formly as possible by requiring the subject to announce whether the kick had been "normal" or "reinforced." The time relation of painful sensations was not studied.

Evidently the range of variation in the phenomenon is exceedingly great and depends upon many circumstances which are not easily controlled. This fact should be borne in mind in interpreting the diagnostic significance of the knee-jerk. There is not only much variation in the size of the kick but there are pronounced changes in its character (easy and hard, slow and quick or peculiarly jerky). These changes have not been sufficiently studied.

It was natural to inquire whether the sensory reinforcements depend upon cerebral or at least higher centres. Reichert (1890) experimented to this end on dogs whose cords were cut in the lower cervical or upper dorsal region. His results were entirely negative. But Sternberg (1891) obtained positive results in such dogs, and this would seem to be in accord with the earlier experiments of Goltz and Freusberg on the isolated lumbar cord.

Hughlings Jackson (1892) has suggested that in many cases where the Kj. is lost (some forms of apoplexy, some epileptic attacks, etc.), a supervenosity of the blood is the cause. This has been worked out more fully by Russell (1893). In the earlier stages of asphyxia there is a very marked increase in the vigor and force of the response, later a diminution and loss with a gradual return upon resuscitation. Russell considers lack of oxygen to be the chief cause of these changes, a definite balance of oxygen being necessary while the action of carbon dioxide is nowhere in play. The action of nitrogen inhalation is similar but the effects come on more slowly. Ferguson (1892) has published several cases which seem to offer a confirmation of Jackson's view. Lombard's earlier experiments with asphyxia are probably complicated by other influences.

As to the general action of drugs on the knee-jerk our knowledge is not very extended or exact, and there is no little disagreement in the reports. Some of the discrepancies are probably due to the varying susceptibility of the animals used.

The jerk is increased by strychnine and absinthe, diminished by morphine, but the authors are not in accord. Bromism augments the reply (Seguin, Ferguson) "by removal of cerebral influences." The phenomenon is abolished in the deep coma of poisoning by cyanide of potassium or illuminating gas, and in the sleep of chloral (but not in the cat even when the insensibility is profound). Alcohol is said to cause at first, in moderate intoxication, an augmentation but later a diminution of the kick; noteworthy is the return of the lost Kj. of ataxia during intoxication, analogous to the return caused by hemiplegia, according to Hughlings Jackson. Cocaine at first increases but later abolishes the phenomenon. Nitrite of amyl is without effect. Curare causes the kick to disappear. Concerning the action of nitrous oxide there is a disagreement: according to Horsley (1883) it causes no abolition even in deep narcosis, while the experiments of Russell (1893) in animals show an abolition with a preliminary exaggeration which also occurs during recovery, as in asphyxia. Ether is said to cause a preliminary exaggeration with loss of the jerk during deep narcosis (but not in the cat) and another period of augmentation as the effect passes off. There are apparently pretty marked differences in the groups of animals. The effect of chloroform is similar except that the Kj. is lost sooner and the return is slower; it also abolishes the Kj. in the cat.

For the production of the knee-jerk an intact "reflex arc" is essential: tendon, quadriceps muscle, crural nerve, and a certain part of the cord. The tendon is believed to act merely as the transmitter of a mechanical stimulus (either a pull or vibrations) since no other form of stimulation is effective, and the tendon may be extensively crushed or replaced by a cord without impairing the response. The stimulation takes place either at the border of tendon and muscle or among the muscle fibres. In the former region are nerve terminations (Golgi's "*organi nervosi terminali musculo-tendinei*," or "tendon spindles") which are unquestionably sensory. In the muscle are the so-called "spindles" whose character has been much discussed. The studies of Sherrington show them to be connected with afferent nerve fibres so that they may have a sensory function. There are also other nerve endings and terminal structures attached to nerves among the muscle fibres capable of acting in a similar fashion. The local action of cocaine in abolishing the jerk favors the view that such sensory nerve terminations are concerned in the act.

The muscle involved is commonly said to be the *m. quadriceps femoris*. On this point the most extended research is that of Sherrington (1892), who, working on the monkey (Macacus rhesus) and other laboratory animals, showed that not all the divisions of this muscle are essential. The portions chiefly concerned are the *m. vastus internus* and the *m. crureus* (*m. vastus medialis* and *m. femoralis* of the new nomenclature).

The nervous pathway, as was seen in the earliest investigations, lies in the crural nerve, but Sherrington found that only the branches pertaining to the muscles named are absolutely essential. All other branches, as well as all other nerves going to the knee region, may be cut and the jerk remains brisk.

The portion of the cord directly involved in the knee-jerk has been studied with great diligence. Tschirjew (1878) showed that the entrance of the sixth lumbar nerve marks the region whose destruction stops the Kj. in the rabbit. This was confirmed by Prévost (1881) and by Sherrington (1892–93), who also found that section of the fifth posterior root is sometimes effective. To Sherrington we owe most extended and interesting studies of this question. In some cats the root on which the Kj. chiefly depends is the sixth lumbar, in others it is the fifth. In the monkey (Macacus rhesus) the spinal centre was found to be in the fifth and fourth lumbar segments (fourth and third of man). The afferent pathway lies in the posterior root of the fifth lumbar nerve (fourth of man) but a small portion of it may lie in the fourth root; the efferent roots essential to the jerk are the fourth and fifth lumbar. This result is also concordant with an observation of Ferguson (1894), who saw a case in which a stab in the back had healed with loss of the Kj. and marked atrophy of the vastus internus and crureus as the only results of note, while the autopsy (fifteen years afterward) showed a destruction of the fourth lumbar nerve, the roots above and below being apparently perfectly healthy.

Sherrington found the posterior root exceedingly sensitive to all sorts of influences. It may be affected (and the Kj. abolished) not only by partial section (demarcation currents), cooling, carbonic-acid gas, cocaine, but even by slight mechanical disturbances (as lifting by a thread) which do not obviously impair the tactile sense. This suggests that the fibres involved may have some peculiarities of structure which may again include peculiarities as to irritability and conductivity. The very earliest students of this question had observed this sensitiveness of the crural nerve.

Important also is the observation that section of the ventral roots below these essential roots makes the Kj. more brisk and section of the dorsal roots has a similar result. This effect persists in the monkey for several months and seems to be due to the destruction of the tone of the hamstring muscles. It resembles the result of high section of the sciatic which also augments the kick, as Tschirjew first showed. The phenomenon in question is something more than a mere mechanical freeing of the knee-joint, it is rather the interruption of a stream of centripetal influences passing from the hamstring muscles to the cord and there exerting a depressing or restraining influence on the jerk. An influence of similar character may be produced by moderate electrical stimulation of the central end of the hamstring nerves, by stretching or kneading the muscles when freed at the knee, or even by electrical stimulation of their motor roots so long as the sensory roots are intact. Such results in relation to the Kj. are said not to be obtained

with other muscles and are due to a reflex tonic action influence of one set of antagonistic muscles upon the other set, despite the fact that they belong to different segments and the reflex is obtained across several intervening segments. This ascending reflex inhibition of the kick is not affected by a median longitudinal section of the cord from the second lumbar segment to the end, nor does such a section impair the Kj. on either side. The observation that pressure on the sciatic inhibits the Kj. (Mitchell) finds an explanation in this hypothesis.

While all agree that the integrity of this reflex arc is fundamental, there is diversity of opinion as to the way in which it participates in the knee-jerk. Some hold with Erb that the entire event is a reflex not essentially different from other reflexes. Others, following Westphal, consider that the jerk is in some fashion a direct response to the pull of the tendon, the arc being necessary to keep the muscle in proper condition for the response by maintaining a tonus. A third view, associated with the name of Gowers, that the stretch of the muscle makes it more ready to respond to local stimulation is a modification of the direct-answer theory and has met with little acceptance. Gotch apparently considers that the reply to the tendon tap may be a direct mechanical excitation or, at times or in certain vertebrates, a true reflex discharge; the result varying with conditions not altogether discernible or under control. A similar view has been advocated by others who, however, have been inclined to go further and think that both forms of reply may possibly occur together. This would explain the great variety in the time of the response.

For those who deny the reflex character of the knee-jerk a strong argument is found in the quickness of the process. Others, realizing that our knowledge of reflex time is at the best very deficient, do not find that argument convincing. It is desirable to remember that the results of the different observers are very far apart, and a suspicion is awakened that the observations may not all belong to the same process. The knee-jerk may be a reflex *sui generis* quite unlike other reflexes as to time because the conditions are peculiar and possibly because nerve fibres of a different conductivity are involved. An extraordinary slowness of responses has sometimes been observed, but its significance is unknown.

The important figures for the time of the knee-jerk in man are these: Tschirjew (1878) 0.0595″; Gowers (1879) 0.10″ (0.09″–0.15″); Brissaud (1880) 0.050″; Waller (1880) 0.035″; de Watteville (1882) 0.03″; James (1882) 0.025″; Eulenburg (1882) 0.0242″; Rosenheim (1884) 0.043″; Lombard (1887) 0.073 (0.051″–0.093″); Jendrássik (1894) 0.032″; Glynn (1896) 0.025″ (noted by Gotch); Stewart (1897) 0.069″. For the crossed reflex the last two observers report the time to be 0.110″ and 0.126″ respectively. It will be observed that some of the higher figures were obtained by experimenters of much skill and experience.

For animals we have also time determinations of this phenomenon. For dogs Applegarth (1893) found the Kj. required 0.014″ to 0.020″, the time being somewhat smaller when the cord is cut than when it is intact. For the rabbit Rosenheim (1884) found 0.033″; Waller (1890) 0.008″ (a result "corrected" from 0.012″), and Gotch (1896) has a similarly astonishing result for a "slip of vastus internus," the time from tendon tap to contraction being 0.005″ which he says should be reduced to about 0.003″!

It is commonly maintained that the time of the Kj. is nearly as quick as that of direct muscle stimulation, but the investigators of this phenomenon are also not in accord. Tschirjew's time for two men is 0.027″–0.026″; Waller's time is 0.020″ (for mechanical stimulation, 0.030″); Lombard for three men has a mean of 0.064″; Jendrássik about 0.0085″. For the rabbit Waller (1890) notes 0.0076 for electrical stimulation (0.0078 for mechanical), Gotch 0.005 as a minimum.

Our knowledge of "reflex" times is also not very satisfactory. Waller gives 0.10″–0.15″ for a reflex from a skin stimulation to a movement of the thigh. He holds this to be a true reflex but thinks that the cerebrum may be involved. Lombard's reflex time for an electrical stimulation of the skin of the knee is 0.253. Applegarth found the reflex time for a skin stimulation of the toes in a dog whose cord had been divided for nine months equal 0.0714″. In the rabbit (in a sort of "hypnotic" state) Waller determined the reflex time for a skin stimulation of the leg to be 0.0333″; for a reflex due to a blow on the board on which the animal lay 0.036″. Broca and Richet found the time of a similar reflex in a rabbit made quiet but extremely sensitive by chloralose to be 0.042″–0.050″ for temperatures of 40°–35° C. The cremaster reflex of the rabbit in reply to an electrical stimulation of the fascia is given as 0.050″–0.060″.

Stress is commonly laid on Exner's determination of the eyelid reflex in 1874 as the best determination of a reflex time. Exner found a mean of 0.0578″ or 0.0662″, according to the strength of the stimulus, and calculates the portion belonging to the process going on in the gray matter to be 0.0471″ and 0.0555″ respectively. Waller says he has verified Exner's results. It is therefore *assumed* that the participation of the gray matter of the cord in the production of the Kj. will require at least this time. If this be true even the figures of Lombard or Stewart are not large enough for a "reflex" after deductions for the time of transmission and for the latent period of the muscle. On the other hand, it seems to be commonly forgotten that Exner's reflex was a crossed reflex from one eye to the other. Then too this reflex time has been much reduced by the newer measurements of Mayhew (1897) using only one eye. The mean time for winking in sixteen persons was 0.042″ (0.0351″–0.0491″). Making the same reduction as Exner made for his results, we have for the time of the central process 0.0313″; whether the time for analogous gray matter activities in the lumbar cord is the same, no man knows.

The tonus theory of the knee-jerk also presents difficulties. For a long time its advocates were rather half-hearted in their support, but of late they have grown more courageous and insistent. It seems to have become a dogma for many that because there is much vagueness about muscle tonus it must needs be denied altogether. On the other hand, an admission of its existence does not involve the admission that the knee-jerk is merely a variation of tonus. Such an explanation of the kick is most unconvincing. So far as the study of the form of the contraction of the quadriceps goes it apparently does not differ from other forms of twitch, but this question calls for further investigation. While it is perfectly true that a certain tension is most helpful, the knee-jerk is often demonstrable when the muscle is perfectly relaxed (Erb, Mitchell). Muskens has urged that the knee-jerk and the true reflexes do not vary together in some lesions of the cord as he thinks they should. He also finds a certain parallelism between the tonus and the tendon reflexes. His cases (as well as those of Fraenkel and Collins, 1900) are not very convincing, and there are many other observations which show that the two processes may well be held to be distinct. Certainly, as Neumann (1896) has remarked, the tonus theory seems to be unnecessary and only complicates our understanding of the tendon phenomenon. The most recent study of tonus and its relation to the knee-jerk will be found in two articles by Langelaan (1901, 1902), but he seems to neglect the fact that the jerk continues when the antagonistic muscles are excluded from all participation in the process. If there be a tonus and it be a reflex, as there is a growing disposition to admit, its time relations present problems not less perplexing than those which belong to the view that the knee-jerk is itself a reflex.

Other advocates of a tonus doctrine seem to take a position rather different from that of their predecessors. Stress is beginning to be laid upon a nervous tonus, which is apparently not quite the same thing as the older muscle tonus, for it seems to mean merely those impulses which flow from higher centres and regulate or tone the condition of the motor cells in the anterior horns. This stream is apparently not necessarily due to incoming peripheral stimulations, although such factors may affect it. This view has been developed to explain the diminution or loss of the Kj. in man when the cord is injured at a high level. A dozen years ago Bastian called attention to the disappearance of the Kj. in such transverse lesions, not altogether unknown before, and since that time many such cases have been reported which seemed to justify the position that the removal of cranial or cerebro-spinal influences was the true explanation of the results. Out of these cases have grown extended discussions, some of which are almost painfully ingenious. The most interesting and important are perhaps those of Van Gehuchten (1897, with a modification in 1901), Koll (1898), and Brasch (1900). Nearly all the cases reported are defective because there is not a complete microscopic examination of the lumbar cord and the structures forming the reflex arc of the knee-jerk. Under these circumstances a single case of complete transverse destruction of the cord without loss of Kj. outweighs any number of uncertain cases and their incidental theories. Such seems to be the case reported by Kausch (1901) in which the cord was accidentally severed in an operation rendered necessary by tuberculous processes going on in the spinal column. At first there was a total disappearance of the reflexes and of muscle tonus. The tonus returned in about forty-eight hours, and is said to have persisted in an exaggerated form until death five months and a half later. The reflexes came back some twenty hours after the operation (*i.e.*, many hours *before* the tonus), both skin and tendon reflexes recurring at the same time. Most of the reflexes persisted and were exaggerated until death, but the Kj. as well as the Achilles tendon reflex grew feeble toward the end and finally disappeared before death, as also happens when the cord is intact.

This brings the human cord again into line with the cord of other mammals, and confirms the opinion that it is easier to believe that the functional activity of the cord is substantially the same in the higher mammals than to assume that the human cord is radically different. It has been shown again and again in the past twenty-five years that the knee-jerk returns when the cord is cut in the middorsal region in most laboratory mammals and persists for a long time. Applegarth experimented with the jerk of a dog nine months after such a section. Sherrington's monkeys regained their knee-jerks after section of the cord at the proper level and retained them for months. The evidence for other mammals is similar, but the observations have not been continued so long. The lumbar cord is the seat of all those spinal processes that are essential to the knee-jerk. By this is not meant that the jerk is necessarily the same after cord section as before, in fact it is generally larger and it may differ in form; there seem to be no exact measurements. Unquestionably there are influences flowing constantly from the various parts of the encephalon which profoundly affect the activities of the cord and may exalt or depress the knee-jerk, but that this permanently disappears when these influences are excluded it is not heresy to doubt. The temporary disappearance may be due to "shock," and this may mean nothing more than a more or less profound alteration of the circulation of the lower cord with incidental nutritive changes from which recovery is quite possible. The stimulation of inhibitory nerve fibres is also a plausible explanation, but this effect ought to pass away speedily in the absence of any irritating or inflammatory reactions. It may be the expression of a decentralization of spinal centres which have been strongly dominated by higher centres, as seems to be more markedly true of the higher vertebrates, and which require time to readjust themselves to a new and more independent condition. On the other hand, we may suppose that peripheral influences are equally constantly flowing into the higher centres to arouse them to participate more actively in the regulation of body movements.

For the participation of the cerebral lobes there is considerable evidence, and some have held the reinforcement of voluntary movements to be due to a diversion of "attention." Weinberg's results (1894) from stimulation or extirpation of motor areas, while in general favorable to the view that the cortex has influence on the Kj., are not so convincing as one could wish. The removal of a cerebral lobe increases the opposite knee-jerk (Russell, 1893). The effect of cerebral hemorrhages and of brain compression seems to show that the cerebrum does inhibit. Uncertain is the interpretation of the action of galvanization through the region of the temples (Mitchell and Lewis). Pándi (1895) seems to suppose the cortex to inhibit through the antagonistic muscles, while the commoner view is that some system of inhibitory fibres runs down the cord and directly affects the motor cells.

Van Gehuchten, although he makes the tendon reflex depend upon a rubro-spinal path (red nucleus, fascicle of von Monakow), and therefore mesencephalic in origin, considers that fibres of the cortico-spinal path have an inhibitory influence.

As to the action of the cerebellum, we have very definite experiments by Russell (1893) showing that the extirpation of a lateral lobe augments the Kj. of its own side and diminishes that of the other side, and a distinct but irregular increase is produced by extirpation of the posterior part of the vermis. The effect persists too well to be irritative; it is paralytic. Whether this is an influence through the cerebrum is unclear. Bechterew's views concerning the paths from the cerebellum to the cortex cerebri seem opposed to this view. The theory of Gowers concerning the cerebellum as a regulating centre for such centripetal impulses of the muscle sense as stand in some special relation to motor processes particularly concerned in equilibrium and in coördination of movements would seem also to become untenable.

Van Gehuchten in his earlier article includes the cerebellum along with the mesencephalon and the rhombencephalon in the structures which constantly send exciting influences to the motor cells of the anterior horn by way of cerebello-spinal fibres and the longitudinal posterior fascicle. In his later article he seems inclined to limit this stimulation to the rubro-spinal path. For him the normal muscle tonus is only the external manifestation of the state of more or less permanent excitation in which these motor cells find themselves. As a condition of tonus exists in the isolated lumbar cord and may be constantly affected by the impulses of the muscles there innervated, as Sherrington's experiments show, this complex relation can only be of secondary importance.

A similar inference seems to be permitted concerning the reflex centre in the "*regio bulbocervicalis*" just below the tip of the calamus scriptorius (Rosenthal and Mendelsohn, 1897), which has been a source of comfort to many neurologists in recent years, a comfort which must be somewhat unreal until the doctrine is much more firmly established.

As to the nature of the reinforcement, both positive and negative, we are very much in the dark. We can hardly attribute them all to mere change of tonus, nor do there seem to be any experiments to show that tonus is thus changed. The theory that there is some sort of an "overflow" for every motor or sensory stimulus, or even emotion, and also the theory that every such stimulus in some way removes a check, does not fully account for the negative phase of reinforcement. The suggestion that a fatigue phase is in play is hardly plausible in view of the slightness of sensory stimulus found to be effective. The theory (Brunton) that nerve impulses may coincide or interfere like light waves, producing an augmentation or diminution according to the phase, is ingenious but difficult of interpretation.

While many of the reflexes are evidently protective, this is not the obvious purpose of the tendon reflexes. It seems reasonable to think, with Koll, that the knee-jerk is an extreme expression of a reflex stimulation constantly produced in a slight form by the tendons, periosteum, and joints and having an important regulatory influence on the entire mechanism of movement. Such tendon reflexes are perhaps of prime importance in certain particular kinds of movements and may have but a small share in the general coördination of body movements. There need then be no pronounced parallelism between the loss of a tendon reflex and ataxy, since the

tendon reflex is only a part of the coördination. A connection between the lumbar reflex arc concerned in the knee-jerk and the cerebellum by means of coördination pathways may be assumed, but there is no reason for postulating a direct pathway to the cerebellum, nor do the pathological observations demonstrate such.

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KNEE-JOINT.—Whether considered from the anatomical or the surgical point of view, this is the most important joint in the body. It is at the same time the most complicated and the most difficult to understand. Its surfaces are necessarily large to support the weight of the body, and as there is not that close adaptation which is shown at the elbow and hip, its great strength depends upon the surrounding ligaments, fascia, and muscles, which are so effective that dislocation is rare. Its vast extent of synovial membrane predisposes it to inflammation, and its exposed situation renders it liable to injury. Its structure is more readily understood when it is regarded as an assemblage of three joints originally distinct, viz., a patello-femoral and two femoro-tibial. That this is a correct assumption is rendered probable by slight furrows upon the articular surface of the femur (not clearly shown in Fig. 3082) which separate a patellar surface from the two condyles, and the arrangement of the ligaments also amply confirms it; there being besides the capsular, investing the whole joint, certain internal ligaments which are vestiges of the original separate condition. From the middle of the joint, between the two condyles, pass downward and outward two folds of synovial membrane laid upon a thin connective tissue. These are the ligamenta alaria, and they indicate the line of separation into three cavities. Again, there are certain bands accessory to the capsule. Externally these are known as the lateral ligaments (Figs. 3082 and 3083), internally as the crucial ligaments (Figs. 3082 and 3083).

The former pass from the tuberosities of the femur to the shaft of the tibia and the head of the fibula on either side; the latter are short bands arising from the femur,

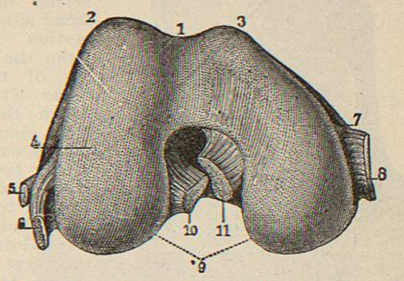

FIG. 3082.—Upper Articular Surface of the Knee-joint. (Sappey.) 1, The patellar groove; 2, outer edge; 3, inner edge, less elevated than the other; 4, outer condyle; 5, external lateral ligament, cut; 6, section of the popliteus muscle obliquely directed downward and inward, and covered by the external lateral ligament; 7, inner condyle; 8, internal lateral ligament, cut; 9, intercondylar notch; 10, section of the anterior crucial ligament inserted upon the posterior part of the inner surface of the external condyle; 11, section of the posterior crucial ligament inserted upon the anterior part of the outer surface of the internal condyle.

on either side of the condylar notch, to insertions in front and behind the spine of the tibia. These accessory bands limit and control the motion of the joint, as do similar structures elsewhere. On complete extension, the whole system is locked by the tension of the lateral and the anterior crucial ligaments, so that no muscular force is required to hold the knee firm in the erect position, the weight of the body falling in front of the joint and fixing it. When the joint is thus fixed and muscular action suspended, a slight blow from behind will throw the whole apparatus out of equilibrium, and occasion a sudden flexion of the limb.

This tripartite division of the joint corresponds to its condition in many lower animals, in which the three synovial cavities are either totally distinct, or communicate by small openings.

The irregular form of the joint surfaces is due mainly to the action of the muscles. While at the elbow the flexors, but two in number, come down and are inserted near the plane of movement, at the knee there is a series of flexors stretching over the joint from above, and inserted partly on the outside and partly on the inside of

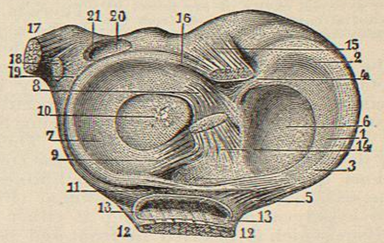

FIG. 3083.—Lower Articular Surface of the Knee-joint. (Sappey.) 1, 2, 3, Internal semilunar fibro-cartilage; 4, its attachment to the depression behind the spine of the tibia; 5, its anterior attachment: 6, that part of the internal glenoid cavity not covered by fibro-cartilage; 7, external semilunar fibro-cartilage; 8, 9, its attachments; 10, part of the external glenoid cavity not covered by fibro-cartilage; 11, transverse ligament; 12, ligamentum patellæ, cut; 13, bursa subpatellaris; 14, tibial insertion of the anterior crucial ligament; 15, of the posterior crucial ligament; 16, band of fibres which unites the external semilunar fibro-cartilage to the posterior crucial ligament; 17, tendon of the biceps, cut; 18, external lateral ligament, cut; 19, groove for the tendon of the popliteus; 20, bursa poplitea; 21, orifice occasionally found by which the cavity of the upper tibio-fibular articulation communicates with that of the knee-joint.