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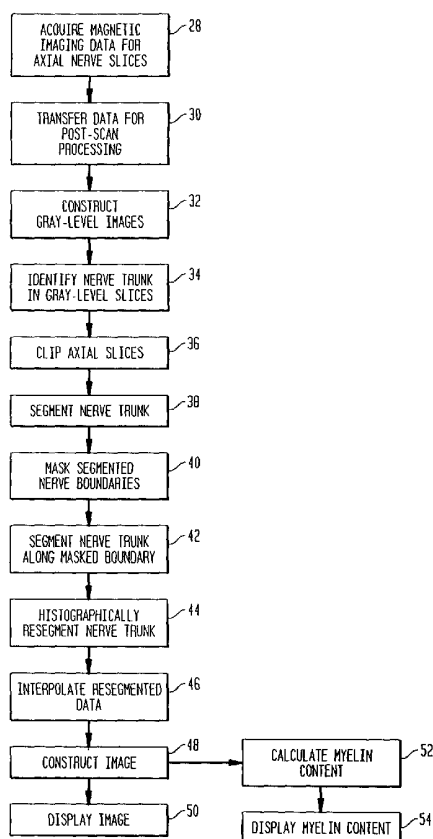
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(54) Title: METHOD AND APPARATUS FOR THE NON-INVASIVE IMAGING OF ANATOMIC TISSUE STRUCTURES

(57) Abstract: A method for the non-invasive imaging of an anatomic tissue structure in isolation from surrounding tissues, including: receiving from an input device magnetic imaging data from a patient of the anatomic tissue structure and surrounding tissues; segmenting the imaging data to isolate the anatomic tissue structure imaging data from the imaging data for the surrounding tissues; separating the anatomic tissue structure imaging data into data populations corresponding to tissue microstructures; constructing an image from the imaging data for at least one of the tissue microstructures; and storing or displaying the image. An apparatus embodying the disclosed method is also described, as well as a method for the quantitative measurement of a nerve tissue suspected of demyelination.

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METHOD AND APPARATUS FOR THE NON-INVASIVE IMAGING OF ANATOMIC TISSUE STRUCTURES

Background Of The Invention

The present invention relates to the non-invasive mag-
5   netic imaging of anatomic tissue structures in isolation from
surrounding tissues, and, in particular, to the non-invasive
magnetic imaging of nerve tissues. The present invention
more specifically relates to the non-invasive quantitative
measurement of damage to nerve tissue, such as the damage
10   that occurs upon compression.

Clinically it is possible to estimate which neural
pathway is involved in trauma by determining the end result
loss of motor function and either abberant sensory function
or complete loss of it. It is very difficult to determine
15   where the lesion is and to what extent it has caused deteri-
oration of the nerves involved.

Peripheral nerves are compound structures. Each nerve
trunk consists of a very large number of nerve "fibers"
(neurites) that are protoplasmic extensions of neuronal cell
20   bodies located in the dorsal root ganglia (sensory neurons)
and ventral horn of the spinal cord (motor neurons). All
nerve fibers (except fine pain fibers) are surrounded by a
fatty sheath of myelin which serves to enhance nerve impulse

conduction (neural flow). The nerve fibers are grouped into fasciculi, bundles of fibers bound together by a fine connective tissue membrane (epineureum). The bundles of fasciculi comprising the nerve trunk are bound by a thicker membrane, the perineureum. The nerve trunk may be surrounded by other layers of protective connective tissue or fat.

Neuropathy in peripheral nerves may occur through the agency of traumatic distortion, including compression, stretch and breakage, and/or associated ischemia. The trauma may be acute, especially when the surrounding tissues are injured, or it may be chronic, and due to pathologic mechanical relations between the nerve and surrounding tissues: regional compression is considered to be the principal etiology in entrapment syndromes. There is rapid recovery from transient compression, but prolonged compression extends the recovery period because the nerve fibers are damaged. Remyelination and re-establishment of conduction must take place. Chronic and repetitive compression prevents recovery and results in severe neurologic impairment.

In chronic and repetitive compressions, which are more common than acute compressions, the damage is more extensive. Nerve trunks become thinned at the site of the compression, but may swell proximally. Characteristically conduction is slowed and conduction blocks occur as long segments of myelin are damaged. Depending on the severity of the chronic compression, the nerve trunk proximally will contain a full complement of myelinated fibers within its fasciculi; but at the level of compression and distally the number of myelinated fibers may be reduced significantly. The relative density of the myelinated fibers between proximal and distal portions of the nerve is a measure of loss of neurophysiologic function in its distal distribution.

Although nerve damage can occur anywhere within the body, some nerves are predisposed to chronic damage because of their structural relationships with other tissues. Classic sites for chronic nerve compression include the brachial

plexus - especially where the cords of the plexus pass be-
tween the rib cage and clavicle, the elbow - where the ulna
nerve winds around the olecranon process of the ulna bone,
the carpal tunnel - where the median nerve lies between deep
5   flexor tendons and the flexor retinaculum, the sacro-iliac
region - where the lumbo-sacral trunk and sacral plexus lie
on the bony surfaces of the pelvis, the gluteal region -
where the sciatic nerve passes between the powerful gluteal
musculature, the neck of the fibula - where the common pero-
10   neal nerve winds about the external surface of the bone, and
the tarsal canal - where the tibial nerve winds beneath the
tarsal bones to enter the sole of the foot.

        Some nerves are vulnerable to acute trauma as a result
of their intimate relationship to bones subject to fracture.
15   These include that portion of the brachial plexus lying
beneath the clavicle, the radial nerve - which winds about
the shaft of the humerus, and the common peroneal nerve,
which winds about the neck of the fibula.

        Carpal Tunnel Syndrome (CTS) is defined as a pathologic
20   condition in which the tunnel size is reduced, causing press-
ure on the median nerve with resultant pain and slight sens-
ory impairment in the digits supplied by the nerve, and some-
times accompanied by slight wasting of the thenar muscles.
The carpal groove is a deep concavity on the palmar surface
25   of the carpus formed by lateral and medial projections of the
carpal bones. The medial projection is formed by the pisi-
form bone and the hamulus - a hook-like projection of the
hamate bone. The lateral projection is formed by the tuber-
cles of the scaphoid and trapezium bones. The carpal groove
30   is converted into an osteofibrous carpal tunnel by a strong
fibrous retinaculum attached to the lateral and medial mar-
gins of the carpal groove. The carpal tunnel transmits the
tendons of the deep and superficial digital flexor muscles
which in this region form a firm bundle.

35   The median nerve lies within the tunnel between the
flexor retinaculum and the flexor tendon bundle. It emerges

from behind the flexor digitorum superficialis distally in the forearm about 5 cm proximal to the flexor retinaculum of the carpus.   It lies superficial to the deep digital flexor tendons and between the tendons of the superficial flexor

5   muscle and the flexor carpi radialis.   The nerve then passes deep to the flexor retinaculum of the wrist where normally it lies superficial to the stout bundle of flexor tendons.

Overt morphology associated with CTS includes carpal dislocations, carpal arthritis and tenosynovitis of the long

10   flexor tendons.   These conditions clearly restrict the space within the tunnel.   There is often no apparent morphologic cause for the syndrome, but as complete division of the flex-or retinaculum results in relief from symptoms in most cases it is assumed that mechanical compression that is not obvious

15   from the gross morphology of the tunnel or its contents causes ischemia or directly compresses the median nerve.

Clinical symptoms includes weakening of the thenar mus-cles, parasthesias of the lateral palm, thumb and first two fingers.   Other symptoms may include stiffness of the wrist

20   and some pain.

Clinical examination consists of identifying those symptoms known to be associated with nerve damage.   The anatomic distribution of the branches of peripheral nerves is constant and well known.   The distribution of abnormal

25   sensation or inability to utilize one or more muscles is a sure indicator of which nerve is involved.

Electromyography is used as a supplement to clinical ex-amination. The technique uses needle electrodes inserted into suspect muscle.   The intensity of the potentials measured is

30   an indirect measure of the level of muscle activity.   Neural flow stimulation also involves the use of needle electrodes. The technique compares input and output values of electric potentials.

None of these diagnostic techniques definitively identifies the focus of the neuropathy. In most cases, if the examination and electromyographic results are typical of those associated with a particular syndrome, the focus of the neu-

5   ropathy can be estimated with some certainty based on experience; but false positive diagnoses are relatively common and may lead to unnecessary surgery or incomplete relief of the symptoms. In addition, electromyography is a relatively complex technique requiring some expertise to obtain a satis-

10 factory diagnosis. Furthermore, the use of needle electrodes is invasive, and may prove painful. This can lead to false readings or patient rejection of the study.

A further problem is experienced with clinical examinations. Numerous patients attempt to simulate symptomatology

15 in order to qualify for insurance compensation. Identifying these patients using an essentially subjective examination is difficult and time consuming for the diagnostician.

Despite conflicting reports in the literature, there is no convincing evidence that nerve morphology viewed in unas-

20 sisted two-dimensional magnetic images is a clinically practical means of obtaining information about histological degeneration and impaired neural flow. At present, CTS patients are not referred for magnetic imaging scans as a diagnostic procedure.

25 Summary Of The Invention

It has now been discovered that post-scan data processing may be employed to resolve the problem of obtaining physiological information with significant clinical diagnostic

30 value from magnetic imaging data. By first segmenting the imaging data to isolate anatomic tissue structures from surrounding tissues, high resolution three-dimensional images are obtained in which tissue microstructures are visible and provide clinically significant information relating to phys-

35 iology. When imaging nerve tissues, it is possible to obtain

neurophysiological information with significant clinical diagnostic value relating to the efficacy of nerve flow.

Therefore, according to one aspect of the present invention, a method is provided for the non-invasive imaging
5   of an anatomic tissue structure in isolation from surrounding tissues, including the steps of:

receiving from an input device, magnetic imaging data from a patient of an anatomic tissue structure and the surrounding tissues;

10   segmenting the imaging data to isolate the anatomic tissue structure imaging data from the imaging data for the surrounding tissues;

separating the anatomic tissue structure imaging data
15   into data populations corresponding to tissue microstructures;

constructing an image from imaging data for at least one of the tissue microstructures; and

storing or displaying the image.

20   The imaging data my be acquired by either magnetic resonance or magnetic transfer imaging. Applications for the method of the present invention are not limited to the imaging of nerve tissue but apply to essentially any tissue structure for which it is difficult to obtain a high resolu-
25   tion image that is not obscured by surrounding tissues. Thus, the method of the present invention is particularly well suited for the imaging of vascular tissue and tumor tissue. The present invention makes possible high resolution images of tumor tissue boundaries that assist the surgeon in
30   achieving the goal of complete tumor removal.

Therefore, according to another aspect of the present invention, an apparatus is provided for preforming the method

of the invention. An apparatus in accordance with the
present invention includes:

an input device for receiving magnetic imaging data from
a patient;

5   a processing unit having:

a first program for segmenting the magnetic imaging
data to isolate imaging data for an anatomic tissue
structure from imaging data for surrounding tissues;

a second program for separating the anatomic tissue
10   structure imaging data into data populations correspond-
ing to tissue microstructures;

a third program for constructing an image from ima-
ging data for at least one of the microstructures; and

a processor for sequentially executing the first,
15   second and third programs;

wherein the processor executes:

the first program using the imaging data from
the input device;

the second program using the anatomic tissue
20   structure imaging data isolated by execution of the
first program; and

the third program using the data populations
obtained by execution of the second program; and

an output device for displaying the image or a storage
25 device for storing the image.

The present invention includes apparatuses for calculat-
ing the presence or loss of myelin in a nerve trunk or tract.

Such apparatuses include devices that measure the myelin without first constructing an image of the nerve trunk or tract. An apparatus in accordance with this aspect of the present invention includes:

5   an input device for receiving imaging data from a patient of a nerve trunk or tract and the surrounding tissues;

a processing unit having:

a first program for segmenting the magnetic imaging data to isolate imaging data for the nerve trunk or
10   tract from the imaging data for the surrounding tissues;

a second program for separating the nerve trunk or tract imaging data into data populations corresponding to fasciculi and other nerve trunk or tract microstructures;

15   a third program for calculating the presence or loss of myelin in the nerve trunk or tract from the fasciculi imaging data; and

a processor for sequentially executing the first,
20   second and third programs;

wherein the processor executes:

the first program using imaging data from the input device;

the second program using the nerve trunk or
25   tract imaging data isolated by execution of the first program; and

the third program using the fasciculi data population obtained by execution of the second program; and

an output device for displaying the myelin calculation
or a storage device for storing the myelin calculation.

The method and apparatus of the present invention are
particularly useful for segmenting nerve tissue imaging data,
5   enabling three-dimensional visualization of individual nerve
fasciculi, and quantification of the percentage of fascicular
tissue present in cross-sections of the nerve trunk. The
numerical values obtained are represented in bivariate plots
of percentage and cross-sectional location and directly
10   indicate to the physician those parts of the nerve trunk
where myelin content is reduced and neural flow is impaired,
and the extent of the degeneration.

Therefore, according to another aspect of the present
invention, a method is provided for the imaging of a nerve
15   trunk or tract suspected of demyelination, including:

receiving from an input device, magnetic imaging data
from a patient of a nerve trunk or tract suspected of demye-
lination and the surronding tissues;

segmenting the imaging data to separate the imaging data
20   for the nerve trunk or tract from the imaging data for the
surrounding tissues;

separating the imaging data for the nerve trunk or tract
into data populations corresponding to the fasciculi and
other microstructures of the nerve trunk or tract;

25   constructing an image from imaging data for at least the
fasciculi of the nerve trunk or tract; and

storing or displaying the image.

The present invention incorporates the discovery that
the imaging data for the fasciculi can be used to calculate
30   the presence or loss of myelin in a nerve trunk or tract.
Therefore, preferred methods according to this aspect of the

present invention further include the steps of calculating
from the imaging data for the fasciculi, the presence or loss
of myelin in the nerve trunk or tract suspected of demyelin-
ation, and storing or displaying the myelin calculation.

5   According to another aspect of the present invention,
the presence or loss of myelin in a nerve trunk or tract may
be calculated from fasciculi imaging data independently of
the construction of the nerve trunk image. The present in-
vention therefore also includes a method for the quantitative
10   measurement of a nerve trunk or tract suspected of demyelina-
tion, including the steps of:

        receiving from an input device, magnetic imaging data
from a patient of a nerve trunk or tract suspected of demye-
lination and the surrounding tissues;

15   segmenting the imaging data to separate the imaging data
for the nerve trunk or tract from the imaging data for the
surrounding tissues;

        separating the imaging data for the nerve trunk or tract
into data populations corresponding to the fasciculi and
20   other microstructures of the nerve trunk or tract;

        calculating from the fasciculi imaging data, the
presence or loss of myelin in the nerve trunk or tract; and

        storing or displaying the myelin calculation.

        The method of the present invention for quantitatively
25   measuring nerve tissue demyelination is particularly useful
for the non-invasive diagnosis of CTS. Therefore, according
to yet another aspect of the present invention, a method is
provided for the imaging of a median nerve suspected of demy-
elination within one of a patient's carpal tunnels, includ-
30   ing the steps of:

receiving from an input device, magnetic imaging data
from a patient including at least a portion of the median
nerve passing through a carpel tunnel;

segmenting the imaging data to isolate the median nerve
5   imaging data from any imaging data for surrounding tissues;

separating the median nerve imaging data into data popu-
lations corresponding to the fasciculi and other microstruct-
ures of the median nerve;

constructing an image from imaging data for at least the
10 fasciculi of the median nerve; and

storing or displaying the image.

This method can also be employed to calculate the pres-
ence or loss of myelin in the median nerve within a carpal
tunnel from the fasciculi imaging data. Methods in accord-
15 ance with this aspect of the present invention further in-
clude the steps of calculating from the fasciculi imaging the
presence or loss of median nerve myelin within the carpal
tunnel, and storing or displaying the myelin calculation.

The presence or loss of myelin in the median nerve with-
20 in a carpal tunnel can also be calculated from the fasciculi
imaging data independently of the construction of a median
nerve image. The present invention therefore also includes a
method for the quantitative measurement of a median nerve
suspected of demyelination within one of a patient's carpal
25 tunnels, including the steps of:

receiving from an input device, magnetic imaging data
from a patient including at least a portion of the median
nerve passing through a carpel tunnel;

segmenting the imaging data to isolate the median nerve
30 imaging data from any imaging data for surrounding tissues;

separating the median nerve imaging data into data populations corresponding to the fasciculi and other microstructures of the median nerve;

5   calculating from the imaging data for the median nerve fasciculi, the presence or loss of myelin in the median nerve within the carpal tunnel; and

storing or displaying the myelin calculation.

A more complete appreciation of the invention and many more other intended advantages can be readily obtained by

10   reference to the following detailed description of the preferred embodiments and claims, taken in conjunction with the accompanying drawings, which disclose the principles of the invention, and the best modes which are presently contemplated for carrying them out.

15   Brief Description Of The Drawings

FIG. 1 is a block diagram of the components of an exemplary apparatus in accordance with the present invention;

FIG. 2 is a flow chart illustrating an exemplary set of steps in accordance with the method of the present invention;

20   FIG. 3 is a prior art axial cross-section of a wrist, including the median nerve, obtained by magnetic resonance imaging;

FIG. 4 is a magnetic resonance image of a healthy median nerve within a carpal tunnel of a patient, constructed by an

25   apparatus of the present invention employing the method of the present invention; and

FIG. 5 is a magnetic resonance image of a median nerve within a carpal tunnel of a patient suffering from CTS, constructed by the same apparatus and method employed to

30   construct the image of FIG. 4.

Detailed Description Of The Preferred Embodiments

Referring to the drawings, in which like reference num-
erals identify similar or identical elements, as shown in
Figure 1, the present disclosure describes a method and app-
5   aratus implementing an imaging device 10, which includes a
processing unit 12 having processor 14, memory 16 and stored
programs 18, including post-scan data processing programs 20.
The processing device also includes an input device 26 and an
output device 28.

10   The present invention is based on the discovery that by
first segmenting imaging data to isolate anatomic tissue
structures from surronding tissues before histographically
resegmenting the imaging data, it is possible to construct
images of the tissue microstructures having exceptional
15   clarity. The new methods and apparatus disclosed herein are
particularly adapted for use in the diagnosis of neuropathy,
especially the neuropathy resulting from compression and the
associated demyelination, such as occurs with CTS.

' In an exemplary embodiment, the processing unit 12 is an
20   R1000 workstation from SGI having about 128 MB associated RAM
memory and a 4 GB hard or fixed drive memory 16. The proces-
sor operates using a UNIX operating system to run application
software 18 implementing the disclosed imaging device 10 and
method.

25   It should be understood that the above described proces-
sor is merely exemplary. Any computer or processing system
having sufficient processing ability and memory may be used.

Imaging data acquired by magnetic resonance or magnetic
transfer imaging is provided by imaging source 24 through an
30   input device 26 to the processor 14. The data source may be
any source for providing magnetic resonance or magnetic
transfer imaging data to a computer, such as a floppy disk
containing an imaging data file, or the processor of a mag-
netic resonance or magnetic transfer imaging device (not

shown), directly linked to a input port of processor 14, or
by means of a modem interface. The input device 26 may be a
floppy disk drive, modem, or other data reading or data input
device, and also includes an interactive, semi-automatic or
5   automatic contouring device for segmenting of anatomic struc-
tures. For purposes of the present invention "anatomic
structures" are defined as the functional substructures
within a gross organ, such as the functional microstructures
within a nerve trunk, i.e., fasciculi, and the like.

10   Input device 26 may also include a keyboard or similar
input device for supplying commands to processor 14. The
command-supplying input device may also be provided as a
second input device (not shown).

        The processor 14 receives commands and imaging data from
15   the imaging data source through the input device(s). The im-
aging data my be stored in memory 16 for further processing
or used by the processor 14 to construct an image of a tissue
target. The constructed image is sent to an output device 28
such as a visual image display device, for example, a video
20   display terminal. A video terminal for displaying the origi-
nal magnetic resonance or magnetic transfer image may also be
included. The constructed image may also be displayed numer-
ically or graphically through an appropriate output device.

        The imaging device 10 performs the applications programs
25   described herein in conjunction with Figure 2, which are im-
plemented from compiled source code in the "C" programming
language. Referring to Figure 2, the imaging device 10 in-
cludes conventional imaging software, such as software for
the display of original magnetic images. The imaging device
30   also includes post-scan data processing programs, such as
"clipping" software for discarding irrelevant data, and soft-
ware for operating interactive, semi-automatic or automatic
contouring devices for segmentation of anatomic structures.

        The imaging device also includes post-scan data process-
35   ing software for the creation of binary images of segmented

structures and binary slices and software for the creation of
three-dimensional binary masks and software for the segmenta-
tion of gray-level data representing the segmented structure
via the binary mask. Post-scan data processing software for

5 the histographic analysis of the gray-level data is also
included, which performs single or iterative segmentation of
the gray-level anatomic tissue structure into the intrinsic
tissue microstructures, as well as software for the defini-
tion of material opacity, emission and surface reflection.

10   The imaging device post-scan data processing software
also includes software for the creation of three-dimensional
images of individual intrinsic tissue microstructures, or
compound images of complete tissue structures, and software
for image smoothing (aliasing). Post-scan data processing

15 software is also included for the calculation of the central
trunk (tract) axis (axes), cross-sections and tissue percent-
ages and the graphical display of values.

       Figure 2 depicts an applications program for the imaging
of a nerve trunk. In step 28 magnetic imaging data is acqu-

20 ired in 1 mm slices along the nerve trunk axial plane. In
step 30 the data is transferred to a processor for post scan
processing. In step 32 gray-level images of the magnetic
imaging slices are constructed by the image display software.

       In step 34 the interactive clipping software identifies

25 the nerve trunk in the gray-level slices and in step 36 clip
the first nerve trunk slice to eliminate the surrounding tis-
sue imaging data. The rest of the slice stack is then auto-
matically clipped, with modification of the clipping boundary
as required. In step 38 the semi-interactive segmentation

30 software identifies the nerve trunk boundary to the computer
in the initial one or two slices, after which the software
automatically segments the remaining slices and then checks
and modifies the identified boundaries.

       In step 40 the binary masking software creates two-

35 dimensional binary masks for the segmented nerve boundaries.

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In step 42 the two-dimensional binary masks are used by the
gray-level data segmentation software to segment the gray-
level data representing the nerve trunk from the original
magnetic resonance or magnetic transfer image slices.

5   In step 44 the histographic analysis software resegments
the nerve trunk gray-level data for the segmented nerve trunk
into nerve trunk microstructure data populations, including
the fascicular bundles, the epineurium and inter-fascicular
fascia. Interpolation of the resegmented data populations is
10   performed in step 46. Software for the definition of mater-
ial opacity, emission and surface reflection adjusts these
features for individual microstructures to enhance their vis-
ualization within compound tissue images.

          Still and movie images are then constructed by the
15   three-dimensional imaging software in step 48. Both individ-
ual nerve tissue microstructure images and compound images of
the nerve trunk composed of the individual nerve tissue
microstructures are constructed.

          In step 50 images are displayed, either as printed ima-
20   ges or by viewing software as video displays. Optionally,
the tissue calculation software determines in step 52, from
the fasciculi imaging data, the amount of fascicular material
in selected cross-sections, the values for which are present-
ed graphically in step 54 by the display software.
25
          Nerve trunks are readily visualized in high resolution
T1 or T2 weighted magnetic resonance (MR) images. In cross-
sections of a nerve trunk the fascicles appear as bright
"spots" interspersed in a darker gray matrix which represent
30   interstitial tissues, surrounded by a dark border of variable
thickness that represents the perineureum and several layers
of thin supporting fascia.

          The relatively high amplitude signal from the fasciculi
relates to the presence of myelin. Myelin is composed of
35   lipids and protein, as in the plasma membranes of other

cells, but the percentage of lipid is higher; and in addition to the usual suite of lipids found in plasma membranes, myelin contains a characteristic glycolipid. Myelin also contains up to 30% bound water.

5   When demyelination occurs, the loss of lipid molecules and the free interstitial water (which will affect ionic exchange rates between the free and bound water) reduces the amplitude of the MR signal within the bounding perineureum. Specifically, a percentage of the bright "spots" will become

10   no longer visible. Pathologic tissues will appear darker in MR images than do normal tissues, and the presence of fasciculi will be less apparent.

The presence of fasciculi can be partially detected by direct visual inspection of cross-sectional MR images. But

15   determination of the number or percentage of fasciculi present in a cross-section, comparisons between different sections is not satisfactory via visual inspection alone. It is often not possible to resolve darker fasciculi and small changes in signal amplitude may go unobserved.

20   The method of the present invention is thus used to generate three-dimensional images of the fasciculi, which can be visualized in a static format, or which may be rotated about the (approximate) long axis of the trunk. The latter enhances the visualization process. Because the three-dimensional

25   image can be limited to the fasciculi, the local density of these structures within the trunk, and their brightness (signal amplitude) are now relatively easy to visualize directly.

With the present invention, it is now possible to quantify nerve trunk demyelination values from the generated ima-

30   ges, which were heretofore measured either invasively or subjectively. Nerve tissue demyelination is determined by first calculating the volume of fascicular tissue as a percentage of the volume of the gross trunk (tract) structure. Next, the area of fascicular tissue as a percentage of the area of

35   the gross trunk (tract) structure as seen in selected cross-

sections of the trunk (tract) is calculated. The contiguous cross sectional areas of the trunk (tract) of specified thickness (i.e., 1 mm) perpendicular to the long axis is then calculated.

5   The percentage of volume of fascicular tissue as a percentage of total volume of the trunk (tract) in contiguous cross-sections is calculated next. A graphical display of the percentage volumes obtained vs. location of the sections on the central axis of the trunk is then constructed. The
10   variation of myelin content as indicated by these percentage values is a measure of the neurophysiologic (flow efficiency) status of the trunk (nerve) and thus a diagnostically significant index.

       This technique enables a comparison of the percentage of
15   fascicular tissue present, for example, in the forearm (where entrapment and compression is unlikely), with the value for fascicular tissue within the carpal tunnel, and in regions of the trunk distal to the carpal tunnel. It is also possible to compare fascicular percentages in homologous regions from
20   different individuals (compare between patients).

       The method of the present invention thus allows for the fascicular percentages to be calculated for cross-sectional areas of a nerve trunk. For the median nerve, fascicular percentages for 1 mm thick contiguous sections normal to the
25   long axis of the trunk may be calculated, and then represented as a bivariate plot of percentage of fascicular material present vs. location within the trunk. This graphical representation provides the CTS diagnostician with a simple and direct means of determining in which precise regions of the
30   median nerve trunk a loss of fascicular material has occurred, and the amount of fascicular tissue lost.

       A drawback in using MR images for inter-patient comparisons is that the scale of gray-level values representing different types of tissue is scanner dependant and consequently
35   varies between scanners. Magnetic Transfer Imaging (MTI) is

a new technique that has two advantages over conventional MR imaging when applied to analysis of nerve trunks. First, the in-plane resolution is improved. Second, the data values obtained with this technique are not scanner dependant and

5   consequently direct inter-patient comparisons are possible.

The possibility of using MTI for the analysis of nerve tissue has been discussed in the literature. The loss of bound protons in the degenerating myelin sheath has the effect, via magnetic transfer, of depressing the MR signal

10   from free protons in the immediate vicinity of the fasciculi. The Magnetic Transfer function can be calculated, and the resultant values used to create MT images. Thus, MTI is particularly well-suited for use with the methods and apparatus of the present invention.

15   The method and apparatus of the present invention are also well-suited for the diagnosis of nerve pathology. In diagnostic methods according to the present invention, a clinical examination is typically first performed to deter-mine the likely location of nerve pathology. A high-resolu-

20   tion magnetic image of the region is then obtained.

The MR data comprises thin (1 mm) contiguous slices in a plane which is more or less normal to the axis of the nerve. High resolution images can be obtained by using scan times up to ten minutes.

25   Post-scan data processing is then applied to the MR data. MR hard-copy (acetate) is not required. The three-dimensional MR data is loaded into the three-dimensional imaging software. Steps in the subsequent data processing are as follows:

30   The original MR slices are displayed. The nerve is identified and image contrast adjusted to maximize its visualization by the operator. This contrast adjustment does not affect the signal differential marking the boundary of the nerve, and is not a factor in subsequent segmentation.

The size of the data set is reduced by data clipping to discard all data except that in the immediate vicinity of the nerve. Once a region of interest has been defined, clipping

5   is automatic; thus, the size of the region of interest relates to the position of the nerve on successive images.

Interpolation of the imaging data is then performed. The original voxels are prismatic; i.e., in the Z direction (thickness of image-slice) they are usually 1 mm. The dimen-

10   sions of X and Y (in the plane of the slice) depend on the imaging protocol. Typically X and Y are 0.5-0.7 mm. Cubile voxels are required for 3-dimensional rendering; thus, it is necessary to interpolate the data set in the Z direction in order to obtain slices corresponding in thickness to the X,Y

15   dimensions. The interpolation process is not simple data averaging; it utilizes a sophisticated algorithm which identifies the "shape" of regions of consistent signal in contiguous slices and calculates intermediate "shapes" (assuming linearity in shape change between slices). Shape based in-

20   terpolation has been shown to produce highly accurate information in the interpolated slices. Interpolation is usually performed after clipping and segmentation on the binary image produced. This reduces the time required to perform interactive contouring during the process of segmentation.

25   Automatic segmentation of MR data is difficult because of the non-linear signal. At present several different techniques are used to contour the boundary of the region of interest on the original MR images. They are interactive, live-wire and live-path contouring.

30   With interactive segmentation the operator traces the boundary of the nerve trunk section, recording coordinates on the boundary in so doing. In live-wire segmentation, the boundary of the nerve as seen in cross-section is identified by the operator and indicated to the computer. The computer

35   is thus able to identify subsequently contiguous voxels with the same boundary signal characteristics. Once the boundary

has been identified, the operator can indicate a starting
point on it, then move the cursor to a next point some
distance away from the first.

5   The computer is able to track the boundary between the
two points using the boundary information provided, and draws
a colored line to mark it. Because the boundary signal var-
ies, and the presence of adjacent non-boundary pixels with
similar signal characteristics, the boundary selected auto-
matically may vary from that which the operator judges to be
10   correct. In this case the boundary is redefined at the point
of divergence (i.e., the boundary-contour is corrected) and
the technique of indicating points at intervals along the
boundary is continued until the boundary is closed. Boundary
identification during contouring is used to refine the suite
15   of signal characteristics used by the computer to determine
the boundary automatically. After one or two boundaries have
been contoured it is usually only necessary to indicate two
or three points to obtain a complete, accurate boundary.

       This technique can be extended to automatic identifica-
20   tion of the boundary in subsequent slices, which speeds up
the procedure. Usually the operator examines the automatic-
ally generated boundary contours and can correct any errors.
The continually refined boundary characteristics are stored
by the computer and can be utilized to segment other data
25   sets obtained via similar imaging protocols.

       Live-path contouring is similar to live-wire contouring,
but the computer only seeks boundary characteristics coincid-
ing with those defined for it in a "path" of limited width on
either side of the cursor. It is possible to run the cursor
30   rapidly around the region of interest, without following the
boundary exactly, to describe a contour within the limits of
the defined path, for a very rapid method of contouring.

       Live-wire and live-path contouring techniques are norm-
ally carried out on all the original MR slices. However,
35   these techniques may be developed so that contours are only

defined interactively on the first two or three slices, after
which the computer will search for the corresponding boundary
in the remaining slices and contour them automatically.

5   The segmentation techniques output the surface boundary
of the region of interest by a binary separation of the three
dimensional data based on those voxels within the boundary
and those without it. Three-dimensional imaging of the bin-
ary data therefore yields a "solid" object. However, the
boundary surface can be used as a "mask" to extract MR data
10   within the region of interest from the original three-dimen-
sional MR data matrix. The extracted MR data set is referred
to as a gray-level image.

        The gray-level image thus contains information about the
tissue microstructures contained within the nerve trunk. The
15   gray-level values for nerve fasciculi, matrix, and perineur-
eum comprise distinct and overlapping populations. In the
region of signal overlap the percentage of signal belonging
to each material can be ranges of signal values assigned
accordingly. This allows the different tissue types to be
20   resegmented automatically based on this histographic data.
The histographic resegmentation may be performed iteratively
in order to resolve any signal overlap to obtain the best
visualization of the nerve tissue microstructures (i.e.,
visualization of the very distinctive fasciculi).

25   Opacity, emission and surface strength parameters opti-
mal for visualization of the nerve microstructures are then
determined by creation of three-dimensional images and exam-
ination of the anatomy. Once values have been determined for
these parameters, they may be used for more automated imaging
30   in subsequent data sets. Improvement of visualization by ad-
justing these parameters is a distinct process from segmenta-
tion and does not select the tissue concerned from its sur-
rounding matrix.

        The output is visual and numerical. Visual results con-
35   sist of three-dimensional renderings of the trunk, including

a compound image of the gross structure, which includes the perineurium, fascicles and interfascicular tissue. The opacity of the perineurium is set so that this tissue is translucent. This enables the content of the nerve trunk to be

5   viewed in the context of the perineurium. Similarly, the opacity of the interfascicular tissue is set to be greater than that of the perineurium, but less than that of the fascicles. The result is to display the microstructures of the nerve in their correct anatomic relationships.

10   To enhance the three-dimensionality of the image, and to enable the anatomic relationships to be examined from all angles, the image is rotated about its long axis and recorded as multiple "frames" which are stored in a "cine" file. This is performed using conventional MR imaging software. Images

15 are also created containing each of the material sets separately, and cine files created for each. These images allow direct examination of each microstructure separately.

A compound image consisting of the perineureum and fasciculae is also created and rendered in a cine file. This

20 image allows the texture and thickness of the perineureum to be examined in the context of the fasciculi, and regions of membrane thickening or thinning compared with regions of MR signal fluctuation in the fasciculi.

The numerical output includes the cross-sectional area

25 value for the nerve trunk normal to its long axis, calculated continuously throughout its length and displayed in a bivariate plot of cross-sectional area vs. section location. A similar bivariate plot is calculated to show the density of fascicular material within the cross-section vs. location.

30   The parameters measured by the method and apparatus of the present invention for nerve tissue include the general morphology of the trunk (tract), the cross-sectional morphology, the size and distribution of the nerve fasciculi and the density of the fasciculi within cross-sections of the nerve

trunk.   These parameters are associated with physiologic
changes accompanying nerve damage and dysfunction.

5   Gross morphology and cross-sectional morphology are phy-
sical reflections of the pressure environment.   It is well
known that in regions of pressure a peripheral nerve reorgan-
izes by becoming flattened in a plane normal to the compress-
ive force.   The amount of flattening almost certainly relates
to altered function, but the sensitivity of the relationship
10   may not be adequate for the purpose of early diagnosis.

In regions of compression the size of the fascicles de-
creases, but they increase in number, forming smaller bund-
les.   The cross-section of the neurites can be measured.

However, cross-sectional fascicular density is a measure
15   of MR signal from the "fascicular material" present in the
section.   The MR signal may be expected to vary with the his-
tochemistry of the nerve fibers (neurites) and their interst-
itial environment.   This includes changes in the structure
and chemistry of the myelin sheaths (composed of complex
20   lipids and a high percentage of bound water) and in the ionic
environment of the neurite and interstitial tissues.   Thus,
variation in the MR signal is an indicator of functional
changes in the neurites, including those due to trauma.

Signal variation can be detected in two ways.   One way
25   is by direct examination of the final image. Regions of nerve
trauma are likely to be represented by localized disappear-
ance of the fasciculi.   The extent of fascicular disappear-
ance is an indication of the severity of the nerve damage.
The MR signal variation can also be quantified by measuring
30   the density of the fascicular material in cross-sections of
the nerve trunk and plotting this data against the locations
of the cross-sections.

Neural flow studies can be made on the median nerve in
the region of the carpal tunnel because of the very superfic-
35   ial placement of the trunk in this region.   However, neuro-

pathies occur in other regions, both within and outside the
central nervous system where neural flow studies are impract-
ical because of the depth of the trunk. The methods and app-
aratus of the present invention provide an innovative means
5   of diagnosing and assessing neuropathy in such deep periph-
eral nerves, and in portions of the central nervous system.

The neuropathy need not be associated with compression
or other trauma, but may also result from other causes, such
as multiple sclerosis and related diseases. Until now it was
10 not possible to assess quantitatively the progression of a
disease like multiple sclerosis, or the effectiveness of
treatment. Instead, practitioners were forced to rely upon
the subjective assessment of the patient. This was particu-
larly inaccurate in most circumstances, in which patients
15 want to believe that a treatment is working and relate their
well-being from this perspective.

The methods and apparatus of the present invention may
also be used to assess other tissues that are inaccessible
because of their depth within the body, including vascular
20 tissues and tumor tissues. The present invention makes it
possible to visualize vascular blockage, as well as tumor
tissue boundaries. The ability to visualize tumor tissue
boundaries makes the present invention a particularly useful
tool for the cancer surgeon.

25   Proof of the concept of method of the invention for the
analysis of neuropathy was obtained via a feasibility study
of the median nerve in patients diagnosed with CTS and non-
symptomatic subjects. The feasibility study is presented to
illustrate certain aspects of the invention, and should not
30 be interpreted as limiting the scope of the invention as it
is defined by the claims.

Twenty wrists, including four cadaver wrists, were
scanned and analyzed using the technique described above.
Subjects scanned in vivo included clinically diagnosed

patients with severe CTS, less severe CTS, and control
(asymptomatic) subjects.

Results showed:

a. Clear feasibility of "dissecting" and quantifying
5   nerve trunk structures is possible using this analytic sys-
tem. A prior art axial cross-section of a wrist obtained by
magnetic resonance imaging is shown in Fig. 3. The cross-
sectional image includes the median nerve and associated
tendons and carpal bones. This Figure illustrates how such
10 images provided little information of clinical diagnostic
value relating to neurophysiology.

A magnetic resonance image of a healthy median nerve
trunk constructed by the method and apparatus of the present
invention is shown in Fig. 4. The white streaks are bundles
15 of myelinated nerve fibers, i.e., fasciculi. This is in
contrast to the magnetic resonance image of a median nerve
trunk of a patient afflicted with CTS, shown in Fig. 5, and
also constructed by the method and apparatus of the present
invention. The nerve fiber demyelination is dramatically
20 evident.

b. MR signal amplitude was reduced where the nerve trunk
passes beneath the flexor retinaculum. Reduction of signal
amplitude is modest in subjects with no clinical symptoms of
CTS, but becomes increasingly significant with CTS symptoms,
25 and is pronounced in subjects diagnosed with severe CTS.

The four cadaver wrists were also subjected to MR
scanning. Evidence of demyelination in these wrists was
partially confirmed by extirpation of the median nerve from
the carpal tunnel and histologic sectioning and staining.

30   Conclusions:

The results strongly supported the hypothesis that nerve
degeneration can be detected and localized in CTS. The ex-

tent of degeneration determined by this procedure in CTS pat-
ients appears to be associated with the severity of symptoms.

Thus, using the methods and apparatus of the present
invention, it is possible to determine if demyelination has
5 occurred, the percentage of myelin loss in the affected
region compared with other "functionally normal" regions, and
to precisely localize the neuropathy. This provides a non-
invasive, objective and quantified diagnostic procedure.

As will be readily appreciated, numerous variations and
10 combinations of the features set forth above can be utilized
without departing from the pre-sent invention as set forth in
the claims. Such variations are not regarded as a departure
from the spirit and scope of the invention, and all such
variations are intended to be included within the scope of
15 the following claims.

WHAT IS CLAIMED IS:

   1. A method for the non-invasive imaging of an anatomic tissue structure in isolation from surrounding tissues, comprising:

5   receiving from an input device, magnetic imaging data from a patient of said anatomic tissue structure and said surrounding tissues;

   segmenting said imaging data to isolate said anatomic tissue structure imaging data from said imaging data for said 10 surrounding tissues;

   separating said anatomic tissue structure imaging data into data populations corresponding to tissue microstructures;

   constructing an image from imaging data for at least one 15 of said tissue microstructures; and

   storing or displaying said image.

   2. The method of claim 1, wherein said magnetic imaging data is acquired by magnetic resonance imaging.

   3. The method of claim 1, wherein said magnetic imaging 20 data is acquired by magnetic transfer imaging.

   4. The method of claim 1, wherein said anatomic tissue structure imaging data is separated into said microstructure data populations by histographic resegmenting.

   5. The method of claim 4, wherein said histographic 25 resegmenting is performed iteratively to separate any over-lapping microstructure data populations.

   6. The method of claim 1, wherein said image is displayed as a visual image.

7. The method of claim 1, wherein said anatomic tissue structure is segmented by interactive contouring.

8. The method of claim 1, wherein said anatomic tissue structure is segmented by live-wire contouring.

9. The method of claim 1, wherein said anatomic tissue structure is segmented by live-path contouring.

10. The method of claim 1, wherein said constructing step comprises constructing a compound image of said anatomic tissue structure from imaging data for a plurality of said tissue microstructures.

11. The method of claim 10, further comprising the step of adjusting at least one of the material opacity, emission and surface reflection for at least one of said tissue microstructures to enhance the visualization of said compound image.

12. The method of claim 1, wherein said target tissue is a nerve trunk or tract.

13. The method of claim 12, wherein said microstructures comprise the perineureum, fasciculi and inter-fascicular tissue.

14. The method of claim 13, further including the step of calculating from fasciculi imaging data the presence or loss of myelin in said nerve trunk or tract.

15. The method of claim 14, further including the step of comparing said myelin calculation to a myelin calculation obtained for another portion of said nerve trunk or tract.

16. The method of claim 12, wherein said nerve trunk or tract is the median nerve.

17. The method of claim 1, wherein said anatomic tissue is tumor tissue.

18. The method of claim 1, wherein said anatomic tissue is vascular tissue.

5   19. An apparatus comprising:

an input device for receiving magnetic imaging data from a patient;

a processing unit comprising:

10   a first program for segmenting magnetic imaging data to isolate imaging data for a anatomic tissue structure from imaging data for surrounding tissues;

            a second program for separating said anatomic tissue structure imaging data into data populations
15   corresponding to tissue microstructures;

            a third program for constructing an image from imaging data for at least one of said microstructures; and

            a processor for sequentially executing said first, second and third programs;

20   wherein said processor executes:

                said first program using said imaging data from said input device;

                said second program using said anatomic tissue
25   structure imaging data isolated by execution of said first program; and

                said third program using at least one of said data populations obtained by execution of said second program; and

an output device for displaying said image or a storage device for storing said image.

20. The apparatus of claim 19, wherein said second program separates said anatomic tissue structure imaging data into said microstructure data populations by histographic resegmenting.

21. The apparatus of claim 20, wherein said second program is executed iteratively by said processor to separate any overlapping microstructure data populations.

22. The apparatus of claim 19, wherein said first program segments said imaging data by interactive contouring.

23. The apparatus of claim 19, wherein said first program segments said imaging data by live-wire contouring.

24. The apparatus of claim 19, wherein said first program segments said imaging data by live-path contouring.

25. The apparatus of claim 19, wherein said output device is a visual display device.

26. The apparatus of claim 20, further comprising an output device for displaying the histograph obtained by said histographic resegmenting.

27. The apparatus of claim 19, wherein said input device comprises a device for receiving imaging data of a nerve trunk or tract and surronding tissues; said second program separates said nerve trunk or tract imaging data into data populations corresponding to fasciculi and other nerve trunk or tract microstructures; said processing unit further comprises a fourth program for calculating from fasciculi imaging data the presence or loss of myelin in a nerve trunk or tract, wherein said processor executes said fourth program after the execution of said second program using imaging data for nerve trunk fasciculi obtained by execution of said

second program; and said output device comprises a device for
displaying said myelin calculation or a storage device for
storing said myelin calculation.

5   28. The apparatus of claim 27, wherein said processing
unit further comprises a fifth program for comparing myelin
calculations from different nerve trunks or tracts or differ-
ent portions of the same nerve trunk or tract, wherein said
processor executes said fifth program after the execution of
10   said fourth program using the myelin calculations obtained by
execution of said fourth program.

        29. The apparatus of claim 26, wherein said output
device is a visual display device.

        30. A method for imaging demyelination of the median
15   nerve within one of a patient's carpal tunnels, comprising:

        receiving from an input device, magnetic imaging data
from a patient comprising at least a portion of the median
nerve passing through a carpal tunnel;

        segmenting said imaging data to isolate the median nerve
20   imaging data from imaging data for surronding tissues;

        separating said median nerve imaging data into data pop-
ulations corresponding to the fasciculi and other microstruc-
tures of said median nerve;

        constructing an image from at least said imaging data
25   for said fasciculi of said median nerve; and

        storing or displaying said image.

        31. The method of claim 30, wherein said method further
includes the step of calculating from said imaging data for
said median nerve fasciculi the presence or loss of myelin in
30   said portion of said median nerve passing through said carpal
tunnel, and storing or displaying said myelin calculation.

32. The method of claim 30, wherein said median nerve imaging data is separated into microstructure data populations by histographic resegmenting.

33. The method of claim 32, wherein said histographic
5   resegmenting is performed iteratively to separate any over-lapping data populations.

34. The method of claim 30, wherein said median nerve imaging data is segmented by interactive contouring.

35. The method of claim 30, wherein said median nerve
10 imaging data is segmented by live-wire contouring.

36. The method of claim 30, wherein said median nerve imaging data is segmented by live-path contouring.

37. The method of claim 30, wherein said median nerve microstructures also include the perineurium and inter-
15 fascicular tissue.

38. The method of claim 30, wherein said imaging data is acquired by magnetic resonance imaging.

39. The method of claim 30, wherein said imaging data is acquired by magnetic transfer imaging.

20   40. The method of claim 30, wherein said constructing step comprises constructing a compound image of said median nerve comprising imaging data from a plurality of said nerve tissue microstructures.

41. The method of claim 40, wherein at least one of the
25 material opacity, emission and surface reflection for at least one of said microstructures of said compound image are adjusted to enhance the visualization of said median nerve.

42. The method of claim 41, wherein said compound image also includes the perineurium and inter-fascicular tissue,

and the opacity of said inter-fascicular tissue is set to be greater than the opacity of said perineurium, but less than that of said fasciculi.

43. The method of claim 42, wherein said opacity of said
5 perineurium is set to appear translucent.

44. The method of claim 30, further comprising the step of comparing said myelin calculation to a myelin calculation obtained for another portion of said median nerve.

45. The method of claim 30, further comprising the step
10 of comparing said myelin calculation to a myelin calculation obtained for the median nerve within said patient's other carpal tunnel.

46. A method for the imaging a nerve trunk or tract suspected of demyelination comprising:

15   receiving from an input device, magnetic imaging data from a patient of a nerve trunk or tract suspected of demyelination and the surrounding tissues;

      segmenting said imaging data to separate said imaging data for said nerve trunk or tract from said imaging data for
20 said surrounding tissues;

      separating said imaging data for said nerve trunk or tract into data populations corresponding to the fasciculi and other microstructures of said nerve trunk or tract;

      constructing an image from at least said imaging data
25 for said fasciculi of said nerve trunk or tract; and

      storing or displaying said image.

47. The method of claim 46, further including the step of calculating from said fasciculi imaging data the presence or loss of myelin in said nerve trunk or tract suspected of

demyelination, and storing or displaying said myelin calculation.

48. The method of claim 46, wherein said imaging data for said nerve trunk or tract is separated into microstruc-
5   ture data populations by histographic resegmenting.

49. The method of claim 48, wherein said histographic resegmenting is performed iteratively to separate any overlapping microstructure data populations.

50. The method of claim 46, wherein said imaging data
10   for said nerve trunk or tract is segmented by interactive contouring.

51. The method of claim 46, wherein said imaging data for said nerve trunk or tract is segmented by live-wire contouring.

15   52. The method of claim 46, wherein said imaging data for said nerve trunk or tract is segmented by live-path contouring.

53. The method of claim 46, wherein said microstructures of said nerve trunk or tract also include the perineureum and
20   inter-fascicular tissue.

54. The method of claim 46, wherein said imaging data is acquired by magnetic resonance imaging.

55. The method of claim 46, wherein said imaging data is acquired by magnetic transfer imaging.

25   56. The method of claim 46, wherein said constructing step comprises constructing a compound image of said nerve trunk or tract comprising imaging data from a plurality of nerve tissue microstructures.

57. The method of claim 56, wherein at least one of the material opacity, emission and surface reflection for at least one of said microstructures of said compound image is adjusted to enhance the visualization of said nerve trunk or
5   tract.

58. The method of claim 57, wherein said compound image also includes the perineurium and inter-fascicular tissue, and the opacity of said inter-fascicular tissue is set to be greater than the opacity of said perineurium, but less than
10 that of said fasciculi.

59. The method of claim 58, wherein said opacity of said perineurium is set to appear translucent.

60. The method of claim 47., further comprising the step of comparing said myelin calculation to a myelin calculation
15 obtained for another portion of said nerve trunk or tract.

61. The method of claim 46, wherein said nerve trunk or tract is the median nerve.

62. An apparatus comprising:

an input device for receiving magnetic imaging data from
20 a patient for a nerve trunk or tract and the surrounding
    tissues;

a processing unit comprising:

        a first program for segmenting said magnetic
        imaging data for said nerve trunk or tract from said
25   magnetic imaging data for said surrounding tissues;

        a second program for separating said nerve trunk or
        nerve trunk imaging data into data populations corres-
        ponding to fasciculi and other nerve trunk or tract
        microstructures;

a third program for calculating the presence or loss of myelin in said nerve trunk or tract from said fasciculi imaging data; and

a processor for sequentially executing said first,
5   second and third programs;

wherein said processor executes:

said first program using imaging data from said input device;

said second program using said nerve trunk or
10   track imaging data isolated by execution of said first program; and

said third program using said fasciculi data population obtained by execution of said second program; and

15   an output device for displaying said myelin calculation or a storage device for storing said myelin calculation.

63. The apparatus of claim 62, wherein said second program separates said nerve trunk or tract imaging data into said microstructure data populations by histographic
20 resegmenting.

64. The apparatus of claim 63, wherein said second program is executed iteratively by said processor to separate any overlapping microstructure data populations.

65. The apparatus of claim 62, wherein said first
25 program segments said imaging data by interactive contouring.

66. The apparatus of claim 62, wherein said first program segments said data by live-wire contouring.

67. The apparatus of claim 62, wherein said first program segments said data by live-path contouring.

68. The apparatus of claim 62, wherein said output device is a visual display device.

69. The apparatus of claim 63, further comprising an output device for displaying the histograph obtained by said histographic resegmenting.

70. The apparatus of claim 62, wherein said processing unit comprises a fourth program for comparing myelin calculations obtained from different nerve trunks or tracts or different portions of the same nerve trunk or tract, wherein said processor executes said fourth program after the execution of said third program using myelin calculations obtained by execution of said third program.

71. A method for the quantitative measurement of a nerve trunk or tract suspected of demyelination, comprising:

receiving from an input device, magnetic imaging data from a patient of a nerve trunk or tract suspected of demyelination and the surronding tissues;

segmenting said imaging data to separate said imaging data for said nerve trunk or tract from said imaging data for said surrounding tissues;

separating said imaging data for said nerve trunk or tract into data populations corresponding to the fasciculi and other microstructures of said nerve trunk or tract;

calculating from said fasciculi imaging data the presence or loss of myelin in said nerve trunk or tract; and

storing or displaying said myelin calculation.

72. The method of claim 71, wherein said imaging data for said nerve trunk or tract is separated into microstructure data populations by histographic resegmenting.

73. The method of claim 72, wherein said histographic resegmenting is performed iteratively to separate any overlapping microstructure data populations.

74. The method of claim 71, wherein said imaging data for said nerve trunk or tract is segmented by interactive contouring.

75. The method of claim 71, wherein said imaging data for said nerve trunk or tract is obtained by live-wire contouring.

76. The method of claim 71, wherein said imaging data for said nerve trunk or tract is obtained by live-path contouring.

77. The method of claim 71, wherein said imaging data is acquired by magnetic resonance imaging.

78. The method of claim 71, wherein said imaging data is acquired by magnetic transfer imaging.

79. The method of claim 71, further comprising the step of comparing said myelin calculation to a myelin calculation for another portion of said nerve trunk or tract.

80. The method of claim 71, wherein said nerve trunk or tract is the median nerve.

81. A method for the quantitative measurement of median nerve demyelination within one of a patient's carpal tunnels, comprising:

receiving from an input device, magnetic imaging data from a patient including at least a portion of the median nerve passing through a carpal tunnel:

5   segmenting said imaging data to isolate said median nerve imaging data from any imaging data for surrounding tissues;

separating said median nerve imaging data into data populations corresponding to the fasciculi and other micro-structures of said median nerve;

10   calculating from said imaging data for said median nerve fasciculi, the presence or loss of myelin in said median nerve within said carpal tunnel; and

storing or displaying said myelin calculation.

82. The method of claim 81, wherein said median nerve
15   imaging data is separated into microstructure data populations by histographic resegmenting.

83. The method of claim 82, wherein said histographic resegmenting is performed iteratively to separate any over-lapping data populations.

20   84. The method of claim 81, wherein said median nerve imaging data is segmented by interactive contouring.

85. The method of claim 81, wherein said median nerve imaging data is segmented by live-wire contouring.

86. The method of claim 81, wherein said median nerve
25   imaging data is segmented by live-path contouring.

87. The method of claim 81, wherein said imaging data is acquired by magnetic resonance imaging.

88. The method of claim 81, wherein said imaging data is acquired by magnetic transfer imaging.

89. The method of claim 81, further comprising the step of comparing said myelin calculation to a myelin calculation obtained for another portion of said median nerve.

90. The method of claim 81, further comprising the step of comparing said myelin calculation to a myelin calculation obtained for the median nerve within said patient's other carpal tunnel.

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FIG. 1

FIG. 2

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┌─────────────────────┐
│   ACQUIRE MAGNETIC  │ ⟋28
│   IMAGING DATA FOR  │
│   AXIAL NERVE SLICES│
└─────────────────────┘
           │
           ▼
┌─────────────────────┐
│   TRANSFER DATA FOR │ ⟋30
│      POST-SCAN      │
│     PROCESSING      │
└─────────────────────┘
           │
           ▼
┌─────────────────────┐
│      CONSTRUCT      │ ⟋32
│   GRAY-LEVEL IMAGES │
└─────────────────────┘
           │
           ▼
┌─────────────────────┐
│  IDENTIFY NERVE TRUNK│ ⟋34
│  IN GRAY-LEVEL SLICES│
└─────────────────────┘
           │
           ▼
┌─────────────────────┐
│   CLIP AXIAL SLICES │ ⟋36
└─────────────────────┘
           │
           ▼
┌─────────────────────┐
│  SEGMENT NERVE TRUNK │ ⟋38
└─────────────────────┘
           │
           ▼
┌─────────────────────┐
│   MASK SEGMENTED    │ ⟋40
│   NERVE BOUNDARIES  │
└─────────────────────┘
           │
           ▼
┌─────────────────────┐
│  SEGMENT NERVE TRUNK │ ⟋42
│ ALONG MASKED BOUNDARY│
└─────────────────────┘
           │
           ▼
┌─────────────────────┐
│   HISTOGRAPHICALLY  │ ⟋44
│ RESEGMENT NERVE TRUNK│
└─────────────────────┘
           │
           ▼
┌─────────────────────┐
│INTERPOLATE RESEGMENTED│ ⟋46
│        DATA         │
└─────────────────────┘
           │
           ▼
┌─────────────────────┐          ┌─────────────────────┐
│   CONSTRUCT IMAGE   │ ⟋48 ───▶ │  CALCULATE MYELIN   │ ⟋52
└─────────────────────┘          │      CONTENT        │
           │                     └─────────────────────┘
           ▼                                │
┌─────────────────────┐                     ▼
│    DISPLAY IMAGE    │ ⟋50      ┌─────────────────────┐
└─────────────────────┘          │ DISPLAY MYELIN CONTENT│ ⟋54
                                 └─────────────────────┘
```
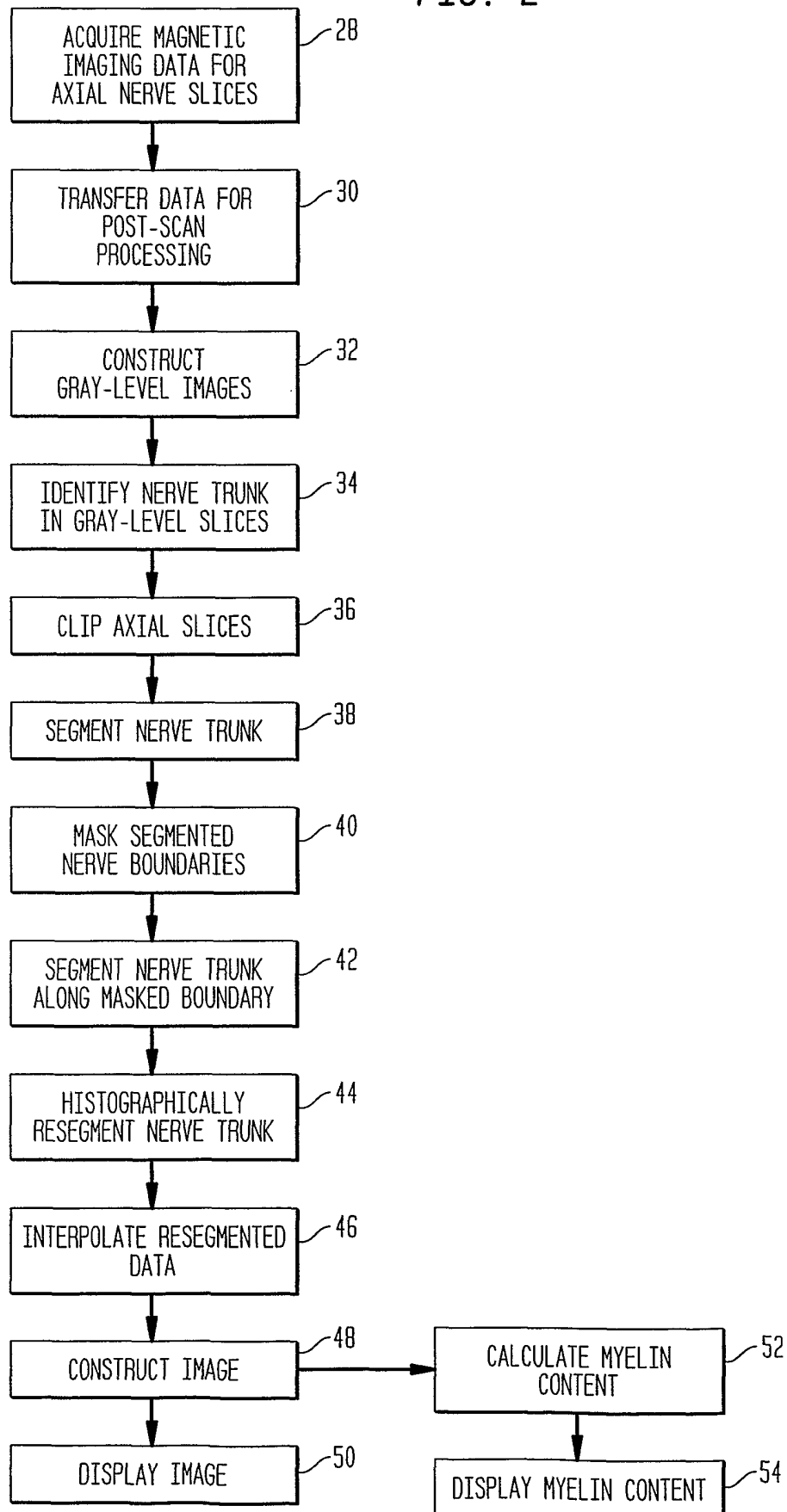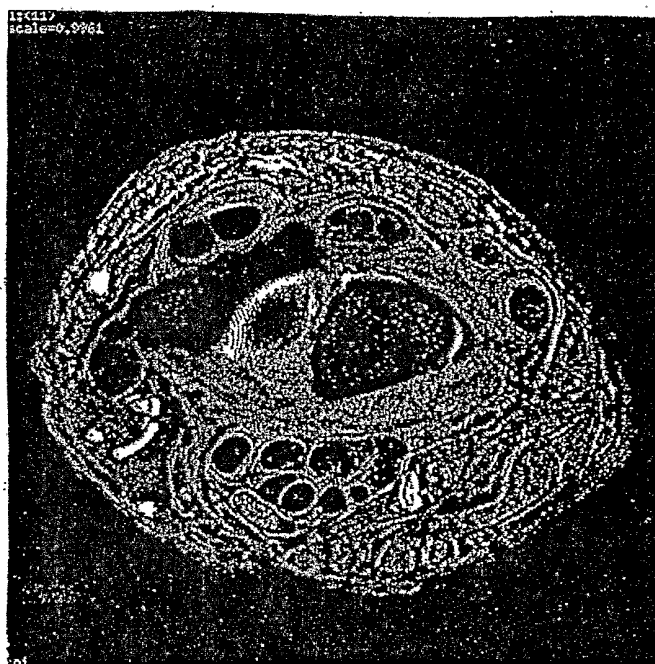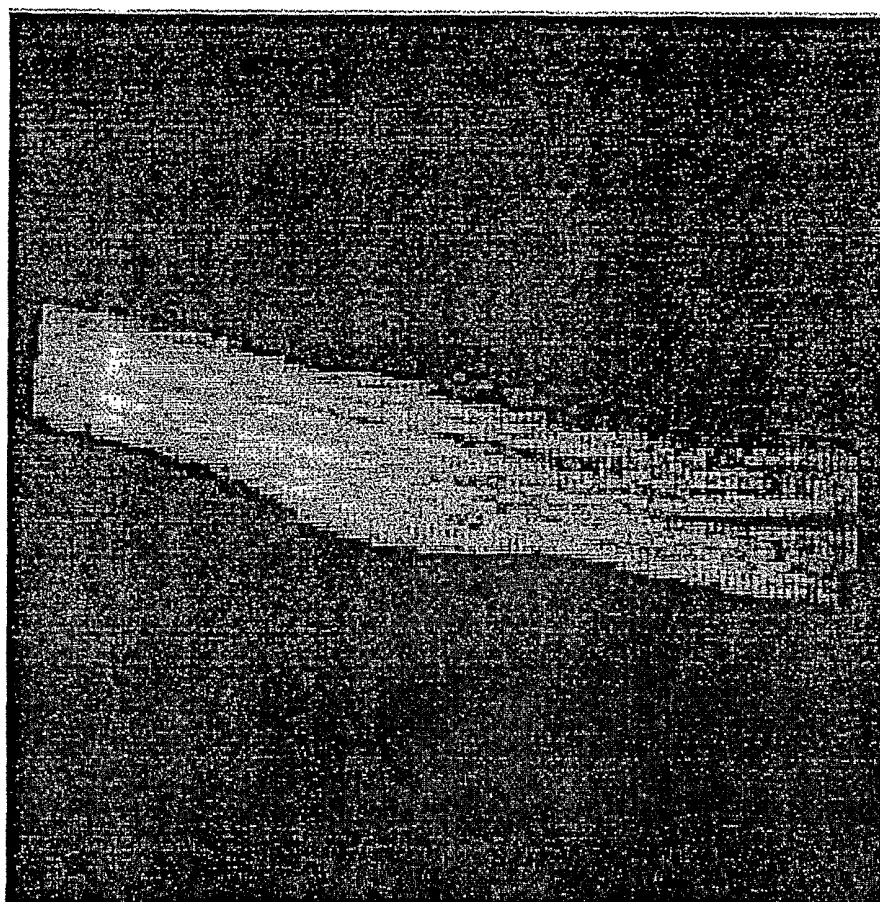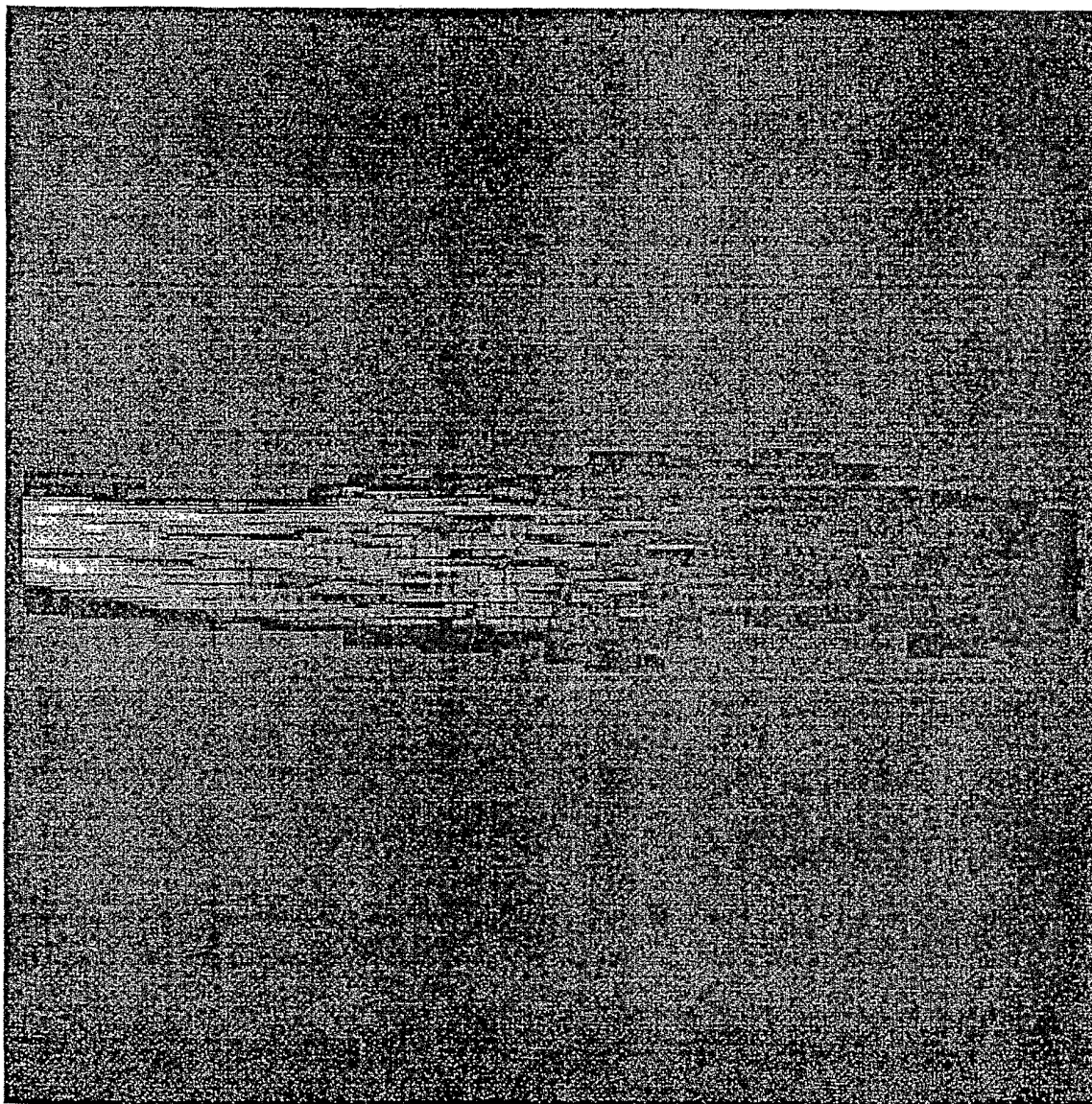
SUBSTITUTE SHEET (RULE 26)

3/5
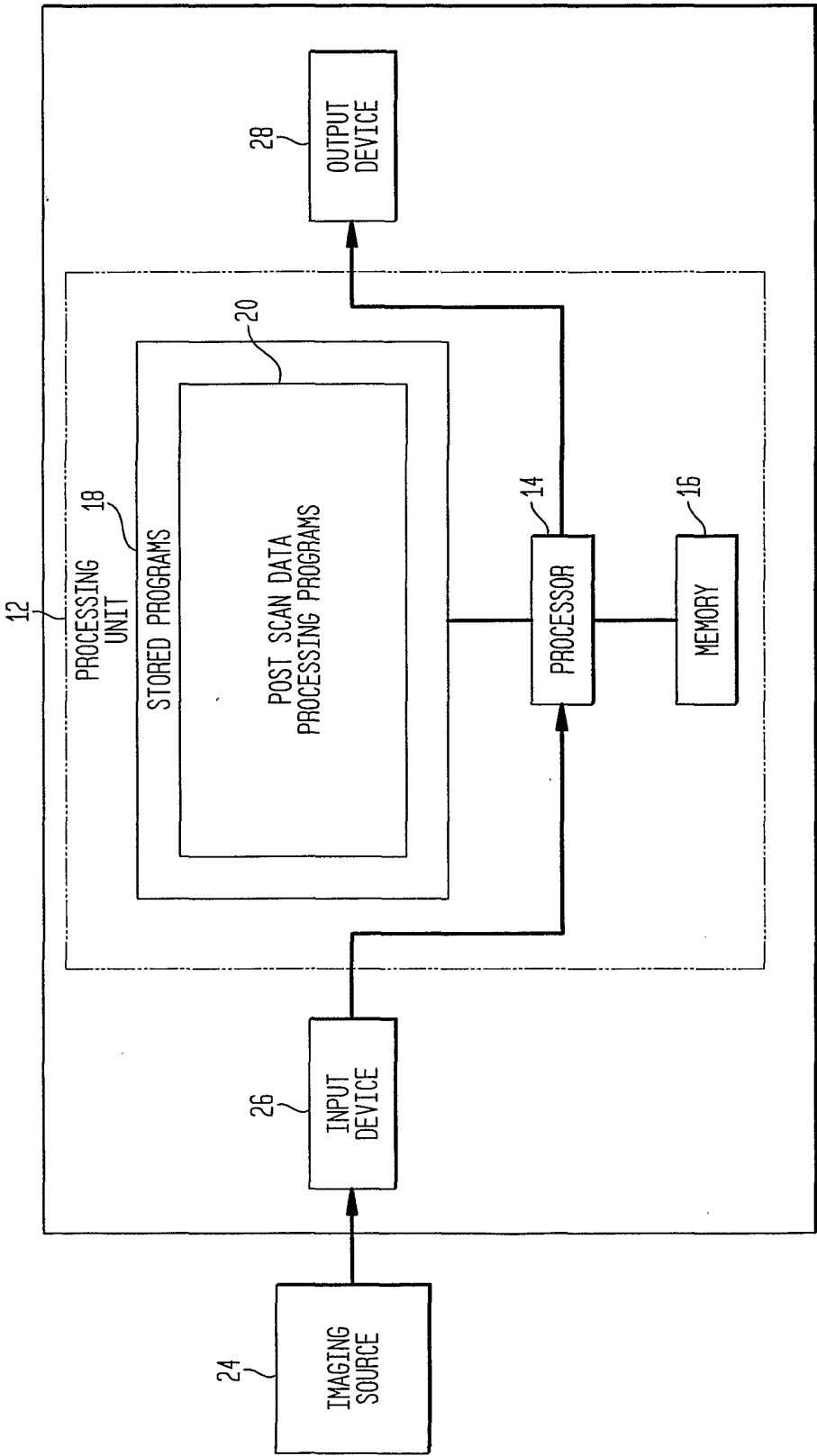
FIG. 3
(PRIOR ART)

FIG. 4

FIG. 5

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7   A61B5/055   G06T5/00   G01R33/56

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7   A61B   G06T   G01R

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, MEDLINE, PAJ, WPI Data, INSPEC, BIOSIS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 560 360 A (HOWE FRANKLYN A ET AL) 1 October 1996 (1996-10-01)	1-4,6, 10-20, 25-32, 37-48, 53-63, 68-72, 77-82, 87-90
	column 6, line 12 -column 7, line 15 column 18, line 53 - line 65 column 27, line 4 -column 28, line 51 column 32, line 10 - line 16 column 32, line 39 - line 47; claims 1-3	
Y		5,7,21, 22,33, 34,49, 50,64, 65,73, 74,83,84
	-/--	

| X | Further documents are listed in the continuation of box C. | | X | Patent family members are listed in annex. |

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
5 October 2001	18/10/2001

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Skalla, J

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INTERNATIONAL SEARCH REPORT

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A	HOWE F A: "MAGNETIC RESONANCE NEUROGRAPHY" MAGNETIC RESONANCE IN MEDICINE, ACADEMIC PRESS, DULUTH, MN, US, vol. 28, no. 2, 1 December 1992 (1992-12-01), pages 328-338, XP000330806 ISSN: 0740-3194 * see the sections "INTRODUCTION" and "CONCLUSIONS" *	1-90
E	US 6 205 235 B1 (ROBERTS DAVID) 20 March 2001 (2001-03-20) * see the whole document *	1-90

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