To the Editor.—First, I would like to congratulate Van Zundert et al.1 for their efforts to elucidate one of the putative mechanisms associated with pulsed radiofrequency (PRF), which may help us to understand its analgesic effect in clinical settings. Unfortunately, the explicit and implicit critique in the editorial by Richebe et al.2 about PRF in general may leave readers not familiar with this technique with a false impression that this modality is all but a speculative, experimental treatment.

The use of PRF is not taken lightly. Last year, more than 350 pain specialists from all over the world met on April 24–25, 2004, in Amsterdam for the First European Scientific Meeting of the International Spinal Injection Society. During this 2-day meeting, we launched numerous multicenter clinical and basic science research protocols and created the European Collaborative Group for PRF research, while exchanging among us vast accumulated clinical experience. It is therefore that I read with some surprise the unsubstantiated remark that “there has been a mass migration to the use of pulsed radiofrequency with few data to support efficacy of this new technique.” I wish to clarify this statement.

In a simple, straightforward, systematic search in MEDLINE®, EMBASE, and Cochrane on PRF, one can generate 269 relevant reports in many fields, including pain medicine. Even by excluding all reports on electrical field research not directly relevant to the nervous system (such as biology, biochemistry, and physics), 38 reports remain available for critical reading. Of these, 1 is a prospective, randomized controlled trial (RCT).3 5 are prospective uncontrolled trials; 7 are case series and clinical audits; 18 are letters, comments, and editorials; 7 are neurobiologic reports; and more than 30 are abstracts from important scientific meetings, including my own presentation at the American Society of Anesthesiologists annual meeting on October 11–15, 2003 (A-1090). The accumulation of these data is impressive and shows unequivocally that PRF is a genuine neurobiologic and clinical phenomenon and is different when compared with continuous radiofrequency (also known as thermo coagulation).4 Although the clinical advantages of this modality are not yet clear, what is clear is that PRF is not merely a whim of “wishful thinking” for those who practice it. Furthermore, exciting data on the effect of electrical fields on neural substrates suggests that PRF may have positive effects on synaptic strength and long-term potentiation,6 and if indeed central sensitization and long-term potentiation share similar mechanisms, these findings are of great interest.6

My second comment regards the implicit critique “Neurobiology in Need of Clinical Trials,” suggesting that clinical trials are indispensable to determine the utility of PRF and that neurobiology is only of intellectual and theoretical interest. Implying lack of knowledge and thus lack of value to any treatment in the presence of marked variation in response is not a trivial epistemological matter. Causality in conditions but merely establishes correlations or contributes to probability of various degrees of belief. A RCTs may sometimes be difficult or unattainable for methodologic or ethical reasons, and one must not forget that the decision to “downgrade” other forms of knowledge, as suggested by the editors in the spirit of EBM (such as clinical audits and basic science experiments), is a decision, not a truism. Systematic reviews may as well be victim to publication bias sullied by commercial influence, sponsorship pressures, and forces beyond control of reviewers. Reviews may suffer from poor delineation of references, simplistic concepts of pathophysiology, and the thought that stand-alone therapies (such as PRF) can be the cause of pain relief. Therefore, I argue that just as “basic scientific studies in the neurobiology of pain models and analgesic techniques are not a substitute for randomized controlled clinical trials,” RCTs are not a substitute for knowledge. EBM is only a methodologic solution to clinical epistemology, and it is blind to and disinterested in mechanisms of explanation and causation. EBM does not test causal hypotheses but merely establishes correlations or contributes to probability of various degrees of belief.

Finally, science is about discovering, recognizing, and changing paradigms, and that is the beauty of the PRF story that I think should be told. For years, heat has been thought to be the cause of pain relief in radiofrequency lesioning, until the ingenuity of Professor Sluijter and others suggested that perhaps it is only an epi-phoneme, and it is the electrical fields that are responsible for the analgesic effect. Saying (again) that we need to perform RCTs is too easy, and perhaps methodologic modesty is the order of the day.

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(Received for publication May 17, 2005.)
To the Editor:—As one of the inventors of the pulsed radiofrequency technique for pain therapy, I disagree with the Editorial View of the history of this technique. The authors state that the history was based on a “personal written communication” from William Rittman, M.S. (Principal, RF Medical Devices, Middleton, MA). The editorial stated that there was a chance meeting at a 1995 scientific conference in Austria between Mr. Rittman and Menno Sluijter, M.D., Ph.D. (Professor Emeritus, Department of Anesthesia, Maastricht University, Maastricht, Netherlands), and a Soviet-bloc scientist, and this scientist challenged the conventional belief that pain relief after radiofrequency treatment was a result of tissue destruction, suggesting that pain relief could result from the strong magnetic fields induced by voltage fluctuations in the area of treatment. Mr. Rittman returned to the bench and quickly devised a means of creating the same high-voltage fluctuations without any heating at the tip of the needle by using pulses of electrical current rather that continuous current. Dr. Sluijter immediately introduced the technique into clinical practice . . .

In my opinion, Mr. Rittman’s view of the history of pulsed radiofrequency, as described in the editorial, is factually incorrect and misleading, and ignores the roles that Dr. Sluijter and I played in it. I give my view of the history here.

I was the scientific director of all radiofrequency generators and radiofrequency electrodes built at Radionics since 1970, including the first pulsed radiofrequency unit in 1995. I was also the overall director of Radionics. Mr. Rittman reported to me, and I was aware of all research he was doing. I was the main contact at Radionics with Dr. Sluijter, with whom I had worked closely since 1977. Therefore, I know the history well.

After the meeting with the Soviet-bloc scientist, Dr. Sluijter and Mr. Rittman were intrigued by his magnetic field idea and discussed it with me. I made quantitative estimates that magnetic field effects are negligible for our parameter range and that only the electrical field could possibly produce biologic effects to reduce pain, outside of the known radiofrequency heating effects. To test the magnetic field hypothesis, Mr. Rittman suggested disconnecting the reference electrode to isolate the magnetic effect and eliminate electric effects. I again argued that pain relief effects when the reference electrode was disconnected could only arise from either a transient electric field pulse when the radiofrequency is turned on or from capacitively induced radiofrequency electric fields. Dr. Sluijter tried this suggestion on a few patients, and some of them experienced pain relief. However, the percentage of success was not high enough to be convincing.

Dr. Sluijter then called me and suggested making a stream of pulses that might work better than a transient electric field pulse that I had postulated earlier. I liked his idea. Intense discussions followed among Sluijter, Rittman, and myself on an appropriate pulsed radiofrequency waveform that would be practically adaptable to the existing Radionics RFG-3C RF Lesion Generator. Careful attention had to be given to what was possible and safe related to the existing generator’s circuits, software, and signal outputs. This led to the specification for the first pulsed radiofrequency generator. The actual design and bench work to build the first pulsed radiofrequency unit in 1995 was not done by Mr. Rittman at all. It was done by two other Radionics engineers: Raymond Fredricks and Jack Thomasiarn. The unit was sent to Dr. Sluijter, and he did a small patient series with the unit in early 1996. The results were encouraging. At that time, I performed more detailed calculations to prove that the magnetic field near our electrode at our radiofrequency voltages and frequencies is about 1 gauss, approximately equal to the earth’s magnetic field. Therefore, the magnetic field is irrelevant. I also calculated that the electric fields and currents are very large, in biologic terms, and are the likely agents to produce the clinical effect observed. Sluijter, Cosman, Rittman, and van Kleef published the world’s first article on pulsed radiofrequency, which included the above work, in The Pain Clinic in 1998. A U.S. patent on pulsed radiofrequency for pain therapy was first applied for in June 1996 with the proper inventors: Sluijter, Rittman, and Cosman. Four U.S. patents were eventually issued stemming from that initial patent application.

The discovery of the pulsed radiofrequency technique for pain therapy involved many events, exchanges of ideas among the inventors, and well-thought-out implementations. It was certainly not a quick, solo performance by Mr. Rittman as the editorial portrays.

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(Accepted for publication May 17, 2005)

Dr. Cosman was a stockholder in and the President of Radionics, Inc. (Burlington, MA), in 1995 and 1996, when the development of pulsed radiofrequency was done. Radionics financed that development. Dr. Cosman was also an author on the four patents issued on pulsed radiofrequency as cited in Sluijter et al. Dr. Cosman sold Radionics in January 2000 and no longer has any financial interest in Radionics or the above-mentioned patents. Dr. Cosman is currently a stockholder in and the president of Cosman Medical, Inc., Burlington, Massachusetts, which manufactures radiofrequency generator systems that can be used in the field of pain management.
To the Editor— I read your editorial view on pulsed radiofrequency\(^1\) with great interest. I wish to point out that the narration of the history of pulsed radiofrequency is incorrect.

I remember this period quite clearly. During the meeting in Austria, Professor Sineik Ayrapetyan, Ph.D., from Yerevan, Armenia, suggested that the clinical effect of radiofrequency could be due to exposure to magnetic fields. In your editorial, it sounds as if this assumption might be right. It is not. The magnetic field at 500,000 Hz is negligible. William Rittman, M.S. (Principal, RF Medical Devices, Middleton, MA), and I did not realize this at that time, but it gave us the idea that the role of heat might be disputable. Mr. Rittman then suggested applying radiofrequency without using a ground lead, thus breaking the circuit. In retrospect, this could only cause a minor biologic effect, but I have tried it. It had an effect in a minority of patients, certainly not enough to follow that road any further.

There was a deadlock then, lasting until approximately 6 months after the Austria meeting. The suggestion that “Mr. Rittman returned to the bench and quickly devised a means…” is therefore fantasy. It was a period of intensive interaction about the subject between Professor Eric Cosman, Ph.D. (then director of Radionics [Burlington, MA]), Mr. Rittman, and myself, but we did not find a workable solution, and no action was taken. Finally, it was my idea to pulse the output of the radiofrequency generator, and it was only then that the deadlock was broken, during the autumn of 1995. An RFG 3C was then adapted to generate the appropriate output. Anecdotally, this museum piece is still in use to treat pain in horses, in a veterinary clinic in Niederlenz, Switzerland. The first clinical application of pulsed radiofrequency was in my practice in Amsterdam, on February 1, 1996.

I read that your information was based on a personal written communication by Mr. Rittman. To put it mildly, I find that an unconventional way to gather information for an editorial in a prestigious journal such as yours. There is nothing against that, provided that the facts are checked. This would have been easy in this case, and it would have prevented you from printing inaccurate information.

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Reference


(accepted for publication May 17, 2005.)
and quickly devised a means . . .”; this was not meant to imply that Mr. Rittman acted alone without many others involved nor that this process did not evolve over time, and Drs. Cosman and Sluijter have filled in these details and given credit to some of the others involved. As to the strong magnetic field *versus* the electrical field being responsible for the biologic effects of PRF, their comments clarify how the original concept was modified based on experimental observation. In the end, my brief account of correspondence with Mr. Rittman and the additional details provided by Drs. Sluijter and Cosman form a seldom-told story about how these innovators were involved in the origins of pulsed radiofrequency treatment that will be of interest to all who are familiar with the technique and historical value as this technique emerges.

Philippe Richebé, M.D.  "The University of Iowa, Iowa City, Iowa. tim-brennan@uiowa.edu"

References


To the Editor—I read with interest the article about intraoperative remifentanil infusion by Lee et al.1 I have major concerns regarding the nonsignificance of chi-square tests for the behavioral pain score during the first 15 min in the recovery room. The bar representation in their figure 1 is appropriate for expressing these results and clearly shows a different comportment of patients in the two groups. After redoing the analysis by extrapolated number of patients according to bar height, it seems that, as expected, significant activity for chi-square tests is very high at all times studied (table 1). Calculations were made with JMP 5.1 (SAS Institute, Cary, NC). The comment in the text says that 60% of patients in the remifentanil group versus 40% in the nitrous oxide group have a behavioral pain score of 0. That does not match the figure in the article. Furthermore, the percentage of total patients exceeds 100% at T5 for the remifentanil group.

If these results are not type errors, we could have questions about the morphine titration. In our study,2 the morphine titration was based essentially on behavioral scale during the first 15 min after extubation, because of the difficulty to have correct pain assessment just based only on the visual analog pain scale score at this moment. Another difference with our study is the use of fentanyl at induction and morphine at skin incision. The time to first dose of morphine does not appear in the results. The authors’ conclusion could be right, but the discrepancies in the presented data may alter this finding. Opioid tolerance is not always clinically significant because of patient variability, surgery duration, opioid dosage, or concomitant medication. Graphics can help us to show clinical evidence, and statistical tests are used to confirm and valid ideas revealed by data.3 The high publication pressure should not deserve statistical review.4 Analysis and criticism are the guaranties of medical research.


References


(Accepted for publication June 7, 2005.)
In Reply.—We thank Dr. Guignard for his comments and interest in our article.1 We have checked figure 1 as presented in the text and found that there was an error in the graphical presentation of this figure. There were higher behavioral pain scores in the first 10 min in patients who had received remifentanil but not at 15 min and, as Dr. Guignard correctly points out, this has not been made clear in the text. For completeness, the tabular data are presented below (table 1), with our statistical analysis using the continuity adjusted chi-square test to analyze the behavioral pain score (statistical software: SAS System for Windows Release 8.02; SAS Institute Inc., Cary, NC).

There was no difference by 15 min and no difference in visual analog pain scale scores. We believe that these differences in the first 10 min relate to pharmacokinetic differences between remifentanil, nitrous oxide, and the titration of drugs at the end of the case because the scores rapidly equilibrated and they are of little significance compared with the main outcome measures of this study. In retrospect, a narrow scoring system such as this may also have limitations in discriminating differences.

There was no difference in the total morphine consumption or the time to the first dose of morphine during the stay in the recovery room. The two groups had similar total morphine consumption in the first 24 h and visual analog pain scale scores at rest and movement. The reported incidence of postoperative nausea and vomiting was 10% in both groups. There was no difference in the sedation scores.

Our main objective was to determine whether the substitution of remifentanil for nitrous oxide, an increasingly common clinical practice, results in acute opioid tolerance. To more tightly control this study, we had to substitute remifentanil for nitrous oxide, as far as possible, while otherwise maintaining a normal standard of care. At our institution, that involves fentanyl coinduction and morphine before skin incision. This is why this occurs in both groups.

We apologize for this oversight in the behavioral pain score data presentation but are confident that this does not detract from the principal conclusions of the study.

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Reference


(Accepted for publication June 7, 2005.)

Some Points Regarding Anesthesia for Patients with Congenital Long QT Syndrome

To The Editor.—I read with great interest the article by Kies et al.1 in the January 2005 issue of Anesthesiology entitled “Anesthesia for Patients with Congenital Long QT Syndrome.” The article is a good review of the subject, but it omits a number of important points regarding the perioperative care of patients with this disease. First, it should be noted that no studies exist comparing the safety of anesthetic agents in long QT syndrome (LQTS). The recommendations are therefore extrapolated from case reports and studies from healthy volunteers. Although isoflurane may indeed shorten the QT interval more than other agents, significant arrhythmias in LQTS patients anesthetized with isoflurane have been reported.2 A number of reports on this subject3,4 have noted that the most prevalent factor associated with significant arrhythmias during surgery and anesthesia is the lack of control of symptoms before surgery. Although halothane and ketamine should probably be avoided, patients whose arrhythmias are well controlled before surgery rarely have arrhythmias during surgery, regardless of the anesthetic technique chosen.

Second, Kies et al. do acknowledge that different genetic subtypes of LQTS are known to exist. However, optimal treatments of the various subtypes differ in important and significant ways. LQTS types 1 and 2 (LQT-1 and LQT-2) are defects on chromosomes 11 and 7, respectively, both encoding for potassium transmission. The standard treatment for both has been β-blockade. β-Blockade may, however, be contraindicated in LQT-3 (a defect in sodium transmission), because bradycardia in these patients can further prolong the QT interval and lead to ventricular arrhythmias.5 In 1991, Moss et al.6 showed that cardiac pacing at a rate sufficient to shorten the QT interval could prove useful in LQTS. This article was written before the genetic subtypes of the condition were known, and the data of Schwartz et al.7 suggest that cardiac pacing might be particularly useful in LQT-3.

Kies et al. do mention the possibility of droperidol prolonging the QT interval. However, numerous drugs do the same and should probably be avoided in patients with LQTS. Those likely to be encountered in the operating room include amiodarone, disopyramide, chlorpromazine, dolasetron, haloperidol, tamoxifen, and many others.8

Although genetic testing is still not easily obtainable, it should be noted that it is often possible to distinguish among the various subtypes of LQTS by the electrocardiographic pattern.9 LQT-1 has a prolonged QT interval with a normal to high T-wave amplitude, a broad-based T wave, and an indistinct T-wave onset. LQT-2 is characterized by a prolonged QT interval, low-amplitude T waves, and bifid T waves in more than 60% of cases. LQT-3 shows a prolonged QT interval with late onset, peaked T waves, and a long, isoelectric ST segment.

Last, despite all efforts, arrhythmic episodes, particularly torsade de points, are common in LQTS patients. Kies et al. do not give specific recommendations for dealing with such arrhythmias when they occur, but intravenous magnesium; intravenous lidocaine; rapid-acting β-block-
Volatile Anesthetics and the Long QT Syndrome

To The Editor—With much interest we read the article by Susan J. Kies et al., regarding patients with congenital long QT syndrome (LQTS). We congratulate the authors on their excellent review but would like to discuss several aspects. As stated in the introduction, patients with LQTS often show a "delayed cellular repolarization and heterogeneity in dispersion of repolarization, which . . . can lead to early after-depolarization, further dispersion of repolarization, and the formation of reentry circuits."

It becomes increasingly apparent that the QT interval prolongation per se is not the crucial pathology in LQTS. The delayed cellular repolarization in LQTS represents either impaired rapid or slow delayed rectifier potassium currents (IKr or IKs) or inappropriately inactivated sodium currents (INa). The main arrhythmogenic substrate resulting from these altered ion currents is an increase in transmural repolarization heterogeneity. This heterogeneity favors the development of torsade de pointes, which is triggered by early after-depolarizations. More than 300 mutations in six genes encoding cardiac ion channel subunits4 and ankyrin B5 have been identified in patients with LQTS. According to the affected ion channel subunit, LQTS is classified into six subtypes with partially different clinical courses and triggers of torsade de pointes.6 Hence, the clinical and electrophysiologic presentations of the syndrome are considerably heterogeneous, and the effects of different drugs may be unpredictable.6

The QT interval obtained by a 12-lead electrocardiogram is only a rough measure of the repolarization time. Diagnosis based solely on summation vectors projected to the body surface is therefore neither sensitive nor specific.7 Accordingly, studies that only focus on drug effects on the QT interval may produce premature conclusions regarding potential safety or risk of these drugs in LQTS. This explains the contradicting results of numerous investigations, which report different effects of drugs on QT interval. Kies et al. recommend isoflurane as volatile anesthetic of choice in LQTS patients. In our opinion, to date, such recommendation cannot be supported. The reported effects of volatile anesthetics on QT interval are inconsistent or even conflicting. Only few studies have focused on QT heterogeneity or ion channel physiology, and it seems that all volatile anesthetics—including isoflurane—interact directly with cardiac delayed rectifier potassium channels.8–11 We therefore propose to avoid this class of anesthetics and would prefer propofol as the anesthetic of choice until more information is available from pharmacologic studies that focus on ion channel physiology and transmural heterogeneity of repolarization. These studies should ideally differentiate between LQTS subtypes.

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References

In Reply.—We appreciate the commentary and the excellent points raised by Dr. Katz. We apologize for the omission of his excellent case report from our extensive though limited bibliography.1 It is true, as it states both in the original article and in Dr. Katz’ letter, that our information about anesthetic management of long QT syndrome (LQTS) is derived primarily from case reports and anecdotal data. We...
On the Origin of Critical Care Units: A Clarification

To the Editor—In delivering the 43rd Rovenstine Lecture, “Assessing the Past and Shaping the Future of Anesthesiology,” which was reprinted in the May 2005 issue of ANESTHESIOLOGY, Jerome H. Modell, M.D., D.Sc. (Hon) (Professor Emeritus of Anesthesiology, University of Florida College of Medicine, Gainesville, Florida), pays tribute to his American mentors, friends, and colleagues.1 Certainly, the credits could be well merited, but in the case of Dr. Thorkild Andersen, they are misplaced. Dr. Modell is correct when he states that “Critical care medicine also is primarily an outgrowth of anesthesiology” but incorrect when he states that it was “Dr. Thorkild Andersen and his colleagues in Copenhagen, Denmark, [who] demonstrated that polio victims could be kept alive if they were intubated and hand ventilated by an anesthesiologist at the bedside.” The honor for demonstrating that polio victims were succumbing considerably more frequently from respiratory insufficiency than from overwhelming virus encephalitis belongs solely to another Danish anesthesiologist: Dr. Bjørn Ibsen.2,3 During the 1952 poliomyelitis epidemic in Denmark, it was he who showed that polio victims, with paralysis of the respiratory or bulbar muscles, could often be kept alive if they were treated as Dr. Modell describes in his Rovenstine lecture. Ibsen’s account of events is available, in his own words.4

In the short term, the contribution of Bjørn Ibsen was of fundamental importance for the victims of polio. But it was the well-deserved credit he gained from his achievements in the great struggle of the polio epidemic that made it possible for Ibsen to open the first multidisciplinary intensive care unit in the world at the Kommune Hospital in Copenhagen, Denmark, on December 21, 1953.5

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To the Editor—The article by Viscusi et al.\(^1\) describing a novel, extended-release epidural morphine formulation is very informative. However, Dr. Viscusi and his coinvestigators have stacked the deck in favor of their study drug by the way they designed their study and presented the data. Their study calls for patients undergoing hip arthroplasty to receive either general or spinal anesthesia; furthermore, median times to first postoperative use of patient-controlled analgesia (PCA) fentanyl were compared. Without knowing who received spinal anesthesia and the duration of the spinal blockade, median times to first postoperative use of PCA fentanyl cannot be interpreted, and neither can the total narcotics use in 24 or 48 h. The study also limited intravascular use of intravenous fentanyl to 250 \(\mu g\) per patient, clearly an inadequate dose for a hip arthroplasty in the general anesthesia group, and disallowed the use of any other pain medication. By artificially prohibiting the control group from receiving adequate amounts of analgesics, it is no surprise that both surgeons and patients were more satisfied if the study drug, the extended-release epidural morphine, was also administered. Figure 3 of the article shows some patients needing as much as 2,500 \(\mu g\) fentanyl in the first 24 h. Programming intravenous PCA fentanyl, a narcotic not commonly used for postoperative pain control after hip arthroplasty, and limiting the doses at 10–20 \(\mu g\) with a lockout interval of 6 min then can be interpreted as some patients almost constantly pressing their PCA buttons and never achieving adequate pain relief. Extended-release epidural morphine is an interesting formulation; however, it has a higher side effect as demonstrated by 12.5% of patients needing opioid antagonist in the study group versus 0% in the control group. Moreover, it is far from clear from the presented data that it is superior to the present-day management of post–hip arthroplasty patients with adequate doses of intravenous PCA morphine plus or minus conventional epidural.

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Reference


(Accepted for publication August 31, 2005.)
It is also important to recognize that the clinical trial of EREM did not permit the use of multimodal analgesia. In clinical practice, the multimodal approach for pain management in postoperative patients is common practice and has proven quite effective for pain management. As shown by a recent meta-analysis, the use of nonsteroidal antiinflammatory drugs can reduce morphine consumption substantially and significantly decrease the rates of adverse events.\(^2\) In my clinical practice, patients generally receive lower doses of EREM (\(\leq 10\) mg) in conjunction with other modalities. Under these conditions, patients frequently transition to oral medications without intravenous PCA. Regular monitoring for adverse events is performed, but the time required for monitoring is more than compensated for by the time saved on PCA setup, monitoring, and maintenance.

In summary, I thank Dr. Roboubi for providing me with an opportunity to dispel a number of common misconceptions regarding randomized clinical trials. Although such studies have limitations in describing how a drug may ultimately be used for effect in real clinical settings, the rigor of randomized studies provides us with greater certainty regarding the study outcomes. No single study can capture the many important nuances of drug performance, and clinicians should always read the product label to ensure that they understand the approved drug doses and indications.

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(Accepted for publication August 31, 2005.)

**Anesthesiology** 2005; 103:1319 © 2005 American Society of Anesthesiologists, Inc. Lippincott Williams & Wilkins, Inc.

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**CORRESPONDENCE**

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**To the Editor.—**I read with interest the article by Naruo et al.\(^1\) entitled “Sevoflurane Blocks Cholinergic Synaptic Transmission Postsynaptically but Does Not Affect Short-term Potentiation." I agree with the authors about the importance of studies at the cellular and molecular levels, which in conjunction with studies at the cognitive science level should provide a comprehensive account of effects of anesthetics on memory. However, my enthusiasm for the authors’ excellent work was marred by the following points. It is not clear how the neurons used in the cell culture are relevant to memory processes. For example, in a similar aquatic invertebrate, *Aplysia*, the sensory and motor neurons of the gill withdrawal reflex are commonly used. The reflex in the intact animal can be classically conditioned and undergoes habituation and sensitization.\(^2\) Does this occur with the neurons used in this report?

It is inaccurate to state that numerous studies found no effect of anesthesia on various types of memories. Anesthetics (in anesthetizing dosages) abolish both short- and long-term memories.\(^3\) The authors cite as a reference,\(^4\) an article that was presented at a symposium in 1995 where the authors sent a questionnaire to a number of consultants regarding their opinions about the existence of implicit learning and memory during anesthesia. However, such existence remains controversial, as best exemplified by the lack of replication of any positive findings (except for one recent work by Deeprose et al.).\(^5,6\)

Although it is true that the anesthetized brain is able to process auditory information, this does not allow cognitive processing during adequate anesthesia. Looking at the auditory evoked responses,\(^7\) the brainstem response is resistant to anesthetic effects. The early or midlatency responses that reflect neural transmission through the medical geniculate body in the thalamus to the primary auditory cortex disappear with deep anesthesia.\(^8\) The late cortical responses that reflect transmission through cortical association areas, the frontal cortex and the hippocampus, and are engaged in cognitive processes are abolished with loss of consciousness. The authors give as a reference for persistence of cognitive processing during anesthesia a meta-analysis of studies of implicit memory before 1996.\(^9\) More studies have been published since then, and as with any meta-analysis, the results are dependent on the quality of the reviewed articles. Finally, the authors state that cellular studies are important in resolving the issue of whether anesthetics affect learning and memory. Perhaps it would be more productive for investigators to start with the forgone conclusion that anesthetics do affect learning and memory and to elucidate the sites and mechanisms of this important interaction.

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(Accepted for publication September 9, 2005.)

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**In Reply.—**I appreciate the interest expressed by Dr. Ghoneim for my article.\(^1\) I am pleased to have invoked a response from my clinician counterpart vis-à-vis the need to understand fundamental mechanisms by which anesthetics may affect learning and memory.

To clarify how cultured neurons may be relevant to memory processes, I wish to point out that at both the cellular and the molecular level, most fundamental mechanisms underlying synaptic plasticity are preserved in a vast majority of in vitro (slices or cultured neurons) preparations. These plastic changes in synaptic activity, in turn, are thought to form the basis for learning and memory in most animals—ranging from worms, snails, and flies to humans. Therefore, it is highly appropriate and useful to take advantage of in vitro preparations for understanding complex processes such as learning and memory. Regarding the usefulness of the model system for studies on synaptic plasticity and learning and memory, I wish to point out that mine was the first laboratory to have reconstructed the entire respiratory network in cell culture.² I demonstrated that the in vitro reconstructed circuit, comprising behaviorally and functionally well-defined neurons, was sufficient to generate patterned respiratory rhythm in a manner similar to that seen in vivo. Both the Lukowiak (University of Calgary, Calgary, Alberta, Canada) and my laboratory have since demonstrated that the respiratory behavior in *Lymnaea* can be operantly conditioned²–⁷ to exhibit short-, intermediately-, and long-term memory and have identified the locus for these memory-related changes at the level of a single neuron. By selectively removing a single cell in the intact animals, I have subsequently provided direct evidence regarding the storage site for learning and memory-related changes in individual neurons.⁸–¹⁵ Moreover, using the cell culture model, I have not only defined the mechanisms that regulate synaptic efficacy¹⁶,¹⁷ but also identified novel proteins¹⁸ that can modulate synaptic strength via interactions with the glial cells. Therefore, I believe that the *Lymnaea* model is equally well suited for studies in synaptic plasticity and learning and memory—as has been the case in *Aplysia*.

Notwithstanding these strengths of my model and a clear demonstration in my article¹ that anesthetics do not affect short-term potentiation, I have still been very careful in drawing a generalized conclusion about the actions of sevoflurane on learning and memory. Specifically, I have explicitly stated in my article that “these data should be treated with caution as learning and memory involve a larger population of neurons, often requiring interplay between complex cognitive information processing mechanisms in the brain” (Discussion, first paragraph, page 924).

In the context of unresolved issues of whether anesthetics affect memory, the bottom line is that we still do not have the answer—notwithstanding Dr. Ghoneim’s claim that anesthetics have been memory, the bottom line is that we still do not have the answer—(Discus-

References


Accepted for publication September 9, 2005.
could influence the results or showed obvious alteration of mental status were excluded. Patients were monitored with an A-2000XP BIS® monitor (Aspect Medical Systems, Newton, MA) using a BIS-Sensor® (Aspect Medical Systems) placed according to the instructions of the manufacturer and an A53 Datex monitor (Datex—Engstrom, Helsinki, Finland) connected by an RS-232 interface to a personal computer using Rugloop II® software for data capture every 5 s. Rugloop II® was used to control via the RS-232 interface the remifentanil infusion pump (Asena Alaris TIVA; Alaris Medical Systems, San Diego, CA) and the propofol infusion pump (Asena Alaris GH, Alaris Medical Systems) using the pharmacokinetic—pharmacodynamic models of Minto et al.3 and Schnider et al.4 for remifentanil and propofol, respectively. Induction of anesthesia was performed with a propofol infusion (target-controlled infusion) with an initial effect site target of 5 μg/ml and a remifentanil infusion (target-controlled infusion) with an initial plasma target of 2.5 ng/ml. Loss of consciousness was defined as loss of eye opening in response to a tap on the forehead and calling the patient’s name. Rocuronium (10 mg/ml Esmeron®; Organon Portuguesa Lda., Lisboa, Portugal) was used for muscle relaxation. The drugs’ target concentrations were manually controlled by the anesthesiologist during the entire surgery.

Data distribution is expressed as mean ± SD. Statistical correlation analysis, linear regression, and the Student t test were performed using MATLAB 6.5.1 (The Mathworks Inc., Natick, MA). P < 0.05 was considered significant. Average BIS and median BIS during the maintenance phase were calculated retrospectively from the anesthetic record and related to the chronological order of the case. The anesthesiologist was blind to the objective of this study.

Forty-five patients met the selection criteria. Patients were aged 49.8 ± 16.5 yr, weighed 67.8 ± 13.4 kg, and were 160.5 ± 8.8 cm tall. Thirty-three were female. The case duration was 287.3 ± 161.6 min. During surgery, the average BIS value was 39.89 ± 4.04, and the median BIS value was 39.49 ± 4.1. The propofol average effect site and plasma concentrations were 3.01 ± 0.86 and 2.98 ± 0.84 μg/ml, respectively. The average propofol dose was 0.10 ± 0.03 mg · kg⁻¹ · min⁻¹. The total amount of propofol was 1,940 ± 24.2 mg. The remifentanil average effect site and plasma concentrations were 3.13 ± 0.89 and 3.15 ± 0.9 ng/ml, respectively. The average remifentanil dose was 0.11 ± 0.04 μg · kg⁻¹ · min⁻¹. The total amount of remifentanil was 2.093 ± 1.555 μg.

There were significant positive correlations between the chronological order of the case and average BIS (P = 0.0164) and the chronological order of the case and median BIS (P = 0.0148; fig. 1). The average effect site propofol concentration decreased significantly over time (P = 0.0094), as did the plasma propofol concentration (P = 0.0112). Figure 2 shows the relation between the average propofol dose during surgery and the chronological order of the case (P = 0.006). There was no significant correlation between the remifentanil dose or concentration and time.

Fig. 1. Linear regression between the median Bispectral Index (BIS) during surgery and the chronological order of the case. Statistical significant correlation (P = 0.0148) and positive slope (P < 0.05).

The possibility of observing the central nervous system response through BIS increased the anesthesiologist’s confidence in the level of depth of anesthesia (learning trend) and improved the clinical management. The increasing trend in BIS values with clinical practice was accompanied by a decreasing trend in propofol consumption. Anesthetic depth is often used as a tool to provide better control of hemodynamic variables.5 However, hemodynamic depression is one of the major factors associated with perioperative coma and death.6 A long duration of intraoperative systolic hypotension is also associated with increased risk of postoperative mortality.7 By controlling depth of anesthesia using BIS, one can more easily control the associated hemodynamic variability (e.g., using nonanesthetic drugs).

In our study, we observed that the regular use of BIS monitoring led to higher BIS values and, therefore, lower propofol consumption. This is in accord with the results of Guignard et al.8 who reported a reduced consumption of isoflurane when its titration was guided by BIS monitoring without higher incidence of light anesthesia.

In conclusion, the regular use of BIS monitoring by the anesthesiologist resulted in average higher BIS values. The increasing BIS trend with clinical practice also represented a trend toward safer BIS values (BIS between 45 and 60). This BIS trend was associated with a decrease over time of propofol average concentrations and consumption. Between the first and the last patients, there was an average decrease of 1.077 mg propofol per patient. The decrease in propofol consumption with time was a consequence of the experience with BIS monitoring acquired by the anesthesiologist (i.e., trying to avoid excessive anesthesia), with potential benefits to the patients.

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*Accepted for publication September 8, 2005*