SELECTED LECTURES

ON SPINE SURGERY

BASIC PRINCIPLES OF SPINE SURGERY

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Any surgical exposure destroys the integrity of the patient' body, for his own benefit. Sometimes, the spine intervention is performed for urgent life-saving indications and is guided by the Straightforward Principle. In other cases, there are no life-saving indications, but surgery aims to restore function and improve appearance. The first step includes careful preparation and planning of surgery. The main principle is a protection of neural structures of the spinal cord and its nerve roots. Slow incremental correction of spinal deformity is often more effective and safer than fast and dramatic one. The ultimate 3D-harmony of the whole spine as a part of the body is better than just a correction of the Cobb angle. The purpose of any surgical fusion is the achievement of 3D-balance both at the whole body level and at levels of junctional discs above and below the instrumentation. The lecture describes in details patient positioning, approaches, instrumentation and implants, main strategies for deformity correction, analysis of deformities (global and local), different ways of correction, most applicable corrective techniques (compression, distraction, translation, and axial rotation), and postoperative examination with particular emphasis on the spine alignment and the achieved balance. Each patient should be regarded as unique, and its treatment should be personalized. It is important to realize that the most effective and urgent treatment should be delivered in cases complicated by neurological symptoms.
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Any surgery affects, to a certain extent, the integrity of the patient's body, of course, for the patient's own sake. In most cases, surgery leaves a mark in the form of a scar, even if a minimally invasive technique is used. The *"primum non nocere"* principle declared in the Hippocratic Oath has remained the most relevant one. Some cases require urgent spine surgery for life-threatening indications when a straightforward principle dominates. In other cases, there are no life-threatening indications for surgery, but there is the need for normalization of the function and appearance. We should remember that in many pediatric cases surgery is carried out to prevent deformity progression or respiratory and cardiovascular system dysfunctions. In adults, the common indications are pain and neurological dysfunctions. Hence, there is the need for a considerable discussion with the patient or patient's parents immediately before surgery. It is necessary to explain and evaluate the advantages and disadvantages of surgery, including possible complications, as well as the surgery goal and anticipated result. The surgeon must be sure that the patient and patient's family have understood everything correctly.

Practice of spine surgery

Basic principles

The first step is careful preparation and planning of surgery

Each case should be regarded as a unique one, and the reality always presents specific details that make the case actually unique. A personalized approach to the patient is very essential because surgery should not look like a routine procedure, otherwise the risk of complications increases.

Before entering the operating room, the surgeon should be clearly imagine all details of surgery of a particular patient: patient positioning on the operating table, involvement of traction, reliable neuromonitoring, the incision level, and the precise localization of the vertebrae planned for manipulations (anatomical landmarks or fluoroscopy). Then, each surgical stage should be successfully implemented, including steps requiring the use of specific tools and devices, according to the preoperative planning. It is necessary to remember the location diagram of CD implants, which is plotted on an X-ray image displayed in the surgeon's field of view the location and orientation of hooks and screws (if their action is directed to compression or distraction).

In general, we may say the following: if the preoperative planning is correct, surgery will avoid any unpleasant surprises; otherwise, unpredictable events may occur, which may lead to the development of early or late complications.

The main principle is to protect neural structures of the spinal cord and its roots

Sometimes, neural structures are involved in the pathological process.

In the case of acute injury, earlier decompression, normalization of the spinal canal shape, and stabilization improve the prognosis for recovery of lost functions.

In the case of chronic compression, decompression should ideally be performed without manipulations on the neural structures. Gradual removal of compressing bone and fibrous tissues should not lead to a dislocation or stretching of the nerve fibers. A typical example is an angular kyphosis where anterior decompression should be started outside the apex. Removal of bone tissue below the apex results in the formation of a cavity with thinner walls; in this case, any contact with the dural sac and its contents should be avoided. The same principle applies to decompression of the root compressed by a herniated disc. Manipulations in the area of neural structures should be careful and minimally invasive; constant compression of the structures should be excluded to avoid disturbing the arterial or venous circulation followed by ischemia of the motor or sensory pathways.

Upon manipulations on the spine under (external or internal) traction during vertebrotomy, laminectomy, etc., upon implantation of hooks, wires, pedicle or corporeal screws, cages, etc., it is most important to protect the neural structures from pressure, stretching, and other impacts.

Before suturing the wound, ensure the stability of all bony structures, implants, and grafts. Remember that the position of all these elements should be biomechanically optimal. In our practice, there was a case of angular thoracic kyphosis where an anterior fibular strut graft penetrated the vertebral body and compressed the dural sac. Control of bleeding is very important to prevent postoperative hematomas that may compress the spinal cord.

Systematic monitoring of the spinal cord function is very important in spine surgery. The easiest and cheapest procedure is a wake-up test developed by Stagnara and his anesthesiologist Vauzelle (1974). Later, somatosensory and then motor evoked potential techniques were developed. These techniques have become versatile and are obligatory for prevention of postoperative neurological complications. If possible, monitoring should be carried out by the neurophysiologist in close cooperation with the anesthesiologist because drugs used during anesthesia may affect recording of evoked potentials.

Slow gradual correction of the spinal deformity is often more effective and safer than fast and abrupt one

The best example illustrating this principle is correction of kyphosis or kyphoscoliosis. In this situation, multiple (4 or 5 levels) vertebrotomies, like the Ponte or Smith-Petersen procedures, provide a small (10°) correction per level, usually with minimal bleeding, which enables a more harmonious and safer correction of the deformity compared to a correction of 45° by pedicle subtraction osteotomy (PSO). Radical surgery requires significant bending of the rod; correction is associated with abrupt concentration of stresses, and bleeding may be very significant. Therefore, complications associated with this technique are more common than those in the former case. This should be considered as a fundamental principle. Therefore, preoperative preparation using a halo apparatus and a distraction corset may provide not only a substantial correction but also improvement of the respiratory function; subsequent instrumental correction is less dangerous than concomitant one that may lead to numerous complications due to increased time of an intervention. Radical surgery is performed in a limited number of clinics after a serious discussion with the patient or patient's family and evaluation of the risk for the patient.

On the other hand, in the case of localized kyphosis due to a segmented hemivertebra, direct and complete resection with limited instrumented fusion provides a more immediate and long-lasting result than epiphysiodesis involving more than one segment above and below the anomaly level.

The final 3D harmony of the whole spine as a part of the trunk is better than just a correction of the Cobb angle

There have been many attempts to correct the scoliotic curve to a Cobb angle of 0° in a frontal spondylogram, with not best results in the sagittal plane. In general, they have resulted in the spine straight in both planes or with a significant decrease in the thoracic kyphosis and lumbar lordosis. In other cases, a shoulder girdle imbalance is observed, which is not so important in terms of the appearance, but may lead to the development of pain in the cervical spine in the future. This occurs upon overcorrection of the primary curve when the fact that the maximum correction is not always optimal for the patient is ignored. Often, there is also underestimation of the fact that the final functional outcome is determined not so much by the length of instrumented and bone blocks as, on the contrary, by the length of unblocked areas providing the necessary compensation that, in turn, enables achieving the harmony and balance of the trunk.

It is worth mentioning some other errors, especially those associated with localized interventions, as in a disc herniation, when short L5–S1 or L4–L5 fusion is carried out. In many cases, spinal fusion is performed in the position of a single-level kyphosis or lumbar lordosis flattening, provided that a lordosis of 30° (!) is normally present at the L5–S1 level. This error, which can be easily avoided by correct positioning of the patient on the operating table, often leads to cascading complications and re-interventions with a permanently increasing fusion area and the final development of a proximal junctional kyphosis (PJK). Therefore, in these operations, a lordosis close to 30°, with the apex at the L5 vertebra level, should be formed.

Of course, this concept is applicable to any spinal level, from the craniocervical junction to the pelvic vertebra, e.g. upon correction of a posttraumatic kyphosis in the thoracolumbar transitional area where the kyphosis from T10 to L2 is normally equal to 0°.

Another example is severe lumbosacral spondylolisthesis when correction of a local kyphosis is much more important for the sagittal contour than elimination of a vertebral displacement.

The purpose of spinal fusion is to achieve the 3D balance both at the whole body level and at levels of the transitional discs above and below the instrumented area

This principle is probably the most important one because it means achieving such a state of spinal structures when the 3D stability and 3D mobility exist at the same level. ***This is the balance that I define as stability in motion.*** Here, it is necessary to emphasize the following circumstances.

At the body level, in accordance with the "chain of balance" concept, a perpendicular (the line of gravity) is erected from the center of the polygon support. This point is the beginning of a chain that includes the lower limb skeleton, pelvic vertebra (the entire pelvis acts like a single intercalary bone between the lower limbs and the spine), then lumbar, thoracic, and cervical vertebrae, and finally cephalic vertebra (the entire head) that is the heavy weight working as a reversing pendulum. It should be understood that motions within this chain occur in all three dimensions. In this case, the horizontal plane, where smooth adaptation/compensation of articulations at each level occurs, is of particular importance. This is how the cone of economy is implemented, within which the body functions like a pendulum, and the minimal muscle activity is required to maintain the balance. Outside the cone (more precisely, outside its interior, small portion), considerable muscle activity is required to maintain the balance.

Subsequently, laboratory or clinical measurements of the amplitude of active and passive motions in every direction at the level of each spinal segment enable predicting the durability of these anatomical structures in terms of degenerative changes as well as the age evolution in the sagittal plane. These measurements should be carried out regularly throughout the entire life; they are very useful because they provide reliable information for evaluation of the functional status before and after surgery.

Under clinical conditions, the following tests can be performed using a simple chronometer: walking 5 m forward and backward, walking up and down 3 steps, squatting and rising, walking and speaking on the phone, talking and counting from 100 to 90, and checking the cognitive capacity (especially in the elderly). These tests provide objective evaluation of the patient's functional capacity, especially in pre- and postoperative periods.

Features of surgical practice

Patient positioning

Preoperative traction is not used in most cases. The patient is usually in the prone position, with more or less hard pillows located under the iliac crests and sternum to avoid pressure on the anterior abdominal wall. This reduces bleeding in the surgical field because increased pressure in the *vena cava* leads to a similar situation in the epidural venous plexus and, therefore, increases blood loss. There are special frames (e.g., Relton-Hall frame) providing an optimal position of the head and endotracheal tube, excluding pressure on the eyes (a risk of postoperative *blindness*), and enabling positioning of the upper limbs and shoulder girdle (prevention of damage or compression of the plexus brachialis), knees, and lower limbs (compression of the skin and nerve trunks).

A very important feature of these frames is flattening of the lumbar lordosis, which facilitates an approach to the spinal canal and discs. During fusion, spinal segments often occur to be fixed in the position of a local kyphosis. If indicated, thoracoscopic approaches may be used because for this positioning they are advantageous in terms of postoperative pain, respiratory function, and bleeding.

Some specific approaches are performed with the patient in the supine position; these include, in particular anterior trans- and retroperitoneal ones, and if a small lateral bending is added, anterolateral ones, including minimally invasive approaches. Lateral, right or left, positioning is provided by fixation of the pelvis with pillows, anteriorly and posteriorly (symphysis and sacrum), and by fixation of the thorax with support on the sternum. In this case, the right upper limb (in the left lateral position) is placed on a support for the hand and wrist, with the elbow joint bent at an angle of 90°. This prevents compression or stretching of the plexus *brachialis*. The operating table plane can be "broken" at any necessary angle to facilitate the approach. Of course, it is necessary to avoid compression of the *n. ischiadicus*. This is the best positioning for the anterior thoracophrenolumbotomic approach in the case of thoracolumbar and lumbar deformities. When approaching the thoracic spine, it is necessary to remember that thoracotomy should be made through the bed of the rib located two segments cranial to the vertebra designated for visualization and manipulation because of the spatial orientation of the ribs. Mini-invasive thoraco- and laparoscopic approaches are easily performed in similar positioning.

Intraoperative traction through the head and lower limbs, with the patient in any of the mentioned positions, can be performed on a conventional operating table after attaching special elements to it or on a special traction table (Cotrel, Jackson).

Traction through the head is performed using a halo apparatus or a Mayfield brace with a dynamometer to control an applied force; traction through the legs is performed using special shoes or skeletal extension applied to the thighs. Standard fixation of the thorax and pelvis is obligatory. If there are no abnormalities confirmed by MRI, the traction force should not exceed 30 % of the patient's body weight.

The advantages of traction include a better view, reduced blood loss, and facilitated correction of the deformity, especially pelvic distortions, due to asymmetrical traction through the lower limbs.

In some situations, traction may be dangerous: excessive tension of the cranial nerves by a halo apparatus in the presence of anomalies of the spinal cord and its meninges or an angular deformity when the dural sac is pressed to a deformed wall of the spinal canal. In this situation, a sudden increase in traction under anesthesia conditions is dangerous, and it should be avoided.

Approaches

Large (anterior, posterior, lateral) approaches are more or less extended ones, regardless of positioning, with particular attention to the quality of hemostasis. During bleeding interventions (like PSO), the anesthesiologist can use special drugs to reduce blood loss. One of the problems typical of the posterior approach is the duration of constant compression of soft tissues by a retractor. Ischemia of muscle walls of the wound may cause necrosis, delayed wound healing, infection (sometimes), and sclerosis (always).

Reduced approaches are those with a relatively small incision due to the use of retractors, improved lighting, and magnifying optics or a microscope. These approaches are used in disc diseases, local spinal stenosis, and anterior fusion at two levels at most.

Minimally invasive approaches are performed through one or more ports to preserve the posterior musculature. They are used more and more often, even if the results of examination do not provide enough arguments against open surgery in terms of the duration of surgery, rate of complications, and development of false joints.

On the other hand, when we see 8 or 9 sequentially placed ports, it is difficult to agree with the fact that muscles in this situation are less damaged than in an open approach.

Calculation of the approach time. Most interventions are performed as "one shot", sometimes with parallel implementation of anterior and posterior approaches. In other cases, surgical stages are performed sequentially, with an interval of several days or a week. For example, the anterior approach is performed at the first stage for the purpose of discectomy and mobilization of the spine without instrumentation; at the second stage, the posterior approach, fusion, and correction with or without instrumented fixation are performed. Traction is usually performed between stages.

The advantages of one-stage surgery include reduced time of hospitalization, immediate correction, and reduced stress for the patient. One drawback is a higher risk of neurological complications because the blood supply to the spinal cord at a particular level can be compromised, while the compensatory vascular branches do not have time to develop. Sometimes, it is better to postpone the second stage in a week to give time for the vessels to develop. On the other hand, this approach also has side effects: longer time of hospitalization, blood loss, a higher rate of respiratory and urinary complications, venous thrombosis of the lower limbs, etc.

Instruments and grafts

Basic instruments are numerous and diverse. Instruments for bone structures include a Cobb elevator, bone pliers, perforators, spoons, Kerrison rongeurs, chisels, gouges, etc., which have various sizes and shapes, with most of them being designated for manual manipulations, as well as drills, bores, and saws. Special instruments are designated for soft tissues, careful manipulations on the spinal cord and its meninges, epidural structures, roots, and blood vessels, resection of discs, and control of bleeding (thermocoagulation, biodegradable foam, etc.). Each surgeon uses instruments matching his skills, which makes him confident.

Implants. These include hooks and screws (pedicle screws were offered by Raymond Roy Camille in 1977), which became popular around the world in the 2000s, as well as rods, wires, synthetic tapes, cages, disc prostheses, artificial ligaments, connecting systems (domino, crosslink), and implants for fixation to the pelvic bones. All of them exist in a variety of shapes and sizes, enabling an almost infinite number of constructs. A combination of these elements depends on the strategy chosen for correction of a particular pathology, and the correction itself is the result of a gentlemen's agreement between rigidity of the vertebral column and the listed instruments. These implants have two significant advantages: the opportunity to apply significant effort during correction and a high degree of rigidity of the "implant – spine" system, which eliminates postoperative immobilization with a corset to form a bone block, contrary to the situation after bone reconstruction without metallic implants.

Bone grafts and bone substitutes. A bone block of two or more vertebrae (classical spinal fusion) is the result of decortication and transplantation of reconstructive material.

Autografts. Decortication of facets of the true joints and posterior elements, up to the apices of the transverse processes, is recommended in the case of posterior fusion. The resulting decorticated bone with or without an additional spongious bone from the iliac crest is placed into a prepared bone bed. A long tibial graft harvested on the inner surface of the tibial diaphysis can be used. The anterior crest of the tibia should be spared for prevention of fractures. This technique enables covering the entire area of planned fusion with biologically active and durable tissue that will firmly adhere to the bed in 15 days and will remain rigid throughout the whole destruction-reabsorption-reconstruction cycle that usually lasts 6–8 months.

After posterior fusion, these processes occur at the vertebral body level. The bone block forms due to decortication of both endplates and introduction of a tricortical autograft from the iliac crest, or a fibula fragment, or a tibial strut into the intervertebral space to maintain the achieved correction. Anterior palisade-like fusion may be recommended for an angular kyphosis. One of the purposes of anterior fusion is to prevent narrowing of the intervertebral foramen with compression of the root, particularly in the treatment of degenerative spine diseases in adults. It is necessary to remember that if metal or polyethylene glycol cages are used, a source of the biological activity is an autobone (spongiosis from the os iliac crest) placed in the cage cavity for formation of a bone bridge between two vertebrae.

Lordosis correction requires anterior compression of the vertebral bodies by metallic implants or anterior and posterior epiphysiodesis of the spine (in children). The latter technique involves exposure and subperiosteal decortication of the posterior parts of the vertebral bodies, careful resection of the discs up to the end plates, and interbody fusion using an inlay technique. Fragments of a cleaved rib are placed into grooves made in the anterior or anterolateral parts of the vertebral bodies and further form biological bridges between the vertebral bodies.

The graft remains non-vascularized during most of the time. However, a vascularized bone graft is required in some cases, e.g. in severe bone dystrophy or a false joint after failed fusion. As a graft, a rib free of microanastomoses (upon thoracic and thoracolumbar localization) or, more often, a rib with microsurgical anastomoses may be used. Another type of a free vascularized graft is the fibula with microanastomoses to the intercostal vessels. The most important property of this graft is its mechanical stability in the implantation area.

Homografts and allografts are prepared in bone banks. However, we have never seen complete bone rearrangement of these grafts. For this reason, we almost always use them only as a supplement to an autologous bone.

Bone substitutes have been developed in a large amount to improve the bone block formation. An example is the bone morphogenic protein (BMP) exhibiting a high efficiency. Bone substitutes can not be used in all cases because of their high cost. There are also some reasons to doubt their safety to bone metabolism. Potential oncogenic properties may not be excluded if bone substitutes are used in large quantities.

Major deformity correction strategies

Posterior spinal instrumentation. Harrington (1960) pioneered modern spinal instrumentation, and the main strategy was a combination of distraction along the concave side and contraction along the convex side of the spinal deformity. Resina, and later Luque (1972), used the translation principle based on a displacement of each vertebra toward a rod that, in turn, was fixed to the end vertebrae of the scoliotic curve by wires or mersilene tapes placed sublaminarly. Later (1983), CD instrumentation was developed (an attempt of the real 3D correction), which was based on the same basic principles. A rotation maneuver (pre-bent rod rotation around the vertical axis) normalized the sagittal contour of the thoracic and lumbar spine, but provided a minor derotation effect. The main advantage of CD instrumentation is a three-dimensional analysis of the entire deformity and identification of the vertebrae strategic for implantation of hooks or screws. The purpose is to clarify the order and sequence of manipulations in the course of correction (concave or convex side of the curve, on the right or left, direction of bent rod rotation). All recent versions of the instrumentation have been based on these principles, although most modern versions are aimed at using a direct derotation force to correct axial vertebral rotation. Actually, the result may not be most attractive because of the development of side effects in other planes, in particular in the sagittal plane. This poorly controlled phenomenon may lead to the formation of a flat spine. In open surgery, like in minimally invasive surgery, we observe similar results and limitations.

Anterior spinal instrumentation. The first real attempt to develop this instrumentation was made by Dwyer (1965). He used screws introduced into the vertebral bodies after complete excision of the discs, with decortication of the end plates for subsequent interbody fusion. The screws were introduced on the convex side of the deformity, in the frontal plane, and interlinked with a flexible titanium cable; then, after filling the intervertebral space with bone grafts, the vertebral bodies were apposed by compression. A few years later, Zielke, who used the same principles, replaced the cable with a threaded flexible rod and supplemented the instrumentation with a derotation device correcting the scoliotic deformity. Both systems had a common drawback formation of the kyphosis or, at least, flattening of the lumbar lordosis. Simultaneously, Pouliquen developed an anterior system based on the use of pre-bent plates. Despite a quite extended instrumented area, good results were obtained in patients with mobile deformities of the thoracic and lumbar spine. Then, Kaneda in Japan suggested using a special metal block with two divergent screws for each vertebral body. The blocks were connected by two parallel rods providing rigid fixation at both short (trauma, tumors, infectious lesions) and long (scoliosis, kyphosis, etc.) distances. Finally, anterior CD instrumentation was developed in 1987, which acted in accordance with the same principles of bent rod rotation and provided effective restoration of the lumbar lordosis. The instrumentation uses one screw per vertebral body and one rod, but there is a version with two screws and two rods per block. All versions of the system are used according to specific indications and depending on the surgeon's experience

Strategy for vertebral pathology without spinal deformity

Neurosurgical approach to the spinal canal

The approach can be minimally open or performed through a port without resection of bone tissue, as in a disc herniation, or through a reduced access with minimal injury to the articular facets in localized lumbar stenosis.

More or less extended laminectomy can be carried out for intradural pathology or multilevel canal stenosis. Extended laminectomy with resection of both articular facets at a single level is well known to lead to the development of kyphosis in 100 % of cases, regardless of the patient's age. Several surgical options have been proposed to prevent this complication:

1) hemilaminectomy whenever possible because preservation of the articular facets on one side prevents kyphosation;

2) when an intradural intervention is planned, and a hemilamina is intact, it is helpful to use laminotomy (en bloc resection of a hemilamina with the maximum preservation of facets, followed by placing the bone cover back, with instrumentation and adequate postoperative immobilization); this technique ensures reliable prophylaxis of kyphosation, especially in the cervicothoracic, thoracic, or thoracolumbar spine in children;

3) if pathology of the bone or soft tissues requires an extended excision of the posterior bony structures, spinal fusion and instrumentation of the area involved in the process should be immediately performed, using intact transverse processes for the formation of a bone block.

It is important to remember the role of soft tissues in functioning of the vertebral machine. For example, only resection of the interspinous ligament may cause the development of kyphosis. The yellow ligaments play a very important role in preserving the sagittal stability, like in the case of surgery on the craniocervical junction, performed with the patient in a sitting position and with flexion of the head and neck to improve an approach and reduce blood loss. If soft tissue suturing is performed with the patient in the same position, this leads to the kyphosis formation in 100% of cases. This can be prevented by soft tissue suturing in the extension position, with particular attention to the *lig. Nuchae*.

Strategy of spinal deformity correction

Deformity analysis

Global analysis should be performed in 3D space, from the head to the legs, in a static posture; from a clinical point of view, evaluation of the trunk position relative to the gravity line is required in this case. This line is represented by a vertical axis erected from the center of the body support. The analysis includes evaluation based on anterior and lateral examination, the Adams test, and measurement of the rib hump and lumbar rotational prominence using a scoliometer. This makes it possible to evaluate the entire deformity in each plane (kyphosis, lordosis, lateral displacement) and prepare a correction plan. It is also necessary to analyze the dynamic function to assess the balance of the patient's trunk. The patient is asked to perform simple exercises (walking forward and backward, up and down stairs, squatting and rising), with all measurements being performed with a simple chronometer. In addition, walking and talking on the phone is a good cognitive test for an elderly person.

The analysis includes an X-ray study of the whole spine, or even the whole body (EOS machine), in two projections with all measurements (Cobb angle, pelvic parameters, transitional areas, deviations from the gravity line, etc.) performed in a manual mode or with a computer.

In local analysis, it is necessary first to accurately determine the number of spinal motion segments. When identifying the future correction area, it is necessary to specify its upper and lower boundaries, apex, position in the horizontal plane, distance from the gravity line, etc.

In the presence of the scoliotic or kyphotic deformity, it is necessary to investigate mobility of the spine using traction in a standing or lying position, lateral bending, and overextension over a bolster. This helps evaluate the planned area of fusion and instrumentation and predict what will happen in the area of an unblocked compensatory curvature. There is software for preoperative simulation of changes in both these areas.

Correction approaches

Preoperative preparation is global in general, but it can also be local. In the past, in the pre-instrumentation era, when corrective surgery was performed inside a plaster corset, which was made before surgery and was not removed for a year to form a bone block, the preparation was long-lasting and took weeks and months. During this time, manipulations, tractions, spinal extension exercises (auto-elongation), etc., were performed to maximally reduce the deformity. Later, preoperative preparation gradually diminished, mainly for economic and partly for psychological reasons, except special cases where normalization of the patient's respiratory function was necessary. However, preparation still is used in some schools and countries, and, ultimately, its efficacy on many levels is proven.

Correction without instrumentation. Regardless of surgery (anterior or posterior, hemivertebra resection), correction in the postoperative period is maintained with a plaster corset (with a collar, if the correction is mainly achieved by traction). In the case of lumbosacral hemivertebra resection, correction should be achieved by means of a plaster corset extending to the thigh, up to the knee joint, to control orientation of the entire pelvis. Excision of a wedge from the plaster corset at the level corresponding to a resected hemivertebra enables achieving deformity correction by closuring the edges of the wedge defect and straightening the spine. This procedure can be performed at any level and in any direction. Postoperative immobilization depends on the patient's age, amount of correction, quality of performed surgery, and also quality of the bone at contact between two surfaces and local fusion.

When correction involves instrumentation, it is necessary to remember about performing basic maneuvers.

Intraoperative mobilization of the vertebral segment. Through the posterior approach, careful excision of soft tissues, ligaments, and intervertebral joints (facets, osteophytes), and even the inferior part of the upper hemilamina with the yellow ligament provides sufficient mobility for correction. However, if the laminae are very rigid, the anterior release with excision of discs has proved its efficacy, greatly increasing the desired mobility. The disadvantages of this surgery include the need for an extra intervention through the anterior approach, which is associated with longer stay at the hospital, increased blood loss, and an increased risk of pulmonary complications on the thoracotomy side. The decision on this surgery should result from an impartial discussion of the preferences and risks, based on the examination data. Ultimately, this surgery is desirable only in specific cases where thoracotomy can not be avoided.

The most common corrective techniques. The first requirement is to achieve the reliability and stability of implants used for the vertebrae: (pedicle, laminar) hooks, screws, wire, and mersilene tapes. They, in turn, should be stably fixed to connecting elements: rods and plates.

Compression is mainly applied symmetrically, on the right and left, to the anterior elements of two or more vertebrae to correct kyphosis; when compression is applied to the vertebral bodies, it facilitates an increase in the kyphosis or flattening of the lordosis.

Distraction applied posteriorly between two adjacent or more vertebrae, symmetrically on the right and left, leads to elongation (which may be dangerous to the spinal cord upon inadequate effort) and flattening of the spine, actually producing the kyphosation effect. On the contrary, when distraction is applied to the anterior parts of the vertebrae, it gives the lordosation effect.

If these two basic maneuvers (compression and distraction) are performed asymmetrically, obliquely directed forces arise automatically, which lead to certain 3D axial rotation of the vertebrae.

Translation is produced by a lateral force that brings an instrumented vertebra close to a medially located rod by means of wire, cables, or tapes. Translation occurs, in particular during a rotation maneuver, when a rod fixed to the end vertebrae rotates about its axis and pulls the intermediate vertebrae, also fixed to the rod, closer to the midline.

Axial rotation is the basic maneuver used in correction of 3D spine deformities. The effect of axial rotation is most difficult to achieve in the thoracic spine due to intervertebral rigidity of this region and because derotation devices affect the entire thorax. Intraoperative excision of intervertebral discs increases mobility of the vertebrae relative to each other. In the lumbar spine, where the vertebrae are more mobile initially, certain derotation is achieved with posterior, and even better with anterior, instrumentation.

Regardless of the amount of intervention (two or more levels), a surgical technique involves elements of all basic maneuvers.

Spinal osteotomies. If the deformity is very rigid, and the surgeon evaluates mobilizing maneuvers as unpromising, osteotomy is the method of choice. Smith-Petersen osteotomy (1939), the first of the well-known osteotomies, involves an excision of a part of the spinous process, both upper facets, a part of the upper hemilamina, and the yellow ligament and reduces kyphosis by 10–15° per segment and up to 45° per four levels. A very similar technique was popularized by Ponte at the end of the last century. If performing these interventions on a previously operated spine, it is necessary to be careful when forming bone defect edges to avoid injury to the dural sac and its contents during lordosis recovery and closure of the defect edges.

To obtain a significant corrective effect at a single level, PSO was described, which included removal of posterior elements and excision of a wedge defect in the vertebral body (symmetrical or asymmetrical) with total or partial removal of the arch pedicles with or without a sub- and superjacent disc. Of course, before performing osteotomy, at least two pairs of pedicle screws (above and below) and a temporary rod should be implanted to prevent instability. These operations may be associated with large blood loss. After complete closure of the edges of a formed wedge defect, it is sometimes necessary to use a posterior support structure (cage) to prevent formation of dura mater folds and a risk of neurological symptoms.

Vertebra resection at one or more levels is indicated in the case of rigid deformities, tumors, congenital anomalies, etc. The anatomy of an affected spine region should be thoroughly investigated using 3D reconstruction, or even a personalized reconstructive three-dimensional model. If the deformity is localized in the thoracic or thoracolumbar spine, an extended posterior approach, up to 5 cm or more, is performed toward both sides of the thorax. The second step is implantation of pedicle screws (three pairs each above and below the resection level) with unilateral placement of a temporary rod to stabilize the system. The third step is the resection starting with exposure of the dural sac and roots at the desired level, using extended laminectomy with bilateral removal of the facets. Then, the ribs (5 cm) are resected on the right and left, with their detachment from the appropriate vertebrae, paying particular attention to preservation of the pleura. The ribs are excised subperiosteally on both sides and toward the rib head that is removed en bloc from the costotransverse junction, which facilitates an approach to the lateral surface of the vertebral body. The roots are better visualized, which enables their more reliable protection. The next step is displacement of large vessels and internal organs from the anterior surface of 1–2 vertebral bodies. One or two spinal motion segments are resected using chisels, hammers, or Kerrison rongeurs, with the dural sac being carefully protected. Necessary corrective manipulations are carried out using bilaterally located rods, with the neural elements being constantly monitored. To prevent excessive shortening of the spinal column and shrinkage of the dural sac, a metallic or plastic cage filled with an autologous bone is implanted between the vertebral bodies. Finally, after testing stability at all levels of instrumentation, posterior spinal fusion is performed using autografts from the iliac crest, rib, or tibia.

Postoperative examination with particular focus on the spine alignment and achieved balance

X-ray control should be performed immediately after surgery to ensure the correct position of implants. When the patient begins to walk, the early result is evaluated based on the position of the spine and trunk in 3D space, and on the way the patient walks, sits, and walks up the stairs. A shoulder girdle imbalance in a standing position can persist for a month because compensation has not yet been achieved. If this situation has not changed for more than three months, it will probably remain in the future. X-ray control of the implant condition, with the patient in a standing position, is necessary within the first month. Then, control examinations are repeated regularly throughout the follow-up period.

Conclusion

Spine surgery possesses a variety of opportunities and techniques. Each patient should be regarded as a unique one, and his/her treatment should be personalized and accompanied by careful pre- and postoperative examination of the functional capacity and anatomical recovery. It is very important to realize that cases complicated by neurological symptoms should receive the most effective and urgent treatment. In this case, the indications for treatment become urgent for protection of the neural structures and recovery of their function.

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