

Submission ID #: 69305

Scriptwriter Name: Poornima G

Project Page Link: <https://review.jove.com/account/file-uploader?src=21138073>

Title: Porcine Cardiac Arrest Model Using an Implantable Defibrillator

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Author Questionnaire

1. 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? **Yes, all done**

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: **02/04/2026**

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: 56 (23 SC)

Introduction

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

INTRODUCTION:

~~What is the scope of your research? What questions are you trying to answer?~~

- 1.1. **Erik Nielsen:** We aimed to establish a reproducible ventricular fibrillation-cardioversion model that enhances consistency and reduces animal use in resuscitation research.
 - 1.1.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera

~~What technologies are currently used to advance research in your field?~~

- 1.2. **Charlotte Ingul:** We use an implantable cardioverter-defibrillator to reliably induce ventricular fibrillation, perform cardioversion and record intracardiac electrocardiogram.
 - 1.2.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera

CONCLUSION:

~~What advantage does your protocol offer compared to other techniques?~~

- 1.3. **Knut Lappegård:** Compared to other methods, our approach achieved a 92% circulation restoration success with artefact-free rhythm monitoring during cardiopulmonary resuscitation.
 - 1.3.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera

~~What are the current experimental challenges?~~

- 1.4. **Knut Lappegård:** The main challenge is the need for specialized equipment and skilled operators for ICD implantation and programming.
 - 1.4.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera

~~How will your findings advance research in your field?~~

- 1.5. **Knut Lappegård**: Our model increases resuscitation success from ~50% to 90%, enabling repeated ventricular fibrillation-CPR-cardioversion cycles per animal and significantly reduces animal use.

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

Videographer: Obtain headshots for all authors available at the filming location.

Ethics Title Card

This research has been approved by the Norwegian Animal Research Authority

Protocol

NOTE: Show this as a title card slide against a plain background just before section 2's title and after the ethics card

Animal preparation:

- Obtain Norwegian Landrace pig (~56 days old)
- Maintain sedation with IV Ketamine or Thiopental
- Wash, shave and disinfect the neck, jaw, groin, and belly
- Attach ECG and pulse oximeter; confirm stable readings
- Start IV infusions (Thiopental; Midazolam + Morphine + Ringer's)
- Provide O₂, intubate under deep anesthesia and initiate controlled ventilation

2. Arterial Catheter and Central Venous Catheter (CVC) Placement

Demonstrators: Benjamin Storm, Bent Nielsen

2.1. After preparing the pig, turn the deeply anesthetized animal into a supine position [1-TXT] and fixate the limbs using a gauze bandage [2].

2.1.1. WIDE: Talent repositioning the pig into a supine position on the procedure table.
TXT: Deep anesthesia: Pentobarbital (200 - 300 mg IV) + O₂ (6 L/min)

2.1.2. Talent securing the pig's limbs with gauze bandages.

Author's NOTE: 2 alternatives were filmed for 2.1.1, 2.1.2, 2.2.1

2.2. Disinfect the neck, jaw, groin, and belly using chlorhexidine at a concentration of 5 milligrams per milliliter in ethanol [1] and cover the disinfected areas with sterile drapes [2].

2.2.1. Talent applying chlorhexidine solution to the neck, jaw, groin, and belly.

2.2.2. Talent placing sterile drapes over the disinfected regions.

2.3. Stretch a hind leg to extend the iliac artery [1]. Using ultrasound, locate the iliac artery [2] and insert a 5 French Pulse Index Continuous Cardiac Output arterial catheter using the Seldinger technique [3].

2.3.1. Talent extending and holding the hind leg to expose the iliac region.

2.3.2. Talent placing the ultrasound probe to identify the iliac artery.

2.3.3. Talent inserting the arterial catheter using the Seldinger technique under

ultrasound guidance.

- 2.4. Connect the arterial catheter to a prefilled pressure transducer and flush set [1]. After zeroing the transducer, confirm a good arterial pressure tracing and then release the hind leg [2].

2.4.1. Talent attaching the arterial catheter to the pressure transducer and flush system.

2.4.2. SCREEN: 2.4.2. SCREEN- Monitor showing a stable arterial pressure waveform. 00:07-00:18 *Video editor: Highlight the red tracing row and red values labeled ABP*

~~2.4.3. Talent releasing and repositioning the hind leg. TXT: Perform bladder catheterization HIND LEG RELEASE NOT FILMED.~~ **NOTE: not filmed, VO merged**

- 2.5. After tilting the pig into the Trendelenburg position, increase ventilator positive end-expiratory pressure to 10 centimeters of water to distend the neck veins [1].

~~2.5.1. Talent adjusting the table to place the pig in the Trendelenburg position~~ **NOTE: not filmed, VO merged**

2.5.2. Shot of the positive end-expiratory pressure being increased to 10 centimeter H₂O.

- 2.6. Using ultrasound, locate the right external jugular vein and insert a three-lumen central venous catheter using the Seldinger technique [1]. Verify venous backflow on all lumens and transfer sedation and fluid infusions to the central venous catheter [2]. Then, connect a pressure transducer to the third lumen and confirm a central venous pressure tracing [3].

2.6.1. Talent inserting the three-lumen central venous catheter using the Seldinger technique.

2.6.2. Talent reconnecting sedation and fluid infusion lines to the central venous catheter.

2.6.3. Talent attaching the pressure transducer to the third lumen of the catheter. **NOTE: Step 2.6 and 3.1 were shot together**

3. Vascular Introducer and Implantable Cardioverter-Defibrillator (ICD) Electrode Placement

Demonstrators: Benjamin Storm, Bent Nielsen, Knut Lappegård

- 3.1. After locating the right external jugular vein, insert a 7 French vascular introducer using the Seldinger technique [1]. Confirm venous backflow and flush the introducer with saline [2].
 - 3.1.1. Talent inserting the vascular introducer using the Seldinger technique.
 - 3.1.2. Talent flushing the introducer with saline.
- 3.2. Decrease ventilator positive end-expiratory pressure to 5 centimeters of water [1] and confirm introducer tip placement by transesophageal echocardiography or fluoroscopy [2].
 - 3.2.1. Ventilator interface showing positive end-expiratory pressure adjusted to 5 centimeter H2O.
 - 3.2.2. Talent showing the echocardiography monitor and pointing to the area to confirm tip placement.
- 3.3. Now, insert a single coil implantable cardioverter-defibrillator electrode through the vascular introducer and advance it into the apex of the right ventricle [1]. Connect the implantable cardioverter-defibrillator lead to a pacing system analyzer using the dedicated connector lead. Ensure that the Intracardiac R-waves are greater than 6 millivolts [2].
 - 3.3.1. Talent advancing the implantable cardioverter-defibrillator electrode through the introducer.
 - 3.3.2. Talent connecting the lead to the pacing system analyzer.
- ~~3.4. Then, expose the helix of the implantable cardioverter-defibrillator lead [1] and fasten the tip to the endocardium of the right ventricle at the apex or distal septum [2-TXT].~~
 - ~~3.4.1. Talent extending the helix mechanism of the lead.~~
 - ~~3.4.2. SCREEN: Imaging view showing the lead tip being fixed to the right ventricular endocardium. TXT: Confirm lead position: Pacing threshold: <2.5 V; 0.4 ms; Impedance: 500-1500 Ω for pacing and 50-100 Ω for shock coil~~
- 3.5. After confirming lead position, using diathermy, make a 4-centimeter horizontal skin incision below the left clavicle [1]. Using forceps and the fingers, create a small subcutaneous pocket large enough to contain the implantable cardioverter-defibrillator

[2].

3.5.1. Talent performing a horizontal skin incision with diathermy below the left clavicle.

3.5.2. Talent creating a subcutaneous pocket using forceps and fingers.

3.6. Connect the lead to the implantable cardioverter-defibrillator and insert the device into the subcutaneous pocket [1] and verify stable right ventricular lead position [2].

3.6.1. Talent connecting the lead to the implantable cardioverter-defibrillator header and placing the device into the subcutaneous pocket. **Author's NOTE: 3.6.1 is included in the attached clip "3.5 Implantation of ICD.mp4" time 1:35-1:58**

3.6.2. SCREEN: 3.6.2 ICD programmers module stable electrical parameters 00:00-00:10. *Video editor: Highlight the tracing in "RV unfiltered" row*

4. Pacemaker/Defibrillator Programming and Therapy Delivery

Demonstrator: Knut Lappegård

4.1. ~~Switch the pacing system analyzer from pacing system analyzer mode to programmer mode [1]. Using the supplied antenna, connect the implantable cardioverter-defibrillator to the programmer and confirm wireless telemetry~~ Program the pacing mode to desired settings after connecting the ICD to the programmer and review the R-wave, pacing threshold, and impedances [1].

4.1.1. ~~WIDE: Talent navigating the pacing system analyzer interface.~~ **NOTE: entire step not filmed, VO is completely changed based on screen recording**

4.1.2. SCREEN: 4.1.2 Intercardiac pacing and R wave threshold 00:06-00:17 *Video editor: Highlight the 4 boxes below 'R.Ventricle' in the middle of the screen and the box "additional parameters" on the right*

4.2. Then, program tachyarrhythmia therapy parameters to the desired values [1]. Now, on the programmer screen, select the **Test** icon and open the **Ventricular Fibber and NIPS** folder [2]. In the **Ventricular Fibber**, select **DC Fibber** at 7.5 volts for 2 seconds to enable ventricular fibrillation induction [3].

4.2.1. SCREEN: 4 2026-0325 Induction of VF and cardioversion - ICD programmer module 2.mov 00:00-00:04. *Video editor: Highlight "Tachy: 1 Zone Configuration" box*

4.2.2. SCREEN: 4 2026-0325 Induction of VF and cardioversion - ICD programmer

- module 2.mov 00:04-00:08. *Video editor: Highlight Ventricular Fibber and Ventricular NIPS.*
- 4.2.3. SCREEN: 4 2026-0325 Induction of VF and cardioversion - ICD programmer module 2.mov 00:08-00:10. *Video editor: Highlight DC Fibber and 2.0 Sec box towards DC fibber's right*
- 4.3. ~~When ventricular fibrillation is induced, select a therapy delivery option from the lower left corner of the screen [1].~~ When ventricular fibrillation is induced, use **Automatic** delivery to allow the device to deliver therapy according to programmed parameters [1].
- 4.3.1. SCREEN: 4 2026-0325 Induction of VF and cardioversion - ICD programmer module 2.mov 00:08-00:10. *Video editor: Highlight the entire box "device based testing"*
- 4.3.2. ~~SCREEN: Automatic therapy option selected. TXT: Choose Timed or Manual delivery as required~~
- 4.4. Induce ventricular tachycardia by selecting the **Ventricular NIPS** icon [1]. Choose the **Burst** icon and set the desired cycle length, such as 240 milliseconds [2], then press **Hold to Apply Burst** for up to 20 seconds [3].
- 4.4.1. SCREEN: 4 2026-0325 Induction of VF and cardioversion - ICD programmer module 7.mov 11:30-11:33.
- 4.4.2. SCREEN: 4 2026-0325 Induction of VF and cardioversion - ICD programmer module 7.mov 11:40-11:48.
- 4.4.3. SCREEN: 4 2026-0325 Induction of VF and cardioversion - ICD programmer module 7.mov. 20:35-20:42
- 4.5. If ventricular tachycardia or ventricular fibrillation is induced, deliver therapy according to the programmed settings in the **Tachy** folder [1]. Select the **Parameters** icon to review settings and ensure restoration of sinus rhythm [2].
- 4.5.1. SCREEN: 4 2026-0325 Induction of VF and cardioversion - ICD programmer module 2.mov" 01:23-01:30.
- 4.5.2. SCREEN: 4 2026-0325 Induction of VF and cardioversion - ICD programmer module 2.mov" 01:54-01:55, hold frame at 01:55 and highlight the entire configuration settings below the "tachy".

5. Establishing Non-Invasive Continuous Carotid Doppler Monitoring and Cardiac Arrest Studies

Demonstrators: Charlotte Ingul and Bjørn Faldaas

5.1. Monitor carotid flow using the intra-arterial pressure tracing from the left carotid artery [1] and supplement this, if available, with a non-invasive ultrasound-guided flow velocity measurement in the right carotid artery using a hands-free continuous Doppler [2].

5.1.1. Talent observing the monitor displaying the intra-arterial pressure tracing from the left carotid artery.

5.1.2. Talent positioning the hands-free Doppler system for continuous monitoring of the right carotid artery.

5.2. Attach the Doppler probe perpendicular to the left carotid artery [1] and apply generous amounts of ultrasound gel to ensure proper skin contact [2].

5.2.1. Talent positioning the Doppler probe perpendicular to the left carotid artery.

5.2.2. Close-up shot of ultrasound gel being applied to the skin under the probe.

5.3. Check the ultrasound monitor to confirm a good carotid flow trace [1] and then confirm the return of spontaneous circulation [2]. Next, fixate the probe thoroughly using adhesive tape [3]. Monitor the cardiac rhythm using the intracardiac electrocardiogram obtained from the pacemaker and the superficial electrocardiogram tracings displayed on the monitor [4].

5.3.1. SCREEN: 5.3.1 5.4.2 2025-0325 RescueDoppler carotid artery blood flow trace
Screen Recording 2026-03-25 095903 00:00-00:05 *Highlight the right panel tracing.*

5.3.2. SCREEN: 5.3.1 5.4.2 2025-0325 RescueDoppler carotid artery blood flow trace
Screen Recording 2026-03-25 095903 00:06-00:09

5.3.3. Talent securing the Doppler probe in place with adhesive tape.

5.3.4. Talent observing the pacing system and monitor simultaneously.

~~5.4. Confirm the return of spontaneous circulation using the invasive arterial pressure from the left carotid artery on the monitor [1] and the non-invasive ultrasound-guided flow velocity measurement in the right carotid artery [2].~~

~~5.4.1. SCREEN: monitor displaying invasive arterial pressure tracing.~~

~~5.4.2. SCREEN: Doppler display showing carotid flow velocity signal.~~ **NOTE: Merged**

with 5.3 as sufficient footage is not available

- 5.5. After inducing ventricular fibrillation or ventricular tachycardia, observe cessation of carotid flow on the Doppler trace and maintain the required no flow period [1]. Perform manual cardiopulmonary resuscitation, mechanical compressions, or other interventions as specified in the study protocol [2].
 - 5.5.1. SCREEN: 5.5.1 Doppler display showing loss of carotid flow signal and 5.6.3 Conversion to sinus rhythm 00:06-00:17.
 - 5.5.2. Talent performing cardiopulmonary resuscitation or initiating protocol-defined interventions.
- 5.6. When required, convert the pig to sinus rhythm by delivering a manual DC shock [1]. ~~Adjust the programmed energy level based on the size of the animal [2].~~
 - 5.6.1. SCREEN: 5.5.1 Doppler display showing loss of carotid flow signal and 5.6.3 Conversion to sinus rhythm 01:00-01:10
 - 5.6.2. ~~SCREEN: Delivery of a manual defibrillation shock through the device.~~
- 5.7. Terminate ventricular fibrillation within 120 seconds to ensure a high conversion rate [1]. If ventricular tachycardia is present, achieve conversion using anti-tachycardia pacing or synchronized cardioversion [2].
 - 5.7.1. SCREEN: 5.7.1 5.7.2 Anti-tachycardia pacing programming and delivery 00:03-00:05 AND 00:10-00:13.
 - 5.7.2. SCREEN: 5.7.1 5.7.2 Anti-tachycardia pacing programming and delivery 00:42-00:59.
- 5.8. Finally, allow the animal to rest and ensure normalization of physiological parameters, including blood pressure, end-tidal carbon dioxide, and pH [1].
 - 5.8.1. Talent monitoring the resting animal after intervention and looking at the screen to check physiological parameters.

Results

6. Results

6.1. Using the ventricular fibrillation fiber mode consistently induced ventricular fibrillation or ventricular tachycardia in all 11 animals and cardioverted all animals to sinus rhythm with return of spontaneous circulation [1].

6.1.1. LAB MEDIA: Table 1.

6.2. The average success rate for achieving return of spontaneous circulation after induced ventricular fibrillation was around 92 percent [1].

6.2.1. LAB MEDIA: Table 1. *Video editor: Highlight the “Arrhythmia conversion rate” column.*

6.3. On average, 18 arrhythmias, including ventricular fibrillation and ventricular tachycardia, were induced per animal using an implantable cardioverter-defibrillator [1].

6.3.1. LAB MEDIA: Table 1. *Video editor: Sequentially highlight the columns under the label “pacemaker induced arrhythmia” consisting “ventricular fibrillation” and “ventricular tachycardia”*

Sedation

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

IPA: /sɪˈdeɪʃən/

Phonetic Spelling: sih·day·shuhn

Ketamine

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

IPA: /ˈkɛtəˌmiːn/

Phonetic Spelling: keh·tuh·meen

Thiopental

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

IPA: /ˌθaɪoʊˈpɛntəl/

Phonetic Spelling: thye-oh-pen-tuhl

Intubate

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

IPA: /ˈɪntuːbeɪt/

Phonetic Spelling: in-too-bayt

Ventilation

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

IPA: /ˌvɛntəˈleɪʃən/

Phonetic Spelling: ven-tuh-lay-shuhn

Catheter

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

IPA: /ˈkæθətər/

Phonetic Spelling: kath-uh-ter

Supine

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

IPA: /ˈsuːpaɪn/

Phonetic Spelling: soo-pyne

Chlorhexidine

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

IPA: /ˌklɒːrˈhɛksɪdɪn/

Phonetic Spelling: klor·hek·suh·deen

Iliac

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

IPA: /ˈɪliæk/

Phonetic Spelling: il·ee·ak

Ultrasound

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

IPA: /ˈʌltrəˌsaʊnd/

Phonetic Spelling: uhl·truh·sownd

Seldinger

Pronunciation link: <https://www.howtopronounce.com/seldinger>

IPA: /ˈsɛldɪŋər/

Phonetic Spelling: sel·ding·er

Transducer

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

IPA: /trænzˈduːsər/

Phonetic Spelling: tranz·doo·ser

Trendelenburg

Pronunciation link: <https://www.merriam-webster.com/dictionary/Trendelenburg%20position>

IPA: /trɛnˈdɛlənˌbɜːɡ/

Phonetic Spelling: tren·del·uhn·burg

Jugular

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

IPA: /ˈdʒʌɡjələr/

Phonetic Spelling: jug·yuh·ler

Echocardiography

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

IPA: /ˌɛkəʊˌkɑːrdiˈɑːɡrəfi/

Phonetic Spelling: ek·oh·kar·dee·og·ruh·fee

Fluoroscopy

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

IPA: /ˌflʊrˈɑːskəpi/

Phonetic Spelling: floor·os·kuh·pee

Defibrillator

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

IPA: /diːˈfɪbrəˌleɪtər/

Phonetic Spelling: dee·fib·ruh·lay·ter

Intracardiac

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

IPA: /ˌɪntrəˈkɑːrdiæk/

Phonetic Spelling: in·truh·kar·dee·ak

Endocardium

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

IPA: /ˌɛndɒsˈkɑːrdiəm/

Phonetic Spelling: en·doh·kar·dee·uhm

Diathermy

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

IPA: /ˌdaɪəˈθɜːmi/

Phonetic Spelling: dye·uh·thur·mee

Subcutaneous

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

IPA: /ˌsʌbkjuːˈteɪniəs/

Phonetic Spelling: sub·kyoo·tay·nee·uhs

Tachyarrhythmia

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

IPA: /ˌtækiəˈrɪðmiə/

Phonetic Spelling: tak·ee·uh·rith·mee·uh

Ventricular

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

IPA: /ven'trɪkjələr/

Phonetic Spelling: ven·trik·yuh·ler

Fibrillation

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

IPA: /ˌfaɪbrəˈleɪʃən/

Phonetic Spelling: fye·bruh·lay·shuhn

Doppler

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

IPA: /ˈdɑːplər/

Phonetic Spelling: dop·ler

Carotid

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

IPA: /kəˈrɑːtɪd/

Phonetic Spelling: kuh·rot·id

Cardiopulmonary

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

IPA: /ˌkɑːrdioʊˈpʊlməˌnəri/

Phonetic Spelling: kar·dee·oh·pul·muh·nair·ee

Resuscitation

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

IPA: /rɪˌsʌsɪˈteɪʃən/

Phonetic Spelling: ree-suh-suh-tay-shuhn

Defibrillation

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

IPA: /diːˌfɪbrəˈleɪʃən/

Phonetic Spelling: dee-fib-ruh-lay-shuhn

Physiological

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

IPA: /ˌfɪziəˈlɑːdʒɪkəl/

Phonetic Spelling: fiz-ee-uh-loj-i-kuhl