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REVIEW

Outpatient neurosurgery

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ABSTRACT
Technological advances in neurosurgery, aided by improvements in anesthesia have resulted in surgery that is faster, simpler and safer with excellent perioperative recovery. As a result of improved outcomes, several centers are performing certain neurosurgical procedures on an outpatient basis; where patients arrive at the hospital the morning of their procedure and leave the hospital the same evening, thus avoiding an overnight stay in the hospital. Apart from the medical benefits of the outpatient procedure, its impact on patient satisfaction is substantial. The economic benefits are extremely favorable for the patient, physician, as well as the hospital. However, due to skepticism surrounding medico-legal aspects, and how radical the concept at first sounds, these procedures have not gained widespread popularity. We provide an overview of outpatient neurosurgery discussing results, outcomes related to patients' quality of life, and impact on the economic burden on currently burgeoning health care costs.

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Introduction

Neurosurgery has dramatically evolved over the turn of the century [1–3]. Tools such as the microscope and endoscope, finer surgical instruments, intraoperative visualization techniques, as well as advances in electrophysiological monitoring have aided evolution of neurosurgical techniques and improvements in patient outcome over the past two decades [4–6]. This is paralleled by proficiency in different types of anesthesia methods, shorter operative durations, and enhanced perioperative care, enabling quicker recovery and earlier discharge. The primary goal of treatment has matured and transformed to encompass preservation of neurological function offering patients a better quality of life [7–10]. Outcome measures are centered on direct patient satisfaction rather than the surgeons' perception of patients' well-being [11–14].

The application of awake craniotomy to the field of neurosurgery has decreased iatrogenic postoperative neurological deficits, allowing for safe maximal resection of tumors and improved health-care resources by avoiding the use of intensive care unit (ICU) beds and permitting early discharge [15–21]. With its introduction came the advent of outpatient brain tumor surgery – a concept introduced by the senior author two decades ago [16,22–25]. Outpatient or day-case surgery is defined as a patient arriving at the hospital the morning of their procedure and being discharged the same evening usually before 9:00 p.m., avoiding an overnight hospital stay. This ideology is widely used in spine surgery that involves both uninstrumented and instrumented procedures [26–40].

In this review, we analyze various intracranial and spinal procedures that have been performed as day surgeries and discuss the advantages and disadvantages of this innovative cost-effective concept. We also delve into various qualitative studies that target the patients' point of view experiencing this underutilized concept.

The focus of this paper will be on surgery for brain tumors, unruptured intracranial aneurysms, outpatient pediatric neurosurgery, spinal decompression and instrumentation – all of which are currently routinely done as outpatient surgeries in select centers of the world. Since other procedures such as diagnostic angiograms, kyphoplasty, vertebroplasty, facet and epidural injections, nerve blocks, laser lumbar discectomy, and peripheral nerve entrapment release surgeries are almost universally done as day-case procedures, we will not include them in this review.

Intracranial outpatient neurosurgery

Brain tumors

Historical perspective

While the idea of awake craniotomy arose from its use in epilepsy surgery in the seventeenth century, its adoption for the resection of brain tumors, with mapping of eloquent cortex has been prevalent over just the past 25 years [20]. Since 1991, the senior author has routinely performed awake craniotomy for intra-axial brain tumors with low complication rates and minimum resource utilization. In 1996, a pilot study was initiated at the senior author's hospital to assess the feasibility of performing craniotomy for tumor resection as an outpatient procedure [41]. The results of this study were reported in 2001. Eighty-nine patients successfully completed the protocol which was later adopted at one center in the United Kingdom after a team came to Toronto to observe the procedure [25].

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Since 1996, the senior author has performed about 700 outpatient brain tumor surgeries (over 500 resections and almost 200 image-guided biopsies and Ommaya reservoirs). While in the initial experience all these cases were done 'awake', with time and experience we have come to learn that general anesthesia (GA) does not preclude same-day discharge following brain tumor surgery [42].

Why outpatient surgery?

Over the years, smaller incisions, precise microneurosurgical technique, a move toward more aggressive resection of intra-axial tumors, and meticulous hemostasis have led to fewer complications, decreased postoperative pain, earlier mobilization, and decrease in hospital stay. Several large scale reports have shown that serious postoperative complications associated with biopsy and craniotomy (in particular, intracerebral hemorrhage) occur usually within 6 h postoperatively [43,44]. This is an important consideration when determining whether keeping a patient overnight provides additional benefit to discharging a patient after 6 h of observation. The privacy of one's own home on the first postoperative day allows for overnight observation and assistance by family members and friends without disturbance by other inpatients and without the possibility of hospital-based complications.

Despite established safety of the procedure, the protocol has not gained widespread popularity among surgeons. Presumably they still believe that delayed neurological worsening after 6 h occurs at a high enough frequency to warrant closer observation in hospital. In a survey of the members of the American Association of Neurological Surgeons and the Congress of Neurological surgeons, only 6% performed outpatient image-guided brain biopsy, although the majority agreed that discharge on the same day would be safe and reasonable [45].

Avoidance of an overnight hospital stay often alleviates the psychological impact of brain tumor diagnosis and treatment, and high patient satisfaction is demonstrated following outpatient craniotomy. Compared with standard hospital experiences the other potential benefits include decreased health-care costs, less exposure to nosocomial infections, less risk of thromboembolism, and less risk of iatrogenic complications from medical errors. With more current data emerging on the benefits of early discharge, not only to the patient but also to health-care providers and hospitals, this procedure will gain further significance and importance [46].

Outpatient surgeries are often performed under local anesthesia, which is generally faster, and hence more cases can be done in day as opposed to inpatients. Also cases done as outpatients do not require an inpatient bed and in strapped health-care systems sometimes patients' surgeries are canceled because of the lack of an inpatient bed, which does not obtain for outpatients. In this way, the procedure benefits the patient, physician, as well as the hospital.

Who is a candidate for outpatient brain tumor surgery?

To avoid complications related to surgery, patient selection is the key for a successful outcome in day-case surgeries. This decision is made preoperatively in consultation with the patient and their families. The decisive inclusion and exclusion criteria are as follows [42]:

Inclusion Criteria

(1) Supratentorial tumor
(2) Patient caregiver available
(3) Patient staying relatively close to the hospital (i.e. no more than 1 h away)

Exclusion criteria

(1) Already an inpatient
(2) Significant cardiorespiratory morbidity
(3) Airway management concerns (e.g. sleep apnea)
(4) Uncontrolled seizures or poor neurological status
(5) Long procedure expected (greater than 4 h)
(6) Psychological unsuitability/patient preference

The age of the patient and the kind of anesthesia administered (local or general) do not feature in decision for day-case surgeries. The nature and location of the tumor (e.g. middle cranial fossa floor tumors tend to be associated with more pain intraoperatively) and the understanding and acceptability of the patient and the motivation of their caregiver to help do determine if they would be candidates for outpatient brain tumor surgery. Increased intracranial pressure is not exclusion for day surgery craniotomy. To reiterate, if the patient is a candidate according to the surgeon, the outpatient procedure is then discussed with the patient and if willing is admitted under the day surgery unit (DSU) protocol. Sicker patients with higher morbidities who are more likely to have complicated courses are not selected for outpatient surgery but are selected as inpatients for obvious concerns of safety.

Protocol for outpatient brain tumor surgery

The protocol for outpatient brain tumor surgery is simple and standardized and involves cooperation among patients and their caregivers [16]. Since there is a significant difference between an 'awake' and an 'asleep' experience during surgery, patient education is of paramount importance for patient preparation before day-case surgery. At the presurgical office visit, patients and family members are educated on the expected course of events, potential complications and informed consent is obtained. A meeting with the anesthetist and the nurse practitioner along with provision of a pamphlet describing the steps of the procedure further alleviates patient concerns.

Key Steps in the Protocol

(1) Patient is admitted to the DSU at 5:30 a.m. and undergoes a limited sequence magnetic resonance imaging for the frameless navigation.
(2) The use of arterial lines, urinary catheters, and central venous lines in the operating room is extremely rare in awake craniotomy cases. Most often all intravenous access is through peripheral lines.
(3) Prophylactic antibiotics and steroids are given prior to skin incision. Anticonvulsants are administered only in cases with prior seizures. Mannitol is almost never administered.
(4) Electrocardiography and pulse oximetry monitoring is performed. The patient is positioned as desired with

the head fixed in a Sugita head rest and the procedure is performed under the appropriate anesthesia for the given case. Microneurosurgical technique is used in every case.

(5) Electrophysiological monitoring/cortical mapping is carried out during the procedure.
(6) After surgery the patient is monitored in the postanesthetic care unit for 2 h and then transferred to DSU for an additional 4 h at least.
(7) A computed tomography (CT) is performed 4 h after surgery and a physician assesses the neurological status, fitness for discharge, and adequate control of pain and nausea (Figures 1 and 2).
(8) Patients are most often discharged home 6 h postoperatively with very clear and strict instructions to return if any new signs or symptoms develop.
(9) Patients who do not fulfill any of the above criteria, or the CT scan demonstrates undue hemorrhage or edema, are admitted to the ward for overnight monitoring.
(10) Patients are followed up in the Clinic at 1–2 weeks, documenting their experiences of the procedure, and appropriate referrals are made (neuro-oncology, radiation oncology, imaging, etc.).

Surgical outcomes (Table 1)

There are very few, large, prospectively conducted trials on the outcome of implementing the outpatient brain tumor craniotomy/biopsy protocol, despite its safety and efficacy being clearly established in a correctly selected group of patients [22–25]. Not only is there no excess morbidity resulting from early discharge after surgery, compared to inpatient admission, but also same-day discharge likely reduces the exposure of patients to nosocomial infection, thromboembolic complications, and medical error, and decreases case cancelation due

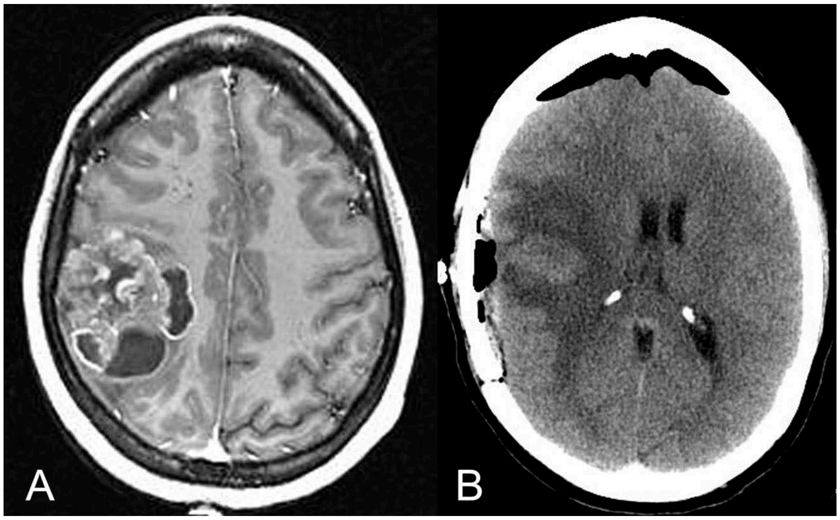

Figure 1. A) Enhanced pre-operative MRI of 35-year-old woman with anaplastic ependymoma. B) CT done 4 hours post-operatively after awake craniotomy and 2 hours prior to discharge from the DSU.

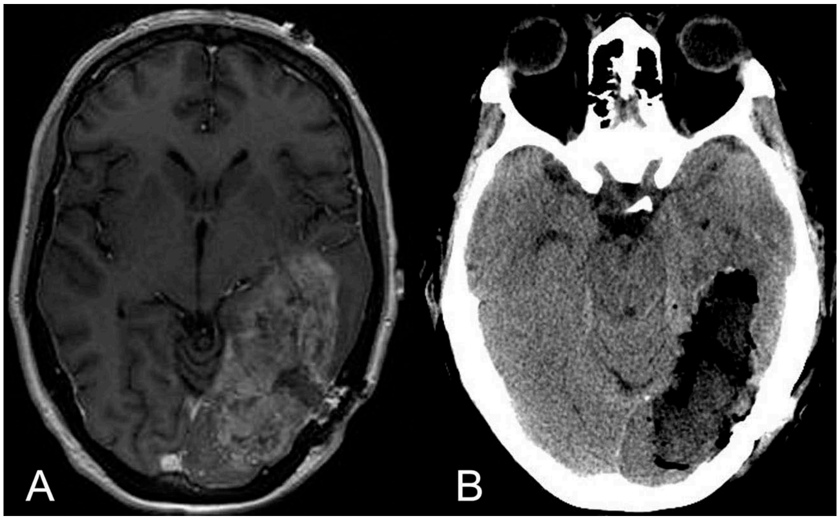

Figure 2. A) Enhanced pre-operative MRI of 54-year-old woman with recurrent glioblastoma. B) CT done 4 hours post-operatively after awake craniotomy and 2 hours prior to discharge from the DSU.

Table 1. Summary of outpatient brain tumor surgery papers.

Author	Procedure and number of patients	Successful discharge	Complications	Comments and reasons for inpatient conversion
Bernstein (2001)	Craniotomy (46 pts)	89%	11%	1 patent had hemiparesis, 1 had a seizure, 1 had an air-embolus and 1 was a family request
Blanshard (2001)	Craniotomy (15 pts)	88%	6%	1 patient had a seizure, 1 headache, 1 nausea
Kaakaji (2001)	Biopsy (71 pts)	82%	6%	Of the 13 pts admitted overnight, only 4 were due to complications
Bharadwaj (2002)	Biopsy (76 pts)	97%	3%	1 patient had a small intraventricular hemorrhage, 1 developed mild leg weakness
Grundy (2008)	Craniotomy (11 pts) and biopsy (30 pts)	82% for craniotomy, 90% for biopsy	18% (2 pts) for craniotomy and 3% (1 pt) for biopsy	1 patient had transient hemiparesis, 1 had a seizure, 1 intraprocedural hemorrhage after biopsy
Boulton (2008)	Craniotomy (145 pts) Biopsy (117 pts)	94% for craniotomy and 93% for biopsy	5% for craniotomy and biopsy	No patient suffered an adverse event with alteration in outcome because of planned outpatient discharge
Purzner (2011)	Craniotomy (249 pts) Biopsy (152 pts)	93% for craniotomy and 94% for biopsy	7% for craniotomy and 6% for biopsy	1 patient had worsening neurological deficit, 1 headache, nausea, 2 had seizures, and a hemorrhage
Park (2011)	Stereotactic biopsy and radiosurgery (30 pts)	87% – 4 patients did not have radiosurgery due to inconclusive diagnosis	0%	Cost saving of about $2200.00 per patient with the outpatient combined treatment
Au (2016)	Craniotomy under general anesthesia (44 pts)	86%	11%	Reasons for admission were seizure, aphasia, wound hemostasis, cognitive impairment, new weakness

to lack of inpatient bed availability, thus improving patient flow.

The initial feasibility study by Bernstein et al. [41] in 2001 showed a successful discharge in 89% with a complication rate of 11% in 46 patients. No adverse outcomes occurred in those patients who were discharged home. This was followed by a larger study sample of 117 patients who underwent brain biopsies and 145 patients who underwent a craniotomy [22]. Successful discharge from the DSU was done in 93% of the brain biopsy patients and in 94% of patients who underwent an awake craniotomy. The reasons for inpatient conversion included hemorrhage with worsening neurological deficit, headache, seizures, air embolism, and familial anxiety. While all of these conversions took place at the time of the afternoon assessment, three patients were readmitted after being discharged home, two of these for headache and one for a seizure the next day. The results of this study parallel the report of a similar study by the same group, which demonstrates similar success and safety profile for outpatient image-guided biopsy. Of the 76 patients, 98% were discharged home with none experiencing an adverse outcome because of their outpatient status [23].

In another prospective study of 401 patients conducted by the same group by Purzner et al. [24] in 2011, of 249 patients who underwent a craniotomy, 93% were successfully discharged from the DSU, 5% were admitted from the DSU, and 2% were discharged and later readmitted. Of 152 patients who underwent a brain biopsy, 94.1% were successfully discharged from the DSU, 4.6% were admitted from the DSU, and 1.3% were discharged and later readmitted. No patients experienced a negative outcome as a result of early discharge.

There are no statistically significant predictors of admission as no study has huge numbers and furthermore the number of patients admitted is low with often one or two patients only in each category. The obvious predictors are significant new neurological deficit but even this factor would not show statistical significance due to small numbers.

Grundy et al. [25] reported a day-case series of 27/30 biopsy and 9/11 craniotomy patients who were discharged 6 h postoperatively. One biopsy case was admitted due to increased headache postoperatively, but with a normal CT and one craniotomy case had transient worsening of lower limb paresis requiring overnight admission. The three other overnight admissions were for patient preference. One biopsy patient was readmitted 30 h postoperatively with a seizure and discharged the following day. No patients suffered an adverse outcome.

Outpatient brain tumor cases have also been performed under GA (Figure 3). Au et al. [42] showed that of a series of 44 cases done under GA but targeted for day surgery, 38 (86%) were successfully discharged the same evening. Of the cases requiring conversion to inpatient admission, one was admitted for ongoing difficulties with wound hemostasis, one for new cognitive impairment, two for new or worsened weakness, and one for new onset of seizure. One patient was discharged from DSU but required readmission on the first postoperative day for new aphasia, with no adverse findings on CT.

The above studies demonstrate the safety and efficacy of outpatient brain tumor surgery. Successful discharge was feasible in 82–97% of the patients and complications ranged from 0% to 11%. No patient had an adverse outcome as a result of early discharge and there were no mortalities.

Unruptured intracranial aneurysms

With the development of minimally invasive techniques, unruptured intracranial aneurysms can be clipped with a very low morbidity. Goettel et al. [47] reviewed outcomes of their DSU program for treatment of these aneurysms. During the study period, 25 patients aged 54 ± 9 years underwent outpatient aneurysm repair under GA. Seventeen patients (68%) successfully completed day surgery and eight patients (32%) were admitted to the hospital after surgery due to perioperative complications. The reasons for conversion to the inpatient status were a decreased level of consciousness, bradycardia, fever,

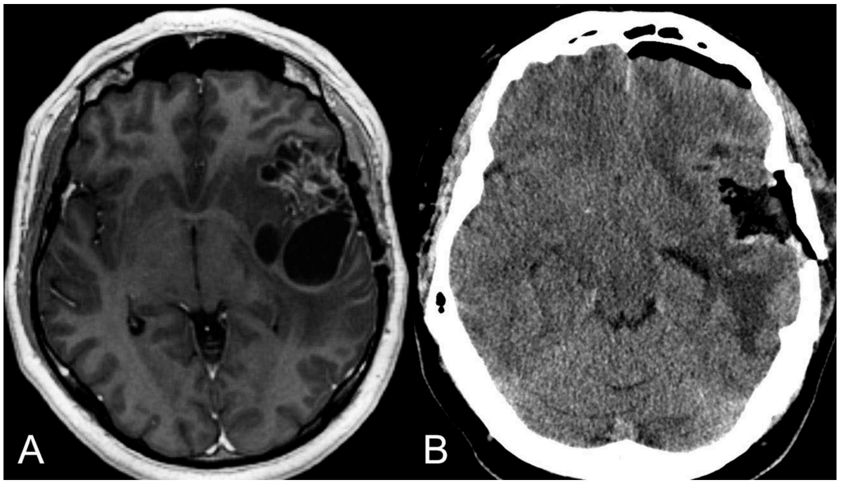

Figure 3. A) Pre-operative MRI of 31 year-old man who one year previously underwent outpatient awake craniotomy for an anaplastic astrocytoma followed by radiation and chemotherapy. He now presents with recurrence and undergoes surgery under general anesthesia. Note the edema and mass effect. B) CT 4 hours post-operatively and 2 hours prior to discharge from DSU.

severe postoperative nausea and vomiting, and seizures. Five patients were discharged home the next day. Duration of hospital stay in the protocol failure group ranged from 2 to 18 days. There was no mortality.

This study does demonstrate that surgical clipping of an intact aneurysm may be performed in a DSU setting. However, more prospective data are required to establish safety or quality of care as compared with the standard inpatient approach. Obviously, ruptured aneurysms would not be suited for this protocol. In order to change practice to clipping of unruptured aneurysms in the DSU setting, the protocol must be safe, efficient, and cost-effective by objective measures compared to the standard inpatient protocol currently being followed at most centers across the world. Using minimally invasive techniques that reduce surgical trauma, minimize surgical time, improve postoperative recovery, and consequently shorten length of stay, the outpatient approach seems to be more plausible [48].

Outpatient pediatric neurosurgery

In 1988, Mawk et al. [49] retrospectively reviewed a group of 31 children who underwent outpatient surgical procedures on a pediatric neurosurgical service to assess safety, outcome, and cost. The majority of the procedures were shunts or shunt revisions while others included cranioplasty, cord detethering, coccygectomy, biopsy of scalp lesions, and muscle biopsies. None of the patients experienced any anesthetic complications. One patient was admitted for management of a surgical complication and was discharged uneventfully 4 days later. No infections were observed in any of the cases.

The authors believe that outpatients coming to a surgery from home are healthier than inpatients. This may be the most important consideration in preventing shunt infections. The authors concluded that neurosurgical procedures can be safely and inexpensively performed on an outpatient basis, even in children. While in the modern era we do believe that some centers might be preforming shunts and endoscopic third ventriculostomies in the DSU setting in children, to our knowledge there are no studies reported on their outcomes in the literature, except for one reporting good outcomes on the safety of outpatient lumbo-peritoneal shunt in adults [50].

Outpatient spinal surgery

The data on outpatient spinal surgery clearly outnumber intracranial procedures. The acceptance and willingness of both surgeons and patients to perform and undergo these procedures in the DSU setting is wider [51]. This is proven by the fact that proportions of discectomies performed on outpatients rose from 4% in 1994 to 26% in 2000 [52]. Akin to intracranial procedures, some authors are even doing these procedures awake (endoscopic lumbar discectomy), under local anesthesia [29].

Eligibility criteria

Chin et al. [40] have proposed selection criteria for lumbar spine surgery in the DSU setting. These would apply to uninstrumented as well as instrumented spine surgery in the lumbar spine and parallel the ones used for day-case brain surgery.

(1) Must be living or staying within 30 min of the hospital
(2) Body mass index (BMI) less than 42
(3) Cardiac evaluation with ECG/stress test if the patient has a history of a cardiac problem
(4) Must have a responsible adult living with the patient who is available to care for them for at least 24 h after surgery
(5) Low-to-moderate anesthesia risk according to American Society of Anesthesiologists (ASA) criteria 1–3

Similar criteria for outpatient anterior cervical discectomy and fusion (ACDF) surgery have been proposed by Stieber et al. [53]. These can serve as guidelines for surgical teams and can be modified to suit their environment.

(1) Primary procedure
(2) 1- or 2-level involvement

(3) C4-5 through C6-7 levels (some authors do one level above and below the proposed levels)
(4) Absence of myelopathy (some authors include myelopathic patients)
(5) Structural allograft (autograft used by some authors)
(6) Estimated operative time <2 h (some authors permit slightly longer operative times)
(7) Exclusion of subjectively large neck size
(8) Appropriate discharge environment

Results of a prospectively studied national database of 597 patients indicated that outpatient ACDF did not carry any increased risk of morbidity relative to inpatient procedures. They indicated that patients aged over 65 years, BMI of >30 kg/m^2, ASA class of 3 or 4, current dialysis, current corticosteroid use, recent sepsis, and operative times longer than 120 min were all independent risk factors for complications [32]. Criteria for discharge included the ability to tolerate a clear diet and ambulate with minimal assistance. Patient selection is the key for a successful outpatient program.

Walid et al. [54] retrospectively studied 97 spine surgery outpatients and 578 inpatients that had proceeded through a common process of surgical selection. The prevalence of diabetes mellitus (19% vs. 10%), congestive heart disease (19.7% vs. 1.3%), coronary artery procedures (15.9% vs. 3.8%), and use of antidepressants (25.4% vs. 11.6%) was higher in the inpatient group ($p < 0.05$). Likewise in another study from four US states (California, Florida, New York, and North Carolina) male gender, private insurance, lower Charleston comorbidity index, and higher volume hospitals were significantly associated with outpatient procedures. Higher income, older age, coverage by Medicaid, African-Americans, and other minority races were associated with decreased odds of outpatient procedures. The rate of 30-day postoperative readmissions was higher among inpatients. Institutional charges were significantly lower for outpatient lumbar discectomies [55].

To reemphasize, not only a good patient selection criteria, but also good discharge criteria are equally important and the decision to discharge on the same day of surgery ought to be a mutual decision made by the patient and the physician, including both the surgeon and the anesthetist.

Lumbar spine

The first outpatient lumbar discectomy was performed in 1985 and in 1994 the results of the first large series of a 103 patients admitted through an ambulatory service were reported [56]. Three patients were kept overnight because of urinary retention or persistent vomiting. One patient with an acute recurrence returned on the fifth day and was treated as an outpatient on the seventh day and did very well. When patients were asked if they would recommend this surgery as an outpatient procedure 92% said yes, 4% were undecided, and 4% said no. At a 3-year follow-up, 88% had good results. At the time there were several other small reports, describing good outcomes, promising its safety and efficacy [57–61].

In another early series of lumbar decompression/discectomy, of the 74 patients who underwent this outpatient procedure, 91.2% were discharged the same day as surgery. Indications for the six patients who were not discharged included incisional pain, CSF leak, nausea, vomiting, and vertigo. No homecare nursing or physician's assistant intervention was required. An et al. [62] reported that only 4 out of 61 patients (7%) were admitted to the hospital after the procedure for reasons of pain control, inability to void, or lack of a caregiver at home. Ninety-three percent had good or excellent results even at long-term follow-up. Bednar et al. [63] found that attention to preoperative patient education and minimization of perioperative narcotic dose significantly improved the outpatient discharge success rate from 82% to 98% in successive cohorts undergoing surgery for sciatica.

In another study, while only 1 of the 212 patients operated as day case for a lumbar disc was admitted overnight in hospital (postoperative hyperglyemia), the authors reported that their long-term outcome success rates of 75–80% were more realistic than those of 90% or more found in some prior reports [64]. The average hospital stay was about 5 h in this cohort.

Of the 122 consecutive lumbar discectomy patients reported by the senior author as outpatients [37], only 5% were admitted to the hospital from the DSU. Likewise, of the 106 patients reported by Shaikh et al. [65], only 6 required unanticipated admission. Two patients were admitted due to nausea and vomiting, one due to severe pain, one due to urinary retention, and two were surgical causes (dural tear). Eight patients had delayed discharge. Anesthesia causes were severe nausea, severe pain, low oxygen saturation, sore throat, and dry eyes. Two patients had surgical causes. In another large prospective study of 406 patients, the acute complication and conversion to inpatient rate was 6.9% and 4.7%, respectively [27].

In 2006, Best et al. [66] reported a large series of 1377 microlumbar discectomies, 1322 (96%) of which were done on an outpatient basis. Of those that were done on an outpatient basis, 17 (1.2%) had complications such as dural tear, urinary retention, infection, and seroma/hematoma, 6 (0.4%) of which returned to hospital after discharge. This was a marked improvement compared to previous studies, which showed a 5–18% conversion to inpatient rate [37,62,63,65]. In their subgroup analysis of 233 patients over 65 years of age, only 4% were converted to an inpatient stay confirming the safety and efficacy of the outpatient procedure in the elderly [67]. On the other hand, some authors continue to caution against the increased prevalence of outpatient procedures, especially in the elderly [68].

More recently certain groups have discussed the feasibility of performing outpatient instrumented transforaminal lumbar interbody fusion [40,69]. Of the 27 patients, 4 patients (14%) who had surgeries performed as DSU had complications within 7 days postoperatively compared with 1 of 25 (4%) patients who had surgery performed as an inpatient with only an overnight stay [69].

Pugely et al. [34] compared inpatient versus outpatient morbidity and mortality specifically in patients who underwent single-level posterior lumbar decompression. Data collected from the American College of Surgeons National Surgical Quality Improvement Program (ACS-NSQIP) for 4310 patients undergoing either inpatient (61.7%) or outpatient (38.3%) lumbar decompression found the overall complication rate to be 5.4% in the inpatient group versus 3.5% in the outpatient group ($p = 0.0068$). Propensity score matching and multivariate logistic regression analysis were used to adjust for confounders and they found several independent risk factors for short-term complications after lumbar discectomy including, age, diabetes, presence of preoperative wound infection, blood transfusion, operative time, and an inpatient hospital stay.

Some authors have focused on developing outpatient laminectomy programs at their centers [70]. Lang et al. [30] presented a retrospective study on 1-level discectomies done at a large-scale academic center before ($n = 643$) and after ($n = 363$) an ambulatory surgery protocol was implemented. There was a significant reduction in the infection rate (12.5% vs. 3.1%) after protocol implementation. The authors also reported that the quality of incident reporting and documentation significantly improved after implementation of the protocol [71].

Cervical spine

In 1996, Silvers et al. [72] were the first to examine the safety and efficacy of ACDF without instrumentation performed on an outpatient basis in a cohort of 50 patients. With one complication each in the outpatient (vocal cord palsy) versus inpatient (wound infection) group, they concluded that no significant additional morbidity was related to the outpatient procedure. The success rates for pain relief and return to work and to normal activities were comparable.

A year later, Tomaras et al. [73] reported the results of outpatient posterior lamino-foraminotomy on 200 patients under GA. No patient required subsequent hospital admission in the immediate postoperative period. Ninety-three percent of patients reported an excellent or good outcome and returned to work or comparable duties at around 3 weeks. The experience of spine surgeons with ambulatory cervical spine surgery using the posterior approach does not necessarily translatable to anterior cervical spine surgery, since the complications related to the anterior approach make ambulatory surgery more problematic.

Stieber et al. [53] described the use of ACDF (with allograft only) with plate fixation, the first to utilize instrumentation in the outpatient setting. Transient dysphagia was the most prevalent minor complication (3/30 patients – 10 %); however, no patient was admitted for this complication since all symptoms were self-limiting. Trahan et al. [38] reported one patient with neck swelling, difficulty in breathing, and anxiety after an outpatient discectomy; this required readmission for 1 day. While airway obstruction and respiratory distress is uncommon, it is potentially life threating. This is more prevalent with multilevel procedures, corpectomies, and longer retraction times. With contemporary anesthesia and surgery techniques, the frequency of these complications has significantly reduced, especially for 1–2-level discectomy.

In a large series of 645 outpatients who underwent an ACDF procedure, there were no airway-related complications [28]. Two patients had an epidural hematoma presenting within 1 h of surgery, well within the 4 h mandatory observation period for the study; one required surgical evacuation. No drains were used for any patient and no patient developed a retropharyngeal hematoma. The unplanned admission rate was 6% with most admissions due to nausea or iliac crest bone graft donor site pain. Some authors believed that the use of an iliac autograft for ACDF was not a limitation to the outpatient procedure and patients could be discharged at a mean time of 2.4 h after surgery and received three home health-care visits over 24 h [26].

The results of the above reports were corroborated by a study of 103 patients, discharged successfully at a median time of 8 h after surgery [74]. They included patients undergoing 3-level surgeries, all of who were admitted for a 23-h stay in their free-standing ambulatory surgery center. In addition, patients were sometimes observed in their surgery center for up to 15 h after completion of the procedure. Their study design calls into question whether it is truly representative of what can be safely accomplished on an outpatient basis in anterior cervical spine surgery, given the long period of postoperative observation in the surgery center. The complication rate was 3.8% and included reaction to medication, radiculopathy, dehydration, and a vertebral fracture [74]. When comparing the outcomes of inpatients ($n = 64$) versus outpatients ($n = 45$) undergoing ACDF with plating, Liu et al. [75] did not find any difference in outcome. There were four complications, all in the inpatient group.

Wohns et al. [39] reviewed the safety of cervical disc arthoplasty in the outpatient setting. The average operative time was 40 min and average recovery time prior to discharge was 3 h. There were no complications in the 26 patients operated.

In a detailed prospective study of 390 patients undergoing ACDF, Lied et al. [76] suggested that a 6-h postoperative observation period after ACDF, followed by discharge is safe. Based on these findings they conducted another prospective analysis [31]. Ninety-five of the 96 patients were successfully discharged either to their home or to a hotel on the day of surgery. Two patients developed postoperative hematoma requiring evacuation. Despite the complication and the hematoma evacuation, the patients were still discharged on the day of surgery. A larger study by the same group from Norway undergoing 1073 lumbar and 367 cervical decompressions found ambulatory surgery safe with 0% mortality and a 3.5% morbidity [77].

Recently, McGirt et al. [33] analyzed a nationwide, prospective quality improvement registry (NSQIP) to compare the quality of ACDF surgery performed in the outpatient versus the inpatient hospital setting. A total of 7288 ACDF cases were identified (outpatient = 1168, inpatient = 6120). After a propensity-matched analysis, rates of major morbidity (1.4% vs. 3.1%, $p = 0.03$) and return to the operating room (OR) (0.34% vs. 1.4%, $p = 0.04$) remained significantly lower after outpatient ACDF. Multivariate logistic regression demonstrated that ACDF performed in the outpatient setting had 58% lower odds of having a major morbidity and 80% lower odds of return to the OR within 30 days.

It is important to remember that selection bias in these studies cannot be completely eliminated. Patients undergoing outpatient versus inpatient ACDF were propensity matched and were similar with regard to all surgical risk factors, but there can still be bias associated with nonrandomization as well as surgeon experience and efficiency/experience of outpatient centers and hospital staff. The level of surgeon expertise, experience of house staff, and competence of outpatient centers/hospitals have not been accounted for in the analysis.

Needless to say, there has been an increase in cervical spine surgeries performed in an ambulatory setting during the last decade. In a study spanning four major US states (California, Florida, Maryland, and New York), ACDF accounted for 68% of outpatient procedures and posterior decompression made up 21%. The majority (>99%) of patients were discharged home following ambulatory surgery [78].

Patients' perception and satisfaction

Brain

Brain surgery has traditionally been thought to be a major procedure that necessitates a prolonged hospital stay and a lengthy recovery period. Very few people have heard of outpatient brain surgery. In a qualitative study, patients were surprised when the idea was first presented to them [14]. However, after having received adequate and relevant information preoperatively, the possibility of being discharged the same day as their operation made the disease and its management seem less serious. This contributes to their well-being and aids their recovery process.

About half the patients believed that they would recover more quickly and comfortably at home. Of particular importance are patients with high-grade gliomas and metastasis. Their limited stay in the hospital helps alleviate the psychological impact of their diagnosis and management and minimizing total hospital time associated with each intervention likely positively impacts their quality of life. For outpatient craniotomy, the element of trust in the surgeon and the system plays a big role. Patients need to believe that the recommendations made by their surgeon are safe and effective and they would be able to tolerate them [14]. Also, there is contemporary emerging data that suggest that cancer patients may live longer if they undergo surgery avoiding the use of volatile agents (i.e. GA) [79].

Spine

In a large series of 1322 outpatient microlumbar discectomies, when patients were asked, 81.6% said they would undergo the procedure again as an outpatient. In 82.1%, the patient's outcome was good, very good, or excellent [66]. However, in the elderly population above 65 years of age studied by the same authors, only 72.4% said they would repeat the procedure as an outpatient and 69.1% stated that their surgery's outcome was good or better.

Hersht et al. [11] found that the role of outpatient lumbar microdiscectomy lead to a significant positive effect on the patient's quality of life. In their qualitative analysis of patient interviews, the authors found that most patients appreciate the need for the health-care system to save money where possible so that it can be spent in other, more resource-intensive areas. Outpatient lumbar microdiscectomy satisfies this goal while retaining high patient satisfaction rates. In patients undergoing lumbar fusion, the mean satisfaction score was 81.1% for patients who had the surgery as an outpatient and 77.5% for patients who were admitted overnight [69].

After giving the option to their patients, the authors experienced a higher percentage of patients choosing the outpatient cervical spine surgery (ACDF with allograft alone) option and many patients who traveled long distances for their surgery preferred to stay at a hotel than at the hospital following the procedure [73]. They found that carefully addressing patients' concerns about postoperative pain and assuring them of the surgeon's availability increases their confidence in accepting outpatient surgery. Immediate resolution of radicular pain further bolsters the patients' confidence in returning home the day of surgery.

After outpatient ACDF, even with the use of an autograft, 95% patients indicated they were satisfied with the surgery and 78% indicated they would have the procedure performed on an outpatient basis again. Similarly, in another study where patient satisfaction on the outcomes of ACDF was assessed using the North American Spine society questionnaire, 91% found the overall results to be excellent, 3% fair, and 6% poor [31].

In a survey mailed to 152 patients 30 days after outpatient discectomy by Sheperd et al. [36], 49% responded. All of them thought of their experience as favorable. Ninety-eight percent of responders thought that the pain was controlled during the first 48 h after surgery; one patient thought that the pain was only partially controlled and another patient experienced postoperative nausea, which the patient thought was 'tolerable.'

The nursing role in outpatient neurosurgical procedures

Besides the surgeon, nurses play a vital role in facilitating a shift in outpatient neurosurgery toward a more patient-care focused environment [80]. By providing information and education to patients and families, nurses have enormous potential to improve satisfaction and outcomes for patients undergoing these procedures. Thoroughly preparing patients for their surgery and helping them manage their care postoperatively are key in decreasing complications and readmission. This role requires constant and repetitive explaining, interpreting, and reinforcing for the procedure to have a successful outcome.

Patients usually have concerns related to the fear of surgery, complications, and levels of recovery. At discharge, they want to know about their medications, how to recognize complications, and what preventive measures they could take to avoid them. Communication of this type is best provided by a dedicated nurse/nurse practitioner. They also help in arranging appropriate referrals in a timely fashion; this improves cost-effectiveness for the system while simultaneously improving the patients' quality of life.

Health-care resources

The ultimate goal of innovation in neurosurgery is to improve patient-care quality and reduce costs [5]. Bhardwaj et al. [23] demonstrated that in 2002, in Canada, where the government is the sole payer, the financial savings to a hospital for an outpatient stereotactic biopsy was around $1140.00 if the patient spent one night in the ward and $2340.00 if the patient spent one night in the ICU.

In a study on the clinical and economic consequences of early discharge of patients following stereotactic brain biopsy at the Cleveland Clinic, the authors demonstrated that extended outpatient observation (8–23 h) compared to early discharge (<8 h) was not clinically necessary and may be economically prohibitive in the setting of a teaching hospital. Average net hospital incomes on technical charges for patients in the inpatient hospitalization, extended outpatient observation (8–23 h), and early discharge (<8 h) groups were $889.00, $1339.00, and $671.00, respectively [81]. Revenue was 6% higher in the extended outpatient observation group compared with the early discharge group, whereas direct costs were 35% higher. The factors that contributed to the increase in cost above that of the early discharge group included pathology, nursing, anesthesia, radiology, and pharmacy.

Total cost per unruptured aneurysm patient was significantly different between inpatient and outpatient using minimally invasive surgery for clipping of an aneurysm. The costs of medical imaging too were lower in the outpatient group [48].

In pediatric patients, savings of at least 49.5% in hospital charges were produced when surgery was performed in the outpatient surgical facility, and a 19.8% reduction in costs was achieved when the main hospital-operating suite was used on an outpatient basis [49]. In a prospective study of 1003 patients who underwent outpatient brain tumor or spinal surgery at a single institution, there were no negative outcomes attributable to early discharge and an estimated saving of a total of $1123,200.00 in inpatient-associated costs alone [24].

Slotman et al. [82] compared the cost efficacy of laparoscopic outpatient discectomy via an anterior approach versus the traditional posterior laminectomy in 1998 and found that the reduced length of stay was associated with lowered patient charges ($4405.00 vs. $7192.00, $p < 0.01$), confirming that the former was safe, cost-effective, minimally invasive alternative to the traditional laminectomy.

The mean cost of inpatient and outpatient lumbar fusion surgeries was $ 67,079.00 and $23,175.00, respectively, in a study that analyzed the characteristics of ambulatory and inpatient surgeries performed in community hospitals in 28 states in the United States of America [83]. Likewise in another study of over 150,000 patients, the median charge for inpatient surgery was $24,273.00 as compared with $11,339.00 for the outpatient setting ($p < 0.0001$) [55].

An economic analysis by Silvers et al. [72] involving patients undergoing outpatient ACDF suggested an average cost savings of $1800.00 per patient, leading to a potential cost saving of $140 million in 1996 if all 1- to 2-level ACDF's were performed as outpatients. Adjusting for utilization of ACDF in 2012, annual cost savings may be as high as $400 million annually [33].

The benefit is similar in patients undergoing cervical disc arthroplasty as well. Wohns et al. [39] in 2010 studied that the average charges for a 1-level outpatient cervical disc arthroplasty were $11,144.00. The average charges for a 1-level outpatient anterior cervical discectomy with fusion were $29,313.00. The average charges for a 1-level inpatient cervical disc arthroplasty were $68,000.00. The average charges for a 1-level inpatient anterior cervical discectomy with fusion were $61,095.00. The cost of outpatient single-level cervical disc arthroplasty was 62% less than the outpatient single-level cervical anterior discectomy with fusion using allograft and plate and 84% less than the inpatient single-level cervical disc arthroplasty.

While prolonged hospital stays may better address problems such as inadequate pain control, urinary retention, constipation, nausea, and vomiting, they are directly associated with rising health-care costs and increased risk of infections, thromboembolic complications, and medical errors. These studies are highly suggestive that outpatient cranial and spinal surgery can provide effective cost-saving measures and can be implemented without affecting quality of patient care.

Conclusions

The first goal of surgery is safety, followed secondarily by efficacy. Outpatient neurosurgery has been shown to be safe and effective in appropriately selected patients. However, to be properly instituted, it requires rigorous adherence to well-established protocols, thorough patient education and a well-versed team of surgeons, anesthetists, and nurses, that is institutional interdisciplinary cooperation. Discharged patients need to be educated and made aware of early signs of complications. A delay in recognizing clinical deterioration can result in devastating outcomes. The heath-care team and the caregiver of the patient must have a low threshold of conversion to inpatient status. A streamlined readmission process must be in place to allow patients a quick return to the hospital if necessary so that they can be managed appropriately.

Despite significant variability in institutional policies in scheduling neurosurgical procedures, we urge our colleagues worldwide to attempt to implement day surgery protocols and programs, which can exist alongside elective and emergency surgeries providing another pathway for patient care. It is up to the decision making of the surgical team to determine the feasibility of specific patients and procedures based on their specific socioeconomic and medicolegal environments. In a time of limited health-care resources, there is a need to create efficient and cost-effective treatments. Despite its proven significant cost-effectiveness, in countries like the United States a single case of litigation over an early postoperative complication has the capability to negate the cost savings realized over thousands of procedures. We encourage departments and institutions to adopt this protocol and amend it to their setting for it to work smoothly and efficiently to benefit a select group of patients. A wider adoption might improve patient satisfaction, societal acceptance, and decrease resource utilization at a global level, with optimal safety and efficacy.

Expert commentary

While the trends in outpatient spinal neurosurgery are rapidly on the rise, outpatient intracranial surgery for brain tumors and unruptured aneurysms is done in very select centers despite its proven safety and efficacy. While awake craniotomy provides a great opportunity to perform brain tumor surgery as an outpatient procedure, GA does not preclude this. Outpatient procedures result in less morbidity in the form of lower infections, fewer thromboembolic complications, and greater psychological advantages to the patient. The procedure is less resource intensive and may be of added value in the developing world.

Five-year view

Surgical outcomes are progressively focusing more on the patients' perspective rather than the physicians' interpretation of his/her operative results. Qualitative studies of patients' experiences will play a greater role in selection of an inpatient versus outpatient procedure, especially if both are reported to be equally safe and effective with no increase in complications with the latter. Minimally invasive procedures with the least possible impairment of quality of life and the chance to curtail medical expenditure will be in wider demand. All these aspects will extend the indications of outpatient neurosurgery. However, for this protocol to work effectively, personal, socio-economic, medicolegal, and ethical issues must be considered.

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The authors have no relevant affiliations or financial involvement with any organization or entity with a financial interest in or financial conflict with the subject matter or materials discussed in the manuscript apart from those disclosed. This includes employment, consultancies, honoraria, stock ownership or options, expert testimony, grants or patents received or pending, or royalties.

Key issues

- Outpatient neurosurgery is defined as a patient arriving at the hospital the morning of their procedure and leaving the hospital by the same evening, thus avoiding an overnight stay in the hospital.
- While most often used for brain tumor patients who undergo awake craniotomy, GA does not preclude outpatient procedures.
- Very strict inclusion and exclusion criteria for patient selection have to be formulated for each procedure for the outpatient protocol to be safe and effective.
- Protocol implementation and strict adherence can be efficient in achieving a goal, especially in large institutions where multiple providers work together as a team.
- Patient education by the surgeon, anesthetist, nurse, and proficient home care by a family member are of great importance for an outpatient program to succeed.
- Early discharge should be a consequence of good patient care and not a primary end point.
- The threshold for conversion to inpatients should be low and is about 5–10% in most studies routinely preforming outpatient procedures.
- The minor and major procedural morbidity is about 5–10% with both intracranial and spinal procedures and patient satisfaction rates are high with outpatient neurosurgery.
- The economic benefits of the outpatient protocol significantly lower the strain on expanding health-care costs.

References

Papers of special note have been highlighted as:
• of interest
•• of considerable interest

1. Apuzzo MLJ. The mariner's compass: a saga of invention, innovation, and opportunity. World Neurosurg. 2010;73(6):595–596.
2. Apuzzo MLJ, Elder JB, Liu CY. The metamorphosis of neurological surgery and the reinvention of the neurosurgeon. Neurosurgery. 2009;64(5):788–794.
3. Elder JB, Hoh DJ, Oh BC, et al. The future of cerebral surgery: a kaleidoscope of opportunities. Neurosurgery. 2008;62(6Suppl 3):1555–1579.
4. Attenello FJ, Lee B, Yu C, et al. Supplementing the neurosurgical virtuoso: evolution of automation from mythology to operating room adjunct. World Neurosurg. 2014;81(5–6):719–729.
5. Witiw CD, Nathan V, Bernstein M. Economics, innovation, and quality improvement in neurosurgery. Neurosurg Clin N Am. 2015;26(2):197–205.
6. Bernstein M, Bampoe J. Surgical innovation or surgical evolution: an ethical and practical guide to handling novel neurosurgical procedures. J Neurosurg. 2004;100(1):2–7.
7. Budrukkar A, Jalali R, Dutta D, et al. Prospective assessment of quality of life in adult patients with primary brain tumors in routine neurooncology practice. J Neurooncol. 2009;95(3):413–419.
8. Jalali R, Dutta D. Factors influencing quality of life in adult patients with primary brain tumors. Neuro-Oncol. 2012;14(Suppl 4):iv8–16.
9. Lwu S, Edem I, Banton B, et al. Quality of life after transsphenoidal pituitary surgery: a qualitative study. Acta Neurochir (Wien). 2012;154(10):1917–1922.
10. Turel MK, Thakar S, Rajshekhar V. Quality of life following surgery for large and giant vestibular schwannomas: a prospective study. J Neurosurg. 2015;122(2):303–311.
11. Hersht M, Massicotte EM, Bernstein M. Patient satisfaction with outpatient lumbar microsurgical discectomy: a qualitative study. Can J Surg J. 2007;50(6):445–449.
12. Manninen PH, Balki M, Lukitto K, et al. Patient satisfaction with awake craniotomy for tumor surgery: a comparison of remifentanil and fentanyl in conjunction with propofol. Anesth Analg. 2006;102 (1):237–242.
13. Wahab SS, Grundy PL, Weidmann C. Patient experience and satisfaction with awake craniotomy for brain tumours. Br J Neurosurg. 2011;25(5):606–613.
14. Khu KJ, Doglietto F, Radovanovic I, et al. Patients' perceptions of awake and outpatient craniotomy for brain tumor: a qualitative study. J Neurosurg. 2010;112(5):1056–1060.
15. Bulsara KR, Johnson J, Villavicencio AT. Improvements in brain tumor surgery: the modern history of awake craniotomies. Neurosurg Focus. 2005;18(4):1–3.

16. Carrabba G, Venkatraghavan L, Bernstein M. Day surgery awake craniotomy for removing brain tumours: technical note describing a simple protocol. Minim Invasive Neurosurg. 2008;51(4):208–210.
17. Dziedzic T, Bernstein M. Awake craniotomy for brain tumor: indications, technique and benefits. Expert Rev Neurother. 2014;14(12):1405–1415.
  • **Extensive review of awake craniotomy**.
18. Howe KL, Zhou G, July J, et al. Teaching and sustainably implementing awake craniotomy in resource-poor settings. World Neurosurg. 2013;80(6):e171–174.
19. Ibrahim GM, Bernstein M. Awake craniotomy for supratentorial gliomas: why, when and how? CNS Oncol. 2012;1(1):71–83.
20. July J, Manninen P, Lai J, et al. The history of awake craniotomy for brain tumor and its spread into Asia. Surg Neurol. 2009;71(5):621–624.
21. Khu KJO, Bernstein M. Letter to the editor: awake craniotomy. J Neurosurg. 2013;119(6):1645.
22. Boulton M, Bernstein M. Outpatient brain tumor surgery: innovation in surgical neurooncology. J Neurosurg. 2008;108(4):649–654.
23. Bhardwaj RD, Bernstein M. Prospective feasibility study of outpatient stereotactic brain lesion biopsy. Neurosurgery. 2002;51(2):358–361.
24. Purzner T, Purzner J, Massicotte EM, et al. Outpatient brain tumor surgery and spinal decompression: a prospective study of 1003 patients. Neurosurgery. 2011;69(1):119–127.
  •• **Largest prospective study of outpatient brain and spine procedures**.
25. Grundy PL, Weidmann C, Bernstein M. Day-case neurosurgery for brain tumours: the early United Kingdom experience. Br J Neurosurg. 2008;22(3):360–367.
26. Erickson M, Fites BS, Thieken MT, et al. Outpatient anterior cervical discectomy and fusion. Am J Orthop (Belle Mead NJ). 2007;36(8):429–432.
27. Fallah A, Massicotte EM, Fehlings MG, et al. Admission and acute complication rate for outpatient lumbar microdiscectomy. Can J Neurol Sci. 2010;37(1):49–53.
28. Garringer SM, Sasso RC. Safety of anterior cervical discectomy and fusion performed as outpatient surgery. J Spinal Disord Tech. 2010;23(7):439–443.
29. Jasper GP, Francisco GM, Telfeian A. Outpatient, awake, ultra-minimally invasive endoscopic treatment of lumbar disc herniations. R I Med J 2013. 2014;97(6):47–49.
30. Lang -S-S, Chen HI, Koch MJ, et al. Development of an outpatient protocol for lumbar discectomy: our institutional experience. World Neurosurg. 2014;82(5):897–901.
31. Lied B, Rønning PA, Halvorsen CM, et al. Outpatient anterior cervical discectomy and fusion for cervical disk disease: a prospective consecutive series of 96 patients. Acta Neurol Scand. 2013;127(1):31–37.
32. Martin CT, Pugely AJ, Gao Y, et al. Thirty-day morbidity after single-level anterior cervical discectomy and fusion: identification of risk factors and emphasis on the safety of outpatient procedures. J Bone Joint Surg Am. 2014;96(15):1288–1294.
33. McGirt MJ, Godil SS, Asher AL, et al. Quality analysis of anterior cervical discectomy and fusion in the outpatient versus inpatient setting: analysis of 7288 patients from the NSQIP database. Neurosurg Focus. 2015;39(6):E9.
  •• **Study from a national database**.
34. Pugely AJ, Martin CT, Gao Y, et al. Outpatient surgery reduces short-term complications in lumbar discectomy: an analysis of 4310 patients from the ACS-NSQIP database. Spine. 2013;38(3):264–271.
  •• **Study from a national database**.
35. Samuel AM, Grauer JN, Rihn JA, et al. Two-level anterior cervical discectomy and fusion: an outpatient surgery? J Spinal Disord Tech. 2015;28(10):349–351.
36. Sheperd CS, Young WF. Instrumented outpatient anterior cervical discectomy and fusion: is it safe? Int Surg. 2012;97(1):86–89.
37. Singhal A, Bernstein M. Outpatient lumbar microdiscectomy: a prospective study in 122 patients. Can J Neurol Sci. 2002;29(3):249–252.
38. Trahan J, Abramova MV, Richter EO, et al. Feasibility of anterior cervical discectomy and fusion as an outpatient procedure. World Neurosurg. 2011;75(1):145–148.
39. Wohns R. Safety and cost-effectiveness of outpatient cervical disc arthroplasty. Surg Neurol Int. 2010;1:77.
40. Chin KR, Coombs AV, Seale JA. Feasibility and patient-reported outcomes after outpatient single-level instrumented posterior lumbar interbody fusion in a surgery center: preliminary results in 16 patients. Spine. 2015;40(1):E36–42.
41. Bernstein M. Outpatient craniotomy for brain tumor: a pilot feasibility study in 46 patients. Can J Neurol Sci. 2001;28(2):120–124.
  • **Pilot study on outpatient brain tumors**.
42. Au K, Bhradwaj S, Venkatraghawan L, et al. Outpatient brain tumor craniotomy under general anaesthesia. J Neurosurg. Forthcoming.
43. Taylor WA, Thomas NW, Wellings JA, et al. Timing of postoperative intracranial hematoma development and implications for the best use of neurosurgical intensive care. J Neurosurg. 1995;82(1):48–50.
44. Bernstein M, Parrent AG. Complications of CT-guided stereotactic biopsy of intra-axial brain lesions. J Neurosurg. 1994;81(2):165–168.
45. Warnick RE, Longmore LM, Paul CA, et al. Postoperative management of patients after stereotactic biopsy: results of a survey of the AANS/CNS section on tumors and a single institution study. J Neurooncol. 2003;62(3):289–296.
46. Sughrue ME, Bonney PA, Choi L, et al. Early discharge after surgery for intra-axial brain tumors. World Neurosurg. 2015;84(2):505–510.
47. Goettel N, Chui J, Venkatraghavan L, et al. Day surgery craniotomy for unruptured cerebral aneurysms: a single center experience. J Neurosurg Anesthesiol. 2014;26(1):60–64.
48. Radovanovic I, Abou-Hamden A, Bacigaluppi S, et al. A safety, length of stay, and cost analysis of minimally invasive microsurgery for anterior circulation aneurysms. Acta Neurochir (Wien). 2014;156(3):493–503.
49. Mawk JR, Peters KR, Borg C, et al. Outpatient pediatric neurosurgery. Childs Nerv Syst. 1988;4(1):22–25.
50. Barcia-Mariño C, González-Bonet LG, Salvador-Gozalbo L, et al. Lumboperitoneal shunt in an outpatient setting for the treatment of chronic hydrocephalus in adults. A study and follow-up of 30 cases. Rev Neurol. 2009;49(6):300–306.
51. Abou-Zeid A, Palmer J, Gnanalingham K. Day case lumbar discectomy–viable option in the UK? Br J Neurosurg. 2014;28(3):320–323.
52. Gray DT, Deyo RA, Kreuter W, et al. Population-based trends in volumes and rates of ambulatory lumbar spine surgery. Spine (Phila Pa 1976). 2006;31(17):1957–1963.
53. Stieber JR, Brown K, Donald GD, et al. Anterior cervical decompression and fusion with plate fixation as an outpatient procedure. Spine J. 2005;5(5):503–507.
54. Walid MS, Robinson JS, Robinson ERM, et al. Comparison of outpatient and inpatient spine surgery patients with regards to obesity, comorbidities and readmission for infection. J Clin Neurosci. 2010;17(12):1497–1498.
55. Bekelis K, Missios S, Kakoulides G, et al. Selection of patients for ambulatory lumbar discectomy: results from four US states. Spine J. 2014;14(9):1944–1950.
56. Zahrawi F. Microlumbar discectomy. Is it safe as an outpatient procedure? Spine (Phila Pa 1976). 1994;19(9):1070–1074.
  • **Pilot study on outpatient lumbar discectomy**.
57. Rogers LA. Outpatient microsurgical management of ruptured lumbar discs. N C Med J. 1987;48(3):117–120.
58. Marcove RC. Ambulatory disc surgery. Compr Ther. 1994;20(8):433–434.
59. Griffith HB. The 100th day case disc. West Engl Med J. 1992;107(2):43–44.
60. Kelly A, Griffith H, Jamjoom A. Results of day-case surgery for lumbar disc prolapse. Br J Neurosurg. 1994;8(1):47–49.
61. Cares HL, Steinberg RS, Robertson ET, et al. Ambulatory microsurgery for ruptured lumbar discs: report of ten cases. Neurosurgery. 1988;22(3):523–526.

62. An HS, Simpson JM, Stein R. Outpatient laminotomy and discectomy. J Spinal Disord. 1999;12(3):192–196.
63. Bednar DA. Analysis of factors affecting successful discharge in patients undergoing lumbar discectomy for sciatica performed on a day-surgical basis: a prospective study of sequential cohorts. J Spinal Disord. 1999;12(5):359–362.
64. Asch HL, Lewis PJ, Moreland DB, et al. Prospective multiple outcomes study of outpatient lumbar microdiscectomy: should 75 to 80% success rates be the norm? J Neurosurg. 2002;96(1 Suppl): 34–44.
65. Shaikh S, Chung F, Imarengiaye C, et al. Pain, nausea, vomiting and ocular complications delay discharge following ambulatory microdiscectomy. Can J Anaesth. 2003;50(5):514–518.
66. Best NM, Sasso RC. Success and safety in outpatient microlumbar discectomy. J Spinal Disord Tech. 2006;19(5):334–337.
67. Best NM, Sasso RC. Outpatient lumbar spine decompression in 233 patients 65 years of age or older. Spine (Pa Pahil 1976). 2007;32 (10):1135–1139.
68. Fleisher LA, Pasternak LR, Herbert R, et al. Inpatient hospital admission and death after outpatient surgery in elderly patients: importance of patient and system characteristics and location of care. Arch Surg. 2004;139(1):67–72.
69. Villavicencio AT, Nelson EL, Mason A, et al. Preliminary results on feasibility of outpatient instrumented transforaminal lumbar interbody fusion. J Spinal Disord Tech. 2013;26(6):298–304.
70. Scanlon J, Richards B. Development of a same day laminectomy program. J Perianesthesia Nurs. 2004;19(2):84–88.
71. Techy F, Benzel EC. Implementing an outpatient ambulatory discectomy protocol at a large academic center: a change for the better. World Neurosurg. 2015;83(3):341–342.
72. Silvers HR, Lewis PJ, Suddaby LS, et al. Day surgery for cervical microdiscectomy: is it safe and effective? J Spinal Disord. 1996;9 (4):287–293.
   - **Pilot study on outpatient cervical discectomy**.
73. Tomaras CR, Blacklock JB, Parker WD, et al. Outpatient surgical treatment of cervical radiculopathy. J Neurosurg. 1997;87(1):41–43.
74. Villavicencio AT, Pushchak E, Burneikiene S, et al. The safety of instrumented outpatient anterior cervical discectomy and fusion. Spine J. 2007;7(2):148–153.
75. Liu JT, Briner RP, Friedman JA. Comparison of inpatient vs. outpatient anterior cervical discectomy and fusion: a retrospective case series. BMC Surg. 2009;9:3.
76. Lied B, Sundseth J, Helseth E. Immediate (0-6 h), early (6-72 h) and late (>72 h) complications after anterior cervical discectomy with fusion for cervical disc degeneration; discharge six hours after operation is feasible. Acta Neurochir (Wien). 2008;150(2):111–118.
77. Helseth Ø, Lied B, Halvorsen CM, et al. Outpatient cervical and lumbar spine surgery is feasible and safe: a consecutive single center series of 1449 patients. Neurosurgery. 2015;76(6):728–737.
78. Baird EO, Egorova NN, McAnany SJ, et al. National trends in outpatient surgical treatment of degenerative cervical spine disease. Glob Spine J. 2014;4(3):143–150.
79. Wigmore TJ, Mohammed K, Jhanji S. Long-term survival for patients undergoing volatile versus IV anesthesia for cancer surgery: a retrospective analysis. Anesthesiology. 2016;124(1):69–79.
80. Zanchetta C, Bernstein M. The nursing role in patient education regarding outpatient neurosurgical procedures. Axone. 2004;25(4):18–21.
81. Kaakaji W, Barnett GH, Bernhard D, et al. Clinical and economic consequences of early discharge of patients following supratentorial stereotactic brain biopsy. J Neurosurg. 2001;94(6):892–898.
82. Slotman GJ, Stein SC. Laminectomy compared with laparoscopic diskectomy and outpatient laparoscopic diskectomy for herniated L5-S1 intervertebral disks. J Laparoendosc Adv Surg Tech A. 1998;8 (5):261–267.
83. Russo A, Elixhauser A, Steiner C, et al. Hospital-based ambulatory surgery, 2007. HCUP Statistical Brief #86. Rockville (MD): Agency for Healthcare Research and Quality; 2007. Available from: http://www.hcup-us.ahrq.gov/reports/statbriefs/sb86.pdf