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Title: Hypercapnic Hyperventilation to Accelerate Emergence from Inhaled Volatile Anesthetics: A Practical Method Using Standard Hospital Equipment

Authors and Affiliations:

Blaz Pecek¹, Lucas T. van Eijk², Jörgen Bruhn²

¹Department of Anesthesia, Izola General Hospital

²Department of Anesthesiology, Pain and Palliative Medicine, Radboud University Medical Center

Corresponding Authors:

Lucas T. van Eijk lucas.vaneijk@radboudumc.nl

Email Addresses for All Authors:

Blaz Pecek	blazpecek@gmail.com
Jorgen Bruhn	jorgen.bruhn@radboudumc.nl
Lucas T. van Eijk	lucas.vaneijk@radboudumc.nl

Author Questionnaire

1. We have marked your project as author-provided footage, meaning you film the video yourself and provide JoVE with the footage to edit. JoVE will not send the videographer. Please confirm that this is correct.

✓ Correct

2. Microscopy: Does your protocol require the use of a dissecting or stereomicroscope for performing a complex dissection, microinjection technique, or something similar? **No**

3. Software: Does the part of your protocol being filmed include step-by-step descriptions of software usage? **No**

4. Proposed filming date: To help JoVE process and publish your video in a timely manner, please indicate the proposed date that your group will film here: 07/06/2026

When you are ready to submit your video files, please contact our Content Manager, Utkarsh Khare.

Current Protocol Length

Number of Steps: 25

Number of Shots: 47

Interviews

Authors: Please note that **the questions will not appear on screen. Please answer in *stand-alone full sentence with sufficient context.***

We have chosen the 5 best answers

INTRODUCTION:

~~**REQUIRED:** Summarize your research focus and the main questions it aims to answer.~~

- 1.1. **Blaz Pecek:** Our research asks whether controlled hypercapnic hyperventilation can accelerate emergence from volatile anesthesia using only standard equipment available in the EU.

- 1.1.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera

~~**Describe the research gap or limitation in existing methods and how this protocol addresses them.**~~

- 1.2. **Blaz Pecek:** Commercial devices for this technique are scarce, so we recreated hypercapnic hyperventilation using equipment that every operating room already has.

- 1.2.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera

CONCLUSION:

~~**What does this protocol allow researchers to study or measure?**~~

- 1.3.. **Blaz Pecek:** This protocol lets researchers measure how controlled carbon-dioxide elevation and increased minute ventilation accelerate volatile anesthetic washout and shorten time to emergence.

- 1.3.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera

~~**Describe the most important consideration or challenge when performing this protocol.**~~

- 1.4. **Blaz Pecek:** The greatest challenge is keeping carbon dioxide within the target range and restoring the breathing circuit to normal.

- 1.4.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera

~~How can future studies build on this work? Describe the questions or research directions that can be investigated next.~~

- 1.5. **Blaz Pecek:** Future randomized trials should compare this technique against propofol-based anesthesia and define safe hypercapnia thresholds in larger, diverse populations.
- 1.5.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera

Title Card

No separate study-specific ethics approval was required, as the work did not involve any additional interventions beyond standard clinical care. The patient provided broad consent for the use of their anonymized medical data

Protocol

NOTE: APF timestamps are added as provided by the authors. The writer has not reviewed the footage for talent shots

2. Preparing the Anesthesia Circuit

Demonstrator: Blaz Pecek

- 2.1. To begin, turn off the volatile anesthetic vaporizer after elective surgery in a hemodynamically stable patient [1]. Ensure that no anesthetic agent is being delivered to the circuit [2].
 - 2.1.1. WIDE: Talent turning off the volatile anesthetic vaporizer connected to the patient. 2.1.1R.Mp4 00:00-00:20
 - 2.1.2. Talent pointing to and confirming that no anesthetic agent is being delivered to the circuit. 2.1.2R.Mp4 00:00-00:20
- 2.2. Set the inspired oxygen fraction to 1 by adjusting the machine's oxygen blender to deliver 100% oxygen [1].
 - 2.2.1. Talent adjusting the anesthesia machine oxygen blender to deliver 100% oxygen. 2.2.1R.Mp4 00:00-00:20
- 2.3. Reduce the fresh gas flow to approximately 0.2 liters per minute using the flow control knobs on the anesthesia machine and promote rebreathing within the circuit [1].
 - 2.3.1. Talent reducing the fresh gas flow to approximately 0.2 liters per minute using the flow control knobs. 2.3.1R.Mp4 00:02-0:22
- 2.4. Then, attach one active charcoal filter to the inspiratory limb, immediately distal to the Y-piece. Ensure the correct directional orientation according to the manufacturer's instructions [2].
 - 2.4.1. Talent attaching a single active charcoal filter to the inspiratory limb of the anesthesia circuit immediately distal to the Y-piece. 2.4.1R.mp4 00:01-00:21
- 2.5. Verify that the filter is securely connected without leaks and that it is correctly oriented for unidirectional gas flow [1].
 - 2.5.1. Talent checking the filter connection for an airtight seal. 2.5.1R.mp4 00:01-00:21

2.6. Refill the breathing circuit with 100% oxygen by flushing the oxygen button for 1 to 2 seconds in the event of an unwanted disconnection [1].

2.6.1. Talent refilling the breathing circuit by flushing the oxygen button for 1 to 2 seconds. 2.6.1.mp4 00:11-00:18 and 2.6.1 v1.mp4 01:00-01:11

NOTE: First 9 seconds is 100% o2 flush and next 11 s is showing bag refill

2.7. Detach the carbon dioxide-absorbing canister containing soda lime from the anesthesia machine to allow carbon dioxide accumulation within the breathing loop [1].

2.7.1. Talent disconnecting the carbon dioxide-absorbing canister containing soda lime from the anesthesia machine. 2.7.1R.mp4 00:01-00:21

2.8. Before and during hypercapnic hyperventilation, continuously monitor the inspired volatile anesthetic concentration [1].

2.8.1. Talent monitoring and pointing to the inspired volatile anesthetic concentration on the anesthesia machine display. hypercapnic hyperventilation_V4_ 2.8 and 2.9_3.1.2_3.2_3.3. mp4 07:05-07:25

2.9. Confirm that all circuit connections are airtight [1] and verify that the anesthesia machine displays the normal pressure and flow readings before proceeding [2].

2.9.1. Talent inspecting all circuit connections for airtight seals. 2.9.1R.mp4 00:01-00:21

2.9.2. Show the anesthesia machine display with the normal pressure and flow readings. hypercapnic hyperventilation_V4_ 2.8 and 2.9_3.1.2_3.2_3.3. mp4 07:31-07:51

3. Inducing Hypercapnic Hyperventilation

3.1. Set the mechanical ventilation to achieve controlled hypercapnia. The protocol can be applied in either mechanically ventilated patients or spontaneously breathing patients, depending on the intraoperative ventilation status at the end of surgery [1].

3.1.1. Talent setting the mechanical ventilation parameters to achieve controlled hypercapnia. 3.1.2R.mp4 00:01-00:21

- 3.2. Increase the tidal volume to 8 to 10 milliliters per kilogram of ideal body weight [1]. Then, adjust minute ventilation to 10 to 12 liters per minute [2].
 - 3.2.1. Talent increasing the tidal volume setting on the ventilator. 3.2.1R.mp4 00:01-00:14
 - 3.2.2. Talent adjusting the minute ventilation setting on the ventilator. 3.2.1R.mp4 00:14-00:28
- 3.3. Reduce the fresh gas flow as demonstrated earlier [1] and remove the carbon dioxide absorber to allow controlled accumulation [2]. Let the rising carbon dioxide levels stimulate the respiratory drive, resulting in a physiological increase in the minute ventilation without external ventilator adjustments [3].
 - 3.3.1. Talent reducing the fresh gas flow. 2.3.1R.Mp4 00:02-0:22
 - 3.3.2. Talent removing the carbon dioxide absorber. 2.7.1R.mp4 00:01-00:21
 - 3.3.3. Shot of the increasing respiratory activity associated with the rising carbon dioxide levels. 4.4.1Rv2.mp4 00:46-01:06
- 3.4. Continuously monitor the end-tidal carbon dioxide via capnography [1].
 - 3.4.1. Show the end-tidal carbon dioxide values on the capnography display. hypercapnic hyperventilation_V4_ 2.8 and 2.9_3.1.2_3.2_3.3. mp4 07:31-07:51
- 3.5. Next, increase the fresh gas flow in increments of approximately 0.1 to 0.3 liters per minute when the end-tidal carbon dioxide exceeds 52.5 to 55 millimeters of mercury [1]. Reassess the value within 1 to 2 minutes after each adjustment to evaluate the response [2].
 - 3.5.1. Talent increasing the fresh gas flow setting. 3.5.1R.mp4 00:00-00:20
 - 3.5.2. Talent pointing to the end-tidal carbon dioxide values after the adjustment. 4.4 and 4.31 and 4.5 and 3.5 and 3.6.mp4 04:43-05:03
- 3.6. Decrease the fresh gas flow to a minimum of approximately 0.2 liters per minute when the end-tidal carbon dioxide is below the target range. Avoid abrupt or large adjustments [1]. Maintain the fresh gas flow within a low-flow range of 0.2 to 1 liters per minute throughout the procedure, titrated according to continuous capnographic feedback [2].

- 3.6.1. Talent decreasing the fresh gas flow setting. 2.2.1R.Mp4 00:00-00:20
- 3.6.2. Show the display indicating maintained fresh gas flow settings while monitoring the capnographic feedback. hypercapnic hyperventilation_V4_ 2.8 and 2.9_3.1.2_3.2_3.3. mp4 08:30-08:50
- 3.7. Increase the fresh gas flow slightly from approximately 0.2 to 0.5 liters per minute once the target end-tidal carbon dioxide range is reached to stabilize the carbon dioxide levels [1].
 - 3.7.1. Talent increasing the fresh gas flow setting slightly to stabilize the carbon dioxide levels. 3.7.1R.mp4 00:01-00:21

4. Patient Monitoring and Recovery

- 4.1. Maintain the fraction of inspired oxygen at 0.7 to 1 during the entire procedure [1]. Monitor inspiratory and expiratory volatile anesthetic concentrations with a calibrated gas analyzer [2].
 - 4.1.1. Talent adjusting the fraction of inspired oxygen on the anesthesia system- 4.1.1R.mp4 00:11-00:31
 - 4.1.2. Talent checking and showing the inspiratory and expiratory volatile anesthetic concentrations on the calibrated gas analyzer. 4.2.2R.mp4 00:06-00:26
- 4.2. Observe the patient's hemodynamics, oxygenation, and ventilation parameters [1]. Continue monitoring until the inspired volatile anesthetic concentration decreases to zero [2].
 - 4.2.1. Show the patient's hemodynamics, oxygenation, and ventilation parameters. 4.2.1.mp4 03:01-03:21
 - 4.2.2. Show the inspired volatile anesthetic concentration until it reaches zero. 4.2.2R.mp4 01:12-01:32
- 4.3. Assess the return of spontaneous breathing [1]. Observe the clinical signs of emergence, including eye opening, purposeful movement, or response to verbal commands [2].
 - 4.3.1. Talent assessing the return of spontaneous breathing. 4.4 and 4.31 and 4.5 and 3.5 and 3.6.mp4 00:40-01:00
 - 4.3.2. Talent observing the clinical signs of emergence. 4.3 and 4.6.1 V2.mp4 00:41-01:01

4.4. Immediately terminate the hypercapnic hyperventilation by increasing the fresh gas flow to 10 liters per minute if oxygen saturation falls, hemodynamic instability occurs, or end-tidal carbon dioxide exceeds the limit despite corrective measures [1-TXT].

4.4.1. Talent increasing the fresh gas flow to 10 liters per minute to terminate the hypercapnic hyperventilation. TXT: $\text{SpO}_2 < 94\%$; $\text{EtCO}_2 > 8.5 \text{ kPa}$; 64 mmHg

First 5 s: 4.4.1Rv2.mp4 02:11-02:16

Second 10 s 4.4.1R.mp4 00:00-00:10

Third 5 seconds:4.4.1Rv2.mp4 02:45-02:50

4.5. Reinstall the carbon dioxide absorber [1] and return the fresh gas flow to the standard settings [2]. Resume the conventional ventilation parameters appropriate for the patient and anesthetic phase [3].

4.5.1. Talent reinstalling the carbon dioxide absorber. 4.5.1R.mp4 00:00-00:20

4.5.2. Talent returning the fresh gas flow to the standard settings. 4.5.2R.mp4 00:00-00:20

4.5.3. Talent adjusting the conventional ventilation parameters appropriate for the patient and anesthetic phase. 4.5.3R.mp4 00:00-00:20

4.6. Finally, proceed with extubation according to the standard institutional criteria [1].

4.6.1. Talent performing extubation after the patient demonstrates adequate conditions. 4.3 and 4.6.1 V2.mp4 00:41-01:01

5. Restoration of the Anesthesia Circuit

5.1. After completing the protocol, remove the active charcoal filter from the inspiratory limb before preparing the circuit for the next case [1]. Visually inspect the circuit and confirm that the filter has been removed [2] and the standard configuration has been restored [3].

5.1.1. Talent removing the active charcoal filter from the inspiratory limb. 4.6.2R.mp4 00:00-00:20

5.1.2. Talent inspecting the inspiratory limb to confirm the filter removal. 4.7.1R.mp4 00:00-00:20

5.1.3. Talent physically checking the circuit to confirm restoration of the standard configuration. 4.7.2R.mp4 00:00-00:20

5.2. Reconnect or reinstall the carbon dioxide absorber with soda lime before initiating anesthesia for the next case [1].

5.2.1. Talent reconnecting or reinstalling the carbon dioxide absorber with soda lime. 4.8.1R.mp4 00:00-00:20

5.3. Confirm normal carbon dioxide absorption [1] and stable baseline capnography before induction for the next case [2].

5.3.1. Talent checking the carbon dioxide absorber. 4.9.1R 00:00-00:20

5.3.2. Talent pointing to and verifying the stable baseline capnography before induction. 4.9.2 V2 00:00-00:20

Results

6. Results

6.1. Oxygenation remained stable throughout the protocol, with the fraction of inspired oxygen maintained around 0.7 [1] and oxygen saturation remaining at 100% [2].

6.1.1. LAB MEDIA: Table 1. *Video editor: Highlight the (FiO₂) column.*

6.1.2. LAB MEDIA: Table 1. *Video editor: Highlight the SpO₂ column.*

6.2. Hemodynamic safety was verified by a stable heart rate [1] and blood pressure throughout the maneuver [2].

6.2.1. LAB MEDIA: Table 1. *Video editor: Highlight the heart rate column.*

6.2.2. LAB MEDIA: Table 1. *Video editor: Highlight the blood pressure (RR MM/Hg) column.*

6.3. The patient spontaneously opened their eyes approximately 3.5 minutes after the initiation of hypercapnic hyperventilation and was extubated without complications [1].

6.3.1. LAB MEDIA: Table 1. *Video editor: Highlight the rows corresponding to t+3 and t+4 minutes .*

6.4. Representative recordings showed that end-tidal carbon dioxide increased progressively from 39 millimeters of mercury at the start of hypercapnic hyperventilation [1] to 54 millimeters of mercury after 5 minutes [2].

6.4.1. LAB MEDIA: Figure 3. *Video editor: Highlight the blue data point labeled 39 at time 0 minutes.*

6.4.2. LAB MEDIA: Figure 3. *Video editor: Highlight the blue data point labeled 54 at time +5 minutes.*

6.5. Expired sevoflurane concentration decreased from 0.9 volume percent before hypercapnic hyperventilation [1] to 0 volume percent within 3 minutes [2].

6.5.1. LAB MEDIA: Figure 3. *Video editor: Highlight the red data point labeled 0.9 before the start of the hypercapnic hyperventilation mark.*

6.5.2. LAB MEDIA: Figure 3. *Video editor: Highlight the red data point labeled 0.0 at t+3 min.*

6.6. Following carbon dioxide elevation, spontaneous breathing with tidal volume and respiratory rate within a physiological range was observed [1].

6.6.1. LAB MEDIA: Table 1. *Video editor: Highlight the rows t+3, t+4, t+5 in the RR column.*

1. Anesthesia
Pronunciation link: <https://www.merriam-webster.com/dictionary/anesthesia>
IPA: /ˌænəsˈθiːzə/, /ˌænəsˈθiːziə/
Phonetic Spelling: an·uhs·thee·zhuh, an·uhs·thee·zee·uh
2. Anesthetic
Pronunciation link: <https://www.merriam-webster.com/dictionary/anesthetic>
IPA: /ˌænəsˈθetɪk/
Phonetic Spelling: an·uhs·thet·ik
3. Vaporizer
Pronunciation link: <https://www.merriam-webster.com/dictionary/vaporizer>
IPA: /ˈveɪpəˌraɪzər/
Phonetic Spelling: vay·puh·ry·zer
4. Hemodynamically
Pronunciation link: No confirmed link found
IPA: /ˌhiːmɒdaiˈnæmɪkli/
Phonetic Spelling: hee·moh·dy·nam·ik·lee
5. Inspiratory
Pronunciation link: <https://www.merriam-webster.com/dictionary/inspiratory>
IPA: /ɪnˈspɑɪrəˌtɔːri/
Phonetic Spelling: in·spy·ruh·tor·ee
6. Distal
Pronunciation link: <https://www.merriam-webster.com/dictionary/distal>
IPA: /ˈdɪstəl/
Phonetic Spelling: dis·tuhl
7. Unidirectional
Pronunciation link: <https://www.merriam-webster.com/dictionary/unidirectional>
IPA: /ˌjuːnədəˈrɛkʃənəl/, /ˌjuːnədaɪˈrɛkʃənəl/
Phonetic Spelling: yoo·nuh·duh·rek·shuh·nuhl, yoo·nuh·dy·rek·shuh·nuhl
8. Hypercapnic
Pronunciation link: <https://www.merriam-webster.com/dictionary/hypercapnia>
IPA: /ˌhaɪpərˈkæpˈnɪk/
Phonetic Spelling: hy·per·kap·nik

9. Hyperventilation
 Pronunciation link: <https://www.merriam-webster.com/dictionary/hyperventilation>
 IPA: /ˌhaɪpərˌvɛntəˈleɪʃən/
 Phonetic Spelling: hy·per·ven·tuh·lay·shuhn
10. Capnography
 Pronunciation link: <https://www.merriam-webster.com/dictionary/capnography>
 IPA: /kæpˈnɑːɡrəfi/
 Phonetic Spelling: kap·nog·ruh·fee
11. Hemodynamics
 Pronunciation link: <https://www.merriam-webster.com/dictionary/hemodynamics>
 IPA: /hiːmɒdaɪˈnæmɪks/
 Phonetic Spelling: hee·moh·dy·nam·iks
12. Oxygenation
 Pronunciation link: <https://www.merriam-webster.com/dictionary/oxygenation>
 IPA: /ˌɑːksɪdʒəˈneɪʃən/
 Phonetic Spelling: ok·suh·juh·nay·shuhn
13. Ventilator
 Pronunciation link: <https://www.merriam-webster.com/dictionary/ventilator>
 IPA: /ˈven(t)əˌleɪtər/
 Phonetic Spelling: ven·tuh·lay·ter
14. Extubation
 Pronunciation link: <https://www.merriam-webster.com/dictionary/extubation>
 IPA: /ˌɛkstjuːˈbeɪʃən/
 Phonetic Spelling: eks·too·bay·shuhn
15. Capnographic
 Pronunciation link: No confirmed link found
 IPA: /kæpnəˈɡræfɪk/
 Phonetic Spelling: kap·nuh·graf·ik
16. Sevoflurane
 Pronunciation link: <https://www.merriam-webster.com/medical/sevoflurane>
 IPA: /ˌseʊʊˈflɔːrɪn/
 Phonetic Spelling: sev·oh·floor·ayn
17. Physiological
 Pronunciation link: <https://www.merriam-webster.com/dictionary/physiological>
 IPA: /ˌfɪziəˈlɑːdʒɪkəl/
 Phonetic Spelling: fiz·ee·uh·loj·i·kuhl
18. Emergence
 Pronunciation link: <https://www.merriam-webster.com/dictionary/emergence>
 IPA: /ɪˈmɜːdʒəns/
 Phonetic Spelling: ih·mur·juhns
19. Volatile
 Pronunciation link: <https://www.merriam-webster.com/dictionary/volatile>
 IPA: /ˈvɑːlətl/, /ˈvɑːləˌtaɪl/
 Phonetic Spelling: vol·uh·tl, vol·uh·tyl

20. Hemodynamic

Pronunciation link: <https://www.merriam-webster.com/dictionary/hemodynamic>

IPA: /ˌhiːmɒdaiˈnæmɪk/

Phonetic Spelling: hee·moh·dy·nam·ik