Summary of P110042/S029 (180-Day PMA Supplement and Amendment 001)
Cameron Health, Inc.
Software Maintenance Release 8 for Subcutaneous Implantable Defibrillator (S-ICD) System

PURPOSE OF SUBMISSION

Cameron Health Inc., a subsidiary of Boston Scientific, is requesting approval for changes to the Q-TECH Programmer software and SQ-RX Pulse Generator firmware. Combined, these changes to the programmer software and pulse generator firmware make up Software Maintenance Release 8 (SMR 8).

Upgrades to the Q-TECH Programmer software include adding in-session system error notifications for the user, improving the PG battery gauge, increasing the number of stored sessions, and improving features related to the programmer's display, functionality, and printing outputs.

Upgrades to the SQ-RX Pulse Generator firmware include increasing the available program memory, prohibiting extended induction time, supporting the use of 2 channel MICS for Japan only, reducing the number of outlier time-to-therapy cases, and adding a new algorithm to detect instances of T-wave over-sensing that can impact the accuracy of heart rate determinations.

A pre-submission process was used to gain alignment on the testing strategy for this algorithm update during the development process. The final validation utilized the agreed upon testing strategy and is being presented in its final form in this document. As per Q131251 no additional clinical data or animal studies were required.

The changes described in this submission also include updates to the Q-TECH Programmer user manual and device labeling. The user manual updates are directly linked to the S-ICD System functionality improvements achieved by SMR 8.

The changes presented in this submission are intended to improve the usability and functionality of the S-ICD System. These changes are product enhancements. The overall safety and effectiveness of the S-ICD System is unchanged by SMR 8 and no new clinical trial data is required to support this submission.

REVIEW OF SUBMISSION

Device Descriptions-General

The S-ICD System is an entirely subcutaneous system. No aspect of the S-ICD System penetrates the venous system and no lead is implanted in (endocardially) or on (epicardially) the heart. The implant procedure may be performed with patients under general anesthesia or using local anesthesia and conscious sedation. The system is designed to be implanted using anatomical landmarks and without the need for fluoroscopy.

The S-ICD System is designed to continuously monitor cardiac electrical activity, detect life-threatening ventricular tachyarrhythmias, and automatically deliver defibrillation (shock) therapy as a means to terminate life-threatening tachyarrhythmias. When required, the S-ICD System is also capable of delivering post-shock bradycardia pacing in a demand mode for up to 30 seconds.

The electrode is comprised of a multi-lumen polymeric tubing through which multi-filars of metallic wire formed into a coil is inserted and includes a defibrillation coil electrode and proximal and distal sensing electrodes. The electrode is subcutaneously implanted from the pulse generator pocket along the rib margin to the sternum, and then along the left side of the sternum toward a distal termination. The proximal termination of the electrode comprises a multi-pole connector to plug into the header of the pulse generator. The header on the PG is designed to mate exclusively with the Q-TRAK Subcutaneous Electrode and also con-

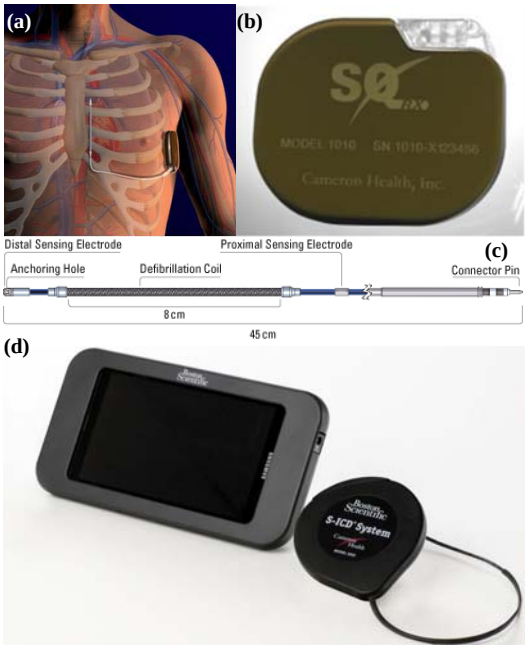

Figure 1: (a) Implant location of the SQ-RX S-ICD and Q-Trak Subcutaneous Electrode. (b) The SQ-RX 1010 IPG. (c) The Q-Trak Electrode. (d) Patient programmer with antenna.

tains the antenna used to facilitate RF telemetry communications with the Q-TECH Programmer. The programmer allows interrogation of various status metrics and control over pulse generator functions. Communication between the pulse generator and the programmer is accomplished through an RF telemetry wand. The radio link operates in the Medical Implant Communication Service band and is licensed under applicable FCC regulations. The programmer is capable of recognizing multiple pulse generators, but active communication is permitted with only one pulse generator at a time. For purposes of printing reports and other information, communication between the programmer and a printer is enabled based on a standard Bluetooth.

In summary the S-ICD System consists of the following devices and

1. SQ-RX Pulse Generator, Model 1010 (software modification)
2. Q-TRAK Subcutaneous Electrode, Model 3010 (not modified)
3. Q-GUIDE Electrode Insertion Tool (EIT), Model 4010 (not modified)
4. Q-TECH Programmer, Model 2020 or Model 3200 (Model 2020 is being replaced with the new Model 3200, Model 2020 Programmers will not be updated to SMR 8)

and accessories

- Programmer telemetry wand included with the Q-TECH Programmer Model 2020 package, and available separately as Model 4510. This wand model will only connect to the Model 2020 Programmer. (Not being updated to SMR 8 as they are being exchanged for new models)
- Programmer telemetry wand included with the Q-TECH Programmer Model 3200 package, and available separately as Model 3203. This wand model will only connect to the Model 3200 Programmer (software modification)
- Magnet, Model 4520 (not modified)
- Suture sleeve included in the Q-TRAK Subcutaneous Electrode package, and available separately as Oscor Model LS-21. (not modified)
- Torque wrench available separately as Model 6942; and included in the SQ-RX Pulse Generator package. (not modified)
- Pre-Operative Patient Screening ECG Tool, Model 4744 (not modified).

Device Descriptions-Over Sensing Algorithm Enhancement

Background

As with all ICDs cardiac over-sensing can elevate the calculated heart rate into a tachyarrhythmia rate zone that may lead to inappropriate shocks. Similar to the rates of inappropriate therapy for traditional ICD Systems, initial results from an S-ICD System registry (EFFORTLESS, n = 210) reported that inappropriate shocks occurred in 7% of patients. Further analysis of these events demonstrated that the majority were due to over-sensing (Lambiase et al. Heart Rhythm Society 2012). Similarly, the S-ICD Investigational Device Exemption (IDE) Study (IDE G090013) followed 314 patients implanted with the S-ICD System for a mean follow-up duration of 11 months. Recently published IDE study results (Weiss et al. Circulation 2013) showed that a total of 13.1% of patients received a shock for a non-VT/VF rhythm. As shown in Figure 2, the root causes for these shocks are classified in two categories: (1) SVT above discrimination zone (5.1%) and (2) Inappropriate sensing (8.0%).

Table 4. Adverse Clinical Events for Inappropriate Shocks by Cause

Cause	Clinical Events	Patients (% of 314)	Patients Managed Noninvasively
SVT above discrimination zone (normal device function)	21	16 (5.1)	12/16
Inappropriate sensing	30	25 (8.0)	20/25
Oversensing, cardiac	27	22 (7.0)	17/22
Oversensing, noncardiac	3	3 (1.0)	3/3
Discrimination errors	0	0 (0.0)	N/A
Total	51	41 (13.1)	32/41

N/A indicates not applicable; and SVT, supraventricular tachyarrhythmias.

Figure 2: Inappropriate therapy in the IDE Study (Weiss et al. 2013, Table 4).

- 'SVT above discrimination zone' describes events with heart rates within the Shock Zone of the device in which heart rate is the sole qualifier for shock delivery. Although these events are clinically inappropriate, in fact, these devices functioned normally as the shock was simply delivered in response to an accurate heart rate, per the current programming of the device. Activation of the optional Conditional Shock Zone allows for discrimination of SVT from VT/VF rhythms, and was the primary mitigation step used to prevent further shock therapy in this category. Additionally, in response to these findings, the nominal setting of the S-ICD System was updated in a prior software release to utilize a two-zone setting to further reduce this category of therapy for non-VT/VF rhythms.
- 'Inappropriate sensing' describes events that led to shock delivery as a result of a miscalculation of the actual heart rate. In general, over-sensing led to a device-measured heart rate that exceeded the actual heart rate of the

rhythm and, subsequently, shock therapy was delivered when the inaccurate heart rate entered the Shock Zone of the device.

The current S-ICD System includes three in-series algorithms that help to reduce over-sensing; (b)(4) TS/CCI provides more information about the current over-sensing algorithms. Once over-sensing is recognized by any of these algorithms, the system corrects for the extra detections and adjusts the resulting heart rate in order to more accurately reflect the true rate of the noted rhythm. Despite their utility, these three algorithms are not perfect in their ability to detect and correct for over-sensing. Dynamic and unpredictable changes in QRS and T-wave morphologies during elevated heart rates (which are not present at lower rates at implant or screening) can occasionally be a challenge to the current detection algorithms in the S-ICD System and were the primary cause of the inappropriate therapy for over-sensing noted in the IDE Study.

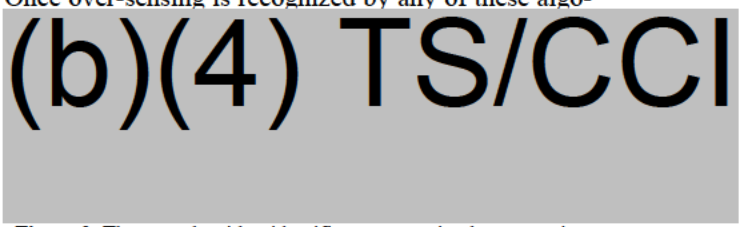

Figure 3: The new algorithm identifies over-sensing by comparing morphologies of three detected complexes and looks for similarity between alternating detections (green circles) with an intervening dissimilar detection (red circle).

The enhancement of the S-ICD System to improve the recognition of over-sensing included in SMR 8 is the addition of a fourth algorithm specifically designed to identify T-wave over-sensing. The current over-sensing algorithms, detailed in exhibit 2 of (b)(4) TS/CCI, utilize (1) morphology comparisons of the current detection to a stored template, (2) morphology comparisons of the current detection to the immediately preceding detection and (3) timing measurements between a series a detections, to recognize and correct for suspected over-sensing.

The new algorithm complements, but is different from, the current over-sensing morphology algorithms in that it does not depend upon a stored Normal Sinus Rhythm (NSR) template. This new algorithm utilizes the morphological relationship of alternating detections to identify when a T-wave over-sense occurs between two QRS complexes, thereby improving the S-ICD System's ability to accurately measure the heart rate.

The SMR 8 T-wave over-sensing identification method analyzes the last three detections and looks for relationships as shown in Figure 3. More specifically, a morphology assessment is used to identify when (b)(4) TS/CCI and the heart rate is adjusted in exactly the same manner as would occur for any of the other three double detection algorithms currently utilized by the S-ICD System.

The key advantage of the proposed algorithm is that it does not rely on a stored QRS morphology template; rather, the method can identify patterns among detected complexes with dynamically changing morphologies. These changes are often unpredictable, and present a challenge to the current over-sensing algorithms.

Currently, the three over-sensing identification algorithms are performed (b)(4) TS/CCI

The morphology assessment calculation used by the new algorithm, including the criteria for "similar" and "dissimilar", utilizes the same technique as currently implemented in the approved S-ICD System; (b)(4) TS/CCI This design enables the additional morphology assessment to be performed without changes to the existing hardware and algorithms. Furthermore, by placing the new calculation after the current series of over-sensing algorithms, it will only be invoked on an as-needed basis when the current algorithms fail to recognize the over-sensing.

NOT Changed- No review required

There are no changes associated with this software maintenance to the following aspects of the pulse generator or the Q-TECH Model 3200 programmer therefore no new testing / review was necessary.

- Electrical Design
- Mechanical Design
- Packaging and Environmental Design
- Biocompatibility
- Sterilization

Labeling Changes

- The updated Model 3200 Programmer User's Manual is based on the previous version of Programmer User's Manual, FDA approved in P110042/S009. **Table 10-1** provides a list of changes and rationale for the changes between the two manuals.
  Review: It was not clear if there is a patient / physicians manual or if there is only one manual that is the Programmer User's Manual. An e-mail exchange clarified that there is only one manual.

  Changes are due to typographical errors, trademark attribution statements, IEC 62366:2007, IEC 60601-1-2:200 and IEC 60601-1:2005+A1:2012(E) labeling requirements, more descriptive details as requested by Australian regulatory agency, description of existing functions (Volume Control), warnings (data loss may occur if a 45 minute period of inactivity occurs during active telemetry session and the programmer is not connected to AC power), updated screens to better represent what is seen by the user. Eight (8) of the 43 updates are significant user interface changes related to SMR 8 and are highlighted in light blue Table 10-1. The updates do not negatively impact safety, effectiveness or change indications for use. The changes are acceptable.
- *The Programmer box label is being updated to reflect changes to the FCC ID to add an additional ID number for Bluetooth (located in the lower left-hand corner of label.) The update does not negatively impact safety, effectiveness or changes the indications for use. The change is acceptable.*
- *The Programmer on-device label is being updated to reflect changes to the FCC/ IC (Industry Canada) information to add additional ID numbers for Bluetooth. The update does not negatively impact safety, effectiveness or changes the indications for use. The change is acceptable.*
- *A new on device label is being added to the case of the Model 3200 Programmer to identify the micro SD card port. This update is to comply with the IEC 60601-1 requirement to label ports. The Programmer User's Manual is also updating to reflect this change, see change 9 of Table 10-1. The update does not negatively impact safety, effectiveness or changes the indications for use. The change is acceptable.*
- *The micro SD card is used for technical support. This micro SD card, Model 3205 Log Data Card, may need to be supplied to the customer to be used under instructions from BSC Technical or Field Support to send data to BSC for further analysis. This card is labeled as Model 3205 Log Data Card; see Exhibit 10-2 for packaging labeling. Minimal information is printed on the card due to the small size of the micro SD card. The update does not negatively impact safety, effectiveness or changes the indications for use. The change is acceptable.*

Summary of Software / Firmware Changes

Table 2-1

#	Change	Description	Reason for Change	Effect of Change	Clinical Relevance
1	In-session system error notification (b)(4) TS/CCI	Currently system errors that occur during a session are not displayed to the user. With this change system errors that occur during a session will now be displayed to the user in that session (typically with a red warning screen). The new behavior is as follows: • The first, new in-session system error will always be displayed. • Additional in-session system errors will be displayed unless an ERI, EOL, or Charge Timeout was previously displayed, either at the start of the session (Integrity Test) or in-session. • Each and every queried system error that occurred insession will be printed with the Summary Report. • System errors are not cleared during the session. • The user is notified of in-session system errors upon transition to the Main Menu. • The System Error screen will display error text on a red back-ground. To reduce complexity, no errors codes will be displayed on the error screen.	Additional information for the user	User is notified of system errors that occur during a session.	No clinical relevance.
2	Prohibit extended induction time (b)(4) TS/CCI	Inductions are initiated by the programmer using the Induction command. The Induction Command will set up the temporary induction parameters and enable induction for 1 second. If the programmer does not send the "continue induction" command to the implanted PG within 1 second, the induction will terminate. The programmer will continue to send the continue induction command until the user releases the "Hold to Induce" button or the programmer maximum induction time expires (10 seconds). Currently, an induction timer limit is only contained within the programmer. This change within SMR 8 adds an additional maximum induction time out feature of 11 seconds in the PG firmware that will stop the induction even if the programmer application fails to enforce the maximum induction time. To facilitate the processing of this timeout, a new charge abort status code was added to the "ChargeAbort" marker to indicate the reason for the charge abort.	System robustness enhancement	If the programmer application fails to enforce the maximum induction time of 10 seconds the firmware will stop the induction after 11 seconds.	No clinical relevance.
3	Outlier time to therapy observed in stored episodes (b)(4) 4) (b)(4) T) TS/CC	The outlier time to therapy adjustment included in SMR 8 is intended to reduce the likelihood of outlier time to therapy events. With 839 induced VF events in the IDE study, the mean time to therapy was 14.6 ± 2.9 seconds, and 95% of induced VF events were treated in less than 21 seconds, with a maximum measured time to therapy of 29.7 seconds. Occasionally, due to highly varying signal amplitudes at the onset of shockable arrhythmias (e.g. VF/PVT), initial detection was slightly prolonged, leading to time to therapy measurements longer than 21 seconds. SMR 8 includes an update that reduces the potential for these longer times to therapy events by adding a (b)(4) TS/CC timer associated with the least sensitive detection profile. None of the detection profiles are changing, only the time at which the least sensitive profile is used The new (b)(4) TS/C s timer ensures that this detection profile is only used during the time in which T-waves can occur, and is not used during the transition to VF detection.	Apply more appropriate detection profile for a special class of arrhythmia	Reduction in outlier time to therapy events	Reduces the time to therapy in the presence of highly varying amplitude shockable arrhythmias (e.g. VF, PVT).
4	Battery gauge presentation (b)(4) TS (b)(4)(4) TS/CC	Currently the programmer displays the battery status on the screen as "Remaining Device Battery Life: x%" and on the report as "Battery Life Remaining: x%". In actuality, the battery life remaining is the percentage to Elective Replacement Indicator (ERI). The text of each label was updated to clearly indicate that the remaining battery percent corresponds to the percent of battery until ERI is reached. In addition, the battery life remaining graphic on the report was updated to more accurately reflect the actual battery life remaining.	The current display could be mistaken as remaining percentage to End of Life (EOL) and cause potential confusion in the field. This is a change in visual presentation only, no actual change to the battery status.	Updated the text and report graphic for the remaining battery life to clarify that it is time to ERI.	No clinical relevance.

5	Support different telemetry communication modes for different countries (b)(4) TS/CCI	SMR 8 supports both 2-channel MICS and 1-channel MICS telemetry modes. The 2-channel MICs mode is designed for certain geographies, e.g. Japan. The system (Programmer and PG) telemetry mode is controlled by certain controlling parameters set during manufacturing. For the geographies using 1-channel MICS mode, the system telemetry behavior remains the same as field with exception of one enhancement: the PG will stay in "fast" listening mode for 2 minutes instead of 1 minute after a telemetry session is ended or interrupted. This will enhance the system telemetry robustness as a PG in "fast" listening mode is easier to be found by the programmer.	Engineering efficiency	One source code base for all.	No clinical relevance.
6	Better sensing implementation to reduce inappropriate therapies caused by T-wave Oversensing (TWOS) (b)(4) TS/CCI	The currently approved S-ICD System includes three in-series algorithms that help to reduce over-sensing. Once over-sensing is recognized by any of these algorithms, the system corrects for the extra detections and adjusts the resulting heart rate in order to more accurately reflect the rate of the noted rhythm. A new algorithm is being added for T-wave over- detection in SMR 8: Alternating Correlation Waveform Appraisal Double Detection (ACWADD). ACWADD detects instances of T-wave over-sensing that are not detected by the current over-sensing algorithms. ACWADD does not depend upon a stored Normal Sinus Rhythm (NSR) template for recognition of over-sensing. Rather, the new algorithm utilizes the (b)(4) TS/CCI thereby improving the S-ICD System's ability to accurately measure the heart rate. If over-sensing is recognized, ACWADD corrects the heart rate using the same method as the currently approved over-sensing algorithms.	The addition of the ACWADD algorithm will reduce instances of T-wave over-sensing, thereby increasing the accuracy of heart rate calculation in the S-ICD system. ACWADD will not significantly increase the time-to-therapy for shockable rhythms.	Reduce the likelihood of the most common reason for inappropriate therapy: T-wave Over-sensing.	More accurate sensing with lower likelihood of inappropriate therapies
7	Save permanent programmable parameters in same FLASH sector as Static Template (b)(4) TS/CCI	Currently, when the permanent programmable parameters get corrupted due to cosmic rays or other reasons, the factory default values are loaded into the buffer. In this case, the system will display a red alert upon the next follow up and will ask the physician to re-program the pulse generator. With SMR 8, the system will maintain a second copy of permanent programmable parameters in FLASH and use it to restore the permanent programmable parameters when needed.	System robustness enhancement	When an error is detected in the permanent programmable parameters, they will be restored from FLASH instead of being set to the factory default values.	This helps mitigate the problem of inappropriate shocks or missing shock therapy in the event that the values programmed for the patient are different than the factory defaults.
8	Increase the size of memory allocated for firmware source code (b)(4) TS/CCI	SMR 8 re-organizes the FW memory allocation map freeing up unused memory to increase the size of firmware source code block	Purely engineering effort to facilitate development	More source code space for implant firmware.	No clinical relevance.
9	Expanded Episode printout option (b)(4) TS/CCI	The S-ICD device records up to 44 seconds of onset EGM data for a stored episode. In the currently approved S-ICD System, a printed Episode Report includes 12 seconds of stored episode onset EGM data; however, an Expanded Episode Report with 44 seconds of onset EGMs can be obtained only through Technical Services. SMR 8 modifies the programmer software to add an option to make these Expanded Episode Reports available.	Provides more printed episode onset data.	The user can print expanded (44 seconds) episode onset EGM data.	Allows greater view of the stored ECG at the onset of ventricular tachyarrhythmia.
10	Improve recovery mechanism from Single Event Upset events in programmer reserved memory (b)(4) TS/CCI	Currently, if the programmer reserved memory blocks get corrupted due to cosmic rays or other reasons, the information stored in this block such as patient name, physician note, etc. is lost. In this case, the system will display a red alert upon next follow up and ask physician to re-program. With SMR 8, the system will maintain a second copy programmer reserved memory and use it to restore the corrupted block of programmer reserved memory.	System robustness enhancement	Less likelihood of programmer reserved memory error which requires reprogramming of patient data.	User convenience enhancement. No clinical relevance.
11	Clarify "Post Shock Pacing" displayed in German or English (b)(4) TS/CCI	In the summary report, the expected German text for post shock pacing under device settings section is "Post Shock Pacing" (same text as in English). But the actual application displays it in German. The screen shows "Post Shock Pacing" in English, so the application will be updated to use the English text in the German report as well.	Consistency (DVT Observation)	Programmer text clean up	No clinical relevance.

12	Increase number of stored sessions on programmer (b)(4) TS/CC 002904	The Stored Patient Sessions feature allows the user to review and print the data from the last 15 connections to implanted S-ICD Systems. SMR 8 is increasing this capacity to a total of 50 stored sessions.	Enhancement: The 15 patient session limit was carried over from the legacy netbook programmer platform, but more stored sessions can be supported by the Android platform	The programmer will store up to 50 patient sessions.	No clinical relevance.
13	Avoid post-shock pacing sequence to restart with magnet application (b)(4) TS/CCI	In the currently approved S-ICD System, a magnet can be used to inhibit all therapy delivery (Shocks and Post- Shock Pacing) from the implanted PG. In a bench environment, it was found that a small timing window exists in which the application of a magnet could reinitiate the Post-Shock Pacing sequence. Although this observation has never been reported in the field with an implanted system, SMR 8 was updated to prevent this undesired outcome and ensures that any use of a magnet will inhibit Post-Shock Pacing, regardless of the timing of its application.	Robustness enhancement	No interference between magnet application and post shock pacing.	No clinical relevance. Robustness enhancement on a theoretical scenario.
14	Provide shortcut link from device status screen to the episode summary screen (b)(4) TS/CCI	Upon connection to an implanted S-ICD System during the follow-up care of a patient, the user is first presented with the Device Status screen which displays the current status of the implanted PG including the number, if any, of stored arrhythmia events that occurred since the last follow-up. If stored events have occurred, the most common next step is to review those episodes; however, the user must know how to navigate to the desired screen in order to download the stored event information. SMR 8 was updated to add a button to the Device Summary screen that allows the user to directly navigate to the required screen in order to streamline the follow-up process.	Ease of use	With one button push the user can get from the device status screen to the episode summary screen.	No clinical relevance.
15	Enhancement to Captured ECG Display by Numbering Captured S- ECG (b)(4) TST (b)(4) TS/CC	The currently approved S-ICD System allows the user to capture up to 15 snapshots of the streaming S-ECG for analysis or archiving purposes. Currently, the printed Captured S-ECG report provided detailed information regarding the sensing configuration that was activated at the time of the S-ECG capture; however, the programming screens itself lacked this information. On the programming screen, rather than simply listing the Captured S-ECGs from 1 – 15, SMR 8 will add the specific sensing configuration data to the title of each listing allowing the user to select the desired report with more ease. In addition, the time that the Captured S-ECG was created will be displayed with more detail. Currently, only the hour and minute are displayed; however, multiple Captured S-ECGs can be created within one minute. As such to improve usability, the Captured S-ECGs will be displayed with hours, minutes and seconds information. This change impacts the user interface display only	User interface enhancement	The Capture S-ECG name displayed is updated to include the Gain and Sensing Vector used during the S-ECG capture.	No clinical relevance.
16	Saving PDF reports to the micro SD card- (b)(4) TS/CCI	The programmer application is being updated to create a PDF report to save along with the existing session data. The PDF report will include the latest Device Summary Report, any Captured S-ECGs and Episode Reports for all episodes which were viewed during the session. These are not new reports, the change is only to have the reports saved to the Programmer, so that they can be later copied to the micro SD card through the pre-existing Copy Data mechanism.	Enhancement for electronic medical record keeping and technical service	The programmer will create and store a PDF report to the programmer.	No clinical relevance.
17	Saving discrete data values to the micro SD card (b)(4) TS/CCI	In order to enhance the customer experience and be able to improve integration with clinic/hospital EMR systems, the programmer will provide a means to save programmable parameters and diagnostic data in a format that could be used by EMR systems. This new data will be saved to the Programmer along with the existing session data, and cab be copied to the micro SD through the pre-existing Copy Data mechanism.	Enhancement for electronic medical record keeping and technical service	The programmer will save a list of parameters and diagnostic data in (b)(4) TS/CCI the programmer	No clinical relevance.

18	Single button to capture all ECGs (b)(4) TS/CCI	The currently approved S-ICD System included the Captured S-ECG feature to allow the user to store a 12- second snapshot of the streaming S-ECG. Upon selection of the Capture S-ECG button, the software captures ECG information only from the currently programmed sense vector. In order to capture ECG for the additional two sense vectors, the user must manually activate each vector and then utilize the Captured S-ECG feature for each. Care must be taken to not permanently activate one of the other sense vectors simply for the purpose of capturing the ECG. With SMR 8, the programmer screen adds a single button which initiates the automatic sequential collection of Captured S-ECGs from each of the three sense vectors. The programmer utilizes the temporary S-ICD sensing parameters to disable automatic therapy and select each sense vector in turn, allowing the S-ICD to revert to the programmed vector automatically after the data has been captured or in the event of telemetry loss.	Ease of use	The programmer added a single button which initiates the automatic sequential collection of 12 seconds of ECG data from each of the three sense vectors.	No clinical relevance.
19	Improved exception handling in programmer communication (b)(4) TS/CCI	This issue corrects a problem which causes the programmer to lock-up. The issue was observed when the Automatic Setup process was canceled. The root cause of the lock-up was found to be an exception occurring at the radio board layer before the Communication System layer sets up the command timeout timer. This caused the state machine at the Communication System layer to get stuck; causing the programmer to lock-up. This change only impacts the programmer application.	Prevent programmer from lock-up	When an exception occurs in the radio board, the programmer will not lock-up.	No clinical relevance.
20	Incomplete file copy from tablet programmer to micro SD card during Copy Data activity (b)(4) TS (b)(4) TS/CCI	Currently, a micro SD card can be used to transfer data from the Programmer to a computer for retention or troubleshooting purposes. Occasionally, the copy process from the Programmer to the SD card results in an incomplete transfer of data. SMR 8 was updated through optimizations to the file copying code in the launcher application to ensure complete file transfer.	Ease of use	The complete set of data files will be copied to the micro SD card during the Copy Data activity	No clinical relevance.
21	Marker alignment enhancement on Real-time S-ECG display on screen (b)(4) TS/CCI	Currently, live streaming S-ECG data from the implanted PG can be displayed on the Programmer screen. This data can also be captured via the Capture S-ECG feature. Occasionally, the displayed markers corresponding to the each QRS detection on the Programmer S-ECG display can be misaligned such that they appear slightly to one side of the actual QRS complex. When the Capture S-ECG feature was used to store and review the same ECG data, proper alignment was noted; the misalignment only occurred with the streaming ECG. SMR 8 corrects the observation such that the markers are properly aligned on the streaming ECG.	Corrected alignment of displayed marker information	The ECG and markers will be better aligned on the live S_ECG screen.	No clinical relevance.
22	Remove Cameron Health Address From Printed Report (b)(4) TS/CCI	The change is to remove the San Clemente address from the printed report. All SMR 8 labeling will point to 4100 Hamline Ave, but instead of changing the report footer to this new address, it will be removed all- together, leaving only the phone numbers.	Change of Legal Manufacture address to 4100 Hamline Ave St. Paul MN	Removed the San Clemente address from the printed reports.	No clinical relevance.
23	Ensure activation of device annunciator when the annunciator control parameter is corrupted. (b)(4) TS (b)(4) TS (b)(4	The S-ICD firmware checks programmable parameters for corruption periodically. Upon detection, the S-ICD will record the system alert, activate the annunciator, and display a red screen notification upon next follow- up. Through code inspection, it was found that if the exact memory that controls the annunciator was corrupted, the corruption would be properly detected, recorded and notified upon next follow up; however, the annunciator might not be activated. This is a theoretical issue and never observed in the field; however, SMR 8 ensures that the annunciator will be activated in the described scenario.	System robustness improvement	The device annunciator will always beep when a programmable parameter is corrupted.	Better patient management in a theoretical scenario
24	Printed reports are output in reverse order. (b)(4) TS/CCI	Currently, a requirement specifically describes the order of the printed pages for printed reports. As per requirement 2-016 (in (b)(4) TS/CCI (b)(4) TS/CCI), "Episode S-ECG's shall be printed by episode start time, in reverse chronological order, with the pages belonging to each episode report printed in order of last through first." In actuality, the application prints the episode ECG reports in order of reverse chronological order with pages first to last. The application is acceptable from a user perspective and, as such, this SCR will be implemented by modifying the requirement and test to match the current application behavior.	Application performance is acceptable from a user perspective; therefore the application will not be changed.	Document change only for Printed Reports	No clinical relevance.

25	Remove "+" sign from phone number in CHI-Launcher (b)(4) TS/CCI	The following three application screens show an unnecessary plus sign before the 1 800 number: Error, Log, and Halt; Software Update Invalid micro SD Card; Software Update Failure. In addition, these screens have spaces between each part of the phone number. This is a display and requirements mismatch, but the actual phone number is correct and clear to the user, so the requirements will be updated to reflect the application.	No change to the application as phone number is clear to the user. The "+" does not interfere with telephone number display.	Document change only	No clinical relevance.
26	Change capitalization of "sekunden" in German SmartCharge screen (b)(4) TS/CCI	Presently, the text expected in the German version of the Reset Smart Charge screen is "Sekunden", but the actual text is "sekunden". The difference is in the capitalization of the first word. The test case will be updated to match the implementation, which uses a lower-cased "s".	No change to the application. Capitalization does not impact the content of the message. German Language only.	Test change only	No clinical relevance.
27	Additional Time zones (b)(4) TS/CCI	To support the Programmer launch in to the Japanese market, two new time zones are required. These two new time zones will be added to the Programmer Settings selection list.	The proper display of date and time information for an implant requires the proper time zone to be selected.	Added two new time zones for user selection.	No clinical relevance.

The software changes were reviewed according to the "Guidance for Industry and FDA Staff -Guidance for the Content of Premarket Submissions for Software Contained in Medical Device, May 11 2005". The results of the review are summarized in the following table. Green indicates that the guidance was followed and the reviewer agrees with the firm, yellow indicates some deviation and potential need for additional information and red indicates missing information and a potential deficiency.

SOFTWARE DOCUMENTATION	MINOR CONCERN	MODERATE CONCERN	MAJOR CONCERN
Level of Concern	A statement indicating the Level of Concern and a description of the rationale for that level.		
Software Description	A summary overview of the features and software operating environment.		
Device Hazard Analysis	Tabular description of identified hardware and software hazards, including severity assessment and mitigations.		
Software Requirements Specification (SRS)	Summary of functional requirements from SRS.	The complete SRS document.	
Architecture Design Chart	No documentation is necessary in the submission.	Detailed depiction of functional units and software modules. May include state diagrams as well as flow charts.	
Software Design Specification (SDS)	No documentation is necessary in the submission.	Software design specification document.	
Traceability Analysis	Traceability among requirements, specifications, identified hazards and mitigations, and Verification and Validation testing.		
Software Development Environment Description	No documentation is necessary in the submission.	Summary of software life cycle development plan, including a summary of the configuration management and maintenance activities.	Summary of software life cycle development plan. Annotated list of control documents generated during development process. Include the configuration management and maintenance plan documents.
Verification and Validation Documentation	Software functional test plan, pass / fail criteria, and results.	Description of V&V activities at the unit, integration, and system level. System level test protocol, including pass/fail criteria, and tests results.	Description of V&V activities at the unit, integration, and system level. Unit, integration and system level test protocols, including pass/fail criteria, test report, summary, and tests results.
Revision Level History	Revision history log, including release version number and date.		
Unresolved Anomalies (Bugs or Defects)	No documentation is necessary in the submission.	List of remaining software anomalies, annotated with an explanation of the impact on safety or effectiveness, including operator usage and human factors.	

Level of Concern: The firm categorizes this as "Major Level of Concern" software based on the intended use of the software, i.e., delivery of ICD shocks when needed. Reviewer agrees with this classification.

Software Description: The firm provides an overall system description including the hardware in section 2.1.1 of the submission. Since the submission concerns a software maintenance release, a full description of each function of the software is not provided, however, this is not necessary since the user manual and combined with Table 2.1 (changes in software/firmware) provides an adequate description. The firm does however provide a detailed description of the additional Over Sensing Algorithm. This algorithm and its verification / validation will be discussed in more detail below.

Device Hazard Analysis: The firm provided various documents with regards to hazard levels and analysis. The summary document (b)(4) TS/CCI provides an acceptable overview of patient hazards, however, it might be helpful to create a hazard matrix based on the changes listed in table 2-1. In particular for changes that do have a clinical impact such a summary would be helpful. A couple of documents could not be found in the submission, (b)(4) TS/CCI and (b)(4) TS/CCI.

Software Requirement Specifications: The firm provided a detailed list of software requirement specifications that are impacted by the maintenance release. However, the reviewer was not able to find some of the documents listed in the trace matrices: (b)(4) TS/CCI (Boot Loader Software Requirements), (b)(4) TS/CCI (Algorithm System Requirements) and (b)(4) TS/CCI (E0 Manufacturing Test Requirements. In page 2 of Document (b)(4) TS/CCI (Summary of Pulse Generator Firmware Verification) the firm states "The features specified by (b)(4) TS/CCI Rev D, Algorithm Requirements Specification and (b)(4) TS/CCI Rev C, Software Requirements Specification for the S-ICD® Boot Loader Module (the requirement and the implementation) did not change in this SMR." This would be sufficient rationale; however, in the case of the Algorithm Requirement Specification it is not clear why the Specification should not change when a new over sensing algorithm has been introduced. The firm should provide these specifications if readily available.

Architecture Design Chart: The firm provided an architecture block for the Q-Tech 3200 programmer (see page 2-8 of the submission) but not for the PG. In an e-mail on June 02 the diagram was requested from the firm. It was received via email on June 05. The explanations provided in the email combined with the diagram were considered sufficient. So was the architecture block for the programmer.

Software Design Specification (SDS): The firm provided a list and the documents for the 12 specifications impacted by the software maintenance release. The documents were reviewed and found to be adequate.

Traceability Analysis: The firm provided three traceability documents: Android Programmer Software Requirements Trace Matrix (b)(4) TS/CCI contains the traceability matrices for the Programmer Software, Implant Software Requirements Trace Matrix (b)(4) TS/CCI contains the traceability matrices for the PG Firmware and System Design Requirement Trace Matrix (b)(4) TS/CCI contains the traceability matrices for the System. The traceability matrices are complete and acceptable.

Software Development Environment Description: The firm provided an overview of the Software Development Process on page 2.6 and 2.7 of the submission. The overview is acceptable.

Revision Level History: The firm provided a list of software changes (Table 2.1 of the submission) and indicated the revision levels for both the programmer and PG software in section 2.3.1 of the submission.

- *The programmer SW is being updated from v2.00.03 to v2.02.01.*
- *The pulse generator FW is being updated from v2.5.366 to v2.7.422.*

The table provided a detailed discussion of changes, impact on clinical outcome, etc. and was found to acceptable.

Unresolved Anomalies (Bugs or Defects): The firm indicates in section 5.5 that there are no known unresolved anomalies. None were noted in the review of the submitted verification and validation documentation.

Verification and Validation Documentation: Design validation testing was done to demonstrate that the S-ICD System continues to conform to user needs and intended use with SMR 8. Design verification/validation testing included:

- *Ripple Effects Analyses*
- *Unit Testing*
- *System Design Analysis Tests (DAT) and Design Verification Testing (DVT)*
- *Simulated Use Tests*
- *Programmer Software DAT and DVT*
- *PG Firmware DAT and DVT*
- *Detection Algorithm re-validation*

- *Over-sensing Algorithm Enhancement Validation*
- *S-ICD System Risk Analysis*

The company indicated that testing demonstrated that the S-ICD System, including the SMR 8 software and firmware upgrades, continues to meet intended uses and all system requirements. The relationship between the design requirements and supporting testing and subsystem requirements are captured in the trace matrices Android Programmer Software Requirements Trace Matrix (b)(4) TS/CCI), Implant Software Requirements Trace Matrix (b)(4) TS/CCI and System Design Requirement Trace Matrix (b)(4) TS/CCI Testing was naturally divided into these three categories: Programmer, IPG firmware and System, i.e., testing capturing the interaction between the programmer and the IPG. The following is of submitted and reviewed documents capturing the analysis and testing performed as a result of the software maintenance release changes:

Title, Document #, Revision
System Ripple Effects Analysis Report for SMR 8 (b)(4) TS/CCI
Programmer REA Report for SMR 8 (b)(4) TS/CCI
Firmware REA for SMR 8 Report (b)(4) TS/CCI
System Ripple Effects Analysis Report for SMR 8 (b)(4) TS/CCI
Programmer REA Report for SMR 8 (b)(4) TS/CCI
Ripple Effect Analysis Report for Implant Software – (b)(4) TS/CCI
Android Programmer Test Coverage Matrix, (b)(4) TS/CCI
Unit Test Summary Report (b)(4) TS/CCI
Android Programmer software Design Analysis Test: Episode Parser (b)(4) TS/CCI
Programmer Software Verification Summary Report, (b)(4) TS/CCI
SMR 8 Implant Firmware Unit Test Report for 2.7.422, (b)(4) TS/CCI
SMR 8 Implant FW Analysis Report Summary, (b)(4) TS/CCI
Summary of Pulse Generator Firmware Verification, (b)(4) TS/CCI
Algorithm Development and Validation Data Summary Report, (b)(4) TS/CCI
Over-sensing Algorithm Enhancement – Algorithm Development and Validation Summary Report, (b)(4) TS/CCI
DAT Report – SMR 8 System (b)(4) TS/CCI
SMR 8 Telemetry DAT Report (b)(4) TS/CCI
SMR 8 System Integration (DAT) Manual Test (b)(4) TS/CCI
System Design Verification Test Protocol (b)(4) TS/CCI
System Design Verification Test Report (b)(4) TS/CCI
Protocol – FCE Simulated Use Testing (b)(4) TS/CCI
Summary Report, SMR 8 Simulated Use Testing (b)(4) TS/CCI
S-ICD System Risk Management Plan (b)(4) TS/CCI
S-ICD Risk Management Report, (b)(4) TS/CCI
Programmer Model 3200 Risk Management Report, (b)(4) TS/CCI

The reviewer agrees with the firm that the submitted documents show that the system continues to meet intended uses and all system requirements, however, the SCR requirements as shown in table 2.1 where not consistently traceable to verification or validation test. Specifically, the reviewer had a difficult time to find testing for (b)(4) TS/CCI Outlier time to therapy) and (b)(4) TS/CCI (Save permanent programmable parameters in same FLASH….). A very brief discussion for (b)(4) TS/CCI is provided in (b)(4) TS/CCI but no data could be found in the submission. In addition, questions arose in the review of (b)(4) TS/CCI SMR 8 – S-ICD Over-sensing Algorithm Enhancement – Algorithm Development and Validation Summary Report). Specifically, on page 18 it is stated that the "two conditions were evaluated at the nominal S-ICD programmable parameter setting: Nominal Setting…). In an e-mail the firm was asked if this testing was also performed at other Conditional Shock and Shock Zone Setting. The firms email response indicates that safety testing was performed at the 170 BPM Conditional Shock setting and a 250 BPM Shock Zone Setting (b)(4) TS/CCI) and there is no impact by the new algorithm to detect VT/VF rhythms.

The reviewer agrees that based on testing presented, there is no impact (degradation) of the system to detect VT/VF and to deliver therapy when required. However, the benefit of the new algorithm was evaluated only at the 200/220 BPM setting. The rationale for the nominal settings, i.e., why 200/220 BPM are nominal settings was provided via a publication reference. The claimed benefit of the new Over Sensing algorithm therefore has been shown for the nominal settings but not for other, corner, settings. It is not clear if the tests were performed and if the benefit would be as substantial in these corner cases. There is some concern that over sensing and therefore inappropriate shock, are reduced over a small (nominal) parameter space but potentially worsened for other parameter settings.

QUESTIONS TO BE ADDRESSED INTERACTIVELY

The questions (deficiencies) raised during the review of the submission can in the opinion of the reviewer be resolved interactively.

1. *You provided a substantial set of documentation in the area of requirement specifications, trace-matrices, software development environment, etc. The documents listed below were referenced in your submission but the reviewer was not able to locate them:*
   - (b)(4) TS/CCI *(Android Programmer Risk Analysis)*
   - (b)(4) TS/CCI *(Android Programmer Fault Tree Analysis)*
   - (b)(4) TS/CCI *4(Software Requirements for the S-ICD Boot Loader module)*
   - (b)(4) TS/CCI *1(Algorithm System Requirements)*
   - (b)(4) TS/CCI *4(E0 Manufacturing Test Requirements*

   Please provide these documents to assist the safety / effectiveness evaluation of your submission. Please also provide clarification as to where the test data for (b)(4) TS/CCI *(Outlier time to therapy) and* (b)(4) TS/CCI *(Save permanent programmable parameters in same FLASH….) are located.*
2. *On page 19 of* (b)(4) TS/CCI *you indicate a reduction in the inappropriate shock rate as a result of the introduction of your new Over Sensing Algorithm. From page 18 of the same document it would appear that these results were obtained for the Nominal Settings mention on this page. FDA is concerned that even though the inappropriate shock rate is reduced under nominal settings the rate could increase for a different combination of parameters, i.e., Conditional Shock and Shock zone settings. Please provide test results or a rationale why this is not the case.*

REVIEW OF ANSWERS PROVIDED TO INTERACTIVE QUESTIONS

As a response to question 1the firm provided the documents asked for as well as pointed out where to locate (b)(4) TS/C (b)(4) TS/CCI *and* (b)(4) TS/CCI *In addition, the firm provided lower level reports*

(b)(4) TS/CCI *; Implant SW DVT Beat Detection Test Report*

(b)(4) TS/CCI *; Implant SW DVT Beat Detection 2 Test Report*

providing additional information to SCR 002927 and

(b)(4) TS/CCI *; Implant SW DVT Therapy Automated Test Report*

(b)(4) TS/CCI *; Implant SW DVT Magnet Test Report*

(b)(4) TS/CCI *; Implant SW DVT Programmable Parameters Test Report*

(b)(4) TS/CCI *; Implant SW DVT System Functions Automated Test Report*

(b)(4) TS/CCI *; Implant SW DVT Scheduled Tests Automated Test Report*

supplementing (b)(4) TS/CCI*. After reviewing the reports, no further questions have been raised and question 1 has been addressed sufficiently.*

In response to question 2, the firm indicated that "It is important to understand that all of the over-sensing algorithms, including the new algorithm within SMR 8, operate independently of the actual programmed zone settings. The heart rate calculations, and subsequent corrections by the over-sensing algorithms, are performed before any therapy decision is evaluated. In other words, these over-sensing algorithms are not activated specifically within particular therapy zones, rather, they operate first. As such, the outcome of the over-sensing algorithms cannot increase the degree of over-sensing or inappropriate therapy; they all work to incrementally reduce that risk. In addi-

tion, the new over-sensing algorithm within SMR 8 was intentionally added last "in series" to the three existing over-sensing algorithms such that it cannot supersede their current (already approved) decision-making process. Thus, the worst case scenario is that the new algorithm will have no effect on the existing overall performance."

Furthermore, the firm stated "Additionally, during our algorithm validation, we also tested the new over-sensing algorithm by using the same zone settings that were in use at the time of the actual patient episodes. The distributions shown in Figure 1 and Figure 2 demonstrate the wide array of zone settings and the number of patients evaluated at each zone setting combination respectively.

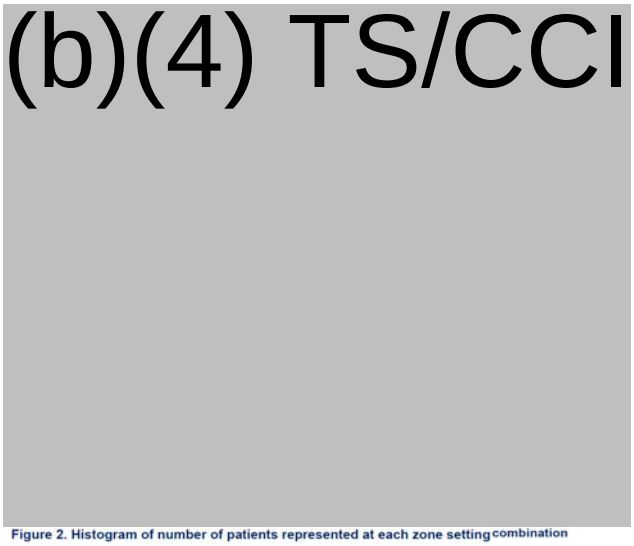

Figure 2. Histogram of number of patients represented at each zone setting combination

The results of the analysis done with these individualized zone settings demonstrate a similar reduction in inappropriate therapy as compared to the nominal dual-zone settings. With or without a template, the results exhibited a mean reduction in inappropriate events of 37.2% and 26.6%, respectively. Thus, the relative improvement with the new algorithm is slightly more muted than the nominal dual-zone results; however, importantly, the inappropriate therapy rate is still diminished, and does not increase with the wide variety of therapy zone settings."

The response to question 2 was adequate and there are no addition concerns.

DEFICIENCIES AND QUESTIONS

None.

OTHER

OAI Firm & Corporate-wide Warning List was checked on March 21, 2014 and the document was found to be clear. A subsequent check on August 18, 2014 gave the same result.