Technical Advancements and Utilization of Spine Surgery

—International Disparities in Trend-Dynamics Between Japan, Korea, and the USA

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Abstract

Spine surgery has made radical advancements in the last two decades and provision has expanded a great deal. The history of the technical development is briefly reviewed. To analyze trends in utilization and to assess the macroeconomic demand for spine surgery, the incidence of all spine surgery per capita is estimated referring to diverse statistical data from the USA, Korea and Japan. When compared internationally, there is a great disparity in the utilization of spine surgery, especially for fusion/instrumentation. Medico-socioeconomic conditions underlying the variations are discussed. Adequate surgeon training has to be supplied in a matched volume, and the number of surgeons to balance the need is estimated.

Key words: fusion techniques, imaging modalities, spine surgery rate, reimbursement, demand/supply balance

Introduction

It is fair to state that spine surgery has transformed most among the various arenas of neurosurgical practices, perhaps along with endovascular treatments and stereotactic functional neuro-modulations. The 1990s were a period of outburst in technical innovations for spinal surgery. Progress of imaging techniques, with the advent of magnetic resonance imaging (MRI) and multi-detector computed tomography (CT) contributed significantly in the advancement of diagnosis and pinpointing the pathophysiology causing the ailment. The other major fulcrum of the outburst in spine surgery was the development of instrumentation techniques. As the effectiveness of the fixation procedure to secure stability is enhanced, hospital stay is shortened, and together with the advances in the sensitivity and accuracy in the diagnosis, utilization of spine surgery has increased dramatically,^{22,24,71)} especially for degenerative spine diseases which have very high incidence and prevalence.^{12,39,41,55,69)} Further, restitutive surgery, which optimizes use of the muscle, skeletal, and fascial reconstruction and to restore stability, physiological motion and alignment, is emerging as a possible alternative to rigid fixations using metal instrumentations.⁴⁵⁾

The present review encompasses the concise history of the technical developments and trends in the utilization of spine surgery. Provision of spine surgery in countries is assessed, and total utilization is estimated as inferred from various sources of statistical data.^{17,22,23,32,71,72)}

Technical Advancements in the Past Two Decades

I. Progress of imaging techniques

The advent of high magnetic field MRI^{6,31,66)} and multi-detector CT with capability of helical or spiral scanning,¹⁴⁾ and subsequent development of computer processing of the data such as multiplanar reconstructions (MPR) or maximum intensity projections,^{25,36,40,59)} enhanced enormously the amount and the availability of information we obtain from neuroimaging studies. This has provided hitherto unavailable insights regarding the pathological processes taking place inside the spinal cord and the nerve roots. Pathologies taking place in the areas previously called the 'hidden zone' surrounded by three-dimensionally complex bony structures and ligaments can be evaluated non-invasively.^{25,36)} High magnetic field MRI (1.5 T to 3 T) and new pulse sequences^{47,61)} and image processing based on three-dimensional (3D) sampling allow better delineation of the roots or radiculomedullary vasculature in addition to the cord.^{6,40,57)} These imaging techniques are immediately applicable to daily practices. MPR can show the nerve root outside the common dural sac. It is most useful when the image is obtained in the coronal plane. When taken in a 3D sampling, the MPR can show the cross sectional shape of the neural structures along any curved line which can be set arbitrarily. It is useful for delineation of impingement of the nerve roots.^{25,36,59)} Diffusion tensor imaging (fiber tracking), MR spectroscopy with and without mapping, and functional MRI are all

being tried in the spinal cord, but we still have to wait for further development of the applications to become useful in our practices.^{50,53,54)}

II. Instrumentation

Various instruments such as wire-cable systems,¹⁵⁾ rods and frames,^{35,51)} plates and screws,⁶⁷⁾ pedicle screws,^{64,74)} and interbody cages⁶³⁾ have been devised and used. For the cervical spine and the cranio-cervical junctions, techniques and instruments such as C2 odontoid screw fixation,¹³⁾ C1-C2 transarticular screws,^{29,43,52)} pedicle screws,^{2,30,33)} lateral mass screws,^{19,68)} anterior cervical plates and screws,^{4,16,37)} and cages³⁸⁾ have been developed and used. Development of what is called the universal spine instrumentation system, which consists of pedicle screws, hooks and rods and rigid locking mechanisms allowing three dimensional degree of freedom in connecting angles, has made fixation easy and reliable. Examples of the early systems include C-D,²⁰⁾ Texas Scottish Rite Hospital⁴⁴⁾ and others,⁵⁾ and there has been explosive commercial developments following these pioneers, with various characteristics built in with the intention for ease of use and sturdier fixation. Systems aimed at specific use in the cervical spine or in the cranio-vertebral junction since have been made. When integrated with navigational capabilities,^{46,65)} precise orientation and placement of screws in the vicinity of critical vascular and neuronal structures are facilitated. Transarticular screw fixation of C1-C2,⁵²⁾ or pedicle screw fixation of the cervical spine^{2,33,46)} are examples of the areas where navigation technology has contributed most for safety in the spine. Artificial disk or arthroplasty^{27,28,49)} is another arena of instrumentation with the idea to preserve motion between the spinal segments, and recently has been a center of interest. Its long-term efficacy and advantage over preexisting technologies are yet to be established.^{7,8,11,76)}

Trend-Dynamics of Utilization of Instrumentation/Fusion

As the result of the technical development and widened indications, spinal surgery has increased greatly in supply volume in the past two decades.⁷¹⁾ Trend analysis of the curve actually demonstrates close chronological correlation with the advent and release of metallic instruments.²²⁾ When compared cross-sectionally between various reference regions in the US, high utilization of instrumentation/fixation is correlated with higher incidence of non-fusion surgery as well.⁷¹⁾ When compared internationally between the US, Korea, and Japan, higher incidence of instrumental fixation is correlated with higher utilization rate of the all spine surgery.

In US Medicare, spine surgery has been performed in a frequency of 3.9 per 1000 enrollees, and

by categories, the distribution is 2.1 for L-discectomy or laminectomy, 1.1 for L-fusion, 0.24 for cervical discectomy or laminectomy, and 0.47 for C-fusions. The ratio of cervical to lumbar spine procedures was 0.22 to 1.⁷¹⁾ Spending for lumbar fusion has increased 500% over the period of 1992 to 2003 from \$75 million to \$482 million, and as a proportion of all spine surgery, from 14% to 47% of the total spending.

In the US, numbers of fusion surgery increased stepwise, and even more when use of the interbody cages was approved for use in lumbar spine surgery in 1996, resulting in 220% increments of lumbar spine surgery over the decade.²²⁾ The advent of the instrument has made interbody fusion from the posterior approach in conjunction with use of pedicle screw fixation very popular. Unlike the preexisting methods of posterolateral fusion, which relied on the bony graft (typically taken from the iliac crest) laid over the exposed and decorticated transverse processes, posterior lumbar interbody fusion (PLIF) uses cages with bone grafts packed inside the disk space and involves exposure limited to between the facets.^{10,18)} Compression force exerted on the cage and bone grafts with pedicle screw/rod system induces better fusion rate.^{3,58,70)} In fact, the use of the cages revitalized the PLIF procedure, replacing the preexisting method which had been performed with bone grafts in the disk space.⁶³⁾ The progress has been furthered with transforaminal lumbar interbody fusion (TLIF),³⁴⁾ in which the facet joint of the symptomatic side is removed totally and the cage is inserted from lateral to the roots, thus avoiding the risks of injury to the cauda equina contained in the common dural sac.²¹⁾ Stability is provided by the pedicle screw together with the cage.

The progress in the technique and the instruments made the procedure more reliable, so that after a certain amount of training, it can be reproduced in the hands of many general neurosurgeons in community practice. PLIF or TLIF have penetrated very rapidly, all the more because of favorable reimbursement as compared to simple decompression and more involvement with the commercial/industrial sectors. In fact, the average Medicare hospital charges for simple fusion surgery (one or two disk levels, single approach) were \$58,511 as opposed to \$23,724 for decompression, and \$80,888 for complex fusion (more than 2 disk levels or combined anterior and posterior approaches).²⁴⁾ Fusion with instrumentation has become a de facto standard for common lumbar lesions such as disk disease or stenosis which do not involve instability normally. The market for spinal instruments and devices is more than 2 billion a year and has been growing 18% to 20% per year.⁵⁶⁾

In the US, there has been a sharp increase in fixation performed for herniated disks. As many as 63% of lumbar fusions were performed for disks, 20% for

stenosis, and only 20% in conjunction with spondylolisthesis or spondylolysis,²²⁾ the authentic indication for fusion/instrumentation. This constitutes a quite unprecedented pattern of utilization for the fusion procedure. As many as 26% of stenosis cases, 70% of degenerative disc disease cases, and 93% of lysis or listhesis cases undergo fusion with instrumentation.²²⁾ In 2007, 33% of Medicare operations performed for lumbar stenosis involved fusion and 14.3% employed complex fusion.²³⁾ Instrumentation/fixation has been utilized for indications other than the instability of the segments, but no evidence for improved outcome for fusion surgery over non-fusion decompression surgery has been presented.²⁴⁾

Disparity in Utilization and Emerging Criticism

Among US hospital reference regions, there are marked variations in the per capita utilization of lumbar discectomies and laminectomies, and the disparity is more than 20 fold for spinal fusion procedures.⁷¹⁾ It is not correlated with the supply of orthopedic and neurosurgeons, and the incidence of fusion is rather moderate in the states or in the hospital reference regions where the accessibility to medical/surgical services is superior. When closely observing the distribution of the lumbar fusion surgery and non-fusion surgery, there is a visible correlation. One study showed significant variability between spine surgeons in their judgment of surgical indications, especially regarding election of fusion vs non-fusion, and choice of implants on simulated cases.⁴²⁾

General perceptions in the public regarding the inconsistency and disparity, with these epidemiological data, have lead to open criticisms and reports casting suspicions as to the authenticities of spine surgery, especially spine fusions, both within the medical communities and within the general public.^{1,9,24,62,72,73)}

Estimation of Demand for Spine Surgery

Incidence of lumbar spine fusion surgery in the USA nationwide was 122,000 in 2001,²²⁾ which corresponds to 61/100,000 adults. The rate was calculated based on the database of the Healthcare Cost and Utilization Project, and varies with different age class. It was 90/100,000 adults for age 60 years and older, and 75 for age 40–59 years, and 30 for age 20–39 years, with 46.1% in the age higher than 60 years group. The numbers give a rough estimate of the age distribution of spine surgery, and together with US census data, helps to extrapolate the Medicare spinal surgery rate to the entire age groups and thus to assess the incidence of spine surgery in the national general population. When calculated in this manner, the nationwide spine surgery annual rate is 1,800/million general population (Table 1).

For the entire US, estimates of L-spine surgery including ambulatory surgery data can also be obtained from the Healthcare Cost and Utilization Project (HCUP) of the Agency for Healthcare Research and Quality.³²⁾ Community Hospitals' Data on inpatient discharges are sent to the HCUP, and the State Inpatient Databases (SIDs) are produced. Each year, a 20% weighted sample is extracted from the SIDs and used to generate the HCUP's Nationwide Inpatient Sample (NIS). Several states submit similar data on ambulatory surgery to the HCUP, which produces the State Ambulatory Surgery Databases (SASDs). Based on the NIS and SASD data, the incidence of L-spine surgery in the US was estimated to be 2.009 (inpatient: 1.62, outpatient: 0.38) per 1,000 adults (age >20 years, 2000).³²⁾ When adjusted to the US census age distribution, the incidence is 156/100,000 population (assuming no incidence below age 20 years). Applying the cervical to lumbar ratio of 0.22 to 1⁷¹⁾ and adding the number for cervical spine surgery to the lumbar surgery rate, the estimate of total spine surgery incidence is approximately 2,000 per million population per year.

In 2001, in Medicare, 4.47 inpatient and outpatient spine surgery procedures were performed per 1,000 enrollees.³²⁾ Adjusting to the age composi-

Table 1 Utilization and supply of spine surgery in US, Japan, and Korea

	Health care system	Surgeon income	Incidence of spinal surgery (n/million general population/yr)	Number of spine surgeons	Load per neurosurgeon/yr
USA	mixed	output based	1,800–2,050	20,000?	121*
Japan	national insurance	salary based	400–725	1,400?	65**
Korea	national insurance	salary based	1,630	977	82***

*In US, total numbers of orthopedic surgeons and neurosurgeons is 18,000 and 3,000. Based on the spine surgery rate (2,000/million/yr) and US population (280 million), total number of spine surgery is estimated to be 560,000. Assuming neurosurgeon is performing 65 % of spine surgery as has been reported in Medicare, and all of 3000+ active members of AANS are engaged in spine surgery, case load per neurosurgeon is estimated to be 121 per year. **193 surgeons were certified for neuro-spine subspecialty, and 1200 are certified for orthopedic spine (2006). Assuming 13000+ cases are operated in the NS community, the work load per neurosurgeon would be 65 cases per year. ***In Korea, there are 980 surgeons specializing in Spine, 520 in NS and 450 in orthopedics. Eighty thousand of spine surgery was performed in 2005 and the load per surgeon would be 82 per year.

tion of the US census and the spine surgery age distribution, the rate converts to an incidence of 2,050 spine procedures per year per million national population (Table 1).

These numbers which the author has generated referring to three independent sets of US data sources corresponded surprisingly well at around 2,000 operations per million general population.

International Comparison— OECD Nations, Japan, Korea and US

When compared with other European countries with advanced health care systems (OECD nations), the incidence rate of spine surgery in US is very high.¹⁷⁾ The US has by far the highest utilization rate for spine surgery. When compared with the US as 100%, incidence of spinal surgery was 33% for Sweden, 44% for Australia, 49% for Ontario Canada and Norway, 56% for Finland, and 64% for Denmark (Table 2). The variation was not correlated with the density of neurosurgeons and orthopedic surgeons in each country.

Japan has a prototypical system of socialized medicine. The national health insurance system was restructured in the post-war order under the auspices of the General Headquarters staffed by the delegates of then Truman administration. The Japanese national health care system encompasses compulsory and universal enrollment and allows its enrollees access to any medical institution in the country. The insurance system provides reimbursement following unified schedules for procedures, and the coverage is 70% (90% if age older than 75 years) for medical and surgical treatments and basic hospital fees.

Statistics of spine surgical procedures are gathered by the Japanese Society of Spinal Surgery, a neurosurgical organization, and the Japanese Society for Spine Surgery and Related Research, an orthopedic organization. Both surveys were based on questionnaires with somewhat limited enrollment (77–62%). Neurosurgeons reported 13,000+ spine procedures in 2004⁷⁵⁾ and orthopedic surgeons reported 16,000+ cases in 2001.⁶⁰⁾ Fifty-three percent of the cases treated by neurosurgeons were cervical cases and 20% for orthopedic surgeons. Another registration survey gathered annually by a

group of hospitals in a north-eastern region, an affiliation to a national university, reported 2900+ cases for 4 million populations in 2007.⁴⁸⁾ In total, the annual number of spinal surgeries in Japan is estimated to be in the range of 400+ to 725 per million population/yr, roughly 20% to 36% of the incidence in USA (Tables 1 and 2).

In Korea, the national health insurance system has a similar basic structure to Japan, with compulsory enrollment (97%) and covering 80% of the hospital charges. The racial characteristics are very close to Japanese. Per capita public expenditure for medical care is approximately 30% of Japan (\$496 vs \$1,672 in 2001, GDP \$19,274 vs \$28,395 in 2003) and reimbursement for neurosurgical procedures is roughly one tenth of Japan as compared with purchasing power parity. There is a remarkable difference in the utilization pattern of spinal procedures between the two societies. Based on the statistics released by the Ministry of Health Welfare and Family Affairs of Korea, 80,318 spine procedures were performed for 49.1 million people in 2005, with a 3-fold increase in five years.²⁶⁾ The per capita number of spine surgery is 1,630 per million/yr, which is nearly 80% of the US, with the proportion of fusion surgery using instrumentation higher than Japan (Table 1).

Demand and Supply

Adequate supply of spine surgeons should be inferred from two sets of numbers; the incidence of spine surgery, and adequate caseloads for a surgeon to maintain proficiency. We can only discuss these points in an arbitrary fashion, but in view of the diversity of complex pathologies that spine surgeons are facing in practice, probably 100 to 200 cases per year would be a practical case load, depending on the degree and proportion of complex lesions. Assuming the need for spine procedure of 1,000 cases per year per million, and surgeon's load of 100–200 procedures per year, the balanced supply would be 5–10 surgeons per million general population. Assuming 20 years of activity after completion of training, the matched annual production rate would be 0.25–0.5 spine surgeons (trainee) per million population.

Conclusion

With entrepreneurial enthusiasm, implants have been strategically designed following market analysis and with intention of ease of use to attain success in the market. Corporate incentives and physicians' drive for financial or non-financial benefit are not always submerged behind the development.¹⁾ These trends are affecting surgeons' behavior in judgment of indication and selection of approaches, and use of instruments to various degrees in different countries with different medico-socioeconomic conditions. The disparity is occasionally raising ethical ques-

Table 2 Nation variety in utilization of spine surgery

USA	1.0
Japan	0.20–0.36
Korea	0.82–0.90
England	0.19
Sweden	0.33
Australia	0.44
Ontario, Canada	0.49
Norway	0.49

tions.⁷³⁾ We find the structure of the health care/insurance system and the policy of reimbursement are critical in determining the behaviors of spine surgeons and can influence the directions of technological development. Reviewing the per capita incidence of spine surgery (and rate of instrumentation), the US has the highest rate, and certainly the rate of fixation among the procedures is high.

In Japan, the incidence of spine surgery is much lower at about one sixth to one third of that in the US. In Korea, the number of spine procedures per capita amounts to 80% of that in the US. The stark difference in the utilization of spine procedures in general and in instrumentation surgery between these two countries sharing similar national health insurance systems and comparable demographic characteristics, appears to be accountable only by the large gap in their reimbursement pricing policy. The low reimbursement in Korea results in much less per capita public medical expenditure, but may make the hospital financial and surgeon behavior sensitive to the influences promoting the provision of the implants. Such disparity in conditions influences the choice of surgical methods and may underlie the variations in the entire "culture" of spine surgery in these societies.

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