Ultrasonic Bone Scalpel and its Role in Spine Surgeries: An Article Review

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Abstract

The past few decades have seen tremendous improvement in the field of spine surgery. Spine surgery involves a number of procedures from simple laminectomy to deformity correction. This requires high surgical skills and care, which is achieved by a number of instruments, which, in turn, protect surgeons from committing complications. Recent advancements in spine surgery include ultrasonic bone scalpel, which cut bone accurately and precisely. It is a unique surgical device which offers a controlled osteotomy which slices the hard bone while the soft tissues remain largely unaffected. The major benefits of using this modern instrument are the soft-tissue sparing, controlled cutting, reduced bleeding, and thereby increasing the effectiveness. The aim of this article is to summarize its uses in current practice of spine surgeons and to focus on its advantages and complications associated with uses of this device.

Keywords: Ultrasonic bone scalpel, spine surgery, complications, safety, osteotomy.

Introduction

The field of spine surgery has undergone one of the greatest transformations in medicine over the past 100 years. In that period, the most significant advancement has come with the evolution of spinal instrumentation and fusion in the past few decades. Both neurosurgical and orthopedic contributions have been tremendous, with continued daily innovation, particularly in the areas of navigation, robotics, material science, and spinal biomechanics. These contributions have allowed for safer, more efficacious, and more efficient methods of treatment, improving outcomes, and quality of life for patients. Looking at the history of spine surgery and its incredible recent journey provides excitement for continued progress in the future [1].

Spinal surgeries involve a number of procedures from a simple laminotomy to a deformity correction. This involves removal of bony elements surrounding neural structures, decompression of neural elements, and, in turn, clearing disease elements per se. This requires high surgical skills and care, which is achieved using various instruments such as rongeurs, high-speed drills (HSDs), and rotating burrs. Kerrison Rongeur has been in use for several years. It has benefits like its availability in different sizes, good cutting property, and low cost. However, it takes longer duration for decompression and has high rates of complications especially in untrained hands. HSDs improved spinal surgeries to a great extent [2, 3]. If not used properly, high-speed drills can cause direct damage to neural structures due to its rotatory mechanism. HSDs also cause indirect injury with heat. There has always been a risk of damage to adjacent soft tissues while using these devices. Incidental durotomies ranging from 0% to as high as 35% have been reported [4]. Complications resulting from dural tears include CSF leak or fistula, meningitis, arachnoiditis, spinal epidural abscess, pseudomeningocele, intraspinal hemorrhage or subdural hematoma, low-pressure headache, acquired Chiari malformation, sensory and motor dysfunction, and pain due to associated nerve root injury or delayed nerve root entrapment [5]. Incidence of dural tears across the studies ranged from 1.6% to 9%.

A recent advancement in this field is the ultrasonic bone scalpel (UBS). This device cuts bone with accuracy and safety. Ultrasonic device was developed for dental procedures and used for the 1st time in 1952. This has been used for skull base surgery for many years. This device

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Figure 1: Ultrasonic bone scalpel and irrigation device courtesy Misonix.

was also used for debulking and removal of soft-tissue tumors in the 1970s. In neurosurgery, ultrasonic aspirators have been used to remove soft-tissue tumors such as meningiomas and vestibular schwannomas [6, 7]. This device has been shown to be a versatile, safe, and efficient method for bone removal within spine surgeries.

The advent of ultrasonic bone dissection is as significant to spine surgery today as the adoption of pneumatic drill was several decades ago. Power drills liberated spine surgeons from the slow, repetitive, fatigue inducing, and occasionally dangerous maneuvers that are characteristic of manually operated rongeurs. Now, ultrasonic dissection with bone scalpel empowers the surgeon to cut bone with an accuracy and safety that surpasses that of the power drill [8]. The greater accuracy of bone scalpel is a result of the back-and-forth micromotion of bone scalpel's thin blade as opposed to the rotary macromotion of a drill's burr. This permits fine and precise bone cuts not afforded by a drill. In addition, bone scalpel has two attributes that provide greater safety. First, elimination of rotary motion avoids many of the risks associated with the drill, such as slipping off the cutting surface and entrapping important soft tissues. Second, bone scalpel cuts bone better than soft tissue. This tissue selectivity, which may seem counterintuitive at first glance, is extremely useful in spine surgery where the surgeon is routinely faced with the task of cutting bone adjacent to dura [8].

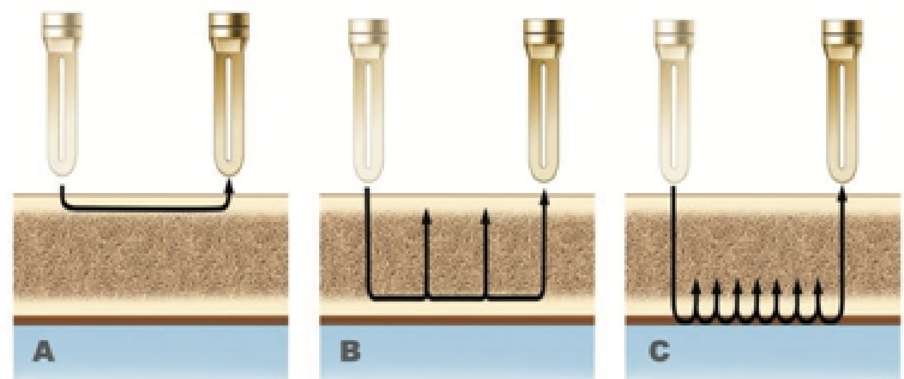

Figure 2: Three steps of cutting bicortical bone. (a) Scoring the outer cortex. (b) Cutting rapidly through soft cancellous bone. (c) Repeatedly penetrating inner cortex with controlled axial pressure.

Mechanism of Action [8,9]

Ultrasound is a wave of mechanical energy propagated through a medium such as air, water, or tissue at a specific frequency range. The frequency is typically above 20,000 oscillations per second (20 kHz) and exceeds the audible frequency range, hence the name ultrasound. In surgical applications, this ultrasonic energy is transferred from a blade to tissue molecules, which begin to vibrate in response. Whether tissue molecules can tolerate this energy transfer or be destroyed by it depends on the density of the tissue and the frequency of oscillation. Dense tissues, such as bone, are ablated by frequencies in the low ultrasonic range.

The bone scalpel assembly consists of an ultrasonic generator/irrigation console that connects to a hand piece bearing a disposable cutting tip. The cutting tip oscillates back and forth a very small distance at a rate of 22,500 times per second (a frequency in the low ultrasonic range). The cutting tip comes in two main varieties (additional ones are being developed): The blade and the shaver tip. The blade behaves like an ultrasonic micro-osteotome to make well-defined cuts in bone and is used for en bloc removal of large pieces of bone. The

Figure 3: Lumbar decompression with the help of ultrasonic bone scalpel.

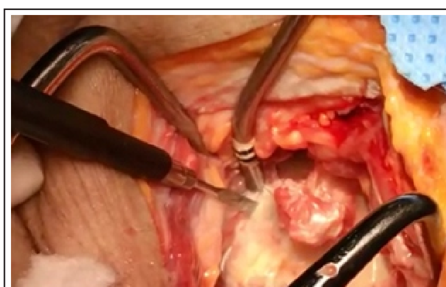

Figure 4: Cervical laminectomy with the help ultrasonic bone scalpel.

Figure 5: Cervical corpectomy with the help of ultrasonic bone scalpel.

shaver tip behaves like a non-rotating burr to selectively ablate bone in a small area. The integrated irrigation feature helps remove bone debris and cool the cutting tip.

The bone scalpel blade's mechanism of action is best understood by analogy to an osteotome. When an osteotome is struck by a mallet, the energy that is transmitted down the shaft of the osteotome is focused along its narrow tip. This focused energy is then transferred from the tip to a very narrow band of bone, which disintegrates in response, thus creating the leading edge of a cleavage plane in bone.

Much like an osteotome, the blade of bone scalpel moves forward (and backward). However, the amplitude of this movement is much smaller than that of an osteotome (35–300 microns), thus transferring only a small amount of energy to bone with each impact. The very high frequency at which the blade moves back and forth to impact the bone (22.5 kHz) compensates for the small energy of each individual impact, thus resulting in a large transfer of energy to bone at the point of contact. Again, this energy disintegrates a narrow sliver of bone and develops a cleavage plane (Fig. 1).

Figure 6: Use of ultrasonic bone scalpel in deformity correction.

The relative selectivity of bone scalpel for bone cutting has to do with the relative rigidity of bone compared to soft tissues. When the blade of bone scalpel comes in contact with rigid bone, the bone does not bend, deform, or move away from the tip. As a result, a large amount of energy is transferred to a small amount of bone at the point of contact, resulting in destruction of that bone. In contrast, soft-tissue structures (such as ligamentum flavum, posterior longitudinal ligament, and dura) can bend, deform, move away, and vibrate on contact with the blade, thus dampening the energy transfer and protecting the tissue from destruction.

Bone Cutting Technique [9]

The analogy to a micro-osteotome whose blade moves back and forth will help the surgeon understand that bone scalpel cuts more efficiently with downward (axial) pressure rather than side-to-side (lateral) movements. A useful strategy for cutting bicortical bone consists of the following three steps: (Fig. 2).

1. Lateral movement with little axial pressure to score the outer cortex of bone to be cut.
2. Axial pressure and liberal lateral sweeps to cut through the cancellous midportion of the bone.
3. Controlled cyclical forward/backward movement with short lateral sweeps to penetrate the inner bone cortex. This step primarily involves the use of controlled axial (downward) pressure. Once the surgeon palpates the intended breach of the inner cortex, he withdraws the blade slightly, moves slightly to one side, and repeats the sequence. It is important to note that one generally cannot visualize the underlying soft tissues through the thin trough that is created and must rely on tactile feedback. If unsure of having penetrated the cortex, the surgeon can momentarily stop the ultrasonic action, palpate the inner cortex with the bone scalpel blade, and then resume cutting.

No instrumentation is without risk, and the surgeon should not plunge into the dura while cutting the inner cortex as it may result in neural injury. Furthermore, they should not linger over the dura to avoid the development of excessive heat and thermal lesion. The heat generated by an ultrasonic device on bone has been reported to be no more than that generated by HSDs. The use of UBS should be avoided in cases where dura is likely to be adherent to the inner cortex.

We searched literature on UBS for spine surgery and found very sparse data. We found that UBS was used safely in various spine surgeries as mentioned by few authors, and we hereby include the data of our articles and the role of bone scalpel in various spine surgeries.

Lumbar Decompression

Moon et al. [10] studied lumbar decompression using UBS compared to conventional technique in a cohort of 93 patients in each group. They have found that the incidence of intraoperative blood loss >100 ml was significantly reduced within the bone scalpel cohort (16.1% bone scalpel, 34.4% conventional, P = 0.04). There was no difference in the incidence of iatrogenic dural breach (9.7% bone scalpel, 16.1% conventional, P = 0.27). There was no significant difference in pre-operative Core Outcomes Measures Index (COMI) between the cohorts (7.91 bone scalpel, 8.02 conventional, P = 0.67) and both cohorts demonstrated a significant reduction in mean COMI at 24 months (bone scalpel P = 0.004, conventional P = <0.001). No difference in mean COMI existed between either cohort at any point across the 24 month post-operative period (P = 0.18).

They have concluded that their data demonstrate a comparable safety profile of the ultrasonic bone curette in degenerative lumbar spinal surgery, with a reduced volume of intraoperative blood loss and an equivalent reduction in patient-reported outcome measures to conventional techniques.

Similar studies were carried out by Hu et al. [11], Hazer et al. [12], Baydon et al. [13], etc., including other surgeries and came to similar conclusion.

In revision laminectomy cases, decompression becomes difficult due to scar tissue, and it takes a longer duration. Decompression may lead to complications like dural leak due to adherence. Using UBS decreased the duration of surgery and avoided CSF leaks [14].

In our experience, the use of UBS in degenerative lumbar spine surgery comes in very handy in long laminectomies, especially in patients with thick laminar plates (Fig. 3). It speeds up the procedure considerably while reducing surgeon fatigue. Since it cuts bone specifically, sparing soft tissues, it has a significant advantage avoiding CSF leaks, especially in the revision cases.

Cervical Laminectomy (CL)

The conventional method (CM) is to use the Kerrison punch and Leksell Rongeur to remove laminae piecemeal or to make troughs on both sides of laminae using Kerrison punch and then remove laminae en bloc. Dave et al. [15] had studied the effectiveness and safety of UBS versus CM. It was a retrospective analysis of 311 patients who were divided into two groups. Group A consists of patients who underwent CL with the help of UBS. Group B consists of patients who underwent CL by CM. They found mean duration of surgery, estimated blood loss, and length of hospital stay was 65.52/70.87 min, 90.24/98.40 mL, and 4.80/4.87 days in Group A and Group B, respectively. Six patients were reported to have dural injuries in each group. In Group A, two cases of C5 palsy and one nerve root injury were observed, while in Group B, three cases of C5 palsy and no nerve root injury was reported. One patient had developed transient neurological deterioration post-surgery in Group A as against 11 patients in Group B.

They have concluded that CL performed with CM and UBS provides comparable results in terms of mean duration of surgery, EBL, and recovery rate. However, post-operative neurological deterioration was observed in CM in a significant number of cases, which necessitated ICU admission, additional morbidity, and additional expenditure.

Similar studies were carried out by Li et al. [16], Onen et al. [17], Al-Mahfoudh et al. [18], etc., and came to similar conclusions.

The authors find the UBS very useful in tight cervical stenosis, where even insertion of the foot plate of the Kerrison punch below the lamina can cause significant counter pressure on the compromised neural structures. Besides, a clear reduction in surgical time and decrease in blood loss make it a handy tool in CL (Fig. 4).

Corpectomy

Corpectomy is a procedure where the vertebral body is removed. It is then replaced by a cage with bone graft and supported by anterior plate in cervical vertebrae or screws in dorsal and lumbar vertebrae. Corpectomy is associated with a large amount of blood loss [19, 20]. Using UBS reduced blood loss while performing corpectomy. Dave et al. [21] performed cervical corpectomy using UBS. After exposing the vertebral level to be removed and clearing the disc cartilage, UBS was used for removing the vertebra until the posterior cortex and remaining was removed using Rongeur. Time taken for single-level corpectomy was 2 min 11 ± 10 s and 3 min 41 ± 20 s for double-level corpectomy. Blood loss ranged from 20 to 150 ml (52.07 ± 29.86 ml) in single level and 40–200 ml (73.22 ± 41.64 ml) in double level. Using UBS was safe, rapid, and effective method for corpectomy.

Corpectomy is otherwise a bloody procedure, and in our experience, the UBS has definite advantage in reducing blood loss as it compacts the cancellous bone as it cuts and minimizes bleeding (Fig. 5).

Foraminotomy

Foraminotomy is a surgical procedure where posterior bony elements are removed to widen space to accommodate spinal cord. This procedure is done where spinal canal space is narrowed due prolapsed discs or degenerative changes which produce neuropathy. While doing this procedure, there are chances of damage to nerve roots around lateral recess. Studies have shown that using UBS enables good access and decompression without any damage to neural elements. Lumbar foraminal stenosis is seen on 8–11% of degenerative spine disorder [22]. Misdiagnosis and inadequate treatment are most common causes for failed back surgeries. Diagnosis of foraminal stenosis is controversial. Clinically, it manifests as radiating back pain with positive Kemp sign. Magnetic resonance imaging (MRI) and MPR computed tomography (CT) are highly sensitive in diagnosing it. However, these are highly sensitive. Root block also helps in diagnosing, but it cannot differentiate between lateral recess compression and extraforaminal compression. If foraminal stenosis is not managed adequately, the symptoms will recur. Surgeons perform medial fenestration to decompress the foramina. In conventional medial fenestration, curette/ Rongeur is used to resect anterior cortex of pars interarticularis, but in cases of severe stenosis, the space left for the nerve roots is minimal, and applying these instruments can lead to damage to a nerve root. In this situation, UBS device helps in removing the anterior cortex safely [23]. Cotton patties can be used around nerve roots while operating with UBS and hence lessen the chance of damage. Morimoto et al. [23] operated 26 cases of lumbar foraminal stenosis with UBS device.

Only one patient had recurrence of radiculopathy which was associated with iatrogenic spondylosis. Post-operative Japanese Orthopaedic Association scores were improved significantly when compared with pre-operative scores, and no patient had spinal instability and malalignment [24].

As the bone cuts have to be minimal and precise while performing a foraminotomy, the UBS seems like a go-to instrument here in our practice.

Laminoplasty

Laminoplasty is a procedure in which bony lamina which is resected after laminotomy is replaced back after the procedure is over. This procedure helps in supporting posterior elements and further prevents kyphosis, serous fluid collection, and subsequent infection. This procedure also helps in preventing recurrent stenosis by avoiding scar formation, which is quite common after laminectomy. It also reduces post-operative axial pain [25, 26, 27, 28]. Conventional laminoplasty is a technically demanding surgery. Surgeons started using HSDs for this procedure, but it can lead to complications like heat damage to the soft tissues [29].

The study by Ito et al. [28] used UBS for laminoplasty in 12 patients. No patient reported any dural leak or nerve root damage.

Matsuoka et al. [30] conducted a similar study in 33 patients where they noted no single complication related to UBS and all the laminoplasties united on subsequent follow-ups.

Parker et al. [31] published a case series where they operated 40 patients of intradural spinal pathology. They performed osteoplastic laminoplasty using UBS. Only one patient had an intraoperative dural puncture which was uneventfully repaired. No patient had spinal instability postoperatively.

Onen et al. [17] studied on 46 patients of cervical spondylotic myelopathy and divided the patients into two groups. In Group 1 (n = 23), UBS and, in Group 2 (n = 23), HSD were used. Parameters taken in comparison were duration of laminectomy, blood loss, duration of hospital stay, and complications. Results showed significant differences between both groups. The duration of laminectomy in Group 1 was 2.2 ± 0.4 min/level, and in Group 2, it was 7.9 ± 2.6 min/level. Mean blood loss in Group 1 was 180 cc, and in Group 2, it was 380 cc. There were no dural tears in Group 1, and there were three dural tears in Group 2. One patient each in Groups 1 and 2 had a C5 radiculopathy postoperatively which resolved on follow-up.

Trench Vertebrectomy

Thoracic disc herniation accounts for 0.25–1.8% of all disc herniations. It is more common in females than males [32, 33, 34]. It is common in the age groups of 20–50 years. Hott et al. [35] described giant calcified thoracic disks (GCTDs) as a specific subgroup of herniated thoracic disks, which occupied more than 40% of the spinal canal based on pre-operative CT, myelography, MRI, or both. Operating a GCTD is a surgical challenge. A study shows a case series of GCTD operated by trench vertebrectomy which involves removal of partial vertebra above and below the involved disc. Sometimes, this procedure is associated with heavy blood loss which may necessitate the ligation of radicular arteries. With the use of UBS, vertebrectomy was performed in a lesser time and with a less blood loss.

We have limited experience of using UBS for laminoplasties and trench vertebrectomies.

Deformity Correction

Modifiable factors influencing blood loss in pediatric spinal deformity correction remain a top area of research interest. Recent studies have identified underlying diagnosis, number of levels fused, patient size, pre-operative Cobb angle, and degree of kyphosis as different variables that can affect the magnitude of intraoperative EBL. Higher intraoperative blood loss increases the likelihood of receiving blood product transfusions, which can result in transfusion reactions, disease transmission, pulmonary complications, an impaired immune response, and increased post-operative bacterial infection risks.

Wahlquist et al. [36] had studied the effect of the UBS on blood loss during pediatric spinal deformity correction surgery in AIS and neuromuscular scoliosis (NMS). They have found estimated blood loss in AIS patients decreased from 1211 mL in the control group to 771 mL in the UBS group with an average total reduction of 440 mL ($P = 0.01$). In NMS patients, blood loss fell from 2171 mL in controls to 1228 mL in the study group with an average total reduction of 943 mL ($P = 0.01$). For comparable patient weight and the number of levels fused, blood loss decreased 26.2% in AIS patients and 46.2% in NMS patients in the UBS group. They concluded that UBS is effective in reducing blood loss in AIS and NMS deformity correction surgery.

However, Garg et al. [37] in their single-blinded randomized control trial had concluded that there was no clinically significant difference in total blood loss, EBL/level, or complications between the AIS undergoing posterior spinal fusion (PSF) and control group. In contrast to reports from other centers, UBS did not lead to reduced blood loss during PSF for AIS.

In our experience, the maneuverability of the UBS also makes it very surgeon friendly, with multiple options in the shapes of the cutting tips and much lighter hand pieces. Osteotomies – from the posterior Ponte's type procedures to the more aggressive vertebral column resections – have all been facilitated by the UBS. We have also used the UBS in internal gibbectomy procedures as well as in costoplasties and anterior releases

(Fig. 6).

Hemostasis and Surgical Duration

Intraoperative bleeding is a major obstacle to decompression. If bleeding cannot be controlled, it can lead to improper vision leading to further soft-tissue damage. It will also lengthen surgical duration, particularly in multilevel decompressions. This can eventually lead to increased morbidity and increased length of stay in the hospital. There are many products in use to control bleeding such as regenerated cellulose (surgical), bipolar cautery, antifibrinolytic agents, gel foam, gelatine material (Floseal), thrombin, and fibrin glue (Tisseel). A comparative study done by Chen et al. [24] showed that there is a significant difference in surgical duration and blood loss. The study showed that combined use of Floseal and UBS had led to lesser surgical duration and lesser amount of blood loss.

Using UBS has shown no bleeding margins from the cut surfaces of the bone. This may be due to the coagulation effect of UBS which coagulates the interstices of the marrow while it cuts. Average blood loss with the use of UBS in a study by Hu et al. [11] was found to be 425.4 ml.

In our experience, UBS is highly effective in decreasing intraoperative blood loss and decreasing surgical timings.

Complications

However, this device use is not without complications. A retrospective study by Bydon et al. [3] showed that five out of 88 cases had incidental durotomies when compared with nine out of 249 with HSD. Although the difference was not clinically significant, we should always keep in mind that complications can occur with UBS too. These dural tears were linear oriented in craniocaudal direction and located on the lateral side, increased age, lumbar surgery, revision surgery, and increased surgical invasiveness were significant risk factors. Primary repair of these tears had a good success rate. Another study has shown that three out of 10 patients had unintended durotomies while operating achondroplasia patients when compared with HSD, which had nine durotomies out of 20. In a study [11] with use of ultrasonic device, they noted two out of 128 cases of dural tears.

Kim et al. [38] conducted a study in 2006 on 546 spine patients who were operated with UBS. They noted that nine out of 546 patients had complications which included five dural punctures and one cord injury. All dural punctures occurred in cases where the bony edge was harboring cord, and this was because the UBS device has an intrinsic property of suction and pulling the dura mater on to the bony edge and caused puncture. However, all the punctures were repaired with 6–0 nylon and fibrin glue patch without any post-operative sequelae. In one patient who suffered cord injury had a diagnosed OPLL with severe cord compression. In this case, they had no evidence of cord injury directly related to UBS device. However, they postulated that cord injury could be due to vibrations transferred and transmitted from the UBS device [38]. However, almost two-thirds of cases (74%) were completed in less than 2 h, and surgeons using the UBS did feel that overall, it reduced the time spent on operating. The incidence of injury to the dura mater has been reported to be similar or even lower by the use of the ultrasonic bone curette when compared with air drill systems [39]. Many have reported no incidence of dural tear as a complication when using ultrasonic bone curettes [6, 7, 14, 25] while others have reported an incidence of dural tears between 1.6 and 9.8% [20, 33, 34].

The heat generated by an ultrasonic device on bone has been reported to be no more than that generated by high-speed drills [39]. The "feel" of when the inner cortex of bone has been cut is intangible but will undoubtedly become more consistent as experience is gained with this new equipment [39]. A number of authors have reported an inherent learning curve for piezo surgery and an associated impact on operating time [28]. A study showed increase in cutting time when compared with traditional drills [3]. As it has a scalpel type tip, it cannot be used in removing bony spurs and ossified lesions while decompressing nerve roots [12].

Summary

During the past 20 years, there have been remarkable advances in the field of spine surgery. UBS is one of the most impactful advances. It is a unique surgical device which offers a controlled osteotomy which slices the hard bone while the soft tissues remain largely unaffected. The major benefits of using this modern instrument are the soft-tissue sparing, controlled cutting, reduced bleeding, and thereby increasing the effectiveness. There are widespread studies in the literature propagating its use in various surgeries such as craniofacial surgeries [40], thoracoplasties, osteotomies, vertebral column resections, laminectomies, corpectomies, laminotomy, facetectomy, and scoliotic surgeries.

The UBS is a novel ultrasonic surgical device that cuts bone and spares soft tissues. This relative selectivity for bone ablation makes UBS ideally suited for spine applications where bone must be cut adjacent to dura and neural structures. Extensive clinical experience with this device confirms its safety and efficacy in spine surgery.

Although not 100%, it can significantly minimize the risk of ripping the tissues as compared to osteotomes, Kerrison, and the high-speed rotating burrs. It also has a distinct advantage of minimizing the thermal damage due to its attached irrigation component. Various studies have proven its efficiency in decreasing the operating time, increased fusion rates, and decreasing the blood loss.

Although it is a relatively easy technique to master, a very basic training is required initially.

Hence, we can safely say that UBS, when used carefully, is an effective and indispensable tool in the armamentarium of today's spine surgeon.

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

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