Journal of Morphological Sciences
J Morphol Sci
Brazilian Society of Anatomy

Original Article
J Morphol Sci 2023;40:300-309

Microanatomy of Muscular trunk and its Branches of Femoral Nerve

Rajani Singh[1]

[1]Department of Anatomy, UP University of Medical Sciences Saifai, Etawah UP India

Disclose and conflicts of interest: none to be declared by all authors

ABSTRACT

Introduction: femoral nerve, the nerve of anterior thigh, gives origin to nerves to Quadriceps femoris muscle and sensory branches. Quadriceps femoris muscle helps in locomotion. If nerves to Quadriceps femoris muscles are injured, the muscle will be paralysed impairing its functions. The functions of quadriceps muscles can be restored by repairing the injured nerves to quadriceps femoris muscle. Currently, nerve cuff electrodes are used to identify the injured nerve as the sizes of fascicles fall beyond the limit of resolution of MRI. But for treatment of femoral neuropathy, the identification of fascicles is essential so, the objective of study is to overcome the limitation of resolution by identifying, locating and tracking the pathway of fascicle in nerves to quadriceps muscle and its branches from inguinal ligament in histological slides.

The muscular trunk of femoral nerve and its muscular branches were cropped, processed and histological slides were prepared and path, shape and size of fascicles, was tracked from inguinal ligament in muscular trunk up to termination of its branches. The study evolved the models of Muscular trunk and its branches revealing the detailed configuration of fascicles. The fascicles were interrupted by transformational process but frequency of these process was very less towards distal end.

For the surgical repair of injury, the location, degree of injury, identification, shape and size of injured fascicles are essential to restore muscle functions. The fascicular models of these muscular branches contain all this information which will aid in grafting/repair of these nerves with least invasion.

Keywords: Femoral nerve; Muscular trunk; Fascicle; Quadriceps femoris muscle.

Introduction

Normally the posterior division of femoral nerve gives rise to nerve to rectus femoris, nerve to vastus lateralis, medialis and intermedius as muscular branches innervating quadriceps femoris muscles also known as nerves to quadriceps femoris muscles including saphenous nerve as a cutaneous branch[1]. But femoral nerve cropped by us bifurcates into cutaneous trunk and muscular trunk below the inguinal ligament. Muscular trunk splits into nerve to rectus femoris (RF), common vastus trunk (CV) and nerve to vastus medialis (VM), below the inguinal ligament. Common vastus trunk gave rise to branch to vastus intermedius muscle (VIA) and CV continued as CV.' Further, CV' bifurcated into nerve to vastus lateralis muscle (VL) and a second branch to vastus intermedius muscle. This branching pattern of femoral nerve was designated as type II in the classification of Singh *et al*[2]. 2016. The labels 'muscular' and 'cutaneous' trunks have been used because exclusively, all the muscular / motor branches emanated from the muscular trunk and all the cutaneous /sensory branches from the cutaneous trunk respectively. These muscular branches namely, nerve to rectus femoris, vastus medialis, Vastus lateralis and vastus intermedius, were innervating respective muscular part of quadriceps femoris muscle.

Quadriceps femoris muscle helps in leg extension at the knee joint and thigh flexion and is critical for sitting, standing and stepping functions[3]. More so, the three vasti muscles are important for standing function; they extend the leg at the knee joint without flexing the thigh. In addition, the vastus medialis muscle is important for locking the knee in terminal extension and preventing the patellar drift and lateral subluxation that could possibly be caused by the pull of the vastus lateralis. Although the biarticulate rectus femoris and sartorius muscles are critically important during the sit-to-stand transition and during stepping and walking[4,5,6], they have undesirable actions for standing such as thigh flexion[7,8,9].

All the functions/activities of muscles are controlled by brain through nervous system by receiving commands from brain for these functions and activities so, in case of injury to these nerves, the communication is disrupted causing impairment of the muscles leading to neuropathy associated with signs and symptoms of discomforts to patients. Thus, to treat the neuropathy, the injury in the nerve is to be restored. For this, the neural disorder is diagnosed and treated. It is pertinent to mention here that the injury in nerve always percolates the internal structures of nerve consisting of fascicles and axons which are the message carriers. Therefore, it is not merely nerve to be diagnosed for injury, rather, the injured fascicle is to be investigated for treatment. Thus, diagnosis and treatment of neuropathy involving nerves to

DOI: 10.51929/jms.40.300.2023
ISSN 2177-0298

quadriceps muscle necessitates the identification of fascicle, its location, normal/morbid morphology, including degree of injury of these nerves. So, internal morphology of these nerves pertaining to fascicle must be known to systematically advance the treatment process. Although this microanatomy of nerve can be imaged by high resolution MRI advanced neurography as claimed by Chhabra *et al*[10]. and Baumer *et al*[11]. But the fascicles damaged cannot be imaged precisely by MR advanced neurography or other imagery tools as the limit of resolution in this tool is not comparable with the size of fascicles. The neurosurgeon, Evans[12] stated that "despite our best efforts in nerve repair, full functional recovery is seldom achieved and motor nerves tend to be more refractory then sensory to full recovery". This may be due to end- to-end mismatching of number and kind of nerve fibres. The ultimate number of fascicles necessary for restoration of function is currently unknown. Thus, identification of fascicles involved in injury is very crucial in this process of repair of fascicle and the diagnosis[12]. Thus, internal structure of nerve not only facilitates to comprehend the communication in the human body but also helps in detecting neural lesions during diagnosis and treatment through stimulation/regeneration of neural tissue by nerve cuff electrode placement[13]. This neurosurgical procedure necessitates knowledge of not only detailed configuration and identification of these injured nerves for repair, grafting but also knowledge of internal morphology of these nerves such as identification of longitudinal pathways of fascicles, their isolation, organizational setup, shape, size, orientation, location and directivity is very essential.

Therefore, an experimental histological study of muscular branches of right femoral nerve, from their origin to the entry point for innervation of quadriceps muscles of lower limb, from a cadaver was planned and designed to study detailed configuration, identification of fascicular pathways and their morphology. The objective of this study is to identify shape, size, configuration and track the longitudinal pathway of fascicles in nerves to quadriceps femoris muscle from their origin from femoral nerve to their terminations in the muscles to provide solutions for possible constraints of micro-neurosurgery pertaining to nerve to quadriceps muscle minimising clinical complications.

Material and Methods

The right femoral nerve of a 70-year-old female cadaver was exposed and extracted from the point of emergence of femoral nerve from lateral border of psoas major muscle to the point of bifurcation into muscular and cutaneous trunk. Muscular trunk and its muscular branches up to their entry into the quadriceps muscles were also exposed and cropped (Fig. 1).

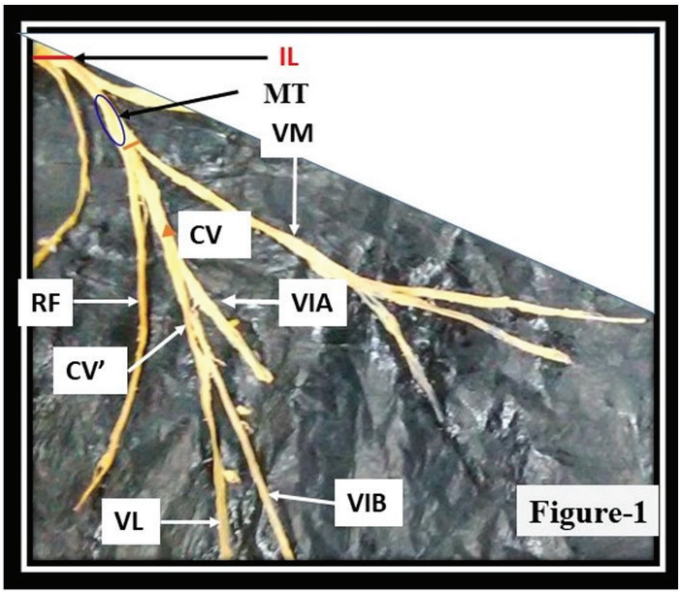

Figure 1. Cropped femoral nerve displaying various muscular branches below the inguinal ligament.
IL= inguinal ligament, MT= muscular trunk, RF=Nerve to rectus femoris, VIA= Nerve to vastus intermedialis (first branch), VIB= Nerve to vastus intermedialis (second branch), VL= nerve to vastus lateralis, VM= Nerve to Vastus medialis. CV= common trunk after emergence of RF, CV'= common trunk after emergence of VIA.

The muscular trunk was cut into pieces forming four blocks (M0, M1, M2 and M3) for preparing slides for correlation of fascicles. The nerve pieces were embedded in paraffin wax and paraffin blocks were prepared. Two blocks of nerve to rectus femoris (RF) namely RF1 and RF2, 3blocks of nerves to Vastus medialis (VM), VM1, VM2 and VM3 were created. After VM3 the VM bifurcated into two branches, VMA and VMB. Two blocks, VMA1 and VMB1 one from each branch were prepared. Vastus intermedius and lateralis sprouted from common trunk which was named as CV. Three blocks of CV namely CV1, CV2 and CV3 were prepared from this common trunk. Then one branch, VIA originated from CV and rest of CV continued further downward as CV′. One block, VIA1 was made out of VIA. One block, CV′1 was prepared from CV′. CV′ bifurcated into VIB and VL. Two blocks, VIB1, VIB2 from VIB and three blocks, VL1, VL2, VL3 from VL each of length 0.5 cm were prepared. These blocks were processed and slides were cut and stained with haematoxylin and eosin. Each section was 5 microns thick. From each block, 3 sets of slide each set consisting of 3-5 slides were prepared. These slides were photographed by 16 mega pixel Sony camera through a high-resolution microscope of model PZRM-26 having software "Future Winjoe".

Reference of measurements: All the lengths of nerve segments have been measured with reference to inguinal ligament. As all the blocks cut, are, below inguinal ligament so distances of all the slides are negative because the measurements above inguinal ligaments are positive, whereas the distances below it, are negative.

Naming of fascicles: As all the fascicles in slide A1 8 were named from CF 1 through 21. The name of fascicles was continued the same till it undergoes transformational process (TP). After the transformational process, its name is sequentially increased from A1 8 through A24 1 during correlation. As after A24 1, the femoral nerve bifurcated into muscular trunk (MT) and cutaneous trunk so after bifurcation, the prefix CF was made MTCF in muscular trunk prefixing the short name of muscular trunk. After muscular trunk trifurcating into nerve to rectus femoris (RF), Nerve to common vastus trunk (CV) and Nerve to vastus medialis (VM) so the fascicles were continued the same name from Muscular trunk till the TP is encountered. After TP the fascicles in RF, CV and VM were similarly, named with prefixes RF, CV and VM as RFCF, CVCF and VMCF having increasing sequential number. The CV bifurcated into nerve to vastus intermedius (first branch A) VIA and CV' and the CV' was bifurcated into nerve to vastus intermedius (second branch B) VIB and nerve to vastus lateralis, VL. Accordingly having same name in consistent part of fascicle but after encountering TP their names were changed with prefix as VIACF, CV'CF, VIBCF and VLCF.

Correlation of nerves and fascicles: All the fascicles from the top of muscular trunk were correlated up to emergence of nerves and thereafter. The fascicles were identified at the emergence of nerve which were correlated upward to the top. Thus, two-way correlation from cranial to caudal and from caudal to cranial end was done. Though the fascicles were identified by giving them numbers. The consistent, correlative and continuous pathways of fascicles were tracked and the distances of slides from the inguinal ligament can be computed as the slides were calibrated with the distance from the inguinal ligament. The transformational processes were also detected.

After correlation of fascicles, schematic models were prepared for these muscular nerve branches by software coral draw through mapping the tracked fascicles revealing the configuration, branching pattern, emitting of the nerve branches, correlation of pathway of fascicles and transformational processes pertaining to split, fusion and multiplexing of fascicles.

Results

Measurements: Length of RF was 8 cm, VM till VM3 is 7.5 cm and its branches VMB1 and VMB2 were 3 cm and 5 cm respectively. Common branch of VI and VL, CV is 4cm long. VI1 is 2 cm long and VI2 is 7 cm long while VL is 12 cm long. MT is 1.5 cm long.

All the CFs were correlated and tracked in slides cranially from A1 8 (8.6035 cm) to caudally up to the terminal slides. CFs, 1-21 having been correlated from A1 8 to A24 1, transformed into CFs {(303, 304); (280, 257, 270, 312, 313): (316, 317, 318)} in A24 1. The CFs {(303, 304); (280, 257, 270, 312, 313): (316, 317, 318)} were observed surrounded by internal epineurium bifurcated into muscular and cutaneous trunks consisting of CFs 316, 317, 318 and {(303, 304); (280, 257, 270, 312, 313)} respectively (Fig. 2). In this study we correlated only fascicles in muscular trunk and its branches which are described below.

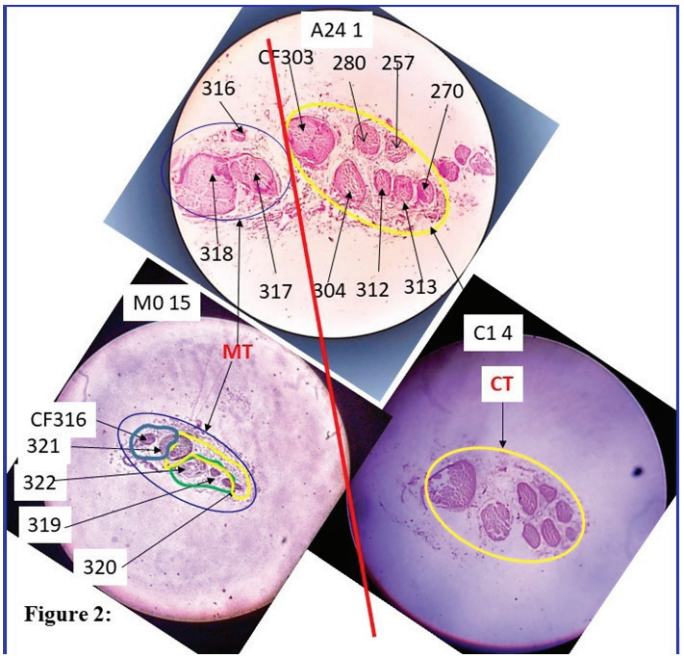

Figure 2. Slide A24 1 represent undivided femoral nerve. This is bifurcated into muscular trunk in M0 15 and cutaneous trunk in C1 4. CFs 316, migrated so location changed in M0 15. CF 317 in A24 1 split into MTCFs, 319 and 320 and CF 318 in A24 1 split into MTCFs, 321 and 322. in M0 15. MT= muscular trunk, CT= cutaneous trunk.

Correlation of fascicles in muscular trunk (Fig. 3): CFs 316, 317 and 318 in A24 1 constitute muscular trunk. M0 15 is the cranial most slide of muscular trunk. CF 316 changed its location. CF 317 and CF 318 in A24 1 splits forming MTCFs 319 and 320 and MTCFs 321 and 322 in M0 15 respectively. Now M0 15 consists of fascicle CF316, MTCFs319, 320, 321, 322. These fascicles were continuous, consistent and correlative up to slide M0 1 except locational change due to migration of fascicles. MTCF 320 in M0 1 splits into MTCFs 323 and 324 in slide M1 15. Now M1 15 consists of fascicles CFs 316, MTCFs319, 321, 322, 323 and 324. These fascicles were persistently present till slide M1 11. MTCF 321 in M1 11 splits into MTCFs325, 326 and 327 in M1 10. So, now M1 10 contains the fascicles CF316, MTCFs319, 322, 323, 324, 325, 326 and 327. These fascicles were continuous, consistent and correlative up to slide M1 1. After M1 1, MTCF 326 splits into MTCFs 328 and 329 while MTCF327 splits into MTCFs 330 and 331. These fascicles were correlative and consistent, till slide M2 13. After this, the fascicles MTCFs328 and 329 fuse together forming MTCF 332. These fascicles were correlative and consistent till M3 18. After this, the fascicle MTCF 332 splits into MTCFs 333 and 334. These fascicles were consistent till M3 1. So, M3 1, caudal most slide of muscular trunk consists of

CF316, MTCFs 319, 322, 324, 325; MTCFs 323, 330, 331, 333, 334 CAE. These fascicles in the slide, M3 1 have been found in three groups surrounded by internal perineurium forming RF, CV and VM (Fig. 4). So, the muscular trunk after M3 1, trifurcated into RF having **CF316, MTCF325;** CV having **MTCFs 323, 330, 331, 333, 334** and VM having **MTCFs 319, 322, 324.** Thus, After M3 1 these fascicles emerged out as nerves to RF, CV and VM.

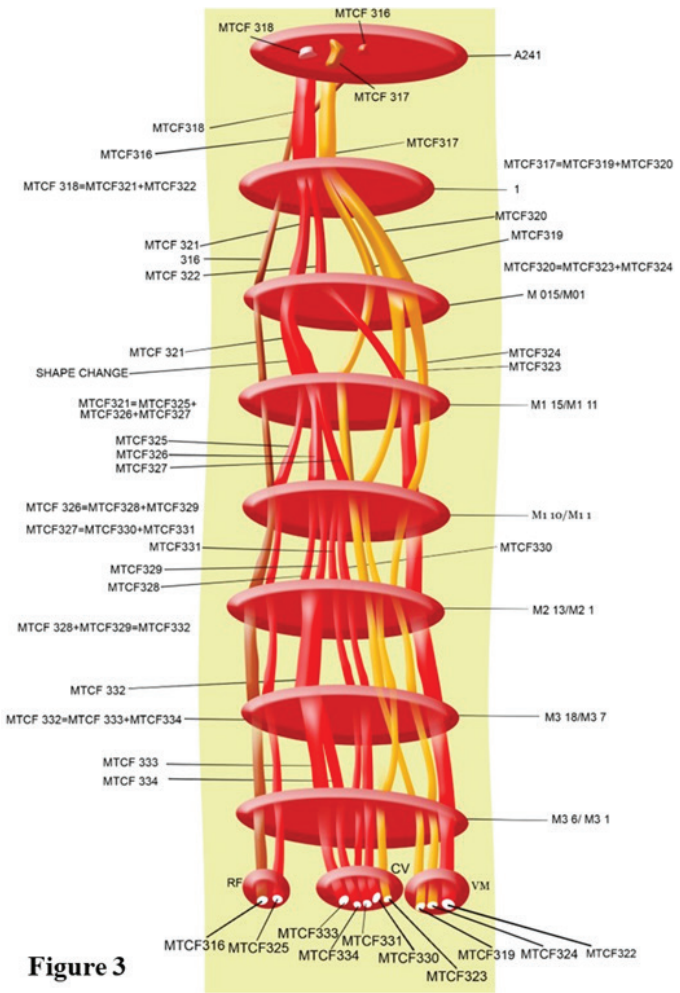

Figure 3. displaying configuration of fascicles in muscular trunk of femoral nerve up to its termination in to RF, CV and VM. RF= nerve to rectus femoris, CV =common trunk, VM= nerve to vastus medialis.

Correlation of fascicles in Nerve to rectus femoris (Fig. 4):

RF1 18 is the cranial most slide of RF1 block. MTCF 325 in M3 1 splits forming RFCF326 and RFCF327 in RF1 18. Thus, RF1 18 consists of CF316, RFCFs 326 and 327 as RF was having CF316 and MTCF325. These fascicles in RF1 18 were continuous and consistent till RF2 6 consisting of CF316, RFCFs 326 and 327. But RF2 10 is the cranial most slide of RF2 block. Thus RF2 10 also contains the fascicles, CF316, RFCFs 326 and 327. CF316 in RF2 6 splits into RFCFs 328 and 329 in RF2 5. Now RF2 5 slide consists of fascicles, RFCFs 326, 327, 328 and 329. Nerve RF with these fascicles enters into the Rectus femoris muscle to innervate it.

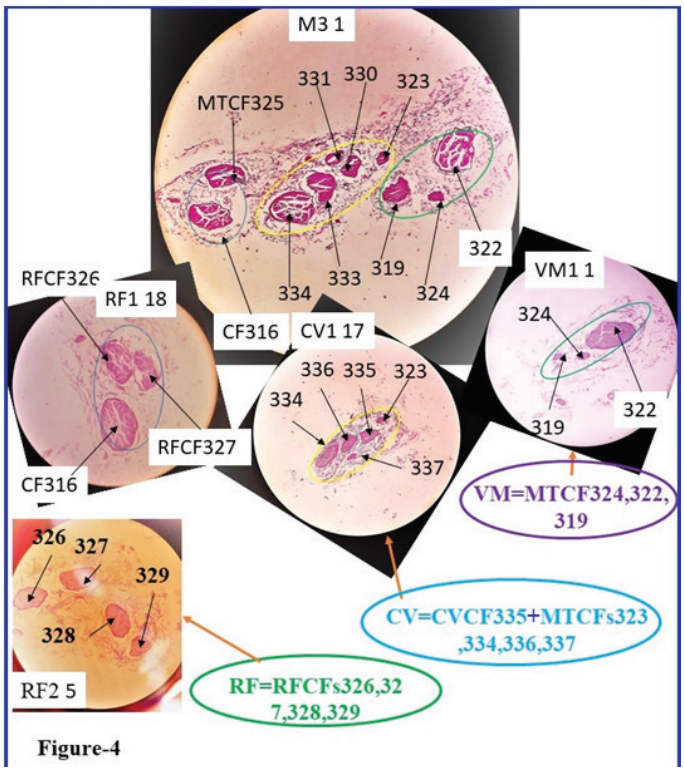

Figure 4. In slide, M3 1 three groups of fascicles are surrounded by internal perineurium forming RF (MTCF 325, CF 316), CV (MTCFs 323, 330, 331, 333 and 334) and VM (MTCFs 319, 322, 324) which emerged out as RF, CV and VM after M3 1. RF1 18 is the cranial most slide of RF consisting of CF316, RFCFs 326 and 327. RF1 18 is correlative with RF2 6. CF316 in RF2 6 splits into RFCF328 and 329 in RF2 5. RF= nerve to rectus femoris, CV =common trunk, VM= nerve to vastus medialis.

Tracking and correlation of fascicles in CV (Fig. 5):

In M3 1 slide, the group of fascicles MTCFs 323, 330, 331, 333 and 334 correspond to CV which emerged out as CV after slide M3 1. But fascicles 331 and 330 in M3 1 fused forming CVCF 335 in CV1 17. MTCF 333 in M3 1 split into CVCFs 336 and 337 in CV1 17. Now CV1 17 will consist of fascicles MTCFs 323, 334, CVCFs 335, 336 and 337. The fascicles in slide CV1 17 are continuous, consistent and correlative till slide CV1 1. CV2 15 is the cranial most slide of CV2 block. CVCF335 and MTCF 334 in CV1 1 splits into CVCFs 338, 339 and 340 and 341 in CV2 15 respectively. Now CV2 15 will consist of fascicles MTCF 323, CVCFs 338, 339, 340, 341, 336, 337. These fascicles in CV2 15 are continuous, consistent and correlative till slide CV2 1 and CV2 1 is further correlative till CV3 6 meaning thereby, the fascicles MTCF 323, CVCFs 338, 339, 340, 341, 336, 337 are continuously present till slide CV3 6. The slide CV3 15 is the cranial most slide of CV3.

CV bifurcated into VIA and CV' after CV3 6 (Fig. 6). The fascicles, CVCFs 340, 341 in CV3 6 fused to form CVCF342 in CV3 5.

CV3 5 is correlative with CV'1 1 so the fascicles, 336 and 342 correspond to CV' in CV'1 15 and fascicles MTCF 323, CVCFs 337, 338, 339 to VIA in VIA1 15. CV' 1 15 slide is continuous, consistent and correlative till slide CV'1 1 and contain the fascicles CVCFs 336 and 342.

VIA1 15 contains the fascicles MTCF 323, CVCFs 337, 338, 339. VIA1 15 is continuous, consistent and correlative till slide VIA1 1. Fascicles of VIA1 1 forming branch of Vastus intermedius enters the vastus intermedius muscle innervating it.

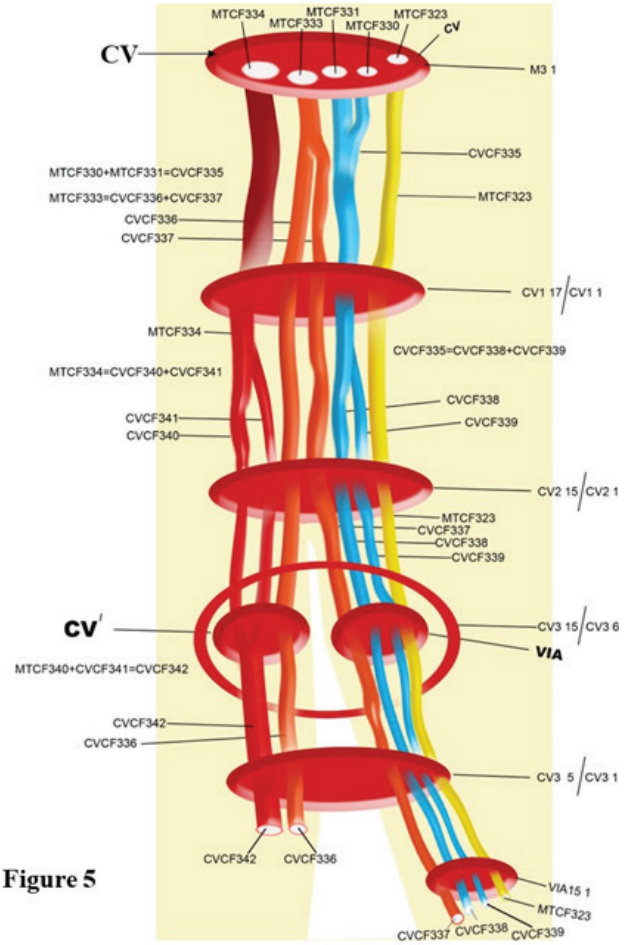

Figure 5. Displaying configuration of CV till its termination into CV' and VIA. CV= common trunk, one of the terminal branch of muscular trunk.CV'= nerve after emergence of VIA. VIA= first branch to vastus intermedius muscle.

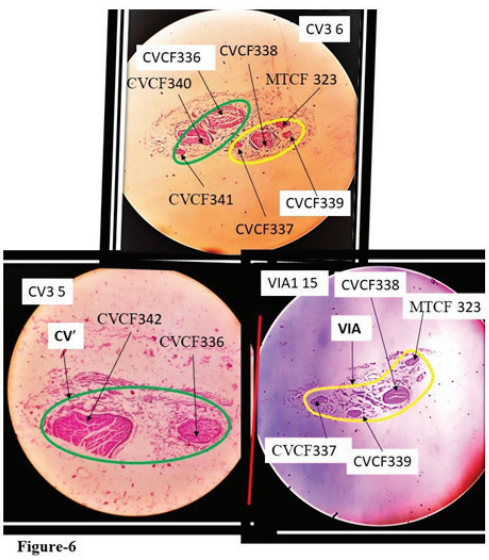

Figure 6. In slide CV3 6 two groups of fascicles are surrounded by internal perineurium corresponding to CV' (CVCF 336, 340 and 342) and VIA (MTCF 323, CVCF 337, 338). CV bifurcated into VIA and CV' after CV3 6. CV' consists of CVCF 336, 342 and VIA consists of MTCF 323, CVCF 337, 338.

CV' bifurcated into VL and VIB after CV'1 1 (Fig. 7).

VL and VIB correspond to fascicles CVCF 342 and CVCF 336 respectively. Thus, VL1 1 contains the fascicle CVCF 342. VL1 1 is continuous, consistent and correlative till slide VL2 6/VL3 16. CVCF342 in VL3 16 splits into VLCFs, 343, 344, 345 and about 5 smaller tiny fascicles. These fascicles in VL3 16 are. continuous, consistent and correlative till slide VL3 1. These fascicles forming VL enters the vastus lateralis muscle to innervate it.

VIB1 1 consists of fascicle CVCF 336 which splits into VIBCFs 337, 338, 339, 340, 341 in slide VIB2 15. These fascicles were continuous, consistent and correlative till slide VIB2 1. The VIB enters the vastus intermedius muscle to innervate it. There was change of location due to migration of fascicles.

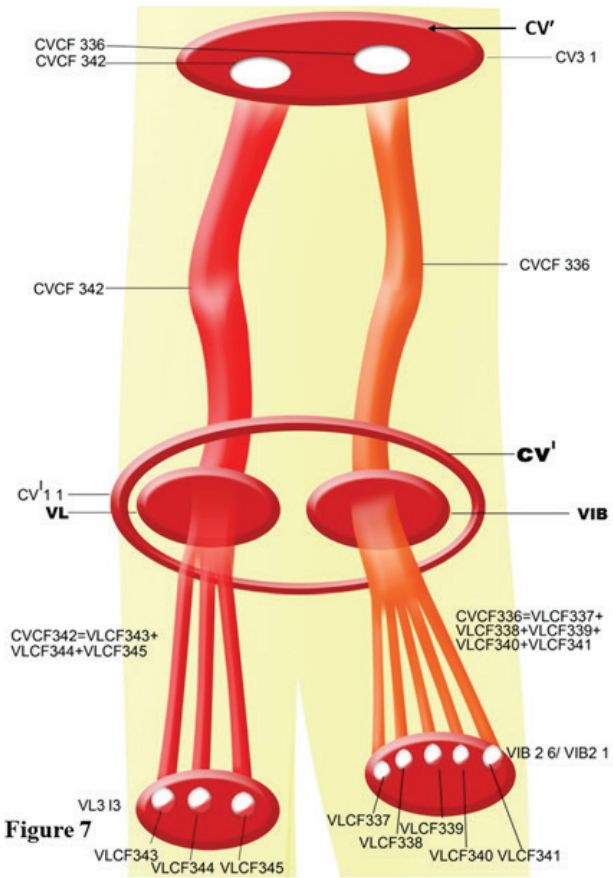

Figure 7. Showing CV' bifurcating into VL and VIB after CV'1 1.

Tracking and correlation of fascicles in VM (Fig. 8):

In M3 1 slide, fascicles MTCFs 319, 322 and 324 constitute VM and these fascicles emerged out as nerve to vastus medialis after slide M3 1. VM1 1 contains the fascicles MTCFs 319, 322 and 324. VM1 1 is continuous, consistent and correlative till VM2 1 slide meaning thereby, fascicles MTCFs 319, 322 and 324 are continuous till the slide VM2 1. MTCF 322 in VM2 1 splits into VMCFs 325, 326, 327, 328 and 329 in VM3 22 and these fascicles continue till slide VM3 6. Thus VM3 22 consists of fascicles MTCFs 319, 324, VMCFs 325, 326,

327, 328 and 329. VM3 22 is continuous, consistent and correlative till slide VM3 6. MTCFs 319, 324, VMCFs 327, 328 in VM3 6 fused together forming VMCF 330 in VM3 5. Now VM3 5 consists of fascicles VMCFs 325, 326, 329, 330. These fascicles are continuous, consistent and correlative till VM3 1. After the slide VM3 1 nerve to vastus medialis bifurcated into VMA and VMB. VMA consists of fascicles VMCFs, 326 and 329 while VMB consists of fascicles VMCFs 325 and 330. These branches entered the vastus medialis muscle innervating it.

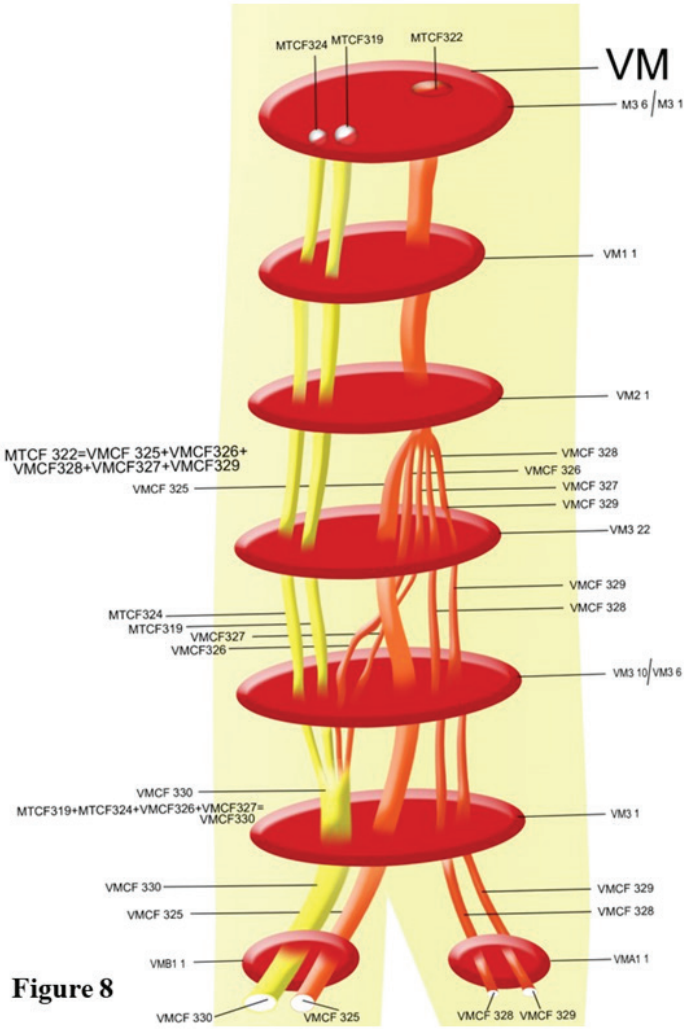

Figure 8. Displaying configuration of fascicles in VM, the nerve to vastus medialis.

The position of nerves and fascicles can be calibrated longitudinally from inguinal ligament and the position of branching point of nerves and configuration of fascicles including position of transformational processes and identification of fascicles has been brought out as given in the Table 1. The size of fascicle, its isolation, orientation, directivity, consisting of axons, end-to-end matching through shapes and sizes of injured and nerve specimen for grafting of CFs are required for planning surgical repair, grafting and regeneration [Payne]. This information can also be derived from the schematic models of our study.

Discussion

The communication between quadriceps femoris muscles and brain for functioning and activities of these normal/morbid muscles while interacting with universe can well be understood as the brain is the centre-point of interaction between the human being and the universe[14] through naturally developed self-defending human system. The neurology and neurosurgery pertaining to the entire nervous system in general and brain in particular, being a nascent science, are less developed. Sciences[15]. Though internal morphology of fascicles by limited samples of histological slides was attempted for designing nerve cuff electrode by Gustafson *et al*., 2009 but for more specific and less invasive treatment at fascicular level, newly conceptualized composite fascicular electrode may be developed for neuro- surgical manipulation to restore the deficits caused by neuropathies[16].

The models, brought out under this study, provide the mapping and correlation of pathways and configuration consisting of location, branching patterns of nerves and fascicles, intermingling of fascicles by splitting, fusion and multiplexing through changing the axonal number causing alterations in shapes, sizes, orientation and identification of nerves/fascicles along the nerves to RF, VI, VM and VL supplying quadriceps femoris muscles of lower limb. The distances of various locations have been measured with reference to prominent landmark, inguinal ligament. Thus, these models provide calibrated location of nerves, branching points, identification of fascicles through numbers, longitudinal calibrated pathways, location of branching points, the location of transformational changes that is point of split, fusion and multiplexing and number of fascicles in branch nerve. The neurosurgical diagnosis and treatment mostly depend on the above facts. These are also very crucial information even for enhancing degree of restoration of impairment due to neural disorders of lower limb. Let us explain, how?

The nerve network in human body is very complex with its innumerable branches and sub-branches innervating the entire body up to the level of a tissue constituting communication channels as electrical wires[13] between brain and each and every tissue of the body. But this communication network of nervous system, in its entirety, regulates the functions and activities of the body in response to, not only, feel of fear/valour, comfort/discomforts, happiness/sorrows, pain/relief but also to activity/functions of various constituents as per requirement of day to day working, producing signs, symptoms and other inconveniences. Therefore, the femoral nerve and configuration of its variant forms including fascicular structures therein coupled with its branching pattern and internal morphology consisting of fascicles like other nerves are important not only to diagnose the diseases but also to cure femoral neuropathy.

Table1. Correlation of fascicles of Muscular nerves and its branches as nerves to quadriceps.

Levels of slides in cm A24 1- M0 15		Involved slides	Participating CF's	Transformation Processes	New CF's
-0.89975		FN bifurcated into CT and MT after A24 1. Into CT and MT; CT=CFs 303,304; 280,257,270 312,313; **MT=CFs316, 317, 318 CRE**			
-0.89975	-1.19325	A24 1- M0 15	CF317	Split	MTCFs 319, 320
			CF318	Split	MTCFs 321, 322
-1.19325	-1.39975	M0 15-M01	CF316, MTCFs319, 320, 321, 322		
-1.39975	-1.69325	M01-M1 15	CF320	Split	MTCFs 323, 324
-1.69325	-1.69525	M1 15-M1 11	CF316, MTCF319, 323, 324, 321, 322		
-1.69525	-1.7955	M1 11 and M1 10	CF321	Split	MTCFs 325, 326, 327
-1.7955	-1.89975	M1 10-M1 1	CF316, MTCF319,323, 324, 325, 326, 327, 322		
-1.89975	-2.2970	M1 1 and M2 9	326	split	MTCFs 328, 329
			327	split	MTCFs 330, 331.
-2.2970	-2.39975	M2 9-M2 1	CF316, MTCF319,323, 324, 325, 328, 329, 330, 331, 322		
-2.39975	-2.69175	M2 1 and M3 18	328,329	fused	MTCF 332
-2.69175	-2.797	M3 18- M3 7	CF316, MTCF319,323, 324, 325, 332, 330, 331, 322		
-2.797	-2.89725	M3 7 And M3 6	332	split	MTCFs 333, 334
-2.89725	-2.89975	M3 6-M3 1	CF316, MTCF319, 323, 324, 325, 333, 334, 330, 331, 322		
-2.89975		M3 1: **MT=CF316 MTCFs 319, 322, 324, 325; MTCFs 323, 330, 331, 333, 334**			
-2.89975		MT trifurcating into RF, CV and VM after M3 1: RF=CF316+MTCF325; CV=334+323+ 330+331+333 **CRE; VM=319, 322, 324**			
		MT → RF= CF316+MTCF325 →			
-2.89975	-3.19175	M3 1 and RF1 18	325	split	RFCFs 326, 327
-3.19175	-7.89725	RF1 18-RF2 6	CF316, RFCFs 326, 327		
-7.89725	-7.89775	RF2 6 and RF2 5	CF316	split	CF316=RFCFs 328, 329
-7.89775	-7.89975	RF2 5-RF2 1	RFCFs 328, 329, 326, 327		
		RF= CF316+MTCF325 CRE; RF= RFCFs 328, 329, 326, 327			
		MT=[CF316, MTCFs 319, 322,323,324, 325, 330, 331, 333, 334] → CV=334+323+ 330+331+333			
-2.89975	-3.19225	M3 1 and CV1 17	330, 331	fused	CVCF335
			333	split	CVCFs 336, 337
-3.19225	-3.39975	CV1 17-CV1 1	MTCFs334+323+ CVCF335+336+337		
-3.39975	-5.69275	CV1 1 and CV2 16	334	Split	CVCFs 340, 341
			335	split	CVCFs 338, 339
-5.69275	-7.2975	CV2 16-CV3 6	MTCF323+CVCFs 340+341+338+339+336+337		
-7.2975	-7.39775	CV3 6-CV3 5	340, 341	fused	CVCF342
-7.39775	-7.39975	CV3 5- CV3 1= **MTCF323+CVCFs 342+338+339+336+337**			
	-7.2975	CV bifurcated into CV' and VIA after CV3 6. CV'=CVCFs 336, (340,341)=342; VIA= MTCF 323, CVCFs 337, 338, 339: CV → CV' =336, 342 and VIA = MTCF 323, CVCFs 337, 338, 339			
-7.39975	-9.89975	CV3 5-CV'1 1	CVCF342, 336		
-9.89975	-8.19325	CV'1 1-VIA1 15/1	CV'= CVCFs 336, 342; and VIA= MTCF 323, CVCFs 337, 338, 339		
	-10.39975	CV' bifurcated into VL and VIB after CV'1 1. VL=CVCFs 342; VIB=CVCF 336; CV' → VL and VIB			
-9.89975	-10.295	CV'1 1-VL1 11/1	VL=CVCFs 342		

-10.39975	-22.19275	VL1 1and VL3 16	342	split	VLCFs343, 344, 345
	-22.19275	VL3 16	VL= VLCFs343, 344, 345		
-9.89975	-10.39975	CV'1 1-VIB1 1	CV' ➔ VIB=CVCF 336		
-10.39975	-14.69275	VIB1 1 and VIB2 16	336	split	VIBCFs 337,338, 339, 340, 341
-14.69275	-14.89975	VIB2 16-VIB2 1	VIB= VIBCFs 337,338, 339, 340, 341		
-2.89975	-3.39725	M3 1-VM1 6	MT ➔ **VM=MTCFs319, 322,324;**		
-3.39725	-6.89975	VM1 6-VM2 1	MTCFs319, 322,324		
-6.89975	-10.09	VM2 1 and VM3 22	322	split	VMCFs=325,326,327,328,329
-10.09	-10.2975	VM3 22- VM3 6	MTCF 319, 324, VMCFs325,326,327,328,329		
-10.2975	-10.39775	VM3 6 and VM3 5	319, 324, 327, 328	fused	VMCF=330
-10.39775	-10.39975	VM3 5-VM3 1	**VM**=VMCFs325,326, 329, 330		
	-10.39975	VM bifurcated into VMA and VMB afterVM3 1. VMA1 1=326,329; VMB1 1=325, 330			
	-11.39975	VMA1 1=326,329			
	-11.39975	VMB1 1=325, 330			

If any of the nerves to quadriceps (RF, VM, VI and VL) and/or fascicles corresponding to the specific nerve innervating the specific muscles, are injured, the functions of corresponding muscle are impaired creating helm of discomforts in form of signs and symptoms such as pain, numbness, weakness, inactive, senselessness, partial/full paralysis and affecting locomotion and other activities of muscle. Such neural insults, with above signs and symptoms, are diagnosed by identifying the injured nerve/fascicle, their location site including configuration, branching pattern of elongated pathways and degree as well as location of injury for planning recovery of functions of muscle through surgical repair/grafting for regeneration. But neuro-surgeons face the impediments of accurately pinpointing the concealed location of specific nerve/fascicle and probable site and degree of injury on it, in live patients as the identification, location of nerve/fascicles and injury thereon fall beyond the resolution limit of imaging tools in the current scenario. The chief tools of examining the insults are imagery in general and MRI in particular but the slicing in high resolution MRI is possible minimum at 2 mm (2000 micron) interval, so, the structures, fascicles having dimensions in the range of 50-800 micron and axons in the range of 1-5 micron have the size of injuries like cut/break/degeneration in the range of 1-100 micron on these structures which is much smaller than 2 mm (2000 micron). So, these injuries can hardly be clearly seen as per Raleigh's criterion, in high resolution MRI. Normally, in routine diagnosis, the identification of injured fascicle is carried out by nerve conduction test through (EMG) electromyography or (FES) functional electrical stimulation with the help of Nerve-cuff-electrode or Muscular electrode. The electrode probe is to be placed rightly, on injured fascicle. But exact location of injury on identified fascicle from the surface of the nerve is not known. So, it is also subjective as it is done by hit and trial method under known neuroanatomy.

However, Chhabra *et al*[10]. and Baumer *et al*[11]. claim that the fascicles and injury thereon may be located by interpretation of frequency coding analysis in MRI advanced neurography, yet, this too is likely to have subjectivity. However, Singh *et al*. suggested a method to locate likely injured fascicle through correlation and mapping of calibrated histological slides of femoral nerve[16] with reference to inguinal ligament in collaboration with high resolution MRI advanced neuro-graphs. The same procedure can be followed in this case. The injured fascicle and injury can be first identified in high resolution MRI neuro-graphs, through methods described by Chhabra *et al*.' and Baumer *et al*.'. Thereafter, nerves/fascicles can be identified in models prepared under this study with the help of distances from inguinal ligament (Table 1) and configuration of correlated fascicle.

Then, the confirmation can be done by nerve conduction test by placing the electrodes on the identified nerve/fascicle. As regards end-to-end matching, alignment and directivity of fibres of in situ nerve and donor nerve, the slides of model may be compared with transverse section of nerve in MRI pertaining to match the shape, size, configuration of fascicles in muscular branches of femoral nerve through number and size of the fascicle such as "it can be done by one-to-one correlation between images of transverse histological section of nerve and transverse neural sections at the same position in high-resolution MRI advanced from inguinal ligament"[16].

This may solve the problem to a considerable extent for enhancing the degree of restoration as reported by Evans[12], 2001.The current approaches to nerve repair include microsurgical alignment, approximation of

the fascicles, postoperative re-education, and no postural positioning (attempting to co-adapt nerve ends by moving the position of the extremity). The ultimate number of fascicles necessary for restoration of function is currently unknown. The identification of fascicles involved in injury is very crucial need in this process of repair of fascicle and the diagnosis[12]. Thus, internal structure of nerve not only facilitates to comprehend the communication in the human body but also helps in detecting neural lesions during diagnosis and treatment through stimulation/ regeneration of neural tissue by nerve cuff electrode placement[13]. Thus, if particular injured fascicle is identified and degree of injury is detected for repair, it will be less cumbersome and minimally invasive. But for the diagnosis of neural insults, not only the location and degree of injury but also identification, isolation, orientation, directivity, end-to-end matching through shapes and sizes of injured and nerve specimen for grafting of CFs are required for planning surgical repair, grafting and regeneration[17].

This is pertinent to mention here that almost all the constraints have solutions in these models collaborated with high resolution MRI advanced neurography while carrying out diagnosis and treatment for femoral neuropathy.

Therefore, the imagery coupled with our microanatomical study of nerves to quadriceps together can refine the interpretation for identification of injured CF and location of injury.

Conclusion

The schematic models and histological slides brought out in present study are boon to femoral neuropathy as it presents identification of fascicles, their configuration, branching pattern, correlation of alterations in shape, size and orientation of fascicles due to intermixing of axons through splitting, fusion and multiplexing. matching, alignment and directivity of nerve fibres for repair and grafting of nerves to Quadriceps muscle with minimum invasion.

Limitations

This work has been carried out on a single femoral nerve. For more clarity and fool proof conclusions, all the variant femoral nerves are to be considered. There are many anthropological parameters on which spread of femoral nerve depends should also be considered. The neurosurgery at fascicular level is currently uncommon however, with upcoming science and technology in tomorrow's world, present study will be highly useful.

References

1. Standring S. Gray's Anatomy:the Anatomical Basis of clinical practice. 39th edn. Elsevier Churchill Livingstone, Spain, 2005; PP-1455
2. Singh Rajani, R. Shane Tubbs, Mukesh Singla. Classification and fascicular analysis of variant branching pattern of femoral nerve for microsurgical intervention -A series of thirteen cadavers. Int. J of Morph 2016; 34(2): 561-569.
3. Gustafson KJ, Pinault GCJ, Neville JJ *et al*. Fascicular anatomy of human femoral nerve: implications for neural prostheses using nerve cuff electrodes. J Rehab Res Dev 2009; 46 (7): 973-984.
4. Davis JA Jr, Triolo RJ, Uhlir JP *et al*. Surgical technique for installing an eight-channel neuroprosthesis for standing. Clin Orthop Relat Res 2001; 385:237–52. DOI:10.1097/00003086-200104000-00035.
5. Kobetic R, Triolo RJ, Uhlir JP *et al*. Implanted functional electrical stimulation system for mobility in paraplegia: A follow-up case report. IEEE Trans Rehabil Eng 1999;7(4):390–98. DOI:10.1109/86.808942.
6. Sharma M, Marsolais EB, Polando G *et al*. Implantation of a 16-channel functional electrical stimulation walking system. Clin Orthop Relat Res 1998; 347:236–42. DOI:10.1097/00003086-199802000-00029.
7. Kobetic R, Triolo RJ, Marsolais EB. Muscle selection and walking performance of multichannel FES systems for ambulation in paraplegia. IEEE Trans Rehabil Eng 1997;5(1):23–29.
8. Triolo R, Wibowo M, Uhlir J, Kobetic R. Kirsch R. Effects of stimulated hip extension moment and position on upper-limb support forces during FNS-induced standing—A technical note. J Rehabil Res Dev 2001;38(5):545–55.
9. Uhlir JP, Triolo RJ, Kobetic R. The use of selective electrical stimulation of the quadriceps to improve standing function in paraplegia. IEEE Trans Rehabil Eng. 2000;8(4):514–22. DOI:10.1109/86.895955.
10. Chhabra Avneesh, Lianxin Zhao, John A Carrino *et al*. 2013. MR Neurography: Advances. Radiology Research and Practice. Volume 2013, 14 pages Article ID 809568.
11. Bäumer Philipp, Sabine Heiland, Martin Bendszus, Mirko Pham. MR Neurography - Diagnostic Criteria to Determine Lesions of Peripheral Nerves. Clinical Neurology 2012; page 10-14. Available at Magnetom Flash • 2/2012 www. siemens. com/magnetom-world.
12. Gregory RD Evans (). Peripheral Nerve Injury: A Review and Approach to Tissue Engineered Constructs. The Anatomical Record 2001; 263:396–404.
13. Kim Ann Zimmermann. Nervous System: Facts, Function & Diseases , Live Science January 26, 2015 to be searched on google
14. Muzumdar Dattatraya . Neurosurgery in the Past and Future. An Appraisal. Ann Med Surg 2012; 1: 13–15. doi: 10.1016/S2049-0801(12)70004-3
15. Raj A, Agrawal A. Neurosurgery in India: Success and challenges. Int J Acad Med 2018; 4:89.
16. Singh Rajani. Microanatomy and clinical significance of cutaneous nerves of thigh. Basic Sciences of Medicine 2020; 9(2): 15-23.
17. Payne S Houston. Nerve Repair and Grafting in the Upper Extremity. J South Orthop Assoc 2001: 10(2). Available at https://www.medscape.com/viewarticle/423216_6.

Mini Curriculum and Author's Contribution

1. Rajani Singh: MS Contribution: Scientific and intellectual participation, data acquisition and interpretation, manuscript righting, review and final approval

Received: January 28, 2023
Accepted: March 3, 2023

Corresponding author
Rajani Singh
E-mail: nani_sahayal@rediffmail.com