Use of $\alpha_2$-Agonists in Neuroanesthesia: An Overview

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ABSTRACT
$\alpha_2$-Agonists are a novel class of drugs with mechanisms of action that differ from other commonly used anesthetic drugs. They have neuroprotective, cardioprotective, and sedative effects. These unique characteristics make them potentially useful during neuroanesthesia and intensive care. We review the effects of dexmedetomidine on cerebral blood flow and cerebral metabolism, along with recent advances in using $\alpha_2$-agonists in neuroanesthesia and neurointensive care.

INTRODUCTION
$\alpha_2$-Adrenergic agonists were introduced to clinical anesthesia for their sympatholytic, sedative, anesthetic-sparing, and hemodynamic-stabilizing properties.1 We review recent advances in the clinical use of $\alpha_2$-agonists in neuroanesthesia and neurointensive care, with an emphasis on dexmedetomidine. This discussion complements reviews that focus on other uses of $\alpha_2$-agonists, especially during anesthesia and in the critical care units.2-4 The sedative effects of $\alpha_2$-agonists are mediated via pathways that also make them promising neuroprotective agents. Much of the knowledge accumulated on the subject of neuroprotection by $\alpha_2$-agonists comes from the ophthalmology literature, where investigators have been searching for agents to decrease retinopathy in glaucoma patients. For example, brimonidine, an $\alpha_2$-agonist, has emerged as an antiglaucoma medication not only because it reduces intraocular pressure similarly to other antiglaucoma medications, but because it also reduces progression to glaucoma retinopathy.5-7

PUTATIVE MECHANISMS UNDERLYING NEUROPROTECTION OF $\alpha_2$-ADRENORECEPTOR AGONISTS

Effects on Catecholamine Release
Engelhard and colleagues8 studied the effects of dexmedetomidine on cerebral and peripheral catecholamines during ischemia in anesthetized rats. Dexmedetomidine given intraperitoneally 30 minutes before ischemia did not inhibit the intraischemic increase in cerebral extracellular catecholamine or glutamate concentrations but did ameliorate the rise in peripheral catecholamine concentrations. The neuroprotective effect of dexmedetomidine during cerebral ischemia, as evident by increased expression of antiapoptotic proteins B cell lymphoma-2 (Bcl-2) and Mdm-2, is therefore primarily related to decreased peripheral catecholamine levels; dexmedetomidine did not inhibit the intraischemic increase of cerebral extracellular catecholamine or glutamate concentrations.9 Neuroprotection observed with reduced sympathetic activity may be related to several mechanisms: (1) high catecholamine concentrations increase the sensitivity of pyramidal neurons to excitatory neurotransmitters such as glutamate,10 which results in elevated intracellular Ca$^{2+}$ concentrations with consequent activation of intracellular catalytic enzymes (excitotoxicity); (2) an increase in catecholamine release might have a direct toxic effect on neuronal tissues11; (3) increased catecholamine metabolism could increase free radical formation5; and (4) increased sympathetic activity may reduce perfusion in the ischemic penumbra. Therefore,
suppression of catecholamine concentrations may be neuroprotective by balancing the ratio between cerebral oxygen demand and oxygen supply, reducing excitotoxicity, ameliorating toxic effects, or improving perfusion in the ischemic penumbra (Figure 1).

Effects on Glutamate-Mediated Excitotoxicity and Intravascular Ca\textsuperscript{2+} Concentrations

The excitatory amino acid neurotransmitter glutamate triggers neuronal death by overexcitation of its receptors when released in excessive concentrations. Oxidative degradation to pyruvate and lactate is probably the main mechanism by which the brain disposes of excess glutamate.\textsuperscript{12} This process is halted during anoxia but is re-established after reoxygenation.\textsuperscript{13} Dexmedetomidine stimulates astrocytic $\alpha_2$-adrenergic receptors, which raises astrocytic [Ca\textsuperscript{2+}] concentrations, in turn stimulating glutaminase activity and the ability of astrocytes to dispose of glutamine by oxidative metabolism.\textsuperscript{14} The $\alpha_2$-adrenergic agonist dexmedetomidine stimulates glutamine oxidation in plasma, an effect sufficiently large that it may affect glutamine content in the brain, thus representing a novel mechanism of action for a neuroprotectant drug. Dexmedetomidine may cause a substantial change in the balance between formation and disposal of glutamine, thus reducing the availability of glutamine as a precursor of neurotoxic glutamate.\textsuperscript{14}

By activating $\alpha_2$-adrenergic receptors, brimonidine may reduce ischemic retinal injury as the accumulation of extracellular glutamate and aspartate is prevented.\textsuperscript{15} Brimonidine-mediated activation of $\alpha_2$-adrenoceptors appears to limit glutamate accumulation by maintaining the glutamate-buffering activity of Muller cells, which are retinal glial cells that are critical for maintaining low levels of extracellular glutamate via the electrogenic Na\textsuperscript{+}-dependent glutamate/aspartate transporter, GLAST.\textsuperscript{15} It has been proposed that GLAST function reverses during ischemia so that intracellular glutamate is pumped into the extracellular space.\textsuperscript{16} Activation of $\alpha_2$-adrenoceptors may therefore prevent glutamate and aspartate accumulation by maintaining activity of the glutamate/aspartate transporters.

Effects on Apoptotic Neuronal Death

$\alpha_2$-Adrenergic receptor stimulation may inhibit proapoptotic mitochondrial signaling.\textsuperscript{17} $\alpha_2$-Adrenergic receptor stimulation can also activate the antiapoptotic phosphatidyl inositol-3-(Pi3) and protein kinase/AKT (protein kinase B) pathways (Figure 2). These are major pathways in the promotion of cell survival that block apoptosis by phosphorylation-dependent inhibition of proapoptotic signaling molecules, including Bcl-2–associated death promoter and Bcl-2–associated protein (BAX) and by increasing prosurvival molecules like Bcl-2. Engelhard and colleagues\textsuperscript{18} compared the effect of dexmedetomidine and S(+)-ketamine on the expression of apoptosis-regulating proteins after 30 minutes of incomplete cerebral ischemia and reperfusion in rats. Thirty-two male rats were divided into 4 groups. In the dexmedetomidine group, 100 $\mu$g/kg of dexmedetomidine was administered intraperitoneally 30 minutes before ischemia; another group was given S(+) ketamine 1 mg/kg. The

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other groups were the control and sham groups. Dexmedetomidine increased the concentration of the antiapoptotic protein Bcl-2. The other important finding was that Mdm-2 was increased in animals treated with dexmedetomidine but not in animals treated with S(+) ketamine. Dexmedetomidine, by increasing Bcl-2 concentration, helps to decrease the mitochondrial membrane permeability during the time of ischemia and consequently the release of proapoptotic protease activity such as cytochrome C or the apoptosis-inducing factor from the mitochondria into the cytosol.\textsuperscript{18,19}

During cerebral ischemia, the tumor suppressor gene, \( p53 \), is induced. \( p53 \) protein induces apoptosis by altering BAX and Bcl-2 expression. Mdm-2 (antiapoptotic protein) inhibits \( p53 \) by concealing the activation domain of the \( p53 \) gene. Mdm-2 concentration is increased by dexmedetomidine; therefore, modulation of \( p53 \) activity by Mdm-2 may be a cofactor in dexmedetomidine-induced neuroprotection.\textsuperscript{18}

**NEUROPROTECTIVE EFFECTS ON THE GROWING BRAIN**

\( \alpha_2 \)-Agonists clonidine and dexmedetomidine exert neuroprotective effects in animal models of perinatal excitotoxic injury and hypoxic-ischemic injury. For example, Laudenbach and colleagues\textsuperscript{20} report that intraperitoneal injection of clonidine and dexmedetomidine before an intracerebral stereotatic injection of the N-methyl d-aspartate receptor agonist ibotenate provided potent neuroprotection by stimulating the \( \alpha_2 \)-adrenoreceptors in perinatal excitotoxic brain injury. The combination of xenon and dexmedetomidine was also shown to have neuroprotective effects in neonatal mice in vitro and synergistically in vivo. In vitro, a primary co-culture of neural and glial cells derived from neonatal mice was deprived of oxygen and glucose, and the resulting neuronal injury was assessed by the release of lactate dehydrogenase (LDH). In vivo, postnatal 7-day-old rats underwent right common carotid artery ligation followed by 90 minutes of hypoxia.

The combination of xenon and dexmedetomidine results in reducing LDH release in vitro and improving the long-term neurologic function with reduction of the infarction area in vivo. Dexmedetomidine and xenon may interact synergistically to reduce intracellular Ca\(^{2+}\) concentrations and upregulate the antiapoptotic protein Bcl-2 during hypoxic ischemia.\textsuperscript{21}

Sanders and colleagues studied in vitro and in vivo the neuroprotective effects of dexmedetomidine against 0.75\% isoflurane-induced neuroapoptosis in postnatal 7-day-old rats. Isoflurane exposure induced long-term memory impairment, which was prevented by administration of dexmedetomidine. In vitro, dexmedetomidine also inhibited isoflurane-induced caspase-3 expression in organotypic hippocampal slice cultures, suggesting that dexmedetomidine may be an important adjunct to prevent isoflurane-induced neurotoxicity.\textsuperscript{22} However, it remains unclear whether volatile anesthetics are harmful in human infants, much less whether dexmedetomidine is protective.

**DEXMEDETOMIDINE AND CEREBRAL BLOOD FLOW**

Early studies in animals raised concern over the potential of \( \alpha_2 \)-agonists to reduce cerebral blood flow (CBF) out of proportion to their effect on cerebral

Figure 2. Possible mechanism by which brimonidine increases ganglion cell survival. Activation of \( \alpha_2 \)-receptors by brimonidine activates PI3 kinase, which subsequently activates AKT (protein kinase B). This phosphorylates Bcl-2–associated death promoter, which prevents it from interacting with the Bcl-2–associated protein and thus prevents apoptosis. (Reprinted with permission of Elsevier. Wheeler L, et al. Surv Ophthalmol. 2003;48(suppl 1):S47-S51.19) PI3, phosphatidylinositol-3; Bcl-2, B cell lymphoma-2; BAD, Bcl-2–associated death promoter; P-BAD, phosphorylated BAD; Bclx, Bcl-2–associated \( \times \) protein.

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metabolic rate of oxygen (CMRO₂). For example, Karlsson and colleagues measured canine global CBF and CMRO₂ during 1 minimal alveolar concentration (MAC) halothane anesthesia. At a dose of 10 μg/kg, dexmedetomidine caused significant reduction in CBF without influencing CMRO₂. Decreasing the halothane concentration to 0.1% did not change CBF reduction but instead increased CMRO₂ by 19%.

In an elegant study, Asano and colleagues compared the effects of locally applied dexmedetomidine versus systemically administered dexmedetomidine on pial arterioles with and without local application of the specific α₂-antagonist atipamezole. Six groups of male rats were anesthetized with isoflurane. Local application of dexmedetomidine caused dose-dependent constriction, which was significant starting at 10⁻⁸ M for small and medium-sized arterioles and 10⁻⁷ M for large arterioles. Intravenous (IV) dexmedetomidine at 1 μg/kg caused modest constriction, which resolved after 8 minutes. However, the 10 μg/kg dose constricted the arterioles of all sizes. The constriction started to resolve after 10 minutes. The major finding in this study was that atipamezole was able to completely abolish the vasoconstricted effect of locally applied dexmedetomidine. However, it partially abolished the vasoconstriction effect of systemically administered dexmedetomidine. The vasoconstrictor response to systemically administered dexmedetomidine might be due to its direct vasoconstrictive actions via α₂-receptors.

McPherson and colleagues studied the effect of intraventricular dexmedetomidine on CBF during normoxia and hypoxic hypoxia in dogs anesthetized with 1.4% isoflurane. Dexmedetomidine decreased normoxic flow in the cerebral hemispheres from 76 ± 6 to 44 ± 4 mL·min⁻¹·100 g⁻¹, with similar decreases in other regions. Regional blood flow during hypoxia, in all regions, was halved by dexmedetomidine (P < .05). However, the absolute change in cerebrovascular tone resulting from hypoxia was unaltered by dexmedetomidine, suggesting that dexmedetomidine does not alter the underlying mechanism for cerebrovascular response to hypoxia.

CMRO₂ was maintained at control values during normoxia despite the reduction in CBF. Dexmedetomidine-induced vasoconstriction is sufficient to limit cerebral oxygen delivery during hypoxia and result in reduced CMRO₂. This finding led the authors to hypothesize that the mechanism of dexmedetomidine-induced CBF reduction is not metabolically mediated. The other interesting finding of the study was that α₂-receptors were mainly accumulated in periventricular brain structures as evidenced by the fact that the concentration of H³-clonidine in the cerebral cortex was approximately 1% of that in the ipsilateral caudate nucleus. This finding led the authors to speculate that if the mechanism of blood flow reduction was mediated by direct vascular effect it would have a greater effect on blood flow in the regions with the highest concentration of α₂-receptors. However, this study demonstrated similar blood flow effect among the different brain regions. The authors therefore surmised that the reduction in CBF by dexmedetomidine was due mainly to its stimulatory effect on the locus ceruleus.

Iida and colleagues compared the constrictive effects of topically applied dexmedetomidine, clonidine, phenylephrine, or epinephrine in 3 different concentrations of spinal and cerebral pial vessels in pentobarbital-anesthetized dogs. In cerebral arterioles, dexmedetomidine and clonidine induced greater constriction than phenylephrine and epinephrine. However, in spinal vessels vasoconstriction was smaller than that induced by phenylephrine and epinephrine. Ogawa and colleagues studied the effect of low-dose dexmedetomidine (loading 3 μg · kg⁻¹ · h⁻¹ for 10 minutes, maintenance 0.2 μg · kg⁻¹ · h⁻¹ for 60 minutes) and high-dose dexmedetomidine (loading 6 μg · kg⁻¹ · h⁻¹ for 10 minutes, maintenance 0.4 μg · kg⁻¹ · h⁻¹ for 60 minutes) on dynamic cerebral autoregulation, assessed by transfer function using the thigh cuff method in 14 healthy male volunteers. The authors demonstrated that dexmedetomidine weakened dynamic cerebral autoregulation and delayed restoration in CBF velocity during temporary decreases in arterial pressure. The authors caution that dexmedetomidine may lead to further sustained reductions in CBF when arterial pressure decreases temporarily with postural changes or release of the tourniquet. Dexmedetomidine was shown to decrease cerebrovascular CO₂ reactivity more than propofol sedation in patients with septic shock. This finding is important because maintaining CBF is crucial for avoiding septic encephalopathy.

Another study by Iida and colleagues evaluated pial vessel diameters, cerebral oxygen extraction, and systemic hemodynamics in pentobarbital-anesthetized, mechanically ventilated dogs before and after cardiac arrest (5 minutes) and resuscitation in the presence or absence of dexmedetomidine. The use of dexmedetomidine during cardiopulmonary resuscitation (CPR) did not alter changes in cerebral arteriolar diameters or cerebral oxygen extraction that occurred after cardiac arrest at resuscitation. The major finding of this study was that dexmedetomidine reduced the dose of phenylephrine used to maintain blood pressure (BP) during CPR; it also reduced the number of ventricular ectopic beats observed after CPR. The authors suggested that dexmedetomidine-induced stabilization of the systemic circulation and maintenance of optimal
In a landmark study, Drummond and colleagues\textsuperscript{30} investigated the relationship between middle cerebral artery velocity (CBFv) and cerebral metabolic rate equivalent (CMRRe) in 6 volunteers under dexmedetomidine sedation. Dexmedetomidine was found to cause a dose-related reduction in both CBF and cerebral metabolic rate (CMR) in healthy subjects. Dexmedetomidine maintained CMR-CBF coupling with no decrease in the CBFv to CMRRe ratio. However, the authors cautioned that their study results do not assure that dexmedetomidine will not cause adverse effects on the CBF to CMR ratio in patients with neurologic injuries. Bekker and colleagues\textsuperscript{31} demonstrated the safety of dexmedetomidine sedation during awake carotid endarterectomy, with no increase in the incidence of intracarotid shunting. The contradiction in the findings from different studies, especially in animal studies, can be attributed to the following factors:

1. Higher doses of dexmedetomidine were used in animal studies compared with human studies.
2. Dexmedetomidine causes greater reduction in CBF in isoflurane- and halothane-anesthetized dogs compared to pentobarbital-anesthetized dogs,\textsuperscript{32} which could explain the contradictory results in dog model studies.
3. There are species differences in \(\alpha_2\)-receptors. In dogs, the concentration of receptors is higher than in humans.\textsuperscript{33}

**THERAPEUTIC ROLE IN NEUROANESTHESIA**

**Neuromonitoring and Depth of Anesthesia**

Dexmedetomidine reduces MAC up to 90%.\textsuperscript{34,35} Similar to the effect of many anesthetics, the \(\alpha_2\)-agonist clonidine significantly increased the latency and reduced the amplitude of the cortical auditory evoked potential.\textsuperscript{36} MAC-sparing effects may be helpful to the clinician, especially in situations in which increased anesthetic concentration is undesirable or not tolerated, such as during multimodal neurophysiologic monitoring. Disappearance of motor-evoked potentials (MEPs) was attributed to the effect of dexmedetomidine in 2 pediatric cases.\textsuperscript{37} However, in this report larger than usual doses of dexmedetomidine were administered, which could explain the disappearance of evoked potentials.

Tobias and colleagues\textsuperscript{38} showed that dexmedetomidine has no effect on sensory-evoked potentials and MEPs when it is used as a component of total IV anesthesia during posterior spinal fusion. In another report, dexmedetomidine infusion also did not affect somatosensory-evoked potentials (SSEPs) in 2 patients undergoing cervico-occipital fusion.\textsuperscript{39} Our own work showed that the use of dexmedetomidine as an anesthetic adjunct at target plasma concentrations up to 0.6 ng/mL does not change SSEPs or MEPs to a clinically significant degree during complex spine surgery\textsuperscript{40} (Figure 3). A unique feature of dexmedetomidine is that at plasma concentrations up to 1.60 ng/mL, it decreases the median frequency of the electroencephalogram but does not affect spike activity in patients with temporal lobe epilepsy anesthetized with 2.5% sevoflurane.\textsuperscript{41} This feature has been confirmed during awake craniotomy for seizure resection. Dexmedetomidine infusion at a dose of 0.2 to 0.5 \(\mu\)g \(\cdot\) kg\(^{-1}\) \(\cdot\) h\(^{-1}\) allows successful sedation for craniotomy and electrocorticography.\textsuperscript{42} It appears that dexmedetomidine at regular doses does not have harmful effects on evoked potential recordings; however, higher doses or boluses could abolish the evoked potential.

**Awake Craniotomy**

Awake craniotomy is one of the most challenging procedures in neuroanesthesia practice. It requires that the patient be hemodynamically stable, comfortable, and sedated but awake enough to perform neuromotor and neurocognitive tests. Opioid-based sedation regimens for awake craniotomy are associated with respiratory depression and hypercapnia, which can result in brain swelling and increased intracranial pressure. Dexmedetomidine provides sedation, analgesia, and anxiolysis with minimal effect on respiratory function during awake craniotomy. Dexmedetomidine was used successfully as a primary anesthetic for brain mapping of the cortical speech area in children undergoing awake craniotomy.\textsuperscript{43} However, it was inadequate as a sole agent and required further supplementation with other anesthetics to achieve sedation for stereotactic radiosurgical ablation of an arteriovenous malformation (AVM) in a 6-year-old boy.\textsuperscript{44}

In adult patients undergoing awake craniotomy, dexmedetomidine has been shown to improve patient safety and comfort with minimal effects on respiratory function, while facilitating sophisticated neurologic testing procedures during awake craniotomy.\textsuperscript{35-47} Dexmedetomidine inhibits hypercapnic cerebral vasodilation, a finding that could be beneficial during awake craniotomy procedures or neurointensive care.\textsuperscript{48} Thus, it could be used as an adjunct to other sedative drugs.

**Implantation of Deep Brain Stimulation**

Deep brain stimulation (DBS) is a procedure that presents many anesthetic challenges. The goal of this therapy is to enhance the quality of life for patients...
Figure 3. Transcranial motor-evoked potentials (TcMEPs) and somatosensory-evoked potentials (SSEPs) at different study recording periods. (A) Right first dorsal interossei (R FD1 C8-T1) and abductor hallucis longus (R AHL S1-2) TcMEP. (B) Left first dorsal interossei (L FD1 C8-T1) and abductor hallucis longus (L AHL S1-2) TcMEP. (C) Left (L) and right posterior tibial nerve (Post Tib) and median nerve (Median) SSEP. (Reprinted with permission of Lippincott Williams & Wilkins. Bala E, et al. Anesthesiology. 2008;109(3):417-425.)
with Parkinson disease and other chronic neurologic disorders such as dystonia, depression, chronic pain syndromes, and minimally conscious states. Various subcortical structures within the basal ganglia, including the subthalamic nucleus, the globus pallidus, and the thalamus, are the targets of electrical stimulation. Anesthesia for DBS placement poses a challenge because of the complex neurocircuitry in the central nervous system of the areas to be stimulated, their sensitivity to anesthetic agents, and the co-morbidities suffered by patients with movement disorders.

The cessation of anti-Parkinsonian medications before the surgery (off-period) can be very unpleasant, particularly for patients with severe off-period pain, dystonia, or depression. Moreover, the avoidance of other narcotics and benzodiazepines to allow proper neurologic assessment in patients with chronic pain syndromes who undergo DBS therapy can be a very challenging task, especially because DBS is considered the last therapeutic measure where other measures failed.

The DBS procedure requires fixation of the patient’s head to the stereotactic apparatus for accurate electrode placement. This can lead to considerable patient discomfort. Dexmedetomidine’s properties make it well suited for sedation during DBS procedures. At doses up to 0.3 to 0.6 $\mu$g · kg$^{-1}$ · h$^{-1}$ dexmedetomidine does not interfere with microelectrode recordings, has little effect on the patient’s motor symptoms, maintains respiratory status, and yet creates an environment in which the patient feels comfortable and relaxed. Dexmedetomidine also helps to maintain BP within the required target. The BP during DBS should be kept below 140 mmHg systolic to avoid the development of intracerebral hemorrhage during the procedure.

$\alpha_2$-Agonists are used to treat sympathetically maintained pain (pain dependent on efferent sympathetic activity) such as complex regional pain syndrome (CRPS). Our clinical experience has been that dexmedetomidine is very helpful in managing CRPS patients undergoing DBS by sparing narcotics during the procedure to avoid interference with neurologic testing.

**Adjuncts to General Anesthesia During Craniotomy**

One of the aims of anesthetic management during craniotomy is to avoid abrupt increases in arterial BP, which may cause bleeding or edema in the operating field. Low arterial pressures, on the other hand, predispose a patient to cerebral ischaemia, because autoregulation of CBF is often impaired near tumors or surgically traumatized areas. In a recent study, dexmedetomidine increased perioperative hemodynamic stability in patients undergoing intracranial tumor surgery. It significantly attenuated the hypertensive hemodynamic responses to both intubation and emergence from anesthesia. In addition, it increased intraoperative cardiovascular stability. Most of the effects were concentration dependent, and a higher dose was more effective. Furthermore, patients receiving dexmedetomidine had their endotracheal tubes removed earlier than those in the placebo group, suggesting that the former group of patients had better respiratory function.

Insertion of a skull-pin head holder during craniotomy results in substantial acute hypertension and possibly increased CBF. These hemodynamic responses may lead to brain edema, increased intracranial pressure (ICP), or intracranial hemorrhage. A single bolus dose of dexmedetomidine before induction of anesthesia attenuated the hemodynamic and neuroendocranial responses to skull-pin insertion in patients undergoing craniotomy. Dexmedetomidine also significantly attenuated isoflurane- and sevoflurane-induced dilatation of cerebral arterioles. The cerebral vasoconstrictive effect of dexmedetomidine might be beneficial to patients requiring higher concentrations of inhalation anesthetics because the attendant augmentation of CBF and brain volume might be avoided during craniotomy operations.

Dexmedetomidine reduces rocuronium requirements during sevoflurane anesthesia, according to a study by Memis and colleagues. The authors hypothesized that dexmedetomidine might alter rocuronium pharmacokinetics. This effect may be helpful in decreasing muscle relaxant requirements during surgery, thereby potentially further reducing the risk of residual muscle weakness during recovery from anesthesia. $\alpha_2$-Agonists induce hypothermia in volunteers by stimulating inhibitory $\alpha_2$-adrenoceptors on central neurons. This effect could be helpful to clinicians attempting to induce or maintain hypothermia for neuroprotection, treatment of stroke, or ICP treatment.

**Interventional Neuroradiology Procedures**

Dexmedetomidine has been used as an anesthetic adjunct during interventional neuroradiology procedures, during which maintaining proper cerebral perfusion pressure and hemodynamic stability represent capstones of anesthetic management. We used dexmedetomidine successfully for managing cocaine and opioid withdrawal in patients undergoing coiling for cerebral aneurysms or angioplasty for cerebral vasospasm. Stenting procedures for intracerebral atherosclerotic disease (ICAD) are gaining popularity. Cerebral ischemia caused by ICAD is associated with...
Increased circulating and extracellular catecholamine levels, which are associated with severe hypertension and hemodynamic instability. Dexmedetomidine for ICAD stenting procedures may attenuate catecholamine-related hemodynamic instability while potentially mitigating the toxic effect of catecholamines.\textsuperscript{8,60} Endovascular therapy for patients with cerebral AVM bears the risk of postocclusion hypertension, which may result in cerebral hemorrhage. The authors combine dexmedetomidine, nicardipine, and inhalation anesthetics to control BP optimally during the procedure and continue dexmedetomidine infusion postoperatively to reduce the requirements for antihypertension medications.

\(\alpha_2\)-Agonists decrease the secretion of vasopressin and antagonize its action on renal tubules.\textsuperscript{61} \(\alpha_2\)-Adrenoceptors are also thought to inhibit the release of renin\textsuperscript{62} and increase the release of atrial natriuretic factor in the rat.\textsuperscript{63} Billings and colleagues\textsuperscript{64} investigated the renal protective effect of \(\alpha_2\)-agonists in radio-contrast nephropathy (RCN) in mice. The authors concluded that the \(\alpha_2\)-agonists clonidine and dexmedetomidine protect mice against RCN by preserving outer medullary renal blood flow.

**POSTANESTHESIA CARE UNIT AND NEUROLOGIC INTENSIVE CARE UNIT**

**Animal Studies Support Applications for \(\alpha_2\)-Agonists in Neurologic Intensive Care Unit and Intensive Care Unit Settings**

Zornow and colleagues\textsuperscript{65} studied the effect of IV dexmedetomidine on ICP in 24 New Zealand white rabbits under halothane anesthesia. Dexmedetomidine (20, 80, or 320 \(\mu\)g/kg IV) or saline solution was infused during a 10-minute period. The ICP transiently decreased by 31% in the 20 \(\mu\)g/kg group (from a mean value of 9.4 \(\pm\) 1.3 to 6.5 \(\pm\) 1.0 mmHg, \(P < .05\)). In the 320 \(\mu\)g/kg group, ICP remained unchanged despite a significant increase in arterial BP (32 mmHg). The authors induced intracranial hypertension (ICH) by a cryogenic lesion. Dexmedetomidine was found to have no effect on ICP in this model of ICH. In the same study, sagittal sinus blood flow was measured by the hydrogen clearance technique after the administration of dexmedetomidine (320 \(\mu\)g/kg IV). Dexmedetomidine was associated with a 14% decrease in sagittal sinus blood flow that was not statistically significant. The authors concluded that dexmedetomidine has minimal effects on ICP in halothane-anesthetized rabbits.

Hofer and colleagues\textsuperscript{66} investigated the therapeutic potential of prophylactic administration of either clonidine or dexmedetomidine in a prospective randomized study. They used a murine model of cecal ligation and puncture-induced sepsis. Animals receiving preemptive injections were treated with either clonidine (5 \(\mu\)g/kg) or dexmedetomidine (40 \(\mu\)g/kg) 1 hour and 12 hours before the operation, as well as 1, 6, and 12 hours afterward. Another group of animals received only clonidine (5 \(\mu\)g/kg) 1 hour, 6 hours, and 12 hours after the procedure. The control group received solvent injections at the respective periods.

Preemptive administration of clonidine or dexmedetomidine induced a central sympatholysis and significantly reduced mortality (clonidine: \(P = .015\), dexmedetomidine: \(P = .029\)), while postoperative administration of clonidine failed to significantly prolong survival. The prophylactic administration of \(\alpha_2\)-agonists was accompanied by a reduction in the proinflammatory mediators interleukin (IL)-1B, IL-6, and tumor necrosis factor-\(\alpha\) as well as a decrease in NF-RB binding activity. Thus, an overwhelming response to sepsis was inhibited, and BP was controlled. The authors advocated the use of clonidine or dexmedetomidine as an adjunct sedative in an intensive care unit (ICU) setting to reduce the occurrence of sepsis.

Kumagai and colleagues\textsuperscript{67} investigated the effects of IV dexmedetomidine on lung permeability induced by ICH in halothane-anesthetized and mechanically ventilated rats. Researchers divided the rats into 4 groups. In 2 groups, a subdural balloon catheter was inflated for 60 seconds to produce ICH. The dexmedetomidine group (\(n = 8\)) received IV dexmedetomidine 80 \(\mu\)g/kg followed by 6 \(\mu\)g \(\cdot\) \(\text{kg}^{-1}\) \(\cdot\) \(\text{min}^{-1}\) for 10 minutes, and the control group (\(n = 8\)) received IV saline. The surgery was performed without ICH with dexmedetomidine (sham-control, \(n = 5\)). In all groups, pulmonary permeability was measured using a modification of Evans blue dye extravasation technique. The authors concluded that prophylactic IV dexmedetomidine decreased lung permeability and attenuated hemodynamic changes induced by ICH in rats. Another interesting finding was that PaO\(_2\) was higher in the dexmedetomidine group than in the control group after ICH (\(P < .01\)). Human studies are needed to prove the beneficial effects of dexmedetomidine sedation on oxygenation and lung permeability in patients with ICH managed in the neurologic intensive care unit (NICU).

**Clinical Studies for Using Dexmedetomidine in the ICU**

Dexmedetomidine represents a suitable sedative for the postoperative period and intensive care environments. The major goals of sedation for patients in the postanesthesia care unit (PACU) and NICU are to provide anxiolysis and analgesia and to...
facilitate therapeutic and diagnostic procedures. It is also crucial to avoid additional cardiorespiratory work and metabolic alterations caused by increased levels of catecholamines and other stress hormones. The ideal sedative should also avoid respiratory depression and hypotension.\textsuperscript{2} Dexmedetomidine and other \(\alpha_2\)-agonists induce sedation by initiating processes similar to those found during natural sleep.\textsuperscript{68} Dexmedetomidine induced a pattern of c-Fos (an immediate early gene product) expression that was qualitatively similar to that occurring during sleep. The maintenance of natural sleep during sedation might speed recovery time in the ICU and counteract the effects of sleep deprivation, a common problem for critically ill patients and patients recovering from surgery.\textsuperscript{99} Dexmedetomidine increases activity in the pulvinar nucleus of the thalamus. As this region mediates the ability of arousal stimuli to produce attention,\textsuperscript{70} a sedative state with good patient cooperation might result.

Early work on sedation of critical care patients with dexmedetomidine demonstrated that 18 of 66 patients experienced significant hypotension or bradycardia; most of those events occurred when the patients received a full loading dose of dexmedetomidine.\textsuperscript{71} More recent work has shown that halving the loading dose preserves dexmedetomidine’s sedative action while eliminating adverse cardiovascular events.\textsuperscript{72} Dexmedetomidine pharmacokinetics (clearance, steady state, volume of distribution, area under the curve) did not differ among young, middle-aged, and elderly adults or between men and women. A given dexmedetomidine infusion is expected to produce the same dexmedetomidine concentration irrespective of age or gender.\textsuperscript{2} Although this might be beneficial for clinical use in that pharmacokinetic variation is reduced, pharmacodynamically mediated differences in patient sensitivity to dexmedetomidine may still occur.

Alpha agonists increase the release of growth hormone and inhibit adipose tissue lipolysis.\textsuperscript{73} Clonidine increases the secretion of thyroid-stimulating hormone.\textsuperscript{36} These effects might prove beneficial in the ICU setting by counteracting catabolic processes. Administration of dexmedetomidine for up to 7 days did not suggest any adrenal shock or impairment of the hypothalamic-pituitary axis in dogs.\textsuperscript{74} However, prolonged use of high dosages of dexmedetomidine may result in accumulation and inhibit cortisol synthesis.\textsuperscript{75} \(\alpha_2\)-Agonists, through their central sympatholytic action, can induce hypothermia and inhibit the shivering response to hypothermia.\textsuperscript{76} Shivering frequently limits the effectiveness of hypothermia measures, and \(\alpha_2\)-agonists may be useful in the management of hypothermia for neuroprotection or ICP control.

Dexmedetomidine and other \(\alpha_2\)-agonists have been used successfully to manage the sympathetic hyperactivity resulting from drug withdrawal syndromes in substance abuse.\textsuperscript{77} In patients anesthetized with ketamine, premedication with an \(\alpha_2\)-agonist may prevent postanesthetic delirium.\textsuperscript{78}

The \(\alpha_2\)-agonists have been found to have the potential to be prophylactic agents in treating sepsis. Kim and Hahn\textsuperscript{79} demonstrated that clonidine premedication was able to significantly reduce the proinflammatory cytokines—IL-1B and IL-6—in patients undergoing hysterectomy. Another study used clonidine as an adjunct sedative in critically ill patients to reduce the occurrence of pneumonia.\textsuperscript{80}

Pandharipande and colleagues\textsuperscript{81} randomized 103 adults in medical and surgical ICUs into either dexmedetomidine or lorazepam groups for periods greater than 4 hours. This prospective, randomized, and double-blinded study showed that the dexmedetomidine group had more days alive and days without delirium. Ruokonen and colleagues\textsuperscript{82} suggested that in long-term ICU sedation for 48 hours or more, dexmedetomidine was comparable to propofol and midazolam in maintaining sedation targets of the Richmond Agitation Sedation Scale (RASS) score 0 to 3 but not suitable for deep sedation (RASS 4 or less). Dexmedetomidine had no effect on length of ICU stay. The authors suggested further studies to examine the effects of dexmedetomidine on duration of mechanical ventilation.

A double-blind randomized trial was conducted in 68 centers in 5 countries between 2005 and 2007 among 375 medical and surgical ICU patients with expected mechanical ventilation of more than 24 hours. Sedation level and delirium were assessed using RASS and the Confusion Assessment Method in the ICU. Dexmedetomidine (0.2-1.4 \(\mu\)g/kg per hour; \(n = 244\)) or midazolam 0.02-0.1 \(\mu\)g/kg per hour; \(n = 122\)) was titrated to achieve light sedation (RASS scores between \(-2\) and \(+1\)) from enrollment until extubation or 30 days. No difference was found between dexmedetomidine and midazolam in the time-targeted sedation level in mechanically ventilated ICU patients. Dexmedetomidine-treated patients spent less time on the ventilator, experienced less delirium, and developed less tachycardia and hypertension.\textsuperscript{83} The most notable adverse effect of dexmedetomidine was bradycardia.\textsuperscript{83}

**Use of Dexmedetomidine for Neurointensive Care**

Talke and colleagues,\textsuperscript{84} in a placebo-controlled, double-blind design using a single dose of dexmedetomidine (plasma concentration 600 pg/mL) versus placebo (0.9% NaCl), studied the effect of
Dexmedetomidine is a new \(\alpha_2\)-agonist sedative agent that has neuroprotective and myocardial protective effects. It is considered the near-ideal sedative agent in the ICU, for it maintains the patient's cooperation with minimal effect on respiratory function. Dexmedetomidine is unique among other sedative agents in that it maintains the normal sleep pattern, which is essential for the patient's well-being. However, despite its beneficial effects, the drug's safety as a sole sedative agent in patients with neurologic diseases or patients with sepsis in the ICU is still controversial. Dexmedetomidine decreases CBF without proportional reduction in CMRO2. Large randomized studies are still needed to assess its safety in patients with neurologic diseases or patients with severe sepsis.

**REFERENCES**


