13 Expandable Cages and Minimal Invasive Approaches to the Thoracolumbar Spine for Anterior Column Reconstruction

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13.1 Introduction

We consider spine stability as its aptitude to counterbalance and react to physiological loads moving its *functional spinal units* inside what we consider the physiological range of movements. Bone, ligaments, muscles, and global spine shape all contribute to the vertebral column stability. It is commonly accepted that the so-called anterior column, including disk and vertebral body, bears most of the mechanical charges during every day activities, so its integrity is essential to preserve spine function. Lack of anterior support is commonly related to spine injuries as a consequence of conservative treatment of underestimated lesions or following inadequate posterior fixation. Moreover, primary tumors and spinal metastases affect the vertebral body in 90% of the cases frequently causing impending fractures or pathologic fractures as a result of bone substitution by newly formed tissue. On the other hand, tumor resection generally leaves the anterior column unsupported requiring a reconstructive step during the same surgery. Spine infections commonly start involving the intervertebral disk, but, if not recognized and treated in the early stage, they will also compromise the adjacent vertebral bodies causing bone destruction and spine instability. Finally, in the last decades, severe osteoporosis has become a common cause of anterior column incompetence following fragility fractures that are difficult to treat because most of posterior and anterior fixation systems are not designed for osteoporotic bone. In conclusion, anterior column restoration is a common issue in spine surgery and brings different questions concerning both surgical approach and type of anterior support to select, making operations challenging and difficult to standardize.

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13.2 Historical Overview

Anterior approach to the thoracolumbar spine can be prepared through the thoracic cavity, through the abdomen or both depending on the level to treat and its extension. Originally, surgical approaches were directly derived from the general surgeons' practice being nonspecifically focused on the vertebral column. These approaches were frequently prepared by an access surgeon and resulted in unnecessarily invasive procedures burdened by perioperative complications and long postoperative hospitalizations. In the last decade, minimal invasive approaches to the thoracic and lumbar spine were developed together with new instrumentation appositely renovated, to help the surgeon avoiding unnecessary anatomical injuries during surgery. As a result, classic thoracotomy turned into video-assisted mini-thoracotomy and, in selected cases, into thoracoscopy. Transperitoneal approaches to the lumbar spine were with time abandoned and substituted by retroperitoneal approaches that progressively became minimal invasive, thanks to special designed self-retaining retractors [1]. Restoration of the anterior support was initially achieved by methyl methacrylate or bone grafting that still remains the gold standard material in order to achieve fusion [2]. Unfortunately, bone graft alone frequently showed inadequate primary stability and support; therefore metal hardware, such as cancellous bone screws, had to be added to prevent graft subsidence while waiting for a solid fusion to occur. Than titanium meshes to be filled with bone graft became available on the market satisfying both the need for fusion and primary stability, as the metal spikes at each edge of the cage could be impacted against the vertebral end plates. Those cages were available in different diameters, and they could be cut in the desirable length straight during surgery. Afterward, modular *Polyether-ether-ketone* (PEEK) and carbon fiber vertebral body substitutes became available. The reason for adopting these new materials was related to their translucency (useful in tumor surgery) and in order to accelerate fusion as their elasticity module was closer to that of bone [3]. Nevertheless, concerning this last feature, their efficacy has never been proven. Titanium cages, outfitted with an expansion mechanism able to lengthen them to the desired size once inserted in the operatory filed, appeared on the market nearly two decades ago but were initially disregarded by most surgeons because of their complexity. As primary stability also depends on the possibility of adding preloading forces while placing the anterior support to fill the vertebral gap, new expandable cages fulfilled this need and, compared to the first prototypes, can now be inserted easily in the gap before activating the expansion mechanism. Finally, the use of angulated or orientable end plates allows the surgeon to follow the natural spine alignment in the different tracts of the thoracolumbar spine.

13.3 Anatomical and Biomechanical Consideration on Thoracolumbar Spine

The thoracolumbar spine consists of 17 vertebras that progressively change in shape as we move from T1 down to L5. Vertebral body and disks gradually increase their dimensions as the load they have to bear increases. Facet joint orientation turns from the sagittal plane, in the cranial tract, to the coronal plane as we get close to the sacrum, as the range of movements that every functional spinal unit must accomplish changes. This circumstance, together with the fact that most of the thoracic vertebras are connected to the rib cage through ligaments and joint capsules, provides a wide range of movement in the lumbar tract, while the thoracic spine remains relatively stiff. This link to the rib cage, also known as "fourth column" [4, 5], provides stability to the thoracic spine that is more resistant to share forces and less prone to get kyphotic under mechanical stress. Conversely, the thoracolumbar junction connects the stiff part to the most mobile part of the thoracolumbar spine concentrating share forces during trunk flexion-extension and rotation movements. As the gravity line normally falls anterior to the thoracolumbar junction, it is commonly accepted that the anterior part of the vertebral column is subject to the highest loads due to vertebral body weight, postural changes during normal activities, and preloading effects due to ligaments traction and muscles tone. Furthermore, the compression forces applied against vertebral bodies and disks increase as we move up from L5 to L1 because the distance between the gravity line and the vertebral body also increases [6]. This fact, and the presence of solid iliolumbar ligaments connecting L4 and, more strongly, L5 to the pelvis, explains the reason because post-traumatic kyphosis is frequently seen in the thoracolumbar junction while is rare in lower lumbar spine as some authors highlighted in clinical studies [7]. On the other hand, the posterior tension band, which includes posterior vertebral arch, ligaments, and muscles, acts to counterbalance these compression forces from posterior, and it can effectively work only if the anterior column (vertebral body and disks) is intact. Whenever the anterior support from the vertebral body and/or disks fails, the tension band becomes unable to support axial loads and the spine becomes unstable [8]. Recent studies highlighted the importance of respecting the physiological sagittal curves of the spine performing deformity surgery and degenerative elective surgery in general. Although there is no total consensus concerning sagittal parameter measurement and their relative importance in planning surgery is quite clear that a spine fusion may lead to further spine imbalance and junctional kyphosis if sagittal alignment is neglected. As there is no reason to believe these rules are not valid in post-traumatic deformity surgery, than deep attention must be paid in planning anterior column reconstruction (ACR) surgery for anterior column incompetence whenever a fixed or mobile deformity is associated. More in general, all the biomechanical aspects highlighted here above must be taken into account planning surgery as a mechanical failure after an ACR may cause the anterior support dislocation into the thoracic or abdominal cavities and bring severe complication like vascular injuries. Such complications are life-threatening and always require major revision surgery that is always challenging and sometimes needs to be carried out in an emergency situation.

13.4 Surgical Approaches

In the last 10 years, minimal invasive or less invasive approaches to the anterior aspect of the thoracolumbar spine have been emphasized in order to minimize access related complication and pain, reducing patient hospitalization. Although everything that is beneficial to the patient is generally well accepted, we should remember that this new surgery requires specifically designed surgical instruments, some of which are disposable, that generally increases the cost for the hospitals. Nevertheless, those higher costs are counterbalanced by a shorter hospital stay, so, at the present time, the trend toward minimal invasive approaches seems reasonable. In our institution, a recent review of 22 cases comparing ten minimal invasive lumbar approaches to 12 standard retroperitoneal approaches showed in the former procedures a reduced postoperative pain (3.2 points less at the VAS scale) and a shorter hospital stay (2.8 days less on the average). Obviously, whenever the primary target differs from anterior support restoration, like in primary tumors resection surgery, then the surgical approach must be tailored to the aim of surgery and the type of approach comes to be less important.

13.4.1 Thoracic Spine

T1 is generally reached via left retropharyngeal approach in case of favorable anatomy. The left side is preferred to avoid injuries to the recurrent laryngeal nerve. Sternal manubrium splitting may be necessary in some cases [9]. The T2–T5 tract is commonly considered the hardest to approach both by standard lateral thoracotomy and both adopting a sternal splitting. Whenever a posterior surgery is planned, then anterior column reconstruction should be planned from posterior as well [10]. The lower thoracic spine can be easily reached by lateral standard thoracotomy, mini-thoracotomy, or thoracoscopy. The mid-part is easier to access from the right side to avoid the aorta. Surgical incision should be performed straight above the level to treat using a radiologic landmark, especially if a minimal invasive approach is planned. Retropleural approach is theoretically feasible in young patient but requires a moderate extension of the surgical incision posteriorly, and, anyway, the pleura is frequently violated despite the surgeon effort [11]. T12 is generally approached from the left side, as the diaphragm needs to be pushed down in the abdominal cavity and these maneuvers result more difficult and may damage the liver on the counter lateral side. Depending on the local anatomy, a minimal splitting of the diaphragm at the costovertebral angle might be necessary if addictive L1–T11 plating has to be performed. Surgeons currently approaching the thoracic spine via thoracoscopy report less postoperative pain and shorter hospital stay in their patient compared to those undergoing standard thoracotomy [12]. On the other hand this procedure requires expressly designed instrumentation and a quite long learning curve.

13.4.2 Lumbar Spine

L1 can be easily approached via left mini-thoracotomy in the same fashion as for T12. The posterior insertion of the diaphragm needs to be detached to remove the vertebral body and insert the support, but this is not a major issue and it is generally not burdened by postoperative complications. Most authors recommend reinserting the muscle before the final closure, but this is not always feasible once the cage or the plate is set in place. L2–L4 tract can be approached from the left via a retroperitoneal transpsoas approach [13]. A 7 cm skin incision is made just above the level

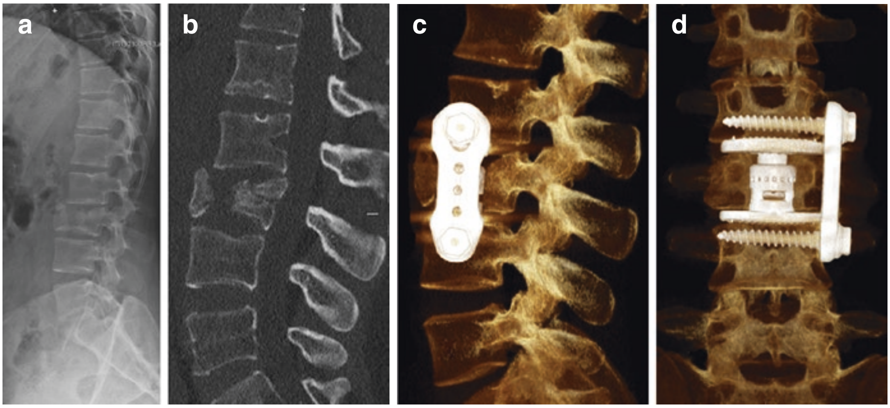

Fig. 13.1 Twenty-seven-year-old female, L3 burst fracture 4 months before, neurologically intact. Anterior column mechanical incompetence is seen in lateral view standing X-ray (**a**) and CT scan (**b**). Reconstruction is made by expandable cage and plating to neutralize share forces due to trunk rotational movements (**c** and **d**)

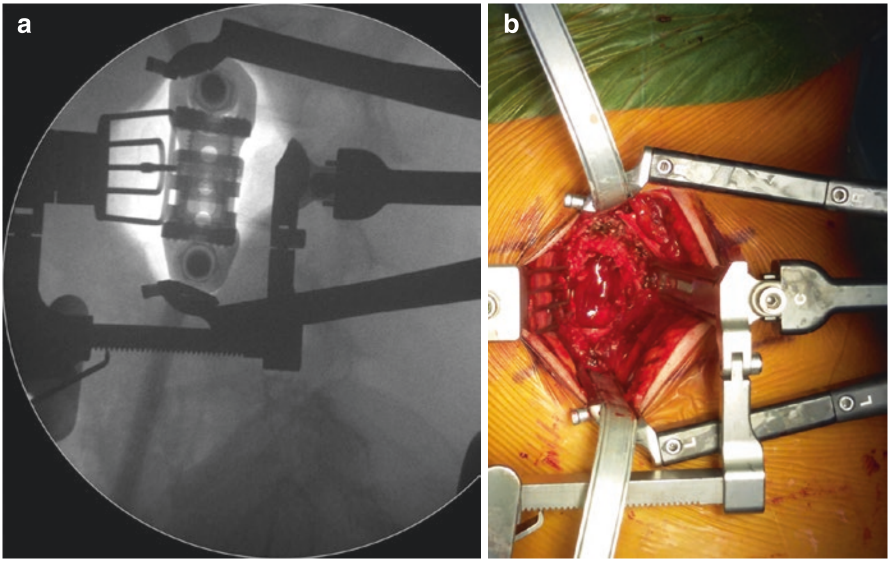

Fig. 13.2 Same case as in Fig. 13.1. Intraoperative X-ray imaging (**a**) and clinical view (**b**) of the left retroperitoneal minimal invasive transpsoas approach. A 7 cm incision allows exposing L3 vertebral body and half of the adjacent vertebra to perform an L2–L4 anterior fusion. Abdominal muscles are splitted along their fibres to reduce the risk for late laparocele

to treat. Abdominal muscle layers are progressively split along their fiber course until the retroperitoneal space is reached. The abdominal content in its peritoneal sac is moved in front by blunt dissection paying attention not to damage the ureter along its course. Psoas splitting is also done along its fibers by mean of an apposite ly designed retractor (Figs. 13.1 and 13.2). Neuromonitoring is strongly suggested during this step to avoid injuries to the lumbar plexus. Compared to the standard approach, the transpsoas one gives major advantages in terms of bleeding, postoperative pain control, and hospital stay, also decreasing the risk of hyatrogenic laparocele. The minimal invasive approach to L5 comes directly from the disk replacement surgery [14]. Skin incision can be transverse below the umbilicus or vertical 4–5 cm left from the midline. The rectus abdominis and its fascia are opened along the muscle fibers a few centimeters from the midline to reach the retroperitoneal space. The abdominal content is gradually dislocated from the left to the right side until the L5–S1 space is reached. Again the ureter needs to be identified and protected during the surgical procedure. In order to reach the disk space above, the major vessels need to be mobilized after ligating the lumbar ascendant vein.

13.5 Preoperative Planning

In recent trauma, MRI can give information on the spinal canal encroachment and spinal cord and, most important, on the posterior longitudinal ligament complex (PLC) integrity [15]. Other basic information required are anterior gap longitudinal extension (to be measured on CT scan 2D reconstruction images both along the posterior and anterior wall lines), local kyphosis and scoliosis if present, and superior and inferior adjacent end plates size. From the abovementioned data depends the implant size although these data are not enough to move in the operatory room. Surgical strategy also relies on multiple further aspects that strongly influence type of surgery, approach, and implant choice. The most important factors are presence of fixed or flexible deformity and previous surgery, with or without posterior instrumentation, and the previously mentioned PLC integrity. Anterior column reconstruction (ACR) alone is feasible in case of no deformity or corrigible deformity; therefore preoperative planning, in ancient trauma, must include flexion-extension and lateral bending X-rays. If incorrigible kyphosis depends on anterior ligament shortening or anterior bone bridging (new callus formation), then ACR only can be still considered, but surgical strategy will include anterior ligament release or bone bridging excision. In these cases, the anterior aspect of the vertebral column needs to be exposed at the chosen level. This can be done by moving in front the major vessels by blunt dissection after ligating and cutting the segmental arteries and veins. Posterior fusion (spontaneous or surgical, with or without instrumentation) and fixed deformity together are a contraindication to ACR alone, and posterior osteotomy (and/or hardware revision) should be considered instead. ACR will follow in case an anterior gap is left after posterior correction (Fig. 13.3). As the cage body is generally smaller compared to its end plates, then a complete corpectomy is generally unnecessary, and the surgeon can leave a bone shell in the front and in the contralateral side to protect the major vascular structures from unwanted injuries. On the other hand, disk removal and vertebral end plate preparation should be impeccable. The surgeono must take care not to break the bone surface during this step to ensure the largest contact between bone and cage end plates and favoring fusion. Expandable cages are very helpful in correcting local kyphosis via anterior approach nevertheless, the risk of cage subsidence through the vertebral end plates during this maneuver is high, especially if the patient bone stoke is not satisfactory.

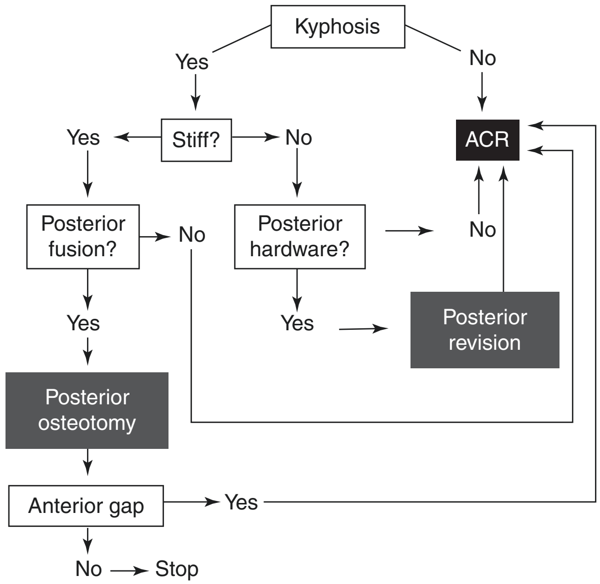

Fig. 13.3 Flowchart showing surgical pathway in case of posttraumatic anterior column incompetence with and without local kyphosis

Accordingly, preoperative dual X-ray absorptiometry scan is strongly suggested in adult patients before a kyphosis correction by ACR, and this procedure should be considered in any case hazardous in female older than 50 and male older than 60. In such cases, vertebral body augmentation by cement ingjection can be achieved during the anterior approach, before cage expansion, reducing the risk for vertebral endplates failure. Relevance of PLC in surgical planning will be discussed later (Sect. 13.6.5).

13.6 Choosing the Right Instrumentation

13.6.1 Expandable Cages

Cage dimension is defined during the preoperative workup but must be confirmed by direct measurement of the anterior gap in the operatory room, and then the cage body is filled by bone graft ore bone substitute. Cage end plates size should be as close as possible to that of the adjacent vertebra's to provide the largest contact surface and leave enough room for additive bone grafting. As the epiphyseal ring is considered the strongest part of the end plate, a direct contact between the cage and this aspect of the vertebra is desirable. Recently, end plates in the shape of the XLIF cages (larger than the vertebral end plate on the coronal plane) have become available on the market and can be helpful in osteoporotic patient as they always provide a direct contact with epiphyseal rings at least at the lateral aspects of the vertebral body (Fig. 13.1). Cage length, before its expansions, should be no more than 3–4 mm shorter than the gap to fill to have at least 1 cm of lengthening available. This is to achieve adequate primary stability through preloading after cage expansion. Angulated end plates are fixed on the cage before its insertion and its final angle (sum of the two end plates

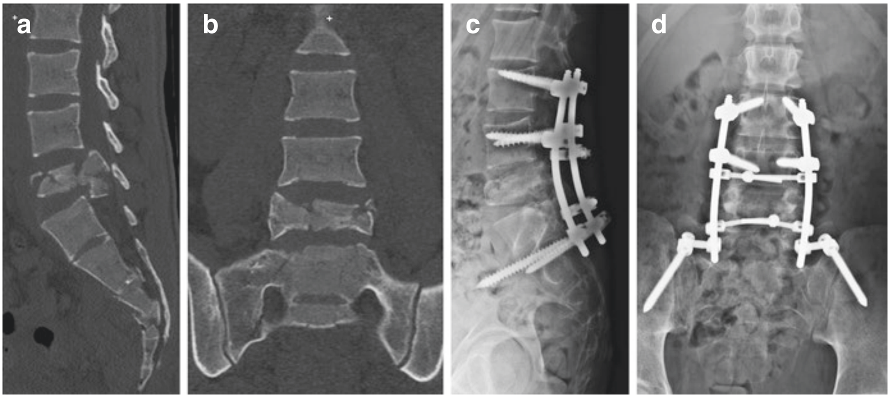

Fig. 13.4 S1 fracture and L5 burst fracture in a 27-year-old male seen in sagittal (**a**) and coronal (**b**) CT reconstruction. Emergency treatment consisted of posterior decompression and lumboiliac fixation is seen on lateral (**c**) and AP (**d**) standard X-rays

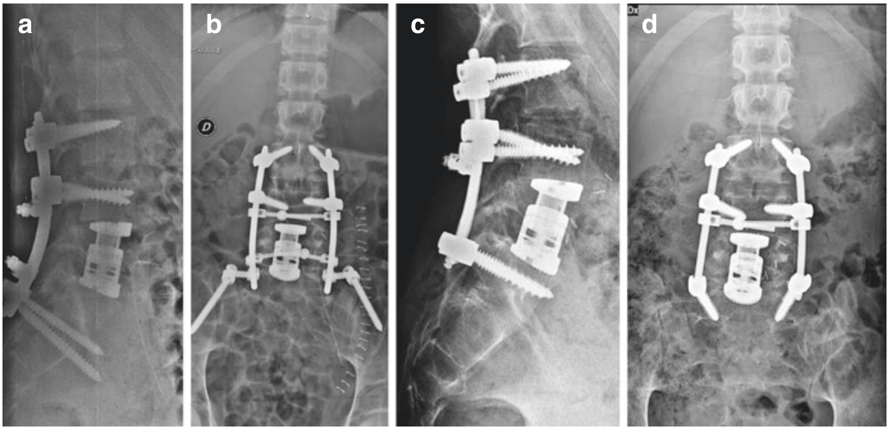

Fig. 13.5 Same case as in Fig. 13.4. Standard X-rays showing anterior reconstruction by expandable cage with angulated end plates completed 4 months after trauma, once sacral fracture is healed (**a** and **b**). Iliac screws are substituted by sacral screws 3 months later (**c** and **d**)

angles) should perfectly match the adjacent end plates inclination, if no correction is required (Figs. 13.4 and 13.5). Conversely, if we intend to correct a kyphotic deformity, then we will consider the sagittal angle we want to obtain. Cage expansion is generally achieved by a mechanical apparatus that, for safety reasons, is self-limiting once a certain pressure against the end plates is achieved. Once the cage location is considered satisfactory, then it can be released from its holder, and the expansion mechanism is finally locked by a safety screw. Hydraulic expansion mechanism is also available and allows the surgeon to check pressure continuously through a manometer. On the other hand, these systems are more complicated and sometimes more expensive. No matter the type of mechanism one would choose the most important point is that, once opened, the cage must be very ease to engage with the proper cage holder, to re-collapse and relocate in a different position, as this eventuality is

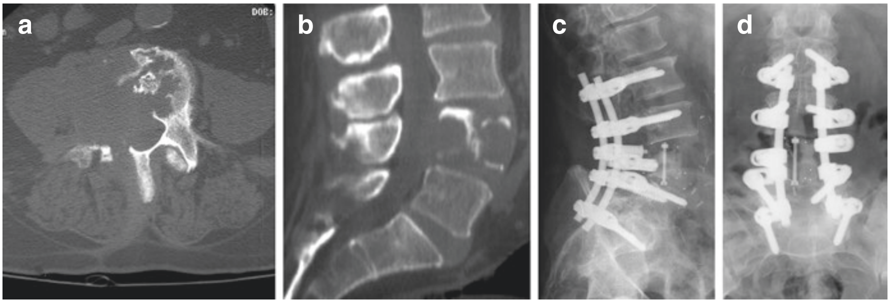

Fig. 13.6 L4 solitary metastasis from renal cell carcinoma in a 50-year-old male seen on CT scan (**a** and **b**). Reconstruction after vertebrectomy by modular carbon fiber cage: cage connection to the posterior instrumentation is visible on standard X-rays (**c** and **d**)

common during surgery. Cages with variable angle end plates are also available and can be placed in the gap with loose end plates and then expanded to enable the best contact with the adjacent surfaces. The further step consists in locking the end plate angle and further lengthens the cage to obtain primary stability through preloading.

13.6.2 Titanium Mesh

As no internal mechanism is enclosed, they provide the largest space to receive bone graft thus improving chances for fusion. Furthermore, they are cheap as their cost is five to six times less compared to the previous type. On the other hand, they need to be cut manually during the surgical procedure; the contact surface is minor and occurs through residual spikes coming from the mesh pattern manual cut. Cage handling must be careful as those spikes may hurt o.r. staff hands during the surgical maneuvers. An internal titanium ring can generally be placed inside both extremities of the cage (at least in the largest diameter ones) to improve stiffness and contact surface. For this reason and because an effective preloading cannot be obtained during surgery, primary stability in stand-alone ACR is inadequate and not advisable. Vice versa, in case of ACR following posterior surgery not requiring sagittal correction, they remain a viable and economic option.

13.6.3 PEEK and Carbon Fiber Modular Cages

The abovementioned concerns about primary stability outfit modular cages as well. The cage is preassembled and filled with graft in OR just before being set in place. Contact surface is generally higher compared to titanium mesh but not primary stability, as there are no metal spikes at the edges. For this reason, in some cases, a connection set (in the fashion of artificial pedicles) between the cage and a posterior instrumentation is also provided to enhance primary stability. Nevertheless, their use is appreciated in tumor surgery because material translucency prevents from CT or MRI artifacts allowing a precocious diagnosis in case of local recurrence (Fig. 13.6). Their cost is generally between that of titanium mesh and expandable cage depending on the number of modules used. Finally, PEEK expandable cages recently became available in the market possibly combining the advantages of both technologies.

13.6.4 Others

Poly-methyl methacrylate (PMMA) is still used as a low-cost option in oncologic patient with poor prognosis, especially to fill small gaps during palliative surgery. Its primary stability is negligible, so it is always used in combination with an anterior or a posterior instrumentation. The use of allograft as a vertebral body substitute has been abandoned because of no primary stability and because it cannot guarantee a long-term support due to the so-called creeping substitution. Furthermore, it requires long modeling work in the operatory room in order to match the gap and it is expensive too.

13.6.5 Role of Posterior Instrumentation and Additive Anterior Plating

A sound ACR can effectively counterbalance compression forces in case of anterior gap, as long as the PLC is intact or artificially substituted by a posterior instrumentation. Conversely, an anterior cage alone will not provide effective stability against share forces during trunk rotation. Since the PLC is intact, an anterior plate located during the ACR surgery will supply this need avoiding unnecessary posterior fixation (Fig. 13.7). If PLC incompetence is present, as it may happen after posterior laminectomy or in case of persistent elongation following posttraumatic kyphosis, then an anterior stand-alone cage may act as a fulcrum when flexion-distraction forces are applied to the vertebral column. In those cases a posterior instrumentation should be associated to the anterior procedure. A posterior instrumentation with a

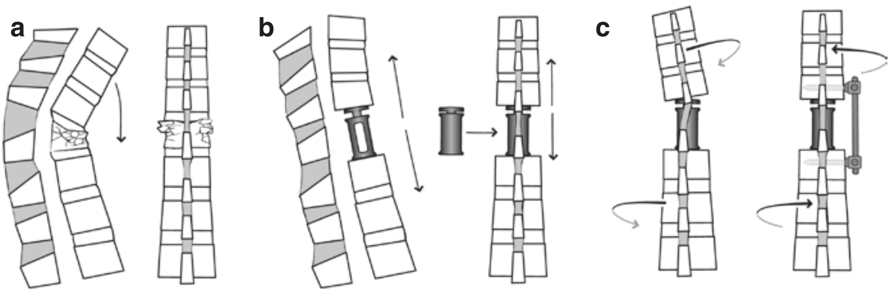

Fig. 13.7 Post-traumatic anterior column incompetence in PLC intact spine (**a**). ACR can adequately compensate flexion/compression forces (**b**). Lateral plate is nonetheless necessary to balance share forces due to trunk rotation (**c**)

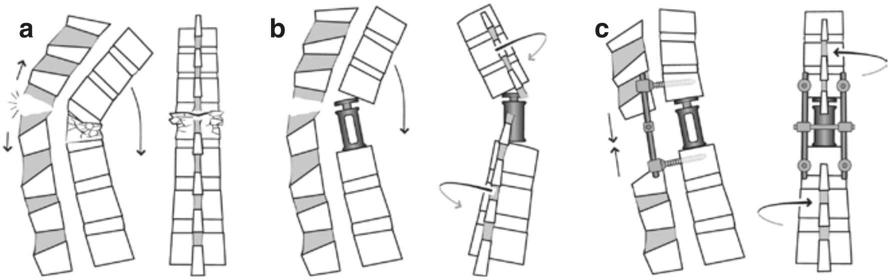

Fig. 13.8 Post-traumatic anterior column incompetence in PLC injured spine (**a**). Stand-alone ACR cannot compensate neither flexion-distraction nor torsion forces (**b**), so posterior fixation is mandatory (**c**)

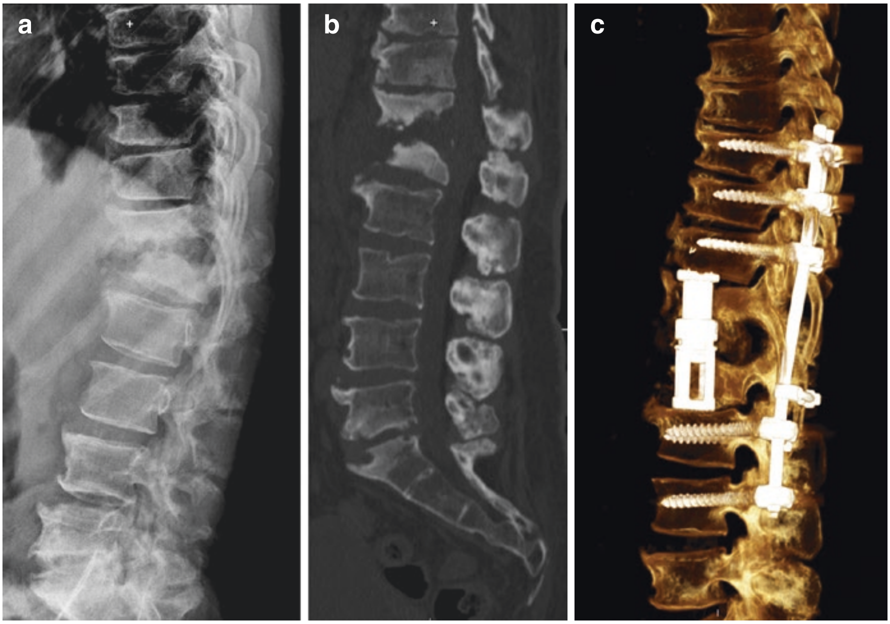

Fig. 13.9 Fifty-nine-year-old male. T12–L1 instability due to a former spondylodiscitis in a paraplegic patient is seen on sitting position X-rays (**a**) and CT scan (**b**). Reconstruction involves both the posterior column by pedicular screws instrumentation and the anterior one by two-level expandable cage (**c**)

cross-link device will also neutralize share forces occurring during trunk rotation movements (Figs. 13.8 and 13.9). Lateral plate mechanical prerequisite to neutralize share forces is angular stability screws locked to the plate. It is also desirable to have a couple screws at each extremity of the plate. Furthermore, bicortical screws will increase stability, as well as a plate compression mechanism if available.

13.7 ACR in Spine Deformities

So far, we considered ACR in a normally shaped spine; nevertheless, lack of anterior support can affect patients with congenital or acquired deformities such as degenerative or idiopathic scoliosis. The basic principle of obtaining the maximum contact between the cage end plates and the adjacent vertebrae remains unchanged but is more difficult to obtain because scoliosis is, in fact, a tridimensional deformity. The easiest way to address the problem is to consider separately vertebral end plates obliquity in the coronal plane and kyphotic deformity in the sagittal plane. So, in order to compensate at our best end plates inclination, we will use one of the cage oblique end plates to achieve the best contact in the coronal plane and the opposite to equalize the sagittal deformity if coexistent. Subsequently preparing our expandable cage in OR before placing it, we must remember that the two metal end plates should be rotated 90° one respect to the other, to obtain the right inclination in both coronal and sagittal plane. If any spine realignment is required, it has to be done from posterior before ACR because in these cases spine must be stabilized before cage expansion as it may cause an unpredictable result in an unstable scoliotic spine (Figs. 13.10 and 13.11). As the maximum cage end plates obliquity available in the market at present is around 15°, deformity higher than 30° in the coronal plane will not allow a satisfactory cage contact with the adjacent vertebrae. In such cases, we can customize a titanium mesh directly in the operating room to fill the anterior gap. Additive lateral fixation during the ACR surgical time is desirable to counteract share forces that are generally high in a scoliotic spine. Here again, standard plates will not fit the scoliotic curves, so better use an old fashion system in which a lateral rod can be freely connected to the screws previously placed in the vertebral bodies.

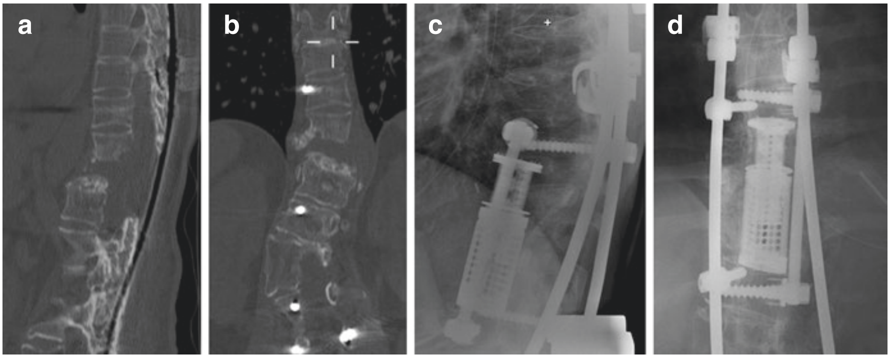

Fig. 13.10 Anterior column incompetence due to a thyroid metastasis in T11 in a patient previously fused for an idiopathic scoliosis is seen on CT scan (**a** and **b**). Reconstruction is made by expandable cage using the inferior end plate obliquity to compensate the scoliotic curve in the coronal plane (**c** and **d**)

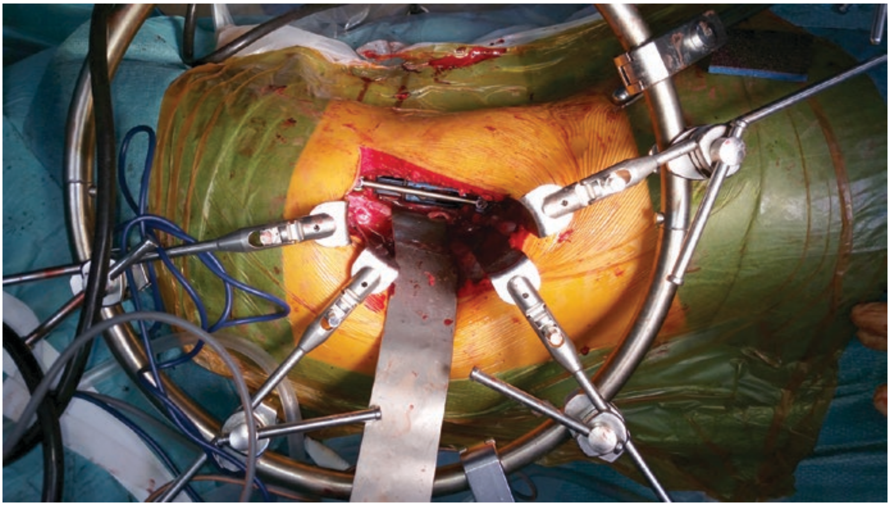

Fig. 13.11 Intraoperative view of the case in Fig. 13.9. A standard retroperitoneal approach, at least three times wider than a minimal invasive one, is used for tumor debulking and ACR

Conclusions

New technologies made ACR procedures less invasive and more effective during the last 10 years. Nevertheless, like before, full understanding of spine biomechanics and sagittal balance rules as well as accurate preoperative workup is necessary to plan an effective ACR that should always be patient tailored. New technologies and minimal invasive approaches are welcome as far as they guarantee at least the same effectiveness as standard techniques. Complications, even though reduced in comparison with the older procedures, are still present and may involve spinal cord, major vessels, urinary tract, and every organ inside the thoracic and/or abdominal cavity possibly leading to death. Therefore, patients should be exhaustively informed about these potential complications, and surgery should be performed once its actual need is recognized. Anamnesis, diagnosis, previous surgery, patient bone stock, and many other factors are still mandatory choosing surgical approach and implant type.

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