Management of device-related wound complications in deep brain stimulation surgery

Clinical article

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Object. Wound complications are uncommon following deep brain stimulation (DBS) surgery. However, certain key technical steps can be performed in each procedure to minimize this still troublesome risk. The authors reviewed the incidence and management of all hardware-related wound dehiscences and infections in a large patient series.

Methods. All patients undergoing new DBS hardware implantation surgery between 2002 and 2010 by a single surgeon (R.K.S.) were entered into a database after undergoing verification by cross-referencing manufacturer implantation records. All hardware-related complications such as wound dehiscence, erosions, and/or infections were identified, and wound location, time of incidence, and mechanism were categorized. Charts were reviewed to evaluate the success of conservative treatment versus partial or total hardware removal.

Results. Seven hundred twenty-eight patients received 1333 new DBS leads and 1218 new implantable pulse generators (IPGs) in a total of 1356 stereotactic procedures for movement disorders. Seventy-eight percent of patients underwent staged lead and IPG implantations. Sixteen patients presented with atraumatic device-related infection and/or dehiscence within 12 months from original implantation; 9 of these patients (1.24%) required additional surgery after antibiotic failure. All 8 patients presenting with cranial wound complications were treated initially by debridement in an attempt to salvage the leads; debridement followed by intravenous antibiotics was only successful in 2 patients presenting with dehiscence alone. One of 2 lead-only removals was successful in infections originating in the cranium; the only IPG-originating infection was treated by partial hardware removal and intravenous antibiotics. Two of 637 IPG replacements resulted in infections within 12 months after revision, requiring either partial or total hardware removal, while 1 dehiscence in this group was treated by debridement alone.

Conclusions. In a large series of new DBS hardware implantations, the incidence of postoperative wound dehiscence and/or infections requiring further surgery was 1.24%. Standard practice for all implantations was a short procedural duration, copious povidone-iodine irrigation, and postoperative antibiotic administration. Partial hardware removal should be initially attempted for infection. Debridement alone is successful in treating dehiscence without infection.

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KEY WORDS • deep brain stimulation • wound complication • infection • prevention • dehiscence • functional neurosurgery

Over the past 20 years DBS has become a widely recognized technique for reversible modulation of brain function that is adjunctive to medical management of movement disorders. The therapeutic effects of DBS are clearly evident and applications of this technique for a larger spectrum of diseases are growing. As this technique evolves, wound complications (including infection) related to the implanted hardware will inevitably arise and need to be treated. The risk of infectious complications from DBS is reviewed in a number of reports in the literature, and varies from 0% to more than 15% per patient.1-6,9,13,15,17,18,21-24,26,27,31,33,36-38 However, interpretation of these rates is difficult because the definition of infection is variable and is further complicated by low series volume, restricted perioperative analysis, and limited discussion of cranial wound management. Few reports detail the comprehensive incidence and management of all postoperative wound complications that are self-limited, in addition to those requiring a return to surgery,26 without excluding noninfectious wound dehiscences and/or erosions over a long follow-up period.26,38 Given that the number of DBS hardware implants will continue to increase and new applications for this procedure appear on the horizon, we must determine how to prevent as well as manage such complications, if and when they arise, in the most expeditious way possible.

In this study we evaluated the incidence and management of peri- and postoperative wound complications related to DBS hardware implantation, including infection,
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wound dehiscence, and/or erosion in a large series of consecutive patients treated by 1 primary surgeon (R.K.S.). We offer our preventative surgical regimen as well as a management strategy for device-related complications arising at all incisions, designed to spare complete hardware removal when possible, and to maximize the treatment benefit for the patient.

Methods

Study Criteria

All patients undergoing new DBS implantation surgery between January 2002 and December 2010 were entered into a database. These patients were identified based on consecutive operative reports of 1 primary surgeon (R.K.S.) operating at multiple campuses in Houston, Texas; procedures were performed at The Methodist Hospital, Saint Luke’s Episcopal Hospital, and Memorial Hermann Hospital. The database was cross-checked with the manufacturers’ records of hardware implantations performed at the participating institutions for data verification. Implantations of DBS devices were primarily Medtronic implants, with a few investigational device implants (Libra DBS System, St. Jude Medical Neuromodulation). For retrospective analysis, the study period was determined to allow a minimum follow-up of 6 months.

Prior to beginning this research endeavor, institutional review board approval was sought and granted at each institution for this retrospective chart review. The charts of the patients identified in this database were analyzed for the occurrence of peri- and postoperative wound complications, including infections both self-limited by antibiotics alone and those requiring a return to surgery for management. Perioperative infections were defined as those occurring spontaneously within 12 months of an original implantation (nonreplacement), without a direct trauma causation. Superficial wound infections were defined as induration, redness, or persistent crusting directly over a hardware component; clinical evidence of device involvement was assumed if there was cellulitis or purulent drainage emanating from an incision over a device implant. The latter infections requiring surgical revision did involve obtaining intraoperative microbiological cultures from the hardware or from fluid in contact with hardware. Implantable pulse generator replacement procedures were identified within this database and the incidences of complications arising from them were documented separately. All wound dehiscences, device erosions, and delayed infections occurring at different time points postoperatively within the 9 years of the study, either spontaneously or trauma induced, arising from the original implantation or following a replacement procedure, were identified and cataloged individually. The charts of patients with wound complications, either self-limited or requiring a return to surgery, were reviewed to assess the success of antibiotics alone, debridement alone, or partial hardware removal.

Surgical Techniques

All patients underwent either stereotactic MRI, or preoperative MRI that was integrated into a cranial CT-based 3D stereotactic coordinate system by landmark-based image fusion. The difference in MRI technique used was based on availability and the standard protocol established at each institution. In all procedures, the Leksell series G (Elekta) frame was used. Targeting of the various structures was usually indirect and then modified based on the patient’s anatomy, as has been detailed elsewhere.16

Implantation of leads was often performed during the same procedural time as placement of the lead extensions and IPG early in the series, but by 2004 these largely became staged procedures. Stage 1 was usually performed under local anesthesia for lead placement and Stage 2 under general anesthesia for lead extenders and IPG placement.

Cefazolin (or vancomycin, if the patient had a penicillin allergy) was administered before surgery. Oral cepalexin (or ciprofloxacin/clindamycin if the patient had a penicillin allergy) was routinely administered to all patients for 7 days after the procedure as prophylactic therapy. Depending on the procedure, the entire scalp or the neck, chest, and/or abdomen were clipped of hair, degreased, and then prepared with 2% chlorhexidine gluconate and 70% isopropyl alcohol (ChloraPrep; Enturia, Inc.).

Stage 1. For Stage 1 procedures, a slightly curved frontal incision is placed at or near the coronal suture to allow access to bilateral bur holes, which are placed posterior to the incision. A 3-cm parietal incision is made in a curvilinear fashion as the access point for the future Stage 2 extension placement procedure, perpendicular to the direction of the lead. Low-profile bur hole ring and cap systems provided by the manufacturer are placed to secure the lead, and redundant lead wiring is coiled in a subgaleal fashion. Grooves are made with a bur in the parietal bone to recess the future extension connections; the proximal part of the lead is coiled at this location for future access. Microelectrode recording is routinely performed for all targets except for the ventral intermediate nucleus of the thalamus, where the Leksell insertion kit (Elekta) is used instead of microelectrode recording at The Methodist Hospital and Saint Luke’s Episcopal Hospital. At all operative locations, intraoperative test stimulation is performed to verify target accuracy and lack of sustained side effects.

Stage 2. Stage 2 procedures involve reopening the parietal incision to externalize the leads and tunneling lead extensions to a 5-cm linear subclavicular and/or subcostal incision, which lies superior to the newly created subcutaneous pocket for the IPG. All incisions are closed with 3-0 resorbable sutures in either the galea or deep subcutaneous tissue, followed by either skin staples or 3-0 running monofilament nylon. Prior to closure in both Stage 1 and 2, irrigation with povidone-iodine solution diluted to near 1% concentration is performed at each incision.

Statistical Analysis

All statistical analyses were performed using standard statistical software (SPSS, version 17.0). Risk factors
for the occurrence of infection, such as age, diagnosis, date of surgery, and institution, were analyzed using multivariate logistic regression. The Student t-test with equal variances was used to compare the following variables between the set of patients requiring return to surgery and those with self-limited infections: age, diagnosis, and time postsurgery until presentation of spontaneous wound infection. Initial antibiotic choice was compared between the 2 groups as well using the Fisher exact test.

**Results**

**Patient Characteristics**

Seven hundred twenty-eight patients received 1333 new DBS leads and 1218 new IPGs in a total of 1356 stereotactic procedures. In this same population, there were 32 lead revisions and/or replacements and 637 IPG replacement procedures performed during this time period.

In this series, 452 patients with PD received DBS implantation, as well as 144 patients with ET and 64 patients with dystonia. Details regarding patient diagnoses, targets of implantation, and surgical staging are shown in Table 1. Of the newly implanted leads, 1312 were Medtronic model 3387, and 21 were St. Jude Medical Libra. Of the newly implanted pulse generators, there were 1116 Soletra, 56 Kinetra, 14 Activa PC, and 11 Activa RC, with 21 Libra from St. Jude Medical. Five hundred ninety-two of the 637 IPG replacements were Soletras, with a few in each other category. Patients ranged in age from 11 to 92 years old (mean 60.8 ± 14.5 years old). There were 13 patients under the age of 18 at the time of DBS implantation, and 65.5% of the entire group was male.

**Atraumatic Presentations Less Than 12 Months From Original Implantation**

The rate of atraumatic presentation of infection and/or erosion occurring less than 12 months from original DBS implantation, requiring additional surgery, was 1.24% (9/728) per patient (Table 2). Five infections were found to originate at the bifrontal incision, 3 at the left parietal connection incision, and 1 at the IPG site. If self-limited superficial infections (those treated successfully by antibiotics alone without further surgery) are included, the incidence was 2.2% (16/728) per patient (Table 3). Six of 7 of these self-limited infections originated at the IPG site, whereas 1 was at the bifrontal incision.

The per-lead risk of infection was calculated based on the origin of the infection: bifrontal and parietal wound infections were assumed to be associated with 2 leads, whereas an infection accompanying a single-channel IPG (such as Soletra or Libra) was assumed to be associated with 1 lead. Of those presentations that resulted in further surgery for treatment, 17 DBS leads were associated with a device infection, with a calculated per-lead risk of 1.27% (17/1333 leads); including all infection presentations, the per-lead risk was 1.95% (26/1333 leads).

The mean age (± SD) of the 9 patients requiring further surgery who presented less than 12 months from original implantation was 52.44 ± 15.62 years old (range 24–79 years old); that of all infections (n = 16) in this category was 54.87 ± 12.80 years old (range 24–79 years old).

Once the patients presented clinically, they were started on a course of oral antibiotics. The details of the antibiotic regimen are provided in Tables 2 and 3. The mean duration of the antibiotic regimen for infections not requiring further surgery was 24 ± 13.7 days (range 7–42 days).

All 8 patients who presented with cranial wound complications were treated initially by debridement in an attempt to salvage the leads. Debridement followed by intravenous antibiotics was only successful in treating the infection in 2 patients, 1 each with bifrontal or parietal origin (25% success rate). One of 2 patients who eventually had the leads only removed (to spare the IPG) was successfully treated. The only infection originating from the IPG was treated by IPG removal alone and intravenous antibiotics.

The mean time to first surgery (either washout or ex-

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**TABLE 1: Diagnosis of 728 patients referred for DBS classified by stimulation target (2002–2010)*

<table>
<thead>
<tr>
<th>Diagnosis or Category</th>
<th>No. of Patients</th>
<th>STN</th>
<th>VIM</th>
<th>GPI</th>
<th>PPN</th>
<th>STN &amp; VIM†</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Unilat</td>
<td>Bilat</td>
<td>Unilat</td>
<td>Bilat</td>
<td>Unilat</td>
</tr>
<tr>
<td>PD</td>
<td>452</td>
<td>72</td>
<td>318</td>
<td>15</td>
<td>17</td>
<td>2</td>
</tr>
<tr>
<td>ET</td>
<td>144</td>
<td>0</td>
<td>0</td>
<td>52</td>
<td>93</td>
<td>0</td>
</tr>
<tr>
<td>dystonia</td>
<td>64</td>
<td>0</td>
<td>1</td>
<td>6</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>PD &amp; ET</td>
<td>30</td>
<td>3</td>
<td>1</td>
<td>13</td>
<td>11</td>
<td>0</td>
</tr>
<tr>
<td>PT or MS tremor</td>
<td>24</td>
<td>0</td>
<td>0</td>
<td>9</td>
<td>15</td>
<td>0</td>
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<tr>
<td>other</td>
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<td>0</td>
<td>2</td>
<td>0</td>
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<td>2</td>
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<tr>
<td>total no. of patients</td>
<td>728</td>
<td>75</td>
<td>322</td>
<td>95</td>
<td>140</td>
<td>9</td>
</tr>
<tr>
<td>total no. of leads§</td>
<td>1333</td>
<td>84</td>
<td>644</td>
<td>115</td>
<td>280</td>
<td>9</td>
</tr>
</tbody>
</table>

* GPI = globus pallidus internus; MS = multiple sclerosis; PPN = pedunculopontine nucleus; PT = posttraumatic; STN = subthalamic nucleus; VIM = ventral intermediate nucleus of the thalamus.
† One side STN and the other side VIM in the same patient.
‡ Right PPN lead added to 2 patients each with bilateral GPI implants (not included in patient total).
§ Only original leads.
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Self-Limited Infections Versus Those Requiring Reoperation

The only variables that were significantly different between self-limited infections and those requiring reoperation were the time after implantation (postoperative day) to clinical presentation, as well as initial antibiotic choice; age and diagnosis were not significantly different. All of the 17 patients with hardware-related infections presented with localized swelling, erythema, or crusting at either the IPG, parietal, or frontal incision. Of these, each of the 9 patients who required further surgery presented additionally with localized drainage at one of these incisions over the evolution of their infection.

TABLE 2: Details of DBS hardware-related complications requiring further surgery*

<table>
<thead>
<tr>
<th>Group</th>
<th>Age (yrs)</th>
<th>Sex†</th>
<th>Diagnosis</th>
<th>Initial Location (Type)</th>
<th>Infection Time Course After Implantation (Day)‡</th>
<th>Antibiotic Prior to Reoperation</th>
<th>I &amp; D Before Removal</th>
<th>Partial Hardware Removal</th>
<th>Final Hardware Removed</th>
<th>Culture Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>atraumatic presentation &lt;12 mos from original implantation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24, M</td>
<td>dystonia</td>
<td></td>
<td>bifrontal</td>
<td>DR</td>
<td>95</td>
<td>ciprofloxacin yes</td>
<td>none</td>
<td>total</td>
<td>P. acnes</td>
<td></td>
</tr>
<tr>
<td>65, M</td>
<td>PD</td>
<td></td>
<td>bifrontal</td>
<td>DE/DR</td>
<td>50</td>
<td>NA vancomycin only</td>
<td>none</td>
<td>none</td>
<td>none</td>
<td></td>
</tr>
<tr>
<td>63, F</td>
<td>PD</td>
<td></td>
<td>bifrontal</td>
<td>DR</td>
<td>75</td>
<td>ciprofloxacin yes</td>
<td>leads</td>
<td>total</td>
<td>MSSA &amp; MRSA</td>
<td></td>
</tr>
<tr>
<td>79, M</td>
<td>PD</td>
<td></td>
<td>parietal</td>
<td>DR</td>
<td>104</td>
<td>cefalexin yes (3 times)</td>
<td>none</td>
<td>total</td>
<td>no growth</td>
<td></td>
</tr>
<tr>
<td>48, F</td>
<td>PD</td>
<td></td>
<td>parietal</td>
<td>DR</td>
<td>50</td>
<td>cepalexin yes</td>
<td>none</td>
<td>total</td>
<td>MSSA</td>
<td></td>
</tr>
<tr>
<td>54, M</td>
<td>PD</td>
<td></td>
<td>parietal</td>
<td>DE</td>
<td>50</td>
<td>cepalexin only</td>
<td>none</td>
<td>none</td>
<td>none</td>
<td></td>
</tr>
<tr>
<td>51, M</td>
<td>dystonia</td>
<td></td>
<td>bifrontal</td>
<td>DR</td>
<td>48</td>
<td>cepalexin yes</td>
<td>leads</td>
<td>total</td>
<td>MRSA</td>
<td></td>
</tr>
<tr>
<td>43, M</td>
<td>PT-tremor</td>
<td></td>
<td>bifrontal</td>
<td>DE/DR</td>
<td>198</td>
<td>cepalexin yes</td>
<td>leads</td>
<td>total</td>
<td>MRSA</td>
<td></td>
</tr>
<tr>
<td>45, M</td>
<td>PD</td>
<td></td>
<td>abdominal</td>
<td>DE/DR</td>
<td>130</td>
<td>ciprofloxacin no</td>
<td>IPG &amp; ext</td>
<td>IPG &amp; ext</td>
<td>no growth</td>
<td></td>
</tr>
<tr>
<td>presentation &lt;12 mos after revision of hardware</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>52, M†</td>
<td>PD</td>
<td></td>
<td>chest (Soletra)</td>
<td>ER/DR</td>
<td>45 mos</td>
<td>none yes</td>
<td>IPG &amp; ext</td>
<td>total</td>
<td>MSSA</td>
<td></td>
</tr>
<tr>
<td>50, M</td>
<td>ET</td>
<td></td>
<td>chest (Activa RC)</td>
<td>DR</td>
<td>7</td>
<td>ciprofloxacin no</td>
<td>IPG &amp; ext</td>
<td>IPG &amp; ext</td>
<td>MSSA</td>
<td></td>
</tr>
<tr>
<td>59, M</td>
<td>PD</td>
<td></td>
<td>chest (Soletra)</td>
<td>all</td>
<td>42</td>
<td>cepalexin no</td>
<td>IPG &amp; ext</td>
<td>MSSA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>27, F</td>
<td>PD</td>
<td></td>
<td>chest (Soletra)</td>
<td>DE</td>
<td>14</td>
<td>cepalexin only</td>
<td>none</td>
<td>none</td>
<td>none</td>
<td></td>
</tr>
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<td>presentation &gt;12 mos after revision of hardware</td>
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</tr>
<tr>
<td>51, M</td>
<td>PD</td>
<td></td>
<td>chest (Soletra)</td>
<td>DE/DR</td>
<td>28 mos</td>
<td>cepalexin no</td>
<td>IPGs &amp; ext</td>
<td>IPGs &amp; ext</td>
<td>no growth</td>
<td></td>
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<tr>
<td>trauma-induced wound complications</td>
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<td></td>
</tr>
<tr>
<td>59, F</td>
<td>PD</td>
<td></td>
<td>frontal</td>
<td>DE</td>
<td>2 mos</td>
<td>none no</td>
<td>rt lead</td>
<td>rt lead</td>
<td>no growth</td>
<td></td>
</tr>
<tr>
<td>77, M</td>
<td>PD</td>
<td></td>
<td>parietal</td>
<td>DE</td>
<td>60 mos</td>
<td>none only</td>
<td>none</td>
<td>none</td>
<td>no growth</td>
<td></td>
</tr>
<tr>
<td>70, M</td>
<td>PD</td>
<td></td>
<td>chest, abdomi- nal (Soletra)</td>
<td>DE/DR</td>
<td>47 mos</td>
<td>none no</td>
<td>IPGs &amp; ext</td>
<td>IPGs &amp; ext</td>
<td>no growth</td>
<td></td>
</tr>
</tbody>
</table>

* DE = dehiscence; DR = drainage; ER = erosion; ext = extension; I & D = incision and debridement; NA = not applicable; P. acnes = Propionibacterium acnes; PT-tremor = posttraumatic tremor.
† Arranged chronologically.
‡ Refers to the length of time after implantation when there was 1) onset of infection (number of days since implantation) and 2) explantation (number of days since implantation).
§ Hydrogen peroxide cleaning only prior to reoperation.
‖ Leads and IPGs implanted during same operation; all other implants staged procedures.

plantation) after initial presentation in those patients in whom antibiotics failed to contain the infection was 32.78 ± 41.22 days (range 2–132 days), whereas the mean time to hardware explantation (n = 7) after initial presentation on antibiotics was 242.12 ± 331.98 days (range 13–942 days). If the outlier case is excluded, then the mean time to explantation after initial presentation (n = 6) becomes 126.17 ± 101.5 days (range 13–239 days), which is significantly longer than the time from presentation to initial surgery (p = 0.02, t-test). The majority of organisms cultured at the time of surgery were consistent with skin flora, with Staphylococcus aureus the most common organism.
Infections that were successfully treated by antibiotics alone presented to clinic earlier (postoperative Day 16.4 ± 8.5 days) than those ultimately requiring further surgery (postoperative Day 89 ± 50 days), which was significant \((p = 0.002, t\)-test). This finding may be skewed because all patients were seen for suture removal within 2 weeks postoperatively, and therefore wound infections could be detected at that visit if they existed and then be treated. Initial antibiotic given upon presentation was significantly different between the 2 groups \((p = 0.017, \text{Fisher exact test})\), but this may be related to the time of presentation and relation to routine postoperative prophylaxis (see Discussion).

### Atraumatic Device-Related Infection Presenting > 12 Months From Implantation

Two patients (0.2%) presented more than 12 months from original implantation; 1 was successfully treated by antibiotics alone, while another presenting with erosion over his IPG underwent successful partial hardware removal with lead salvage, followed by replacement, only to have a new infection develop cranially requiring subsequent partial and then total system removal.

### Postrevision Device-Related Infections or Erosions

Five patients (0.7%) presented less than 12 months from revision of hardware. Two (0.2%) of these patients were successfully treated using antibiotics alone, and 3 (0.4%) required further surgery. One patient presented with a visible dehiscence 2 weeks after replacement and underwent debridement alone, without evidence of infection. Another patient demonstrated evolution of erythema from the IPG site to extension into the neck, requiring removal of the IPG and extension, an intravenous antibiotic course, and then later replacement. Another patient presented with wound drainage at the IPG site that quickly evolved to erosions over both the IPG and parietal incisions, leading to total system removal.

### Trauma-Induced Wound Complications

Three patients (0.4%) presented with posttraumatic wound dehiscences over a component of their DBS system, all requiring surgery. One patient presented with gross unilateral lead exposure at the bur hole after sustaining a fall, requiring removal alone, without sequelae. One patient presented with a parietal wound dehiscence following a fall and was successfully treated by intraoperative wound washout alone. Following a seat belt injury, 1 patient suffered hematomata and dehiscences at his right chest and subcostal IPG sites; despite quick removal of IPGs and extensions alone, infection occurred and spread to later necessitate total system removal.

### Risk Factors for Device-Related Infection

Patient age, diagnosis, date, and place of surgery were not predictive of infection risk, based on a multivariate logistical regression analysis. Although 8 of 9 infections requiring reoperation within 12 months of the initial DBS hardware implantation were the result of staged procedures, the majority of total cases performed were staged; therefore, this finding is expected and not considered a risk factor. Other potential risk factors such as comorbidities that could cause immunocompromise (diabetes, and idiopathic or acquired autoimmune diseases) could not be analyzed due to their lack of incidence in the infected patient group. All of the patients (100%) requiring reoperation for wound infection 12 months from surgery and 5 of 7 patients presenting with superficial infections

### TABLE 3: Details of superficial infections requiring no further surgery*

<table>
<thead>
<tr>
<th>Presentation Group</th>
<th>Age (yrs), Sex</th>
<th>Diagnosis</th>
<th>Location (Type)</th>
<th>Antibiotic Time Course After Implantation (Day)‡</th>
<th>Incision</th>
<th>Procedural Type</th>
<th>Antibiotic Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>atraumatic &lt;12 mos from original Implantation</td>
<td>46, M PD</td>
<td>chest (Soletra)</td>
<td>15 22 redness unstaged</td>
<td>levofloxacin</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>60, F PD</td>
<td>chest (Kinetra)</td>
<td>8 28 redness staged</td>
<td>cephalexin</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>63, M PD</td>
<td>chest (Soletra)</td>
<td>7 21 redness staged</td>
<td>ciprofloxacin</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>62, M PD</td>
<td>chest (Eon)</td>
<td>14 45 scab staged</td>
<td>levofloxacin</td>
<td></td>
<td></td>
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<td>47, M PD</td>
<td>chest (Soletra)</td>
<td>14 28 redness staged</td>
<td>cephalexin</td>
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<td></td>
<td>65, M PD</td>
<td>chest (Soletra)</td>
<td>25 67 redness staged</td>
<td>levofloxacin</td>
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<td></td>
<td>63, M PD</td>
<td>bifrontal</td>
<td>30 70 crusting staged</td>
<td>levofloxacin</td>
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<tr>
<td>atraumatic &gt;12 mos from original Implantation</td>
<td>81, F PD</td>
<td>bifrontal</td>
<td>84 mos 92 mos drainage unstaged</td>
<td>levofloxacin</td>
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<td>&lt;12 months after revision of hardware</td>
<td>47, M PD</td>
<td>chest (Soletra)</td>
<td>12 19 redness staged</td>
<td>cephalexin</td>
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<td></td>
<td>31, M dystonia</td>
<td>parietal</td>
<td>75 115 redness staged</td>
<td>cephalexin</td>
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* Arranged chronologically.
‡ Refers to the day number after implantation when 1) antibiotics were begun (number of days since implantation) and 2) when antibiotics were stopped (number of days since implantation).
Management of wound complications in deep brain stimulation

each had 2 implanted Soletra IPGs. However, we do not interpret these data as a risk for infection because Soletra IPGs comprised 92% of all implanted IPGs during the study period, and accordingly it is expected that most infected patients would be from this group. Also, only 1 of 9 patients requiring a return to surgery had the origin of infection at the IPG site, further removing the IPG type as causative.

Lead Replacements

During this 9-year series, 22 DBS leads were replaced in 13 patients who underwent their original implantation by a different surgeon at an outside institution; 32 DBS lead replacements were performed in patients originally implanted after 2002 by the same surgeon (R.K.S.; Table 1). None of these patients developed an infection. These 32 leads are included in the total number of implantations because they represent new lead placements, which occurred after removal of an old lead, under the same detailed stereotactic procedure followed by a separate new lead extension and IPG placement.

Discussion

The risk of infectious complications in DBS is reviewed in a number of reports in the literature, varying from 0% to 15% per patient.\(^1\)\(^{-}^3\)\(^,^6\)\(^,^9\)\(^,^13\)\(^,^15\)\(^,^17\)\(^,^18\)\(^,^23\)\(^,^24\)\(^,^26\)\(^,^27\)\(^,^31\)\(^,^33\)\(^,^36\)\(^,^38\) However, interpretation of these rates is difficult because the definition of infection is variable and is sometimes inclusive and/or exclusive of erosions and/or dehiscences without infection\(^26\)\(^,^38\) or infections that are self-limited.\(^38\) In this paper we have detailed a categorical analysis of the incidence and management of all postoperative wound complications, over both a short term (<12 months) and longer term. Perhaps of greater value is that the groups are classified as “spontaneously” occurring as compared with those that are secondary to revision or trauma, both of which subject the system to potential recontamination. Eight of 9 infections that were grouped in the spontaneous (<12 month) incidence group did, in fact, present less than 6 months from implantation, so these data strongly correlate with data from other large case series analyzing infections due to DBS hardware.\(^33\)

Management of Spontaneous Atraumatic Wound Infections Presenting Less Than 12 Months

In the present series, 9 patients developed infections that required further surgery less than 12 months from original implantation (Table 2).

Cranial Origin. All 8 of 8 infections presenting with wound drainage at cranial incisions were first treated with a wound washout. This was performed in an attempt to save the hardware, or at least have the patient continue to benefit from stimulation for a longer period of time. Unfortunately, only 1 of 5 infections originating bifrontally and 1 of 3 infections originating parietally were successfully treated by wound washout alone. This failure rate is similar to the findings of other published studies. In the series by Sillay et al.,\(^33\) 2 patients presented with infections originating at their frontal incisions and 2 at their parietal incisions. Wound washout was attempted in only 1 infection originating frontally, which ultimately failed to control the infection. All 4 of these patients underwent complete hardware removal; there was no attempt at lead removal only. In the series by Oh et al.,\(^26\) 5 of 6 patients with infections underwent unsuccessful initial hardware salvage attempts via wound debridement followed by intravenous antibiotics. All 5 of these patients had total device removal.

Cranial wound debridements have been reported to be successful in the literature. Temel et al.\(^26\) initially performed an operative debridement in 1 patient in their series, who presented with left frontal and right cervical wound dehiscences and purulent discharge despite antibiotics; this operation ultimately failed, but the patient only required removal of the right extension cable and IPG, sparing the leads, followed by further debridement, graciloplasty, and antibiotics.

It is interesting to note that in the 2 patients in our series in whom wound washout was successful, intraoperative cultures revealed no growth. As implicated in other series\(^33\) and in other surgical specialties involving hardware implantation,\(^26\) wounds contaminated with \textit{S. aureus} are unlikely to be cured without hardware removal. In our series, 4 of the 7 patients’ wounds ultimately requiring hardware removal were positive for \textit{S. aureus}, supporting this position.

This raises the question of whether incision and debridement of wound dehiscence and/or infection occurring cranially is the best initial step. As stated above, in the current series, the mean time to explantation after presentation on initial antibiotics was more than 126 days in 6 patients, which is 94 days longer than the time to first surgery (wound washout in 8 of 9 patients). This difference in time is significant (p = 0.02) and can be viewed as either a delay in the likely inevitable total explantation, or conversely as a real gain in benefit derived from leaving the stimulation in situ. This protracting of the treatment regimen by more than 4 months is meaningful, because none of the patients who had their entire systems explanted later underwent reimplantation (confirmed by the Medtronic database). If immediate removal of hardware as the first surgery occurred in these patients, then they would have benefited less from DBS overall. Reasons for this may include the possibility that the initial surgery was too painful a process (personal patient communication).

Thus, although infections originating cranially are, fortunately, a rare occurrence, the larger number of cases studied in this series gives us more evidence that perhaps the initial treatment should be a wound incision and debridement, in the hope of prolonging the benefit from stimulation and possibly succeeding at ending the infection. Initially attempting to keep the system intact should be tried in these rare cases, followed by partial device removal (removing the leads and sparing the IPGs) in the hope of future reimplantation. This course, however, may ultimately fail, requiring total system removal and prolonged antibiotic administration. As should be the case in all surgery, communication and counseling with each individual patient needs to be performed so that an
formed decision about the next step in the process can be made.

**Origin of the IPG.** In most series reported in the literature, the presenting infection was over the IPG site in the majority of infected patients.\(^5\) In this present series there was only 1 infection originating over the IPG, which was ultimately treated by IPG and associated extension removal, followed by intravenous antibiotics and reimplantation 2 months later, saving the brain leads. This lead-salvage technique through partial hardware removal has been reported to be successful by others,\(^{22,24,33,36}\) and our data certainly corroborate that success.

**Management of Wound Dehiscence and/or Erosion**

Wound washouts were the end treatment option for 4 patients, who required no further surgery or device removal. Three of these patients presented with wound re-opening without associated induration, erythema, drainage, or other signs of infection. Likely in these instances, the simple washout and postoperative antibiotic regimen was successful because it allowed wound closure and it was performed in a timely manner, within a few days of presentation, before there was clear evidence of infection.

Management of erosions without evidence of infection is not prominently noted in the literature because most patient series combine these complications. Oh et al.\(^26\) reported 8 of 12 erosions and/or infections in their series of 79 patients, with 7 of these occurring at the connector site and 1 at the IPG. Only 1 patient was successfully treated by wound washout, with the others undergoing hardware removal. In contrast, Voges et al.\(^38\) reported only 1 patient with an erosion at the connector site that was managed by simple debridement and transposition of the connector, but they accounted for this 1 case as due to a high-profile connection that has since been abandoned. As supported by our data, we find that debridement alone is sufficient initially in the cases of dehiscence and/or erosion without evidence of infection.

**Source of Infection**

We did not observe a cerebral infection in any patient in this series. Although some series show a lower incidence of infection at cranial incisions,\(^33\) 8 of 9 presenting infections requiring a return to surgery for management originated at either the bifrontal or parietal locations. It is interesting that this was the case, given that our overall infection rate requiring reoperation was lower than most, if not all, rates in other published series. Some contend that this higher rate of infection may be due to a lack of adequate sterile technique or exteriorization of leads.\(^9,26,35\) However, Oh et al.\(^26\) reported 4 of 10 infections originating at the bur hole, and 5 of 10 infections at the connector site, but report that most of these occurred after 12 months from implantation, and discount the brief 1-week externalization period as causative.

Sillay et al.\(^33\) reported 4 of 19 infections originating cranially; of the 420 patients in their series, this results in a risk of 0.95% per patient. In our series, 8 of 728 patients presented with infections of cranial origin, of similar incidence (1.1%) to this larger series.

**Antibiotic Choice in Relation to Presentation**

All patients are given 1 week of cephalexin treatment for prophylaxis postoperatively, or ciprofloxacin/clindamycin if there is a penicillin allergy, and then return to the clinic for suture or staple removal within 1–2 weeks. Interestingly, the observation that self-limited infections presented at a significantly earlier time than those requiring further surgery is likely (and logically) dependent upon this postoperative visit, at which a nurse and/or physician can inspect and treat wounds causing concern.

The timing of presentation of such wounds in relation to the postoperative visit also likely affects the antibiotic choice, as this initial antibiotic given upon presentation also differed significantly between the 2 groups. Five of 7 infections that were ultimately cured by antibiotics alone presented within 2 weeks of surgery. Four of these 7 patients returning with incision concerns despite prophylaxis received levofloxacin; 2 of the 7 that continued on cephalexin experienced minor wound appearances that were of concern (slight redness). One patient continued on ciprofloxacin due to a penicillin allergy. There is no final proof of organism, but likely the infections were treated successfully due to early treatment using an antibiotic. 13

**Current Technique to Minimize Infection Risk and Prophylaxis for Infection**

The surgical technique employed in each of the procedures presented in this series has varied little over time despite institutional differences, and continues to this day. Other centers have presented in great detail their protocol to minimize complications.\(^20,33,36\) We agree with many of these, and offer our key points in summary below.
Management of wound complications in deep brain stimulation

Like others, we use antistaphylococcal antibiotic administration within 1 hour of skin incision.\textsuperscript{20,33} We choose to clip all hair on the patient’s head followed by chlorhexidine skin prep; shaving with a razor is avoided, as is temporary externalization of the leads.\textsuperscript{9} Meticulous draping of the frame and of the scalp must be performed, with no openings to the patient.

Some authors have conjectured\textsuperscript{27} and proven\textsuperscript{27} that straight incisions resulted in worse infection risk than curvilinear ones. In bilateral implantations, we routinely use a slightly curved bifrontal incision slightly anterior to the coronal suture and bur holes. Likewise, the parietal incision is curvilinear but perpendicular to the axis of lead passage; grooves are made in the skull to recess the lead-extension connection and thus decrease the profile here as well.

The use of copious amounts of diluted povidone-iodine irrigation (1% concentration) for both Stage 1 and Stage 2 procedures prior to closure must also be underscored. Povidone-iodine has bactericidal activity against a wide spectrum of pathogens, including MRSA, and is maximally effective against MRSA in a dilution of 1:25 to 1:200 (0.5–4% betadine).\textsuperscript{1,7,11} This has been shown to be superior to saline irrigation alone.\textsuperscript{7,8} Haines\textsuperscript{14} concluded that bacitracin irrigation in neurosurgery is beneficial for surgical wounds with high infection risk (> 15%), but additionally that there is no scientific evidence to support the use of prophylactic topical antibiotics for wounds with a risk of infection less than 5%. Indeed, our use of povidone-iodine has possibly contributed to minimizing our patient infections, possibly due to its bactericidal activity. Other groups that performed DBS surgery have experienced success in reducing their own patient infection rates using other antibacterial applications prior to wound closure;\textsuperscript{25} the need for a more systematic review of intraoperative agents is apparent.

The routine postoperative administration of oral staphylococcal prophylaxis via cephalaxin (or ciprofloxacincldamyacin in penicillin allergy) for 7 days following each procedure also could potentially contribute to this low infection rate, but this cannot be adequately proven nor supported. There is only anecdotal evidence to support the extended use of perioperative antibiotics after implantation of devices into the CNS. The use of systemic antibiotic prophylaxis for more than 24 hours after ventriculoperitoneal shunting is uncertain, as concluded by a recent meta-analysis.\textsuperscript{29}

What has been demonstrated, aside from evidence suggesting decreased postoperative infection with antibiotic-impregnated devices (such as catheters in shunting\textsuperscript{42}) and frequent glove changing,\textsuperscript{40} is that reducing operative time is directly associated with reduced infection risk during implantation procedures.\textsuperscript{2,39,36} The procedural time from incision to closure is routinely under 2 hours for a Stage 1 bilateral lead placement; Stage 2 procedure time is 30 minutes on average. It is important to minimize handling of the implant, reduce operating room traffic, give attention to meticulous surgical tissue manipulation, and work with an experienced team.\textsuperscript{28}

As with ventriculoperitoneal shunting procedures, there is likely to be a wide variability in infection rates following implantation of DBS hardware; this rate varies by surgeon performing the implantation, hospital, patient, and likely additional unknown factors, as contended by a recent retrospective cohort study.\textsuperscript{24} The more systematic and regimented a procedure that can be performed, the easier extraneous factors can be identified and removed to decrease complications.

Conclusions

In a large series of new DBS hardware implantations, the incidence of postoperative wound dehiscence and/or infections requiring further surgery was 1.24%. Standard for all implantations was a short procedural time, copious povidone-iodine irrigation, and postoperative antibiotic administration. Wound washout and/or partial hardware removal should be initially attempted for infection, depending on the individual case; debridement alone is successful in dehiscence without infection.

Disclosure

Dr. Simpson is a consultant to Medtronic and received clinical or research support for this study from St. Jude’s Medical.

Author contributions to the study and manuscript preparation include the following. Conception and design: Fenoy. Acquisition of data: both authors. Analysis and interpretation of data: Fenoy. Drafting the article: Fenoy. Critically revising the article: both authors. Reviewed submitted version of manuscript: both authors. Approved the final version of the manuscript on behalf of all authors: Fenoy.

References


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