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(54) Title: CYCLIC CONTROLLED DYNAMIC DEVICE FOR THE CORRECTION OF SPINAL DEFORMITIES

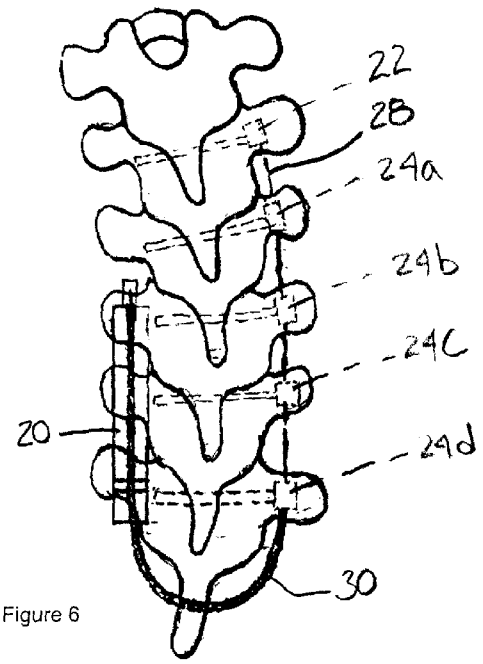

Figure 6

(57) Abstract: A fusionless instrumentation suited for providing initial and long term correction of spinal deformities through the use of combined controlled dynamic recurrent sequences of compression and distraction and mechanical bone growth modulation, respectively. The device seeks to provide controlled dynamic compression to the targeted growth plate over the convexity of a spinal deformity alone or combined with posterior controlled dynamic distraction to the growth plate over contralateral side of the deformity. In turn, this will retard local growth on the convexity of the curve where compression is applied and will accelerate local growth on the concavity of the curve where distraction is applied, resulting in the reduction, elimination, or reversal of vertebral wedging and, consequently, realignment of the spine, using more physiological (controlled dynamic) loadings that allow improved growth modulation, as compared to current fusionless devices which are based on static/non-cyclic principles.

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CYCLIC CONTROLLED DYNAMIC DEVICE FOR THE CORRECTION OF SPINAL DEFORMITIES

FIELD OF THE INVENTION

[0001] The present application relates to the field of correction of spinal deformities devices, such as those used for scoliosis, hyperlordosis, hypokyphosis, and more particularly concerns device for the correction of juvenile and adolescent idiopathic scoliosis.

BACKGROUND

[0002] Growth modulating devices for the correction of spinal deformities has long been attempted. To date, there has been much improvement in instrumentation technologies allowing the development of several new devices and approaches. These devices have been explored in published clinical trials and patent literature. Application of the technology is aimed at reducing, halting or, ideally, reversing the progression of curves in spines with idiopathic scoliosis. Internal bracing has been used for applying static forces between pairs of vertebrae. The concept lies upon the theory that manipulation of local vertebral geometry (as a result of controlling growth) will allow to correct global spinal curvatures that are phenotypic to spinal deformities.

[0003] Known prior art devices seeking to introduce corrective forces within the spine are basically "passive/non-cyclic" systems. Typically, the corrective forces are introduced at the time of surgery and remain under this initial setting over the course of the device`s presence on the spine.

SUMMARY

[0004] It is therefore an aim to provide a surgical device that actively provides dynamic forces for the correction of spinal deformities via growth modulation.

[0005] According to a first aspect, there is provided a surgical instrumentation adapted to be implanted on the vertebral column of a patient, the surgical instrumentation being powered by an actuator which may be externally controlled for varying the force magnitude and loading frequencies as desired over the course of the treatment and disengaged, if desired, following treatment.

[0006] In accordance with another general aspect, there is provided a surgical device aiming at correcting spinal deformities via growth modulation. According to this aspect, bone screws (or any other suitable attachment system) may be inserted into the vertebrae on the convexity (for local growth plate compression) or concavity (for local growth plate tension) of the spinal deformity and are attached to one another with a wire/cable which may be made from a variety of material such as stainless steel 316L, Nickel Titanium, Polyethylene or any other suitable material known by one skilled in the art. Along or at one end of the wire, which can cross one or several vertebrae, an actuator, which may take the form of a small motor and a cam (crankshaft), is attached. This system provides a cyclic type tension (i.e. a sequence of repeated applied forces) in the device's wire or truss, which can be assembled to provide either compression (convexity) or distraction (concavity). Using dynamic compression (or tension) of the growth plates on the convexity (or concavity) of the scoliotic deformity will provide growth modulation, and, as a result, realignment of the spine with physiological (dynamic) loading values that allow better stimulating growth modulation than static loading. Moreover, with a dynamic/cyclic system, as proposed herein, that is exteriorly or interiorly powered and exteriorly or interiorly controlled, the force magnitude and frequencies may be altered as desired over the course of the treatment and disengaged, if desired, following treatment. A force-feedback system may be used to interiorly control the dynamic/cyclic system.

[0007] According to another aspect, there is provided a surgical device suited for use in correcting spinal deformities via lateral, posterior or combined lateral and posterior controlled dynamic bone growth modulation. The device

comprises a first set of bone anchors adapted to be inserted laterally into the vertebrae on the convexity (for compression) of the spinal deformity, and an at least partially flexible force transmitting member interconnecting the bone anchors to one another. The force transmitting member may take the form of a wire/cable, such as a Bowden cable. The force transmitting member, which can cross one or several vertebrae, may comprise an inner cable and hollow outer cable housing. The inner cable is attached at a first end thereof to an actuator, which may be installed on the posterior region of the spine. The inner cable is free to slide longitudinally within the hollow outer cable housing under the action of the actuator. The relative action of the inner cable and the hollow outer cable housing via a cyclic motion of the actuator provides a cyclic type compression action between the bone anchors on the convexity of the deformity. The back and forth or reciprocal movement generated by the actuator allows to apply a cyclic type loading, thereby providing for a desired or recurrent sequence of loading actions. The device may also comprise a second set of anchors (e.g. eyelet type or tulip screws) configured to allow the wire/cable to be guided and to slide freely along the vertebrae.

[0008] According to a further aspect, the cyclic motion of the actuator may be used to apply a distraction force between a bone anchor and the linear actuator which could be fixed on the posterior concave side of the spine via a rod or an at least substantially rigid link.

[0009] Various combinations of the above described components may be used to generate controlled dynamic asymmetrical loading of the growth plates of the scoliotic deformity in order to provide bone growth modulation, and, as a result, realignment of the spine with less soft tissue damage than conventional static loading.

[0010] When attached posteriorly to the spine, the actuator connected to the at least substantially rigid link may also provide the spine with enough distraction forces in the sagittal plane to avoid the reduction of the physiological sagittal curves or to correct kyphotic deformities.

[0011] In accordance with a further aspect, there is provided a system for treating spinal deformities, the system comprising: an exteriorly or interiorly powered implantable actuator having a driving member movable between back and forth positions, a first anchor for posterior anchoring the actuator in a fixed position within the patient's body, at least one force transmitting member operatively connectable to the driving member of the actuator, a second anchor for anchoring the at least one force transmitting member to a vertebral body of a deformed portion of a patient's spine, the actuator being post-operatively controllable for cyclically applying corrective forces to the deformed portion of the patient's spine between said first and second anchors via said force transmitting member.

[0012] In accordance with a further aspect, there is provided a system for treating spinal deformities in skeletally immature spine, the system comprising: at least two vertebral anchors for anchoring into two different vertebral bodies laterally; an actuator post-operatively operable for providing controlled dynamic cyclic loading; at least one flexible force transmitting member attachable at a proximal end thereof to the actuator and at a distal end thereof to a most distant one of the at least two vertebral anchors relative to the actuator; a hollow outer housing extending over the flexible force transmitting member between the actuator and a nearest one of the at least two bone anchors relative to the actuator, the at least one flexible force transmitting member being slidable within the hollow outer housing to transmit forces based on the Bowden cable concept, the actuator being post-operatively operable to apply via the at least one flexible force transmitting member and the hollow outer housing a sequence of repeated applied forces between the at least two bone anchors.

[0013] In accordance with a further aspect, there is provided a system for treating spinal deformities, the system comprising: an exteriorly or interiorly powered implantable actuator having a driving member movable between back and forth positions, a first anchor for posterior anchoring of the actuator in a fixed position within the patient's body, at least one force transmitting

member operatively connectable to the driving member of the actuator, a second anchor for anchoring the at least one force transmitting member to a vertebral body of a deformed portion of a patient's spine, the actuator being post-operatively controllable for cyclically applying corrective forces to the deformed portion of the patient's spine between said first and second anchors via said force transmitting member.

[0014] In accordance with a further general aspect, there is provided a system for treating spinal deformities, the system comprising: an actuator having a reciprocable driving member, at least one implantable force transmitting member operatively connectable to the driving member of the actuator, an anchor for anchoring the at least one force transmitting member to a vertebral body of a deformed portion of a patient's spine, the actuator being post-operatively controllable for cyclically applying corrective forces to the deformed portion of the patient's spine via said force transmitting member.

[0015] In accordance with a still further general aspect, there is provided a method for treating a spinal deformity, the method comprising: dynamically controlling bone growth modulation by mechanically applying a cyclic type loading on the spinal deformity, including applying at a predetermined frequency a sequence of repeated corrective forces of predetermined magnitude.

[0016] The loading parameters, including the frequency and the magnitude, may be varied during the course of the treatment. A combination of parameters or individual parameters may be varied.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] Figures 1a and 1b are respectively sagittal and coronal/frontal views of a set up of an embodiment of a dynamic fusionless device comprising an actuator, bone screws, and attachment.

[0018] Figures 2a and 2b are respectively sagittal and coronal/frontal views of an embodiment of the dynamic device with actuator fixation at the bottom of successive attachments.

[0019] Figures 3a and 3b are sagittal views illustrating two different implantation arrangements of the dynamic device with actuator fixation between most superior and inferior bone screw and attachments.

[0020] Figures 4a to 4e depict possible bone screw design and actuators with respective force frequency plots for the dynamic device.

[0021] Figures 5a and 5b are respectively sagittal and posterior views illustrating an embodiment of a cyclic fusionless bone growth modulating device installed to provide lateral dynamic compression on the convex side of a spine deformity.

[0022] Figure 6 is a posterior view of a variant of the compression based dynamic fusionless device shown in Figs. 5a and 5b illustrating how the device can be instrumented over a plurality of vertebrae.

[0023] Figure 7 is a posterior view illustrating how the dynamic device can be configured to provide cyclic posterior dynamic distraction on the concave side of a spine deformity.

[0024] Figure 8 is a posterior view illustrating how the dynamic device can be configured to provide cyclic lateral compression on the convex side of a scoliotic spine combined with posterior distraction on the concave side of the scoliotic curve.

DETAILED DESCRIPTION

[0025] Figures 1a and 1b illustrate a first embodiment of a device for correcting spinal deformities via fusionless instrumentation and dynamic growth modulation. The device is installed on the convexity of the spinal deformity. The device generally comprises: a flexible force transmitting member, for instance a wire or cable 1; an exteriorly or interiorly powered actuator 2 (rotary, linear solenoid, compressed air piston or any other suitable force translation device known by one skilled in the art); and anchors such as bone screws 3 and 3'. The screw penetration into vertebral bodies may use cortical-to-cortical or unicortical methods to insure adequate fixation.

[0026] The wire 1 is fixed at its upper end to the uppermost bone screw 3. The other end of the wire is attached to the actuator 2 which is in turn anchored on the convex side of the spinal deformity by the lowest bone screw 3'. The actuator 2 may be post-operatively operated over time to pull on the wire 1 and, thus, apply a sequence of repeated compression forces between the instrumented vertebrae on the convex side of the spinal deformity. It is understood that the device may be instrumented over the number of vertebrae desired. In such an event, one or more actuators may be used. It can be appreciated that the illustrated combination of actuator, wire and anchors may be used to induce a variable compression (frequency and/or magnitude) on the convexity of the spinal deformity. The converse, expansion on the concavity side of the spinal deformity, may be achieved by utilizing a rigid link/truss instead of a flexible pulling member/wire.

[0027] Figures 2a and 2b illustrate an alternative configuration of the dynamic fusionless device. At insertion points 4 and 6, the wire is respectively secured to the bone screw and actuator (cam, linear solenoid, compressed air piston...). Insertion points 5 include a screw/wire fixation which comprises a degree of freedom. In insertion 5, the wire is allowed to freely slide within a guiding structure (e.g. eyelet) integrated to the head of the bone screw. The configuration suggested in figure 2 allows for one actuator to power as many spinal levels as desired. The location of the screws on the vertebral body is as desired. Alternative embodiments for these elements will be readily understood by the person skilled in the art.

[0028] As shown in Figs. 3a and 3b, the actuator action may be adjacent to the wire. According to this configuration, the actuator action is used to alter the tension in the wire by pressing up against it. Technically, this method would require less power than the one presented in Figure 2, with a lower profile. When a cam rotates in engagement with the wire or when a linear motor is extended to laterally push on the wire, the tether tension would be increased to a previously calibrated amount, thereby applying forces at the point of attachment of the wire to the spine. The embodiment shown in

Figures 3a and 3b may comprise: items 4 and 5 from the embodiment shown in Figures 2a and 2b; and an actuator 7 to press on wire/tether to alter its tension (rotary, linear solenoid, compressed air piston... as indicated in Figures 4b, c and d items 10,12, and 14 respectively);

[0029] Possible bone screws and actuators (including possible stimulation frequencies and amplitudes) within the dynamic fusionless device are depicted in figures 4a to 4d and may include but are not limited to: threaded bone screw 8 with insert for wire; bone screw insert 9 (set crew) to insure wire fixation – this may provide a secure fixation between wire and bone screw or may allow wire to slide through bone screw within the degree of freedom desired as demonstrated in figures 2 and 3 items 5; rotary motor 10 powered by an external power source with attached cam which, when attached to (figure 1 item 2 and figure 2 item 6) or pressed against (figure 3 item 7) wire, will provide cyclic motion or cyclic wire tension; 11. example of possible stimulation frequency and amplitude achieved with rotary apparatus (Fig. 4e); linear solenoid motor 12 powered by an external power source with attachment for wire; reference numeral 13 illustrates an example of possible stimulation frequency and amplitude achieved with linear solenoid apparatus; reference numeral 14 designates a compressed air piston (push and/or pull) with hose attachment; and a hose attachment 15 extending externally of patient for connection with controlled compressed air machine. As shown in the second graphic of Fig. 4e, the magnitude of the applied corrective forces may vary continuously over time between a maximum value and a minimum value. Accordingly, the magnitude of the corrective forces continuously varies below and above a predetermined average value. In the illustrated example 13, the magnitude of the corrective forces varies according to a sinusoidal function.

[0030] The above proposed device motors/drivers (rotary, linear solenoid, compressed air piston or any other force translation device known by one skilled in the art) are to be driven by a power source that allows controlling accurately the amount of forces being achieved by the dynamic

fusionless device described herein. This power source could be located externally or internally of the patient.

[0031] In yet another aspect of this embodiment is providing alternate positioning of motor and bone screws on spinal deformity.

[0032] The motor used with this device may provide, in the wire/tether/rigid link, compression on the convexity or distraction on the concavity of a scoliotic spine. This alternate force possibilities may be achieved by using different initial configurations for a cam (i.e. initial bottom position would provide a distraction force between adjacent vertebrae once cam reaches top position with rigid link, the converse holds true) or different orientations of a linear solenoid (push or pull powered thrust).

[0033] Figs. 5a and 5b illustrate a further example of how a dynamic fusionless bone growth modulating device may be configured and implanted to provide lateral dynamic compression on the convex side of a spinal deformity. The cyclic application of compressive loads on the convex side of the spine may be used to retard the growth of the spine on the convex side relative to the concave side, thereby eventually providing for a correction of the spine lateral curvature.

[0034] The device shown in Figs. 5a and 5b generally comprises at least one actuator 20, a pair of bone anchors 22 and 24 respectively anchored to the uppermost and the lowermost vertebrae of the spine segment to be treated, and an at least partially flexible force transmitting member 26 operatively connected to the actuator 20 for applying compression forces between the bone anchors 22 and 24 on the convex side of the spine deformity.

[0035] The bone anchors 22 and 24 are made of a biocompatible material and may use cortical-to-cortical penetration or unicortical methods to ensure adequate fixation. In the illustrated embodiment, the anchors 22 and 24 are provided in the form of bone screws. However, it is understood that other suitable anchors could be used.

[0036] The actuator 20 may adopt various forms. For instance, it could be provided as a hermetically sealed implantable micro-motorized linear actuator or even a reversible rotary motor. For illustration purposes, the actuator 20 could be a linear solenoid, a compressed air piston, an electric motor or any other suitable driving units that could be operated at predetermined intervals of time to periodically vary the magnitude of the corrective forces applied to the spine. A cam or other transmission arrangements may be used to convert rotational motion into linear motion when a rotary actuator is used. The actuator 20 may comprise a power source (e.g. a lithium battery) and a unit adapted to receive and process control signals. Alternatively, the actuator 20 could be powered by an external source via a power cable or feed line extending externally of the patient for connection to the power source (see for instance Figs 4b and 4c). In the case of a pneumatic actuator, a hose line may extend externally of the patient for connection to an external controlled compressed air machine (see Fig. 4d). The actuator may be pre-programmed or even be externally operable to allow the surgeon to periodically adjust the force application cycle (including the magnitude and frequency of the corrective forces).

[0037] In the embodiment illustrated in Figs. 5a and 5b, the actuator 20 is shown as an implantable micro-motorized piston and cylinder arrangement including a piston 23 mounted for reciprocal movement within a barrel 25. As can be appreciated from Figs. 5a and 5b, the actuator 20 may be posteriorly anchored on the concave side of the spinal deformation. However, the location of the actuator 20 is not critical. The actuator 20 could even be external (outside de body of the patient). However, in the illustrated embodiment, the actuator is implantable and mounting brackets and bone anchors 21 (or sublaminar wires) are provided for the posterior fixation of the actuator 20 in a rigid portion of the spine and/or the rib cage.

[0038] Still referring to Fig. 5a, it can be appreciated that the bone anchors 22 and 24 may be positioned at or slightly in front of the coronal plane. The anterior positioning of the anchors 22 and 24 (in front of the neutral

axis of the anterior spine) and, thus, of the force application points allows to create a kyphosis moment in the sagittal plane, in addition to the moment in the coronal plane to correct the scoliosis deformity. This would be helpful in cases of hypokyphosis. The positioning of the anchors 22 and 24 in the middle of the vertebral bodies could be used to create a moment merely only in the coronal plane to correct the scoliosis deformity, without affecting the sagittal profile. Finally, posterior positioning of the anchors 22 and 24 (behind the neutral axis of the anterior spine) could be used to create a lordosing moment in the sagittal plane, in addition to the moment in the coronal plane to correct the scoliosis deformity. This would be helpful in cases of hyperkyphosis to correct the sagittal plane in addition to the coronal plane. It is understood that the relative positions of the anchors could be selected to induce detorsing forces in the transversal plane.

[0039] The force transmitting member 26 is made of biocompatible material and may be provided in the form of a Bowden cable having an inner cable 28 free to slide longitudinally within a hollow outer cable housing 30. The outer cable housing 30 extends from the actuator 20 to the nearest bone anchor 24 (the lowermost anchor in the illustrated example), whereas the inner cable 28 extends from the actuator 20 to the most distant bone anchor 22 (the uppermost anchor in the illustrated example).

[0040] The proximal end of the inner cable 28 is fixedly interconnected to the piston 23 of the actuator 20 while its exposed distal end is fixedly attached to the head of the most distant bone anchor 22 on the convex side of the spine deformity. The portion of the inner cable 28 extending out from the outer cable housing 30 is slidably engaged in an eyelet or other suitable guiding structure integrated to the head of the nearest anchor 24. The inner cable 28 is, thus, free to slide relative to bone anchor 24 in response to the movement of the piston 23 inside barrel 25.

[0041] The opposed ends of the outer cable housing 30 bear against the anchor 24 and the barrel 25 of the actuator 20 in order to be able to transmit compression forces. In the illustrated example, the distal end of the

outer cable housing 30 is fixedly attached to the nearest anchor 24. The proximal end of the outer cable housing 30 bears against the barrel 25 of the actuator 20 but is not fixed thereto.

[0042] Accordingly, when the inner cable 28 is pulled by means of the actuator 20, the relative movement of the inner cable 28 relative to the outer cable housing 30 results in the application of compressive loads between the bone anchors 22 and 24 on the convexity of the deformity. By reciprocating the piston 23 back and forth in the barrel 25, the compressive forces may be applied and relieved at virtually any desired frequencies and in accordance with any predetermined sequence. The magnitude of the compressive forces may be adjusted/varied as desired by controlling the movement of the piston 23 in the barrel 25. The actuator 20 provides controlled dynamic forces over time to the Bowden cable and, thus, to the instrumented vertebrae.

[0043] Please note that the above described arrangement could be inverted to have the actuator at the top with the inner cable pulling upwardly on the lower instrumented vertebrae.

[0044] Fig. 6 illustrates a variant of the compression based dynamic fusionless device shown in Figs. 5a and 5b. As can be appreciated from Fig. 6, the device can be instrumented over a desired number of vertebrae. According to this variant, an anchor may be implanted in each of the vertebrae of the spine segment to be treated. In the illustrated example, the uppermost anchor 22 relative to the actuator 20 has an attachment or anchoring structure integrated to its head (see for instance insert 8 shown in Fig. 4a) on the convex side of the spinal deformity for secure engagement with the inner cable 28. Accordingly, the distal end of the inner cable 28 is fixedly attached to the uppermost anchor 22. The anchors 24a, 24b, 24c and 24d implanted in the other instrumented vertebrae have an eyelet or other suitable guiding structure (see for instance structure 9 in Fig. 4a) integrated to the heads thereof for slidably receiving the inner cable 28. The inner cable 28 extends through eyelets of the anchors 24a, 24b, 24c, and 24d and is freely slidably movable therethrough. As for the embodiment of Figs. 5a and 5b, the

outer cable housing 30 is attached at its distal end to the lowermost anchor 24d. The configuration shown in Fig. 6 allows for one actuator 20 to power as many spinal levels as desired.

[0045] Fig. 7 illustrates another possible configuration of the dynamic fusionless device. This configuration allows using the cyclic motion of the actuator 20 to apply cyclic distraction forces on the posterior concave side of the spine. According to this version, the at least partly flexible force transmitting member is provided in the form of an articulated link 32 having first and second substantially rigid link segments 32a and 32b (e.g. rods) joined to one another by a hinge joint 34 or another type of articulation allowing the link segments 32a and 32b to pivot relative to one another in the sagittal plane. Joint 34 allows the vertebra connected to link segment 32a to flex in the sagittal plane in response to a translation of the articulated link 32. The articulated link 32 is operatively connected to a linear actuator 20 fixed on the posterior concave side of the spine by appropriate means as described herein before. The first link 32b may be pivotally connected to the outwardly projecting portion of the piston rod 23a of the linear actuator for limited pivotal movement with respect thereto in the sagittal plane. It is understood that various joint arrangements may be provided for allowing the flexion of the link 32 in the sagittal plane. The second link 32a may be fixedly attached at its distal end to a bone anchor 36 implanted in the uppermost vertebrae of the spine segment to be laterally re-aligned. Alternatively, the second link 32a could be articulated to the anchor 36 for rotation in one or more planes. With such an arrangement the piston rod 23a of the actuator 20 may be displaced from a retracted position to an extended position in order to apply a distraction force between the actuator and the anchor 36, thereby providing for a re-alignment of the spinal column in the coronal plane. The distraction force can be removed as desired by retracting the piston rod 23a. By reciprocating the piston rod between its retracted and extended positions, it is thus possible to modulate the magnitude of distraction forces. Also, the distraction forces can

be applied at the desired frequency by controlling the operation of the actuator 20.

[0046] The arrangement shown in Fig. 7 may be used to provide the spine with enough distraction forces in the sagittal plane to avoid the reduction of the physiological sagittal curves and hopefully to correct kyphotic deformities. It is understood that the device may be instrumented over the number of vertebrae desired.

[0047] Fig. 8 illustrates another possible configuration of a dynamic fusionless device. Under this configuration, a combination of the lateral compression system on the convexity of the deformity and the posterior distraction system on the concavity of the deformity is used. The embodiment of Fig. 8 is a combination of the devices shown in Figs. 6 and 7. A duplicate detailed description of the common features will, thus, be omitted for brevity.

[0048] In the lateral compression system of the device, movement of the inner cable 28 relative to the hollow outer cable housing 30 by means of the actuator 20 transmits cyclic compression between the uppermost and the lowermost bone anchors 22 and 24e on the convexity of the deformity while the posterior distraction system of the device uses the cyclic motion of the actuator 20 to apply distraction forces between the uppermost bone anchor 22 and the linear actuator 20 fixed on the posterior concave side of the spine. Technically, this method would simultaneously help 1) correcting the deformity in the coronal plane and 2) controlling the appropriate correction of the physiological sagittal curves at the same time. The joint between the link segments on the concave side of the spinal deformity allows to induce a kyphosing effect.

[0049] The various described configurations provide for controlled cyclic dynamic forces within the spine. In this way, the device may be used to modulate the growth of the spine. The advantages over known concepts include: improved bone growth modulation from dynamic stimulation, and control of the magnitude and frequency of the stimulation provided by the

device (i.e. device can be active only at night or during the day) as well as controlling the deformation in sagittal, frontal and transverse planes of human body at the same time by using combinations of posterior and lateral instrumentations. In short, the embodiments described herein above advantageously provide a system which permits correction of spinal deformities without spinal fusion using controlled dynamic (cyclic) loading. The system is useful in correcting spinal deformities including all types of scoliosis. The device provides for the introduction of controlled dynamic forces (frequency and magnitude) to generate improved growth modulation using more physiological (dynamic) loading. The positioning of elements permits a gradual correction of a three-dimensional deformity in both coronal, sagittal and transverse planes through growth of vertebral bodies and spinal column.

CLAIMS:

1. A system for treating spinal deformities in skeletally immature spine, the system comprising: at least two vertebral anchors for anchoring into two different vertebral bodies laterally; an actuator post-operatively operable for providing controlled dynamic cyclic loading; at least one flexible force transmitting member attachable at a proximal end thereof to the actuator and at a distal end thereof to a most distant one of the at least two vertebral anchors relative to the actuator; a hollow outer housing extending over the flexible force transmitting member between the actuator and a nearest one of the at least two bone anchors relative to the actuator, the at least one flexible force transmitting member being slidable within the hollow outer housing to transmit forces based on the Bowden cable concept, the actuator being post-operatively operable to apply via the at least one flexible force transmitting member and the hollow outer housing a sequence of repeated applied forces between the at least two bone anchors.

2. A system for treating spinal deformities, the system comprising: an exteriorly or interiorly powered implantable actuator having a driving member movable between back and forth positions, a first anchor for posterior anchoring of the actuator in a fixed position within the patient's body, at least one force transmitting member operatively connectable to the driving member of the actuator, a second anchor for anchoring the at least one force transmitting member to a vertebral body of a deformed portion of a patient's spine, the actuator being post-operatively controllable for cyclically applying corrective forces to the deformed portion of the patient's spine between said first and second anchors via said force transmitting member.

3. A system for treating spinal deformities, the system comprising: an actuator having a reciprocable driving member movable in a cyclic fashion, at least one implantable force transmitting member operatively connectable to

the driving member of the actuator, an anchor for anchoring the at least one force transmitting member to a vertebral body of a deformed portion of a patient's spine, the actuator being post-operatively controllable for cyclically applying corrective forces to the deformed portion of the patient's spine via said force transmitting member.

4. The system defined in claims 2 or 3, wherein the at least one force transmitting member comprises a Bowden cable having an inner cable slidably received in a hollow cable housing.

5. The system defined in claim 1,2 or 3, wherein the actuator is implantable to the spine for positioning with anchorage into a rigid section of a bone of the spine or rib cage.

6. The system defined in claim 1, wherein the at least one flexible force transmitting member and the hollow outer housing are positionable on a convex side of the spinal deformity for constraining spinal growth on the convex side by means of a cyclic application of compression forces controlled in magnitude and frequency by the actuator.

7. The system defined in claim 1, wherein the at least one flexible force transmitting member is selected from a group consisting of: a biocompatible wire, cable and an at least partially flexible segment.

8. The system defined in claim 1, 2 or 3 wherein at least one further vertebral anchor is implantable posteriorly to anchor a substantially rigid link on a portion of the spine on a concavity of the deformity at a same level where the at least two lateral vertebral anchors are positioned; the substantially rigid link being connected to the actuator; in use, the actuator altering its length in a cyclic manner providing distraction on the concavity while simultaneously providing compression on the convexity of the spine.

9. The system defined in claim 1, 2, 3 or 8, wherein the at least two vertebral anchors for constraining the flexible force transmitting member are positionable on the convexity of the deformity laterally involving the apex of the deformity.

10. The system defined in claim 8 or 9, wherein the at least one further bone anchor for constraining the substantially rigid link is positionable on the concavity of the deformity posteriorly involving the apex of the deformity.

11. The system defined in claim 1, 2, 3 or 8, wherein the at least one force transmitting member is secured to the most distant vertebral anchor through a selected one of: a fix interconnection and a joint allowing rotation in one or more planes.

12. The system defined in claim 1, 2, 3 or 13, wherein the at least one force transmitting member is engaged with one or more intermediate vertebral anchors through gliding interconnections and involving the apex of deformity.

13. The system as claimed in claim 8, wherein the substantially rigid link is secured to the most distant bone anchor via a fix interconnection or a joint allowing rotation in one or more planes.

14. The system as claimed in claim 8, wherein the substantially rigid link is engaged with intermediate bone anchors through a gliding interconnection.

15. The system as claimed in claim 1, wherein the at least one flexible force transmitting member comprises a biocompatible cable.

16. A system for treating spinal deformities in skeletally immature spine comprising: an implantable actuator for anchorage to a bone structure, at least one vertebral anchor for anchoring into a rigid portion of a spine posteriorly; a substantially rigid link comprising at least two segments connected with a hinge joint for relative pivotal movement in a sagittal plane when implanted in a patient body, a first one of said segments being connected to the at least one vertebral anchor for applying a distraction force on the concave side of the spinal deformity, a second one of the segment being operatively connected to the implantable actuator, the actuator being post-operatively operable for controlling a distraction loading frequency as

well as a magnitude of distraction forces applied on a concave side of the deformity.

17. The system defined in claim 16, wherein the implantable actuator is a linear actuator implantable to the spine through a posterior approach and positionable with anchorage into a rigid section of a bone of the spine or rib cage.

18. The system defined in claim 17, wherein the linear actuator alters its length in a cyclic manner providing cyclic distraction on the concavity of the deformity by means of the substantially rigid link.

19. The system defined in claim 16, wherein the substantially rigid link is secured to the at least one vertebral anchor through a fix interconnection.

20. The system defined in claim 16, wherein the at least one vertebral anchor is applied on the concave side of the spinal curve and involving the apex of deformity.

21. The system defined in claim 16, wherein the substantially rigid link comprises a biocompatible rod and a hinge joint.

22. The system defined in claim 1, 2, 3 or 16, further comprising a force feedback unit.

23. A method for treating a spinal deformity, the method comprising: dynamically controlling bone growth modulation by mechanically applying a cyclic type loading on the spinal deformity, including applying at a predetermined frequency a sequence of repeated corrective forces of predetermined magnitude.

24. The method defined in claim 23, comprising varying the frequency.

25 The method defined in claim 23 or 24, comprising varying the magnitude of the corrective forces.

26. The method defined in claim 23, wherein applying a cyclic type loading includes operating an actuator having a cyclic type motion to apply at least one of: a sequence of compression forces on a convexity of the deformity and a sequence of posterior distraction forces on a concavity of the deformity.

27. The method defined in claim 23 or 26, comprising using a combination of alternate lateral and posterior dynamic loading.

28. The method defined in claim 26, comprising attaching the actuator posteriorly to the spine, and post-operatively operating the actuator.

29. The method defined in claim 28, comprising installing a Bowden cable on the convexity of the deformity, the Bowden cable comprising a cable slidably received in a hollow housing, the cable being attached at a proximal end thereof to the actuator and at a distal end thereof to a first bone anchor fixed to a vertebra at a first end of a spinal segment to be treated, the hollow housing extending between the actuator a second bone anchor fixed to a vertebra at a second end of the spinal segment to be treated.

30. The method defined in claim 25, comprising determining an average force, a maximum force and a minimum force, and gradually varying the magnitude of the corrective forces between the minimum force and the maximum force over time.

31. The method defined in claim 30, wherein the magnitude of the applied corrective forces varies as a sinusoidal function between the maximum and minimum forces.

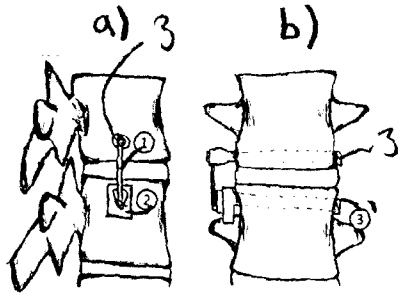


Figure 1

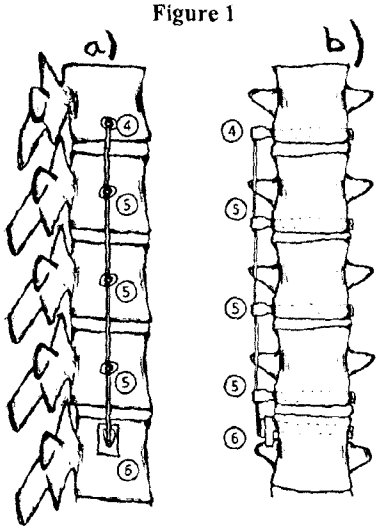


Figure 2

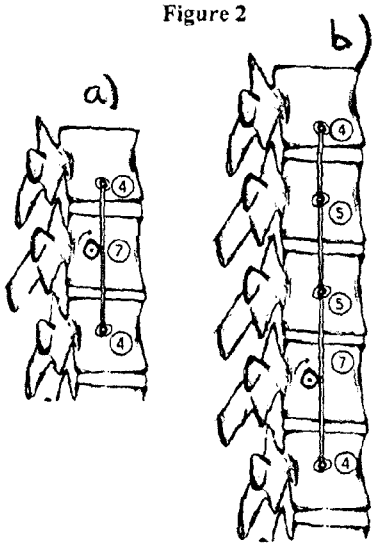
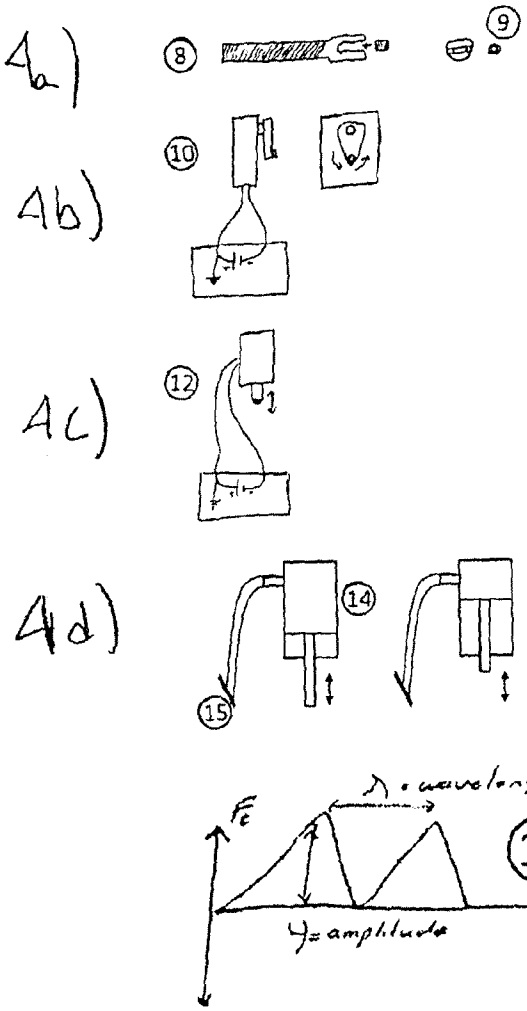


Figure 3


4a)
8
9
4b)
10
4c)
12
4d)
14
15
λ = wavelength
11
y = amplitude
t

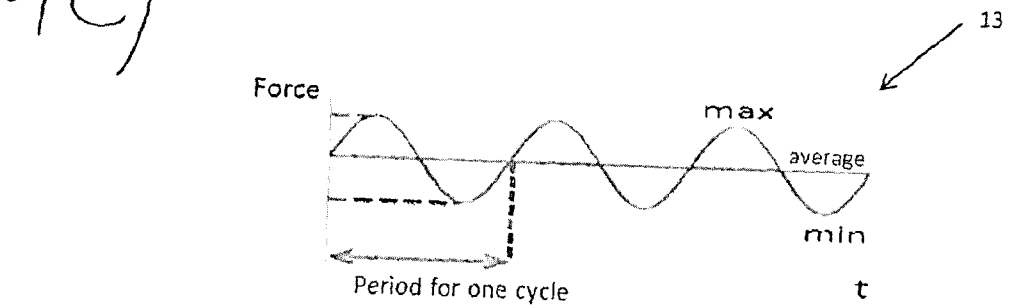

4e)
13
Force
max
average
min
Period for one cycle
t

Figure 4

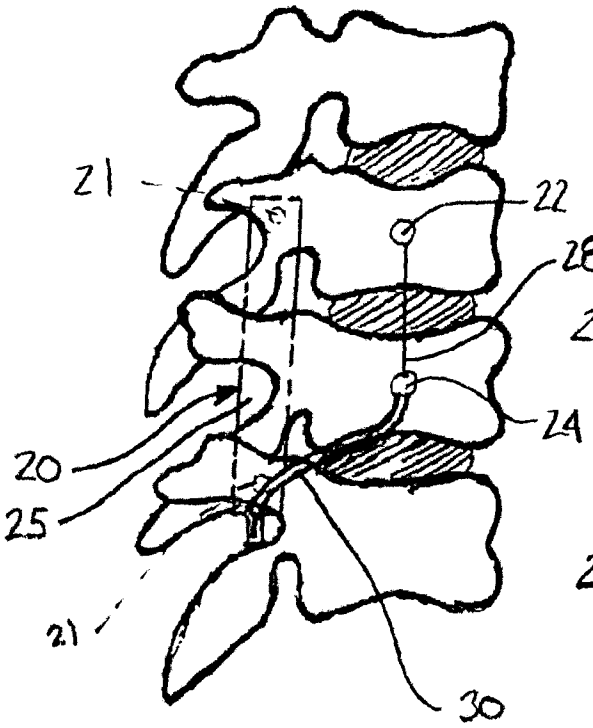


Figure 5a

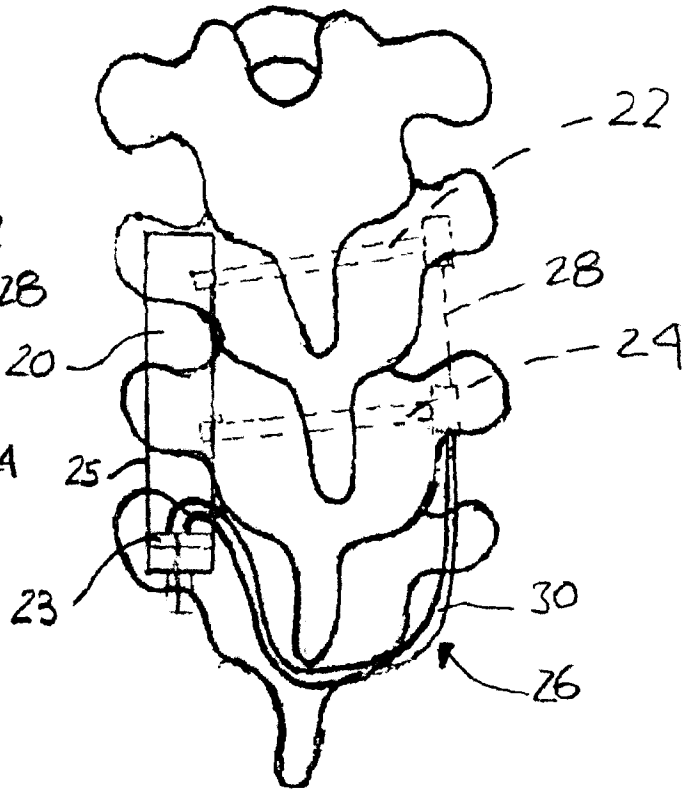


Figure 5b

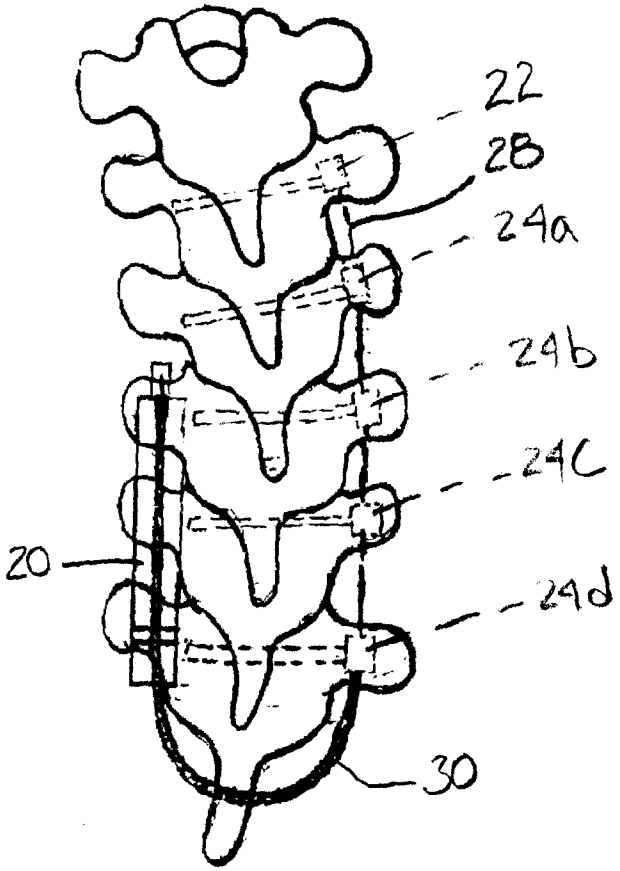


Figure 6

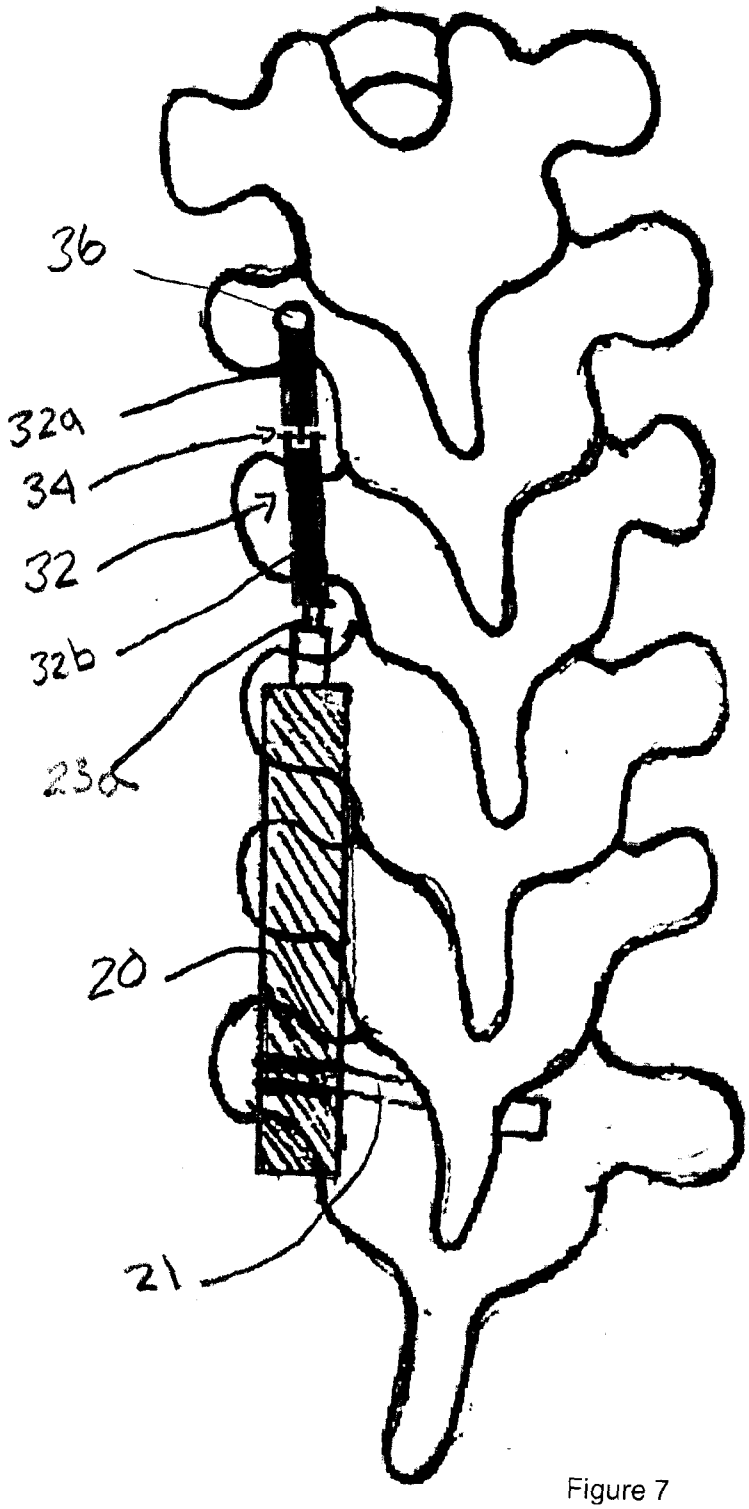


Figure 7

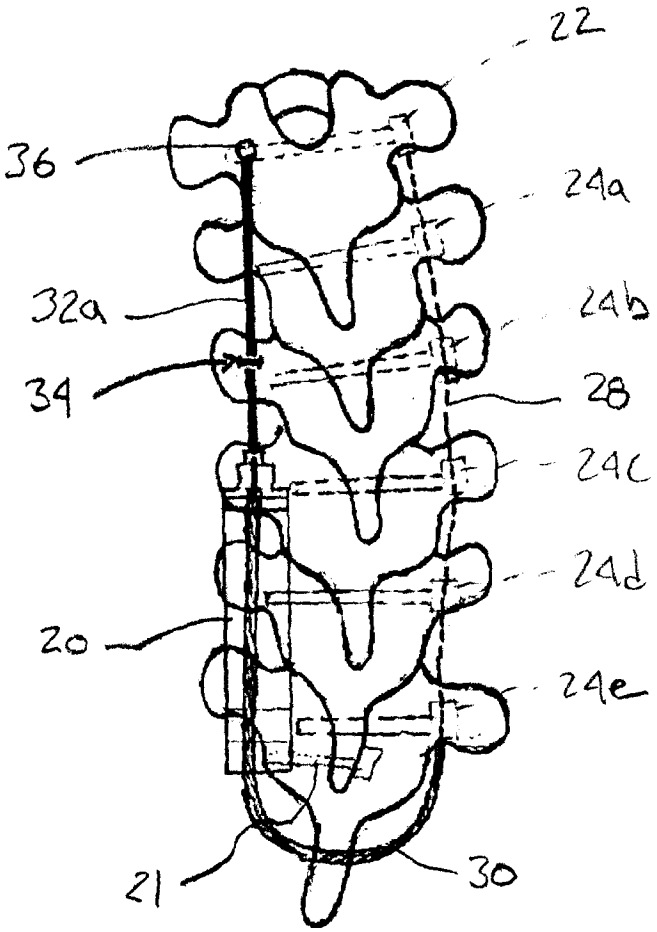


Figure 8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2014/000143

A. CLASSIFICATION OF SUBJECT MATTER
IPC: ***A61B 17/70*** (2006.01), ***A61B 17/56*** (2006.01)

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(2006.01): A61B17/70; A61B17/56

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

Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)
EPOQUE (Epodoc): spinal deformity, kyphotic deformity, Bowden cable, vertebra, actuator, cable, wire, spine, piston.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US 8162979 B2 (SACHS, D. et al.) 24 April 2012 (24-04-2012) *Entire document*	1-4, 7, 11-15, 22 6, 9, 10
X Y	US 2009/0306717 A1 (KERCHER, J. et al.) 10 December 2009 (10-12-2009) *Entire document*	2, 3, 5, 8, 11 6, 9, 10
X	US 2006/0047282 A1 (GORDON, J. D.) 2 March 2006 (02-03-2006) *Entire document*	2-5
A	US 2010/0324600 A1 (BIYANI, A.) 23 December 2010 (23-12-2010) *Entire document*	1-22

☑ Further documents are listed in the continuation of Box C.

☑ See patent family annex.

*	Special categories of cited documents:
"A"	document defining the general state of the art which is not considered to be of particular relevance
"E"	earlier application or patent but published on or after the international filing date
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O"	document referring to an oral disclosure, use, exhibition or other means
"P"	document published prior to the international filing date but later than the priority date claimed
"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&"	document member of the same patent family

Date of the actual completion of the international search 29 April 2014 (29-04-2014)	Date of mailing of the international search report 12 May 2014 (12-05-2014)
Name and mailing address of the ISA/CA Canadian Intellectual Property Office Place du Portage I, C114 - 1st Floor, Box PCT 50 Victoria Street Gatineau, Quebec K1A 0C9 Facsimile No.: 001-819-953-2476	Authorized officer Daniel Cormier (819) 997-2754

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2002/0055739 A1 (LIEBERMAN, I. H.) 9 May 2002 (09-05-2002) *Entire document*	1-22
A	US 2012/0290014 A1 (PARENT, S. et al.) 15 November 2012 (15-11-2012) *Entire document*	1-22
A	US 8147521 B1 (CORNWALL, G. B. et al.) 3 April 2012 (03-04-2012) *Entire document*	1-22

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2014/000143

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of the first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☑ Claim Nos.: 23-31
because they relate to subject matter not required to be searched by this Authority, namely:

Claims 23-31 relate to a method for treating spinal deformity. The subject matter of claims 23-31 is subject matter that this authority is not required to search in view of PCT Rule 39.1. As no search has been performed on the subject matter of these claims, no comment is made regarding their novelty, inventive step and industrial applicability.

2. ☐ Claim Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claim Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claim Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CA2014/000143

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