New Frontiers in Spine Surgery

Akshay Gadia[1], Kunal Shah[1], Abhay Nene[1]

Background

With the ongoing advancement in the field of spinal imaging, surgical techniques and postoperative care of patient it has become convenient for spine physicians to provide optimal treatment with short surgical time and decreased hospital stay. The aim of this article is to highlight the developments in the modern era of spine surgery while providing an insight into the exiting future trends in patient's care. Advances in the management of spinal degenerative disorders, primary and metastatic spinal tumors, spinal trauma, pediatric and adult deformity, infections, use of osteobiologics, biomaterials, computer assisted navigation and robotics are described with the reference to the published papers.

Degenerative disorders of spine:

Cervical Spondylotic Myelopathy (CSM):

The term CSM includes degenerative pathologies (e.g: cervical spondylosis, degenerative disc disease, ossification of posterior longitudinal ligament) resulting in compression of spinal cord and a cluster of clinical features characterized by imbalance, decreased fine motor function of hands with or without sphincter dysfunction. Due to variability in the etiology and natural history of CSM the controversies in the management are related to timing of surgery as well as surgical approach. In a prospective international, multicenter study (n=479), authors found surgical decompression was effective in moderate and severe CSM. In another prospective international observational multicenter study (n=264) authors found no difference in outcomes of anterior versus posterior surgery. However there is still no consensus in the literature with respect to efficacy of MIS versus open cervical decompression, laminectomy versus laminoplasty and the role of adjuvant pharmacological treatment in CSM.[1]

In another level 2 mataanalysis of ACDF performed on outpatient basis (n=2448), 63.8% patients undergoing one level surgery while almost all rest of the patients undergoing 2 level surgery were included in the analysis. 2% patients required readmission. Author's thus concluded that outpatient ACDF is becoming increasingly useful and safe in an adequate setup. However the optimal patient selection for this modality of treatment it is still a matter of debate. [2]

Segmental cervical kyphosis has been considered to be one of the important predictors of outcome following cervical decompression in patients with CSM. In the retrospective analysis of 68 patients, Jain et al compared the functional outcome in patients with overall lordotic alignment with those having segmental kyphosis. At the mean follow up period of 5 years, authors found no difference in functional outcome between the two groups thus establishing the notion that segmental alignment of cervical spine does not affect the long term outcome following laminectomy. [3]

Disc replacement:

In a level 1 study, 99 patients were randomly divided into 2 groups; one group receiving Mobi-C (Zimmer Biomet) TDA implant and other group undergoing ACDF. These patients were followed for 5 years. The prevalence of further surgery differed significantly between the 2 groups ($p = 0.049$); 7 patients who underwent ACDF required further surgery compared to only 1 patient requiring reoperation in the Mobi-C group. There were significant differences ($p < 0.001$) between the 2 groups in the imaging-defined range of motion of the treated segment. However, treatment with use of the Mobi-C implant and ACDF both were effective in improving patients' clinical symptoms. [4]

In another level-1 prospective randomized control trial, Sasso et al. examined the 7-year and 10-year outcome of cervical arthroplasty and anterior cervical discectomy and fusion (ACDF). As a part of FDA IDE trial, 47 patients were randomized in a 1:1 ratio to ACDF or cervical arthroplasty (BRYAN, Medtronic) group. 22 patients received arthroplasty while 25 received an ACDF. Outcomes were assessed by Neck disability index (NDI) and Visual analogue scales (VAS) for neck and arm pain. Success of both surgical interventions remained high at the 10-year interval. Both arthrodesis and arthroplasty demonstrated statistically significant improvement in neck disability index, visual analog scale neck and arm pain scores at all intervals including 7- and 10-year periods. Cervical arthroplasty demonstrated an advantage in comparison to arthrodesis as measured by final 10-year NDI score (8 vs. 16, P=0.0485). At 10-year follow-up the reoperation rate in the arthroplasty cohort of this investigation is lower but not statistically different (9%) than that observed in the arthrodesis cohort (32%) (P=0.05551). 3 patients (13.63 %) crossed over to arthrodesis group from arthroplasty group due to technical difficulty in implanting arthroplasty device. Authors concluded that at 7 years and 10 years, cervical arthroplasty had favorable outcome in comparison to ACDF in highly selected population with radiculopathy.[5]

[1]. Wockhardt hospital, Anand rao nair marg, Mumbai central
[2] "We are spine" centre, Aarav polyclinic, Ghatkopar, Mumbai
Address of Correspondence
Dr Kunal Shah , Consultant spine surgeon, "We are spine" centre
Aarav polyclinic, LBS Road,ghatkopar west, Mumbai-400086
Email-orthokunal@yahoo.com

Lumbar canal Stenosis:

In a level 2, case matched observational study from Norwegian registry for spine surgery; authors evaluated the effectiveness of decompression alone compared with additional fusion for lumbar spinal stenosis with degenerative spondylolisthesis. 260 patients from each group were studied for functional outcome. Primary outcome were measured for leg pain and back pain by NRS (numeric rating scale) and ODI score at 12 months. Though the authors were not able to conclude the superiority of decompression alone over decompression with additional fusion, they however highlighted the fact that considerable number of patients can be treated with decompression alone owing to small difference in group's effect sizes in the mentioned study. [6]

Spinal Deformity:

Early onset scoliosis (EOS):

Decreased amount of lengthening over a period of time is one of the known problems that haunt the management of early onset scoliosis with traditional growth rods (TGR). The 'law of diminishing returns' defines the amount of lengthening that a TGR can undergo before stiffness across the construct prevents further increases in overall length. In a retrospective analysis of consecutive series of 54 patients of Magnetic expansion control growth rods (MCGR), Gardner et al stated that 'The law of diminishing returns' does not affect the serial lengthening of MCGR. They also proposed that it is growth velocity rather than the total number of lengthening episode independent of age of child is a better measure of the success of system that maintain the spine growth. [7]

In another retrospective review of prospectively collected clinical and radiographic data of 30 patients with minimum 2 year follow up, Kwan et al studied the unplanned reoperations and other complications associated with MCGR surgery for EOS. Mean age of implantation of MCGR was 7.2 years with mean follow up of 37 months. 14 (46.7%) patients underwent reoperation with in the follow up period. The mean time for reoperation was 23 months (5-48 months) after initial surgery. They found that patients undergoing frequent distractions (1 week – 2 months) hade higher rate of reoperations compared to patients undergoing distraction at the longer interval (3-6 months). They found jamming of rod, failure of proximal construct, rod breakage and infections as a cause for reoperation. [8]

Adolescent idiopathic scoliosis:

In a level 3, retrospective cohort study of 149 patients of adolescent idiopathic scoliosis; Ohrt-Nissen et al. compared the radiographic outcome and health related quality of life in patients treated with hook/hybrid (H/H) or all-pedicle screw (PS) instrumentation. SRS-22 score was used to measure functional outcome. All patients were followed for minimum of 2 years of postoperatively. H/H and PS group had 85 and 64 patients respectively. Mean curve correction at final follow up was 31% ± 13% versus 49% ± 12% in the H/H and PS group, respectively ($p < .001$), and mean loss of correction was 7° versus 4° ($p < .001$). The Cincinnati correction index was significantly higher in the PS group at final follow-up ($p < .001$). SRS-22 scores did not differ between the two groups ($p > .090$), and the reoperation rate at final follow-up was 9% in the H/H group and 6% in the PS group ($p = .556$). The authors found that PS instrumentation compared to H/H instrumentation had significantly better curve correction and less loss of correction. However, there was no significant difference between SRS-22 scores at final follow up. [9]

Postoperative loss of correction has been reported with the use of modern segmental instrumentation. In a level 4 retrospective analyses of 42 patients of Lenke 1 AIS, Le Navéaux evaluated the 3D changes in spine and rod in 2 years after AIS instrumentation with different rod materials. This was a unique study as it tried to establish the relation between postoperative loss of correction with the different rod materials. Rods made up of titanium, stainless steel and cobalt chrome were studied. The main thoracic (MT) curve (61±9°) was corrected on average by 75% (15±6°, $p<0.01$) with no change at 2-year follow up (2YFU) (17±7°, $p=0.14$). The apical vertebral rotation (23±7°) was corrected by 44% (13±9°, $p<0.01$) with no change at 2YFU (14±9°, $p=0.64$). The thoracic kyphosis (24±12°) remained unchanged ($p=0.78$). Rod curvature and deflection also remained unchanged (all $p>0.05$). 3D curve correction was maintained in the 2YFU for all rod materials subgroups (all $p>0.05$). Authors concluded that there was no significant change in the 3D shape change of instrumented thoracic spine or of the rods for any of the cases irrespective of rod material used. [10]

Adult degenerative Scoliosis:

In an ambispective study of 125 elderly patients (> 65 years) undergoing elective spine surgery for correction of adult degenerative scoliois, Adogwa et al. studied the effects of early mobilization on patient outcomes, complications and 30 day readmission rates. Patients in the top and bottom quartiles were dichotomized into "early ambulators" and "late ambulators", respectively. Early ambulators were ambulatory within 24 hours of surgery, whereas late ambulators were ambulatory at a minimum of 48 hours after surgery. The prevalence of at least one perioperative complication was significantly lower in the early ambulators cohort (30% vs. 54%, $P = 0.06$) compared to late ambulators. The length of inhospital stay was 34% shorter in the early ambulators cohort (5.33 days vs. 8.11 days, $P = 0.01$). Functional independence was superior in the early ambulators cohort, with the majority of patients discharged directly home after surgery compared with late ambulators (71.2% vs. 22.0%, $P = 0.01$). Authors suggested that even the delay of 24 hours in ambulation was associated with higher complications rate and inferior functional outcome.[11]

In a level 1 meta-analysis, Lee et al., reviewed the literature for identifying advantages and disadvantages of long versus short fusion for patients with spinal stenosis with balanced de novo degenerative lumbar scoliosis without substantial sagittal imbalance. Data from 6 studies involving 362 patients was analyzed (short fusion in 202 and long fusion in 160

patients). The long fusion group showed a substantial decrease in Cobb angle (WMD, 8.94; 95% CI, 2.55–15.33) and in C7 plumb (WMD, 5.90; 95% CI, 0.39–12.18), compared to the short fusion group. At final follow-up, ODI had decreased similarly in both groups (WMD, 1.70; 95% CI, 13.04–9.65). The short fusion group showed advantages including decreased blood loss (mean difference, 739.9mL) and shorter operative time (mean difference, 68.0 minutes) compared to the long fusion group. Based on these results, authors suggested that short fusion might be reasonable option for patients with sagittaly balanced degenerative scoliosis.[12]

Spinal Trauma and spinal cord injury:
In a prospective multicenter study to find out burden of spine fractures in India, Aleem et al. analyzed 192 patients over a period of 8 weeks across 14 hospitals in India. The aims of this study were to determine the characteristics of patients sustaining spinal trauma in India and to explore the association between patient or injury characteristics and outcomes after spinal trauma. This srudy was in affiliation with ongoing INternational ORthopedic MUlticenter Study (INORMUS). Mean age was 51.0 years, 72 % patients were injured from falls. Thirty-day mortality and complication rates were 2.6% and 10.0%, respectively. Care in the public hospital system (odds ratio [OR] = 6.7, 95% CI = 1.1-41.6), chest injury (OR =11.1, 95% CI = 1.8-66.9), and surgical intervention (OR = 4.8, 95% CI = 1.2-19.6) were independent predictors of major complications. The presence of chest injury and surgical intervention following spinal trauma were predictive of adverse outcomes in 30 days. The limitation of this study was that the follow-up period was only 30 days. Hence, complications arising after 30 days were not analyzed. [13]

Spinal tumors:

In a retrospective analysis, Patil et al studied 5 patients for early results of total en-bloc spondylectomy for solitary metastatic lesion. Average duration of follow-up was 18 months (range 16-20 months). The average preoperative visual analog scale score of 9.4 (range 9-10) improved to 2 (range 1-4) at last followup. Average blood loss was 1440 mL (range1000-2000 mL). Average duration of surgery was 198 min (range180-240 min). Significant pain relief was noticed in each patient in the immediate postoperative period and during followups. Authors suggested that en bloc spondylectomy has good short-term results for solitary, metastatic, high-grade vertebral body tumors. [14]

Spinal Infections:

In a level 3 retrospective study of, 84 patients were analyzed to determine the role of fixation in deep spinal infections. Patients were divided in 3 groups; those treated with antibiotics alone, those treated with antibiotics and debridement and those treated with antibiotic, debridement and instrumentation. Patients were compared for mortality, reoperation and reinfection rates. Patients were analyzed using multivariate logistic regression model. The most common form of infection was osteomyelitis and spondylodiscitis (69.4%). Staphylococcus aureus was the most common causative organism (61.2%). There was no difference in terms of reoperation or relapse for patients treated with antibiotics alone, antibiotics with debridement, or antibiotics with debridement and instrumentation. However, compared with antibiotics alone, the crude in-hospital mortality was lower for patients treated with instrumentation (odds ratio, OR, 0.82; P = 0.01), and antibiotics with debridement (OR 0.80; P = 0.02). Authors suggested that spinal instrumentation in infected spine is safe and not associated with higher reoperation and relapse rates. Mortality is lower for patients treated with spinal instrumentation. [15]

Navigation and robotics in Spine surgery:

Molliqaj et al. analyzed 169 patients, with the aim to compare the accuracy of robot guided and conventional free hand-fluoroscopy guided pedicle screw placement in thoracolumbar surgery. Pathological entities included degenerative disorders, tumors, and traumatic cases. In the robot-assisted cohort (98 patients, 439 screws), pedicle screws were inserted with robotic assistance. In the freehand fluoroscopy-guided cohort (71 patients, 441 screws), screws were inserted using anatomical landmarks and lateral fluoroscopic guidance. The accuracy of screw placement was assessed based on the Gertzbein-Robbins scale by a neuro-radiologist blinded to treatment group. The radiological slice with the largest visible deviation from the pedicle was chosen for grading. A pedicle breach of 2 mm or less was deemed acceptable (Grades A and B) while deviations greater than 2 mm (Grades C, D, and E) were classified as misplacements. In the robot-assisted cohort, a perfect trajectory (Grade A) was observed for 366 screws (83.4%). The remaining screws were Grades B (n = 44 [10%]), C (n = 15 [3.4%]), D (n = 8 [1.8%]), and E (n = 6 [1.4%]). In the fluoroscopy-guided group, a completely intrapedicular course graded as A was found in 76% (n = 335). The remaining screws were Grades B (n = 57 [12.9%]), C (n = 29 [6.6%]), D (n = 12 [2.7%]), and E (n = 8 [1.8%]). The proportion of non-misplaced screws (corresponding to Gertzbein-Robbins Grades A and B) was higher in the robot-assisted group (93.4%) than the freehand fluoroscopy group (88.9%) (p = 0.005). In this retrospective review, authors found that robot-guided pedicle screw placement is a safe, useful, and potentially more accurate alternative to the conventional freehand technique for the placement of thoracolumbar spinal instrumentation.[16]

Biomaterials and tissue biologics:

A level 1 study compared the use of osteogenic protein-1 (OP-1, also known as bone morphogenetic protein [BMP]-7) combined with local autograft in comparison with iliac crest autograft combined with local autograft in posterolateral lumbar fusion. This randomized prospective study was performed at 4 centers in Europe and included 119 patients. Fusion was documented on computed tomography (CT) scans. The authors found a 54% fusion rate in the OP-1 group and a 74% fusion rate in the iliac crest group. The authors concluded that OP-1 was not as

effective as autologous iliac crest bone for achieving posterolateral lumbar fusion. The fallacy of this study was being a randomized control trial there was no standard uniform technique that was used for preparation of graft bed, which is equally important for fusion. [17]
In a case series study, 10 patients undergoing anterior cervical corpectomy and fusion (ACCF) with use of trabecular titanium metal interbody implants had frequent radiographic subsidence, but radiographic fusion and an improved functional outcome at 2 years of follow-up.[18]

3D printing in spine surgery:

In a systemic review, Wilcox et al., searched 6 electronic database with the aim to summarize literature on use of 3D printing technologies for planning or production of patient-specific implants for spinal surgery. These searches returned a combined 2,411 articles, of which 453 duplicates were removed, before the remaining 1,958 articles were screened by title and abstract for relevancy, leaving 75 articles for full text review. Of these, 54 were included in this review. Authors concluded that 3D printing technology is being used profoundly for surgical planning, intra operative surgical guides and customized prostheses as well as "Off-the-shelf" implants. The technology allows manufacturing implants with enhanced properties as well as decreasing the surgical time and improved patient outcome. Though the technology looks promising, larger scale studies and longer-term follow-ups will enhance the knowledge of 3D printing and its impact on spine surgery. [19]

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