Review Article
Back Bone: The Spine Journal | April - September 2022; 3(1): 07-13

Spine Surgery: A Narrative Review About Recent Updates and Future Directions

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Abstract

Background: Advances in case selection, operative methods, and postsurgical care have facilitated spine surgeons to manage complex spine cases with short operative times, decreased hospital stay and improved outcomes.

Methods: This is an overview of recent updates and future directions in the field of spine surgery. All the articles were obtained through a literature review on PubMed.

Results: Minimally invasive spine procedures like Endoscopic spine surgeries, Oblique Lumbar Interbody Fusion, use of retractor systems, etc. are emerging in rapidly in modern world. Fusion surgeries are associated with adjacent level disease hence, motion preservation surgeries that mimic the natural biomechanics of the spine are being explored as alternatives. In view of risks to vital structures, nerve injury due to mal-positioning, etc.; robotic spine surgery has paved a way to allow surgeons real-time procedural manipulation along with instrument control, real-scale magnification. Many high-impact discoveries in cancer research, stereotactic radiotherapy, newer combinations of chemotherapy, and tumor-specific antibodies have increased our understanding of spine oncology. Past two decades have seen many advancements in treatment of spine deformities right from initial radiographic assessment, surgical planning to postoperative care.

Conclusion: All in all, all stakeholders in innovation including the industry, scientists and surgeons must work in an open and honest collaboration to benefit the future patients and continue the evolution in Spine Surgery.

Keywords: Spine surgery, Recent updates, Minimally invasive surgery, Artificial disc replacement, Artificial intelligence

Introduction

Advances in case selection, operative methods, and postsurgical care have facilitated spine surgeons to manage complex spine cases with short operative times, decreased hospital stay and improved outcomes. As it is rightly said, "Teamwork makes the dream work", continued team work is required on part of spine surgeons, scientists, nurses, allied care professionals, and rehabilitation specialists to take this success forward. It is difficult predicting rapidly changing practices in field of spinal surgery. However, we focus this narrative review on a few areas which have shown maximum development in the last decade. Minimally Invasive Spine Surgery (MISS), artificial disc replacement, robotic spine surgery and neuro navigation, use of biologics, spine oncology and imaging modalities are few of them [1, 2]. Through this review article, we hope to provide the readers with an insight into the latest in spine surgery and also throw a glimpse into the future.

Materials and Methods

For the narrative review, the database search was limited to specific keywords: "Recent updates" OR "future directions" AND "spine surgery". We started the search with above mentioned keywords in the "PubMed" database. Only English language literature was considered. The initial search yielded 596 articles out of which 30 articles were relevant to this review and were included. Cross references of the included articles were searched and 19 additional articles were added. Additional repeat assessment by two independent reviewers

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Submitted: 05/11/2021; Reviewed: 12/12/2021; Accepted: 15/01/2022; Published: 10/04/2022

Back Bone: The Spine Journal (The Official Journal Of "Spine Association of Gujarat") | Available on www.backbonejournal.com | DOI:10.13107/bbj.2022.v03i01.033

were done for validation and confirmation of the literature review. Key literature pertinent to the current topic have been cited and emphasis has been placed on English literature published within the last decade to provide the most current recommendations.

Observations/ Review

Minimally Invasive Spine Surgery

Tubular retractor system (METRxTM, Medtronic, Memphis, TN, USA) introduced by Foley and Smith have allowed treatment of herniated lumbar discs using minimally invasive methods [3]. The pioneers in MISS have demonstrated that routine procedures like microdiscectomy can be performed using a novel retractor system with an attachable endoscope. This allows better visualization and causes minimal obstruction for the passage of instruments through a small working channel. Now this technique is used for treating wide spectrum of spinal pathologies like lumbar canal stenosis, synovial cysts, tumors, tethered cords, etc. [4-9]. Minimally invasive approaches are being used in lumbar fusion surgeries (i.e., minimally invasive Transforaminal lumbar interbody fusion [MI-TLIFs]) for treatment of spondylolisthesis, degenerative disc disease, and traumatic fractures. The outcomes are comparable to open surgery. Moreover, there are fewer complications, shorter hospital stays, and lesser blood loss with this technique [10, 11]. The size of tubular retractors is also reducing with improvements in visualization methods and surgical technique. Recent reports show successful outcome with a 12 mm retractor [12]. Extreme Lateral Interbody Fusion (XLIF) or Direct Lateral Interbody Fusion (DLIF) are minimally invasive procedures for thoracolumbar spine. This approach also known as lateral, trans-psoas muscle approach was initially used by Pimenta and others for the treatment of degenerative disc disease [13]. It facilitates working channel to disc space and vertebral body which useful for treating multiple spine pathologies. This approach has been used as a powerful adjuvant when combined with posterior instrumentation for improved correction of spinal deformity [14-16]. Also, this approach has been used for placing an intervertebral artificial disc and has been recently approved by FDA outside USA [17]. This approach for disc replacement may eventually replace anterior approach as it reduces the risk of injury to vital intra-abdominal structures like the iliac vessels, neural elements, and genitourinary tract. This approach however, carries a risk of injury to the lumbar plexus and thus, continuous use of intraoperative neuromonitoring is required. The safe corridor between the psoas muscle and the great vessels can negate this risk. This promising approach is called Oblique Lumbar Interbody Fusion (OLIF) and is increasingly being utilized for the treatment of adult degenerative disorders [18].

Figure 1: Unilateral Biportal Endoscopy with a viewing portal and working portal

Endoscopic spine surgeries have grown leaps and bounds in the last decade and no discussion on minimally invasive spine procedures can be complete without mentioning endoscopic spine surgery. Procedures like Percutaneous Endoscopic Lumbar discectomy (PELD) done via the transforaminal approach is truly minimally invasive. This surgery is carried under local anesthesia and can be done as a daycare procedure. With the advent of UBE (Unilateral Biportal Endoscopy) for the management of lumbar canal stenosis, acceptance of endoscopy for other conditions is increasing (Figure 1). There are even published reports of endoscopic fusion surgery (Endoscopy TLIF) [19]. These endoscopic spine procedures hold great promise and but, their long-term results are awaited. Also, they have a relatively steep learning curve.

Artificial Disc Replacement

Philosophy concerning the cervical and lumbar fusion surgery has witnessed a change in the past decade. Fusion surgeries are associated with adjacent level disease hence, motion preservation surgeries that mimic the natural biomechanics of the spine are being explored as alternatives. First device for use in the lumbar spine was the Charite disc (DePuy, Ranham, MA, USA) which was approved in the United States in 2004 [20-22]. Its benefit for the relief of axial back pain is well documented. ProDisc-L (Synthes, Paoli, PA, USA) was released in 2006. It has shown results that are comparable to historical fusion procedures [23]. However, efficacy of these products as well as their comparison to reported outcomes in lumbar fusion surgery are needed. Cost considerations also have to be considered while evaluating these devices from an Indian perspective. Unlike cervical disc arthroplasty, lumbar disc arthroplasty carries risks to vital structures like the

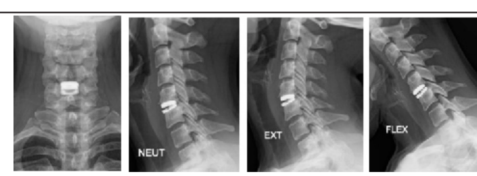

Figure 2: (A, B, C, D): Anteroposterior and lateral neutral and dynamic radiographs showing cervical disc replacement and restoration of range of motion in a 38 years old post-operative female with cervical radiculopathy.

lumbosacral vessels, neural elements, and genitourinary structures. In future, with better preoperative imaging assessment and minimal access surgeries this may improve. Moreover, approaches like OLIF may reduce these risks and become the preferred surgical approach. FDA-approved cervical disc arthroplasty devices and lumbar implants are composed of materials which do not allow for appropriate visualization of the operated disc level (Figure 2 A, B, C, D). Major drawback of these devices is that it frequently obscures the adjacent segments while evaluating with MRI. A study by Sekhon et al, evaluating the ability to visualize the spinal canal and adjacent segments after cervical disc arthroplasty, found only the Bryan (Medtronic) and Prestige LP (Medtronic) implants allowed for adequate visualization [24]. The artifact produced by these implants can be avoided with the use of non ferromagnetic biomaterials which allows for postoperative imaging and evaluation. The design of future intervertebral disc prostheses may employ use of polymers and ceramics. The design will provide mechanical support, motion sparing and easy imaging with MRI and also better mimic the natural biomechanics of the spine [25]. Many patients do not fit the criteria for disc arthroplasty due to pathologies like the cervical subluxation, lumbar spondylolistheses, lack of motion related to severe spondylosis. In these patients, fusion surgery remains the mainstay of treatment. Traditional titanium-alloy plates and screws are used frequently for these fusion surgeries. One can slowly witness a trend towards bio-absorbable plates and screws, and smaller plating systems that have reduced the incidence of iatrogenic adjacent segment disease. For many years, bio-absorbable instrumentation has been in use in plastic surgery and neurosurgery for craniofacial reconstruction, however, in spine surgeries the bio-absorbable anterior cervical plating systems have been available only since the last few years [26]. They offer a viable alternative to their metal counterparts. It also negates the effect of an artifact on post-operative MRIs. They provide temporary stabilization till the graft unites or the bone has healed. However, long term results of these with implants are awaited.

Artificial Intelligence, Robotics and Neuro-Navigation

In spine surgeries accuracy is an absolute necessity. Common complications include risks to vital structures, blood vessels, viscera and the neural elements. On utilization of instrumentation, mal-positioning of the hardware may occur causing nerve injury and compromised stability of the construct. Studies have reported that dural breach occurs in 3.5 percent of primary discectomies and 13 percent of revision discectomies owing to mistakes in surgical techniques (visualization or instrument control) [27]. This is more common especially for a young surgeon at the beginning of his learning curve. In view of these challenges, robotic spine

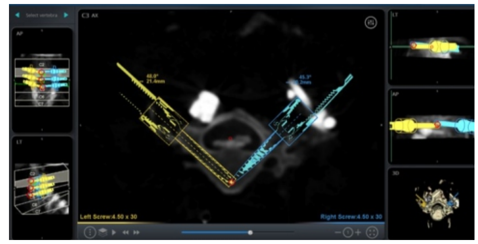

Figure 3: (A): Mazor X robotic guided instrumentation planning showing axial images with 3d orientation. (B and C): Lateral and Anteroposterior intraoperative images showing the robotic assisted instrumentation for minimal invasive transforaminal lumbar interbody fusion.

surgery has developed in recent years. Its advantages include it allows surgeons real-time procedural manipulation along with instrument control, real-scale magnification and eliminates tremors. Anatomical spine navigation with precise surgical technique causes minimal bony damage and blood loss. Despite this, robotics had limited applications in spine surgery due to challenges like cost, training, and alternatives like minimally invasive techniques which are more commonly used. Computer-assisted navigation (CAN) has transformed spine surgery. It provides real-time data based on intraoperative radiography and registration points. It is of great help in cases of oncological resections with distorted anatomy and unclear margins. Here MRI co-registration provides data which is beyond the realm of direct vision [28]. In case of thoracolumbar pedicle screw placement, it is reported in several meta-analyses of thousands of screws that CAN has shown superior accuracy as compared to freehand techniques. But, there is no statistically significant difference in patient outcomes [29, 30]. The applications for CAN continue to widen in scope and in combination with the digitization of patient anatomy, facilitates robotic surgical technologies into spine surgeries. SpineAssist/Renaissance/Mazor X (MAZOR Robotics Inc., Orlando, Florida) robot is a pioneer which has shown greater accuracy than fluoroscopic- or navigation-guided techniques in insertion of percutaneous or open pedicle screws (Figure 3) [31, 32]. Other systems that have been introduced include ROSA (Medtech, Montpellier, France) and the Da Vinci Surgical System (Intuitive Surgical, Norcross, Georgia). Robotic-assisted surgery have many advantages for the surgeon. It significantly improves the dexterity with a reduction in physiological tremor, reduces X-ray–induced radiation, provides 3-D visualization, causes significant improvement in ergonomics with less pain, strain, and stiffness [33, 34]. There is possibility of minimal muscle dissection, retraction, and bleeding [35, 36]. Also, the learning curve is not too steep as has been previously reported in case of radical nephrectomy using the Da Vinci system [37]. Robotics in the spine come with their own disadvantages. Lack of haptic feedback from tissue manipulation, need for increased training for the surgeon and other operating room staff, increased operating time and significant cost. It has been reported that the estimated cost of acquiring a Da Vinci system is in the range of $1.1-$1.7 million [36]. Moreover, increased operating time and training needs also add to the cost. Additional funds are required to transform the particular platform for its applicability to the spine. Additional attachments such as bone drills and ronguers may be required. Despite the disadvantages, the longer term of spine surgery will need to include these devices and tools which increase patient safety, improve surgical outcomes, improve surgeon dexterity while reducing discomfort and do so seamlessly. Robotics and spinal/neuro-navigational devices can be teamed up in surgeries for better outcome. In spite of this, many hospitals which offer complex spine surgery do not consider navigation as a routine component due to significant investment in cost, space, and the lack of belief in its utility for improve outcomes over and above non-navigation techniques [1]. Intraoperative navigation has been available since a decade. It's evolved from plain fluoroscopy to 2D then 3D fluoroscopy acquired intraoperatively then co-registered with preoperative imaging [38]. Further development in navigation is the creation of an intraoperative CT scanner. The O-arm® (Medtronic, Inc., Louisville, CO, USA) is a CT scanner that allows imaging of the screws intraoperatively. Here, a reference pin or anatomical landmark is co-registered with an acquired CT scan and linked to a navigational software program. Ughwanogho E et al, in their study compared navigated and non-navigated pedicle screws and assessed their relative accuracy. They used the O-arm system. They found that 0.6% of the navigated screws needed to be removed intraoperatively compared with 4.9% of the nonnavigated screws. They also defined "significant" medial breach, as 50% excursion of the screw diameter and this was almost eight times more likely to occur without navigation. They concluded that imaging guidance leads to more accurate placement of pedicle screws [39]. Overall, navigation improves the accuracy of surgical instrumentation and reduces radiation exposure significantly. Similar to the robotic surgeries, it can be associated with increased operative time, risk of exposure to infection during draping and un-draping, and the learning curve for both surgeons and operating room staff. Navigation adds little benefit to routine surgical cases where bony anatomical landmarks are sufficient for placement of screws and instrumentation. Whereas it has greatest application in cases with significant deformity or dysplastic changes in the spine or the craniovertebral junction with a complex anatomy and scoliosis cases with significant rotational deformity in the thoracic region where accuracy is critical.

Spinal Biologics

Osteobiologics form the core of modern spine surgeries. Interbody cages which have been in use since the 1980s have shown progress by changing their composition from original stainless steel 'Bagby cage' to fusion-promoting titanium-PEEK composites, silicon nitride ceramics, and hydroxyapatite-coated implants [40]. BMP-2 is another novel product which induces robust osteogenesis by activating serine-threonine kinase receptors on cells. This acts even in cases with poor bone quality. Its use has reduced after several studies reported complications associated with rhBMP-2. Nevertheless , there are many cases where it remains an important adjunct for bony fusion [41]. Advancement in the stem cell technology had led to the comeback of biomaterials as vectors for delivering cells and slow-release growth factors. There is increased integration of collagen, PLLA, hyaluronan methylcellulose, demineralized bone matrix, and self-assembling peptides into spine surgery [42]. Theoretically, placing biologically active agents inside intervertebral disc helps regenerate or stabilize the degenerative changes [43]. Minimally invasive techniques are used to place these agents as described in previous studies [44]. Animal studies show that placing osteogenic protein-1 halts the disc degeneration process as seen by changes observed on MRI. This need to be assessed for safety and efficacy in humans through clinical trials. This kind of preventative strategies may decrease number of spine surgeries performed in the future. Other upcoming strategies in preventing disc degeneration or regeneration after failure are injections of growth-stimulating protein like bone morphogenetic protein-2 (BMP-14), virus mediated in vivo genetic therapy, and cell therapy (mesenchymal stem cell, chondrocyte) etc. Non-degradable acrylic bone cement (ABCs) and degradable calcium phosphate cement (CPCs) are two main types of bone cements widely studied for vertebral augmentation procedures. PMMA-based hybrid or composite cement have been developed. They incorporate CaPs or polymers for combining bone augmentation characteristics of ABCs & biodegradability of CPCs. These may lead us to discovery of tailored bone cement specifically for VP or BKP. Young patients having traumatic burst fractures require excellent biocompatibility and degradability of cement for facilitating bone formation and remodeling. However, elderly OVCF patients require immediate weight-bearing stability. In this case, the cement providing long-term multidirectional stability and slowly resorption is desired and this led to development of composite CPCs (strontium enhanced etc.) [45]. Novel approaches for traumatic spinal cord injuries (SCI) are being developed. These injuries carry devastating implications for patients, caregivers, and the society. Pharmacotherapy like riluzole, minocycline, anti-Nogo antibody, Cethrin, Hepatocyte Growth Factor, and Granulocyte colony-stimulating factor are on the verge of being translated to actual patient care in case of traumatic SCI. Non-pharmacological therapy like spinal cord stimulation, CSF drainage, biomaterials, and cell-based therapies (e.g. neural precursor cells, mesenchymal stem cells, olfactory ensheathing cells, etc.) have also shown promising results. Further, clinical trials are needed to validate these results [2].

Spine Oncology

Management of primary spinal tumors is challenging. It requires unprecedented team efforts across disciplines to improve survival, quality of life, and decrease treatment-related morbidity. Previously performed extensive resection and morbid procedures have made way for advanced percutaneous diagnostic techniques in combination with targeted biologics (e.g., RANKL for giant cell tumors). Stereotactic radiosurgery (SRS), proton-beam therapy, and carbon-ion therapy is being increasingly performed on radio-resistant tumors. Molecular markers (e.g., RUNX3 in chondrosarcomas) are helping in stratification of tumor subtypes in turn guiding treatment and prognosis. Our understanding for treatment of common spinal tumors i.e. metastatic spinal tumors is the result of many high-impact discoveries in cancer research, role of radiotherapy, newer combinations of chemotherapy, and tumor-specific antibodies. There is increased emphasis on early tissue diagnosis. This helps in genetic analysis, risk stratification and development of personalized treatment plans. (e.g. Erlotinib and pemetrexed–cisplatin for non-small cell lung cancer with an EGFR mutation). Better surgical techniques have evolved which have decreased morbidity and more acceptability from patients. PMMA augmentation has shown to decrease pain in patients with spinal metastases. MISS techniques such as tubular resection, endoscopic decompression, introduction of PEEK cages, and percutaneous pedicle screws have also shown good results. 3-D printing is being used for reconstruction after radical surgeries for a spine tumor as per the anatomy of patients' vertebra. Cases like anterior column reconstruction which are a challenge also use this technique. Instituto Orthpedico Rizzoli have reported the initial outcomes of 3D printed cages in a series of 13 patients. They have also attempted a “spine in the spine” transplant. Here, after a vertebrectomy, the vertebra from a fresh frozen cadaver is used to replace the patient's vertebra. This is also an alternative for anterior column reconstruction [46].

Spinal Deformity

Past two decades have seen many advancements in treatment of spine deformities right from initial radiographic assessment, surgical planning to postoperative care. Management of adult thoracolumbar deformity has seen improvements in understanding alignment goals, better tools in radiological analysis, stereo radiography, strategies for minimizing complications, outcome scores, and advances in minimally invasive techniques. Pediatric deformity management have shown marked improvement by closely aligning biotechnology and surgical research. Promising results are seen with 3-D imaging and growth-friendly implants like the magnetic growing rods. Identification of critical risk factors like frailty and stratification of patients using predictive analytics have reduced the rate of complications [47].

Imaging Modalities

A variety of pathophysiological processes affect the spine. Thus, brain and spine imaging involve use of advanced MR imaging techniques. Diffusion-weighted imaging owing to its benefits in neuro-radiology have been incorporated into majority of the imaging protocols (Figure 4). Advances in scanning hardware/software technology benefit in phase-contrast flow quantification for evaluation of the Chiari 1 malformation. DTI and BOLD fMRI is useful in pre-surgical planning for patients with spine and brain tumors [48]. EOS imaging provides 3D visualization of the vertebral column and lower limbs of the patients. It limits the X-ray dose absorbed by the patient. This imaging has promotable future especially in the field of spinal deformity [49].

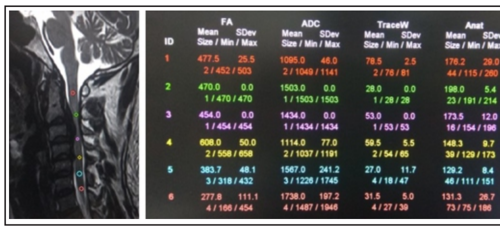

Figure 4: DTI MRI showing FA and ADC values at different levels in the cervical spine

Limitations: This is a narrative review and not a systematic review or a meta-analysis. The search was restricted to PubMed database only and no other search engine was utilized. We limited the search to English language literature. Hence, there may be articles focussed on the topic that may have been missed, though we have tried our level best to summarize all the available literature current updates in spine surgery.

Conclusion

Future of spine surgery in India and throughout the world will be greatly affected by the economic impact on healthcare. Considering the socio-economic scenario and demographics of our country a large population will have to be provided care at reduced costs greatly affecting the innovation in our specialty. It is said “Change is the law of Life”. Hence, it is pertinent that all stakeholders in innovation including the industry, scientists and surgeons must work in an open and honest collaboration to benefit the future patients and continue the evolution in Spine Surgery.

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Declaration of patient consent: The authors certify that they have obtained all appropriate patient consent forms. In the form, the patient has given his consent for his images and other clinical information to be reported in the Journal. The patient understands that his name and initials will not be published, and due efforts will be made to conceal his identity, but anonymity cannot be guaranteed.

Conflict of Interest: NIL
Source of Support: NIL

How to Cite this Article

Marathe NA, Mhatre PP, Date S, Sharma A | Spine Surgery: A Narrative Review About Recent Updates and Future Directions | Back Bone: The Spine Journal | April-September 2022; 3(1): 07-13.