rabbits and in the human subject, and opposed to the opinion I have formed as to the part played in the reparative process by the extremities of the old tendon. The only explanation I could see of this abortive attempt at the formation of a connecting bond of new tendon was, that the small quantity of areolar tissue connected with each extremity of the divided tendon formed the matrix (as by its structure and vascularity it is undoubtedly capable of doing) in which the new material had been effused and developed, and it appeared to me that traces of this areolar tissue, with its included particles of fat, might be detected as now forming a component part of the small portions of connective tissue described.

Even when the posterior tibial tendon is divided a little above its dense tubular sheath, as was the case in the specimen just described, there seems to be a danger of non-union, when the separation is wide, in consequence of the lower extremity being drawn into the tubular portion of the sheath. Hence, in a case of varus, in which the posterior tibial tendon has been divided, it is clearly desirable not to straighten the foot quickly, where this is practicable; and in my opinion, at least a fortnight or three weeks should be allowed to elapse, in order to ensure union before the foot is brought into a straight line with the tibia.

These circumstances, then, interfere with the perfection of the reparative process of divided tendons, as required for the cure of deformities; and when we consider that the reparative effort required in tendons divided for the cure of deformities is not simply a joining of cut extremities, such as would be sufficient to unite a ruptured tendon (a process which might be compared with the union of bone), but consists in a perfect regeneration of tendinous tissue between the cut and purposely separated extremities of the old tendon, and that this newly developed portion of tendon is to form a permanent connecting bond of union, equal in

bulk and strength to the original tendon which it serves to connect, and from half an inch to two inches in length, our surprise will be, not that there are so many conditions likely to interfere with the perfection of this reparative process, but that under any conditions the process of regeneration of tendon is as perfect as I have shown it to be, when the required conditions exist, and are preserved by appropriate treatment.

The conclusions which I would deduce from the observations I have had the opportunity of making on the reparative process of tendons divided subcutaneously for the cure of deformities in the human subject, and above detailed, are as follows :

1st. That tendon is one of the few structures of the body capable of reproduction or regeneration, and that the newly formed tissue acquires, within a few months of its formation, the structural characters of the old tendon so perfectly as to be, under the microscope, with difficulty distinguishable from it; but it does not acquire (at least it has not up to three years, the latest period to which these observations extend) through its substance the uniformly opaque, pearly lustre of old tendon; in the mass it retains a grayish, translucent appearance, streaked only with opaque fibres at a late period, so that the recent section affords an easy method of distinguishing the new from the old tendon.

2d. That when a tendon has been divided subcutaneously, and its cut extremities are separated and held apart during the early stage of the reparative process, *i.e.* the first two or three weeks (as by mechanical extension employed with variable rapidity in different cases, according to certain rules in the cure of deformities) new tendon is formed, of variable length, according to the extent of the separation, for the purpose of reuniting the divided extremities of the old tendon. The greatest length of perfectly formed new tendon thus obtained, and equal in bulk and thickness to the tendon it served to unite, which I have

seen in the human being, is two inches and a quarter, and this was in the tendo Achillis of a girl, aged nine years, a year and a half after the tendon had been divided by Mr. Curling (Case 11 of the present series). It is probable that when the tendo Achillis has been divided in children for the cure of deformities, the length of new tendon is generally from half an inch to an inch, and in adults from one to two inches.

3d. That the process, by which new tendon is formed for the purpose of reuniting the separated extremities of a tendon divided by subcutaneous section, is essentially similar in animals and in man. That the perfection of the process is in direct proportion to the absence of extravasated blood and inflammatory exudation; and that the sheath of the tendon, when consisting of loose-textured areolar tissue, as in the tendo Achillis, and other tendons surrounded by soft tissues, is of importance—1st, in preserving a connexion between the divided extremities of the tendon; 2dly, in furnishing the matrix in which the nucleated blastematous, or proper reparative, material is effused; and 3dly, in giving definition and form to the newly developed tendinous tissue.

4th. That the perfection of the reparative process, especially in non-congenital cases of deformity, in which more or less paralysis frequently exists, may be interfered with by injudicious after-treatment, so that an elongated and attenuated uniting medium may be formed. And that when tendons situated in dense fibrous sheaths of a tubular form are divided, there is great danger of complete non-union, the divided extremities of the tendon becoming adherent to the inner surface of the sheath, without any direct connexion with each other. This I have shown to occur in the posterior tibial tendon, when divided immediately behind the inner malleolus.

The practical rule, therefore, is never to divide a tendon as it passes through the denser portions of its sheath, and when the operation is performed near to such portions of the sheath the extension must be conducted very slowly.

5th. That there is no reason for believing that, in the treatment of deformities by tenotomy, direct approximation and union of the divided extremities of the tendon must be first obtained, and that the required elongation is afterwards to be procured by gradual mechanical extension of the new connecting medium, as we should stretch a piece of india rubber; but, on the contrary, all my observations lead me to consider that the required length of new tendon should be obtained during the time occupied in its formation, *i. e.* from about two to three weeks under the ordinary conditions of health, but in paralytic cases this period may be doubled. Therefore, the object of gradual mechanical extension during this time, is to regulate the length of new tendon, by overcoming ligamentous resistance in some cases, especially in those of long standing and of congenital origin, in which it is difficult to separate sufficiently the divided extremities of the tendon; and by preventing excessive separation of the extremities of the tendon in other cases, especially in those of non-congenital origin, in many of which the ligaments offer no resistance, and the reparative power is very feeble from partial or complete paralysis, and also when tendons situated in or near dense tubular sheaths, as the posterior tibial, are divided. Hence the mechanical extension must always be proportionate to the activity of the reparative process, and in the tendo Achillis, and other superficial tendons, this can be judged of by external examination and manipulation.

6th. That the new tendon remains during life as a permanent tissue, and as an integral portion of the tendon, the divided extremities of which it has been formed to reunite.

I see no reason for believing that the newly formed tendinous structure has any disposition to undergo a process of gradual contraction, such as we see taking place in the cicatrices of the skin after burns, to which it has been compared; and that ultimately it becomes absorbed, the muscular structure at the same time becoming elongated by the force of the contraction of the cicatrix, so as to allow of the

re-approximation of the ends of the divided tendon, and the formation of a "*linear cicatrix*."

Difficult as it may be to conceive the occurrence of this process in infants, in whom the muscular structures are all essentially healthy, it appears to me to be impossible to conceive its occurrence in cases of paralytic deformity, in which the muscles of the calf are found to be in a most advanced stage of fatty degeneration, so that under the microscope scarcely a trace of muscular tissue can be found, this being replaced by fibrous and fatty tissue.

The explanation given of the mode in which deformities are supposed to be cured upon this *linear cicatrix* theory, viz., by "an altered sphere of muscular action," does not appear to be at all intelligible. Yet this is the theory at present in vogue, having been originally propounded, and being still maintained, by my colleague, Mr. Tamplin,¹ as a modification of the views of Stromeyer, and supported by my colleagues, Messrs. Brodthurst² and Coote.³

Upon this *linear cicatrix* theory I am utterly unable to understand the use of tenotomy in the cure of deformities; whereas, in the facts demonstrated in the present communication, we see sufficient evidence that, in the cure of deformities, muscles are elongated by the increased length of their tendons, obtained by means of subcutaneous division, and the development of new tendon formed for the purpose of reuniting the divided extremities of the old tendon.

7th. That the effect of this permanent elongation of the tendons of contracted muscles, or, more properly speaking, muscles shortened by adapted growth, or adapted atrophy, is not only to correct deformities mechanically, by allowing certain bones to be brought into their normal anatomical relations; but that, having obtained this end, its higher physiological object is to allow of motion being gained or, as it may happen to be, regained, in joints which were previously rendered fixed and motionless by the contraction

¹ 'On Deformities,' p. 5.

² 'On Club-foot,' p. 103.

³ 'Med. Times and Gazette,' Jan. 9th, 1858.

and structural shortening of the muscles. The mechanical conditions necessary for motion are thus obtained, and if the muscles themselves are in a healthy condition, voluntary motion is also obtained, and is followed by an increased development of the muscular structure, so that the bellies of the muscles operated upon progressively enlarge, and in a case of congenital talipes varus the gastrocnemius and soleus muscles, thus brought into use, attain in a few years a very fair proportionate size, instead of undergoing a process of progressive atrophy, as is seen in cases of club-foot which have remained unoperated upon till the period of youth, or adult life. The effect of the operation in increasing the size of the calf is very conspicuous, when a case, which has been successfully operated upon at an early age, is compared with a case which has not been operated upon, or subjected to other treatment; and it is thus proved that, when the possibility of muscular improvement exists, the muscular strength of the limb is very materially increased, instead of being diminished, by the operation of tenotomy. The extent to which muscular power is restored, with its attendant advantages, must of course depend upon, and be proportionate to, the healthy condition of the muscles, and *vice versâ*; so that, in cases of complete atrophy and degeneration of the muscular structure, as in old paralytic cases, the results of the permanent elongation of the tendons is purely mechanical.

8th. That when recontraction of the foot takes place, and the deformity returns at a distant period after tenotomy, this does not depend upon absorption of the new material, or new tendinous tissue formed previously to unite the divided extremities of the old tendon, but upon structural alterations taking place in the muscular tissue, either of an active character, as in spasmodic cases, or of a passive character, as in paralytic cases, and cases produced by position, &c., in which the muscles, by a process of *adapted atrophy*, as described by Mr. Paget, simply adapt themselves to the altered mechanical relations of the parts with which they are connected.

In three cases of relapsed deformity of the foot examined by me, Nos. 10, 11, and 12, of the present series, the new tendinous tissue formed after the previous operations remained, preserving its translucency and other characters, by which it could be easily distinguished from the old tendon. This fact must be regarded as additional, and I may say conclusive, evidence against the soundness of the *linear cicatrix* theory, and the supposed temporary nature of the new material above adverted to.

9th. That the ultimate perfection of the reparative process by the regeneration of tendinous structure, and the elongation of a shortened muscle by the insertion of a portion of new tendon into its length, equal in strength to the old tendon, and closely resembling it in its microscopic characters, is marred only by the adhesion of the deep surface of the new tendon to a greater or less extent with the neighbouring fibro-cellular tissue. These adhesions may limit the free play of the tendon, but will not interfere with sufficient motion being obtained. In cases of relapsed deformity, however, these adhesions will prevent sufficient separation of the divided extremities of the tendon being obtained. Therefore, if much separation be required, a second operation is generally unsatisfactory in its result, and beyond a second operation very little advantage can ever be obtained from operative treatment. Hence the necessity of the closest attention to the treatment after the first operation, and the explanation of the complete failure after repeated operations for the cure of deformities. The adhesions after several operations were so numerous and so strong along the tendo Achillis in Case 12, that no further benefit could have been obtained by tenotomy.