Infection on neurological implanted devices

Challenging complex infections for ID physicians

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Disclosures

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Outline

- Diagnosis of implant-associated infections
- Treatment concepts of implant-associated infections
- Specific infections associated with the following implants:
Risk of implant-associated infections

<table>
<thead>
<tr>
<th>Device</th>
<th>No. inserted in the US, per year</th>
<th>Infection rate, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fracture fixation devices</td>
<td>2,000,000</td>
<td>5–10</td>
</tr>
<tr>
<td>Dental implants</td>
<td>1,000,000</td>
<td>5–10</td>
</tr>
<tr>
<td>Joint prostheses</td>
<td>600,000</td>
<td>1–3</td>
</tr>
<tr>
<td><strong>Neurosurgical implants</strong></td>
<td><strong>450,000</strong></td>
<td><strong>3–15</strong></td>
</tr>
<tr>
<td>Cardiac pacemakers</td>
<td>300,000</td>
<td>1–7</td>
</tr>
<tr>
<td>Mammary implants</td>
<td>130,000</td>
<td>1–2</td>
</tr>
<tr>
<td>Mechanical heart valves</td>
<td>85,000</td>
<td>1–3</td>
</tr>
<tr>
<td>Penile implants</td>
<td>15,000</td>
<td>1–3</td>
</tr>
<tr>
<td>Heart assist devices</td>
<td>700</td>
<td>25–50</td>
</tr>
</tbody>
</table>
**Concept and diagnosis of biofilm**

### Biofilm
- Bacteria adhere to implant surface
- Embed in a matrix
- In stationary growth phase
- Slowly replicate

### Sonication
- Sonication of implants*:
  - Detachment of biofilm
- Sonication fluid plated on culture media

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*Cranioplasty, shunts, screws, plates, stimulators, etc.

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Characteristics of implant-associated infections

- **Route of infection: Exogenous inoculation**
  - Preoperative (skin defects, open wounds)
  - Intraoperative (100 microorganisms sufficient, from wound border)
  - Postoperative (first 2-4 days of wound healing, persistent wound drainage)

- **Discrepancy between good in vitro susceptibility and poor clinical and bacteriological outcome in vivo**
  - Routine susceptibility testing is performed on growing and planktonic microorganisms

## Classification of infections

Extrapolation from other implant-associated infections

<table>
<thead>
<tr>
<th>Early infection</th>
<th>Delayed / late infection</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 4 weeks after implantation</td>
<td>&gt; 4 weeks after implantation</td>
</tr>
<tr>
<td>Clinical presentation: acute</td>
<td>Clinical presentation: low-grade</td>
</tr>
<tr>
<td>Fever, local signs if infection</td>
<td>Persistent wound drainage, fistula</td>
</tr>
<tr>
<td>“Immature” biofilm</td>
<td>“Mature” biofilm</td>
</tr>
<tr>
<td>Debridement and implant retention</td>
<td>Removal or exchange of the implant necessary</td>
</tr>
<tr>
<td>possible</td>
<td>(1- or 2-stage exchange)</td>
</tr>
<tr>
<td>Anti-biofilm antibiotic treatment for 12 weeks</td>
<td>Anti-biofilm antibiotic treatment for 12 weeks</td>
</tr>
<tr>
<td>- Usually 2 weeks i.v.</td>
<td>- Usually 2 weeks i.v.</td>
</tr>
<tr>
<td>- Then 10 weeks oral treatment</td>
<td>- Then 10 weeks oral treatment</td>
</tr>
</tbody>
</table>

Treatment concept
 Implemented from other implant-associated infections

**Surgery**
- Debridement
- Implant retention or change
- Soft tissue coverage

**Anti-biofilm treatment**
- Rifampin combinations against staphylococci
- Fluoroquinolones against gram-negative bacilli

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**Microorganism known, susceptible to anti-biofilm antibiotics**

- **Implant debridement and retention in early infection**
  - 12 weeks anti-biofilm antibiotic therapy*

- **One-stage exchange of implant**
  - 12 weeks anti-biofilm antibiotic therapy*

- **Two-stage exchange of implant (short interval, 2 weeks without implant)**
  - 12 weeks anti-biofilm antibiotics*

**Microorganism known, NOT susceptible to anti-biofilm antibiotics**

- **Two-stage exchange of implant (long interval, 6-8 weeks without implant)**
  - 6 weeks antibiotic therapy

- **Implant retention and lifelong antibiotic suppression therapy**

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* Usually 2 weeks i.v. and 10 weeks oral treatment

Adapted from Zimmerli W. *N Engl J Med* 2004; 351:1645-1654
Post-craniotomy and cranioplasty-associated infections
Post-craniotomy infections

- **Indication:**
  - Brain biopsy, drain brain abscesses

- **Infection rate:** 0.5-7%
  - Epidural > intracerebral > subdural

- **Interval between craniotomy and postoperative infection**
  - Median 1.5 months (range 4 days - 5 years)

- **Most common pathogens**
  - *S. aureus*, coagulase-negative staphylococci, gram-negative bacilli

**Symptom**

<table>
<thead>
<tr>
<th>Symptom</th>
<th>Total n=50 patients</th>
<th>Number of patients n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mental status change</td>
<td>18 (36)</td>
<td></td>
</tr>
<tr>
<td>Purulent wound drainage</td>
<td>17 (34)</td>
<td></td>
</tr>
<tr>
<td>Fever</td>
<td>11 (22)</td>
<td></td>
</tr>
<tr>
<td>Headache</td>
<td>10 (20)</td>
<td></td>
</tr>
<tr>
<td>Swelling</td>
<td>7 (14)</td>
<td></td>
</tr>
<tr>
<td>Seizure</td>
<td>2 (4)</td>
<td></td>
</tr>
</tbody>
</table>

Dashti S. *Neurosurg Focus* 2008;24(6):E10
Post-craniotomy infections: Risk factors

<table>
<thead>
<tr>
<th>Risk factor</th>
<th>OR (95% Confidence Interval)</th>
<th>Author</th>
</tr>
</thead>
<tbody>
<tr>
<td>External CSF drainage</td>
<td>7.2 (2.9-18.1)</td>
<td>Sneb</td>
</tr>
<tr>
<td>Preoperative chemotherapy</td>
<td>5.2 (2.3-11.6)</td>
<td>Lieber</td>
</tr>
<tr>
<td>Postoperative CSF leakage</td>
<td>3.5 (1.4-8.5)</td>
<td>Chiang</td>
</tr>
<tr>
<td>Wound class 2</td>
<td>3.2 (1.2-8.1)</td>
<td>Lieber</td>
</tr>
<tr>
<td>Wound class 3</td>
<td>8.0 (2.6-24.5)</td>
<td>Lieber</td>
</tr>
<tr>
<td>Morbid obesity (BMI ≥40 kg/m²)</td>
<td>3.1 (1.4-6.8)</td>
<td>Lieber</td>
</tr>
<tr>
<td>Emergency operation</td>
<td>3.0 (1.1-8.1)</td>
<td>Sneb</td>
</tr>
<tr>
<td>Respiratory failure</td>
<td>3.0 (1.1-8.2)</td>
<td>Sneb</td>
</tr>
<tr>
<td>Prior neurosurgical operation (&lt;30 days)</td>
<td>2.3 (1.1-5.0)</td>
<td>Lieber</td>
</tr>
<tr>
<td>Preoperative hospitalization ≥1 day</td>
<td>1.9 (1.1-3.3)</td>
<td>Chiang</td>
</tr>
<tr>
<td>Chronic steroid use</td>
<td>1.9 (1.0-3.4)</td>
<td>Lieber</td>
</tr>
<tr>
<td>Operation duration (per hour increase)</td>
<td>1.2 (1.1-1.3)</td>
<td>Lieber</td>
</tr>
</tbody>
</table>
Cranioplasty-associated infections

- **Indications for craniectomy**
  - Decompression (trauma, intracerebral hemorrhage)
  - Infected bone flap

- **Cranioplasty**
  - Bone flap reuse (risk: aseptic bone necrosis)
  - PEEK*, PMMA*, titanium or other foreign material

- **Infection rate:** 1-25.9%
  - Pathogens: *S. aureus*, coagulase-negative staphylococci, gram-negative bacilli

- **Average time to cranioplasty:** 7.3 months (range 1-40)
  - Disfiguring deformity
  - Lack of brain protection
  - Hydrocephalus (altered CSF dynamics)

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*PEEK: Polyether ether ketone. PMMA: Poly methyl methacrylate

Effect of material and early surgery on cranioplasty-associated infections

Systematic review reveals that

- The material used for the cranioplasty (autologous vs. allogeneic) has no effect on the infection rate

- The time when the cranioplasty is performed (early <3 months vs. late >3 months after craniectomy) has no effect on the infection rate
Distinction between “superficial” and “deep wound” infection is not possible

- **Reasoning**
  - Compartments are in contiguity after craniotomy
  - Any craniotomy infection should be considered as deep and bone flap/cranioplasty-associated

- **Requires surgical revision (debridement)**
  - Evacuate pus and infected tissue
  - Remove infected bone flap for debridement, remove/replace implants
Post-craniotomy and cranioplasty-associated infections: Treatment recommendation

- **Standard management**
  - Delayed cranioplasty (weeks to months)
  - With foreign material once the infection is cleared

- **New concept: anti-biofilm therapy in infected implants**
  - Immediate cranioplasty in low-grade infection (1-stage)
  - Short implant-free interval of 2 weeks (2-stage)
  - Bone flap reuse, PEEK**, PMMA** or other
  - Anti-biofilm antibiotic treatment for 12 weeks

→ Better cosmetic results
→ Protection of underlying brain

*Susceptibility to anti-biofilm treatment given
**PEEK: Polyether ether ketone. PMMA: Poly methyl methacrylate
CSF shunt- and external ventricular drainage-associated infections
### Ventricular shunt- and external ventricular drainage-associated infections

<table>
<thead>
<tr>
<th></th>
<th>Ventriculo-peritoneal (VP) and ventriculo-atrial (VA) shunt</th>
<th>External ventricular drain (EVD)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Indication</strong></td>
<td>Chronic, persistent hydrocephalus</td>
<td>Acute hydrocephalus</td>
</tr>
<tr>
<td><strong>Infection risk</strong></td>
<td>5-15%</td>
<td>10-15% (increases with time)</td>
</tr>
<tr>
<td><strong>Risk factors</strong></td>
<td>Serial revisions, postoperative CSF leakage, earlier infection, prolonged intervention time</td>
<td>EVD indwelling time, intracranial hemorrhage, cranial fracture with CSF leakage, EVD irrigation</td>
</tr>
<tr>
<td><strong>Infection acquisition</strong></td>
<td>- Intraoperative (n=56, 72%)</td>
<td>- Contiguous</td>
</tr>
<tr>
<td></td>
<td>- Contiguous (n=21, 27%)</td>
<td>- Intraoperative</td>
</tr>
<tr>
<td></td>
<td>- Skin wound, perforated gut (VP shunts), etc.</td>
<td>- Contiguous</td>
</tr>
<tr>
<td></td>
<td>- Hematogenous (n=1, 1%)</td>
<td>- Intraoperative</td>
</tr>
<tr>
<td></td>
<td>- VA-shunts</td>
<td></td>
</tr>
<tr>
<td><strong>At the end</strong></td>
<td>Shunt dysfunction, hydrocephalus</td>
<td>Up to 44% require internal shunt</td>
</tr>
</tbody>
</table>

VA- and VP-shunt-associated infections: Clinical signs and symptoms (n=78)

**Proximal shunt part:** Ventriculitis, meningitis

**Distal shunt part:** Fever, endocarditis, septic emboli, shunt nephritis

**When VA-shunts?**
- Previous abdominal surgery, history of peritonitis, morbid obesity, VP-shunt failure
- Lower infection rate, but higher mortality rate and more difficult revisions

**Clinical sign and symptom** | **Total n=78**
--- | ---
Fever | 61 (78)
Neurological signs and symptoms | 50 (64)
Local signs of infection | 38 (49)
Symptom duration before infection diagnosis | 5 days (range 0-21 days)

Chronic VA-shunt-associated infections: Complications (endocarditis and nephritis)

- 26 year old female: Hydrocephalus since birth
  - Actual VA-shunt since 14 years
  - Symptoms: Recurrent fever, myalgia
  - Blood cultures, TEE, lumbar puncture: No infection

- 4 years later: End-stage renal disease, hemodialysis
  - Kidney biopsy: Diffuse mesangiocapillary GN
  - TEE: Vegetation on tricuspid valve
  - Shunt valve puncture: Propionibacterium acnes

- Treatment: Complete shunt removal, i.v. penicillin
  - Endoscopic third ventriculo-cisternostomy
  - Kidney transplantation

- Coagulase-negative staphylococci and P. acnes
- Subacute bacterial endocarditis and shunt nephritis

Burström G. BMJ Case Rep 2014
Where to puncture in VP-shunt-associated infections: CSF leukocytes & culture (n=78)

- 80% with elevated CSF leukocyte count
- 91% positive culture results from any collected material

Site of specimen collection:
- Wound swab (n = 28)
- Shunt tip (n = 55)
- CSF from shunt valve
- Ventricular CSF (n = 40)
- Lumbar CSF (n = 22)
- Blood culture (VA shunt) (n = 6)
- Blood culture (VP shunt) (n = 47)

Site of CSF collection:
- Ventricular
- Lumbar
- Valve

CSF overall 66%

CSF: cerebrospinal fluid
VA: ventriculooatrial
VP: ventriculoperitoneal

Conen A. CID 2008; 47:73-82
VP-shunt-associated infections: Microbiology (n=78)

<table>
<thead>
<tr>
<th>Pathogen</th>
<th>Overall (n = 78)</th>
<th>Early&lt;sup&gt;a&lt;/sup&gt; (n = 48)</th>
<th>Delayed&lt;sup&gt;b&lt;/sup&gt; (n = 22)</th>
<th>Late&lt;sup&gt;c&lt;/sup&gt; (n = 8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coagulase-negative staphylococci&lt;sup&gt;d&lt;/sup&gt;</td>
<td>29 (37)</td>
<td>19</td>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>* Staphylococcus aureus&lt;sup&gt;d&lt;/sup&gt;</td>
<td>14 (18)</td>
<td>9</td>
<td>5</td>
<td>...</td>
</tr>
<tr>
<td>Propionibacterium acnes</td>
<td>7 (9)</td>
<td>5</td>
<td>2</td>
<td>...</td>
</tr>
<tr>
<td>Viridans group streptococci</td>
<td>3 (4)</td>
<td>2</td>
<td>1</td>
<td>...</td>
</tr>
<tr>
<td>Enterobacteriaceae&lt;sup&gt;e&lt;/sup&gt;</td>
<td>3 (4)</td>
<td>3</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Nonfermenters&lt;sup&gt;f&lt;/sup&gt;</td>
<td>2 (3)</td>
<td>...</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Enterococcus species</td>
<td>1 (1)</td>
<td>...</td>
<td>1</td>
<td>...</td>
</tr>
<tr>
<td>Polymicrobial&lt;sup&gt;g&lt;/sup&gt;</td>
<td>12 (15)</td>
<td>4</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Culture negative</td>
<td>7 (9)</td>
<td>6</td>
<td>1</td>
<td>...</td>
</tr>
</tbody>
</table>

* Intraoperative or postoperative contamination  
** Wound dehiscence or gastrointestinal perforation  

Early: <1 month after implantation  
Delayed: 1-12 months after implantation  
Late: >12 months after implantation  

Conen A. *CID* 2008; 47:73-82
Only one randomized controlled trial for optimal treatment strategy in children (n=50)

Table 6. Therapy and Results in CSF Infected Shunts

<table>
<thead>
<tr>
<th></th>
<th>Number of patients</th>
<th>Successful trials</th>
<th>Unsuccessful trials</th>
<th>Mortality</th>
</tr>
</thead>
<tbody>
<tr>
<td>With removal of shunt *</td>
<td>22</td>
<td>21</td>
<td>95%</td>
<td>1</td>
</tr>
<tr>
<td>With removal**</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>and immediate replacement</td>
<td>17</td>
<td>15</td>
<td>88%</td>
<td>2</td>
</tr>
<tr>
<td>Without removal of shunt**</td>
<td>11</td>
<td>4</td>
<td>36%</td>
<td>7</td>
</tr>
</tbody>
</table>

* Includes one patient who received intravenous antibiotics only (lumbo-peritoneal shunt).

1 week intraventricular and i.v. antimicrobial treatment; as soon as infection is eliminated: reinsertion of a new shunt

** 2 weeks intraventricular and 3 weeks i.v. antimicrobial therapy

Microorganisms: 31 S. epidermidis\textsuperscript{a}, 5 S. aureus\textsuperscript{a}, 2 streptococci, 2 Haemophilus influenzae, each 1 Micrococcus, P. aeruginosa\textsuperscript{a}, E. coli, P. acnes, Corynebacterium sp.; 5 polymicrobial infections

\textsuperscript{a}Associated with treatment failure

VP-shunt-associated infections: Therapy (n=78)

Overall success: 96%
Antibiotics & surgery: 98%
Antibiotics only: 87%

Retention or 1-stage exchange of VP-shunt possible with antibiotics against biofilms

Figure 3. Antimicrobial and surgical treatment strategies and treatment outcomes of CSF shunt–associated infections. During follow-up, 2 relapses and 4 reinfections occurred. 1Removal, for noninfectious reasons. 2Relapse, coagulase-negative staphylococci, rifampin resistant. 3Death, *Pseudomonas aeruginosa* infection associated with ventriculoperitoneal shunt; surgical treatment refused.
Proposed algorithm for the management of shunt-associated infections

**Shunt-associated infection**

**Diagnostic:**
- CSF sample (valve puncture)
- Blood cultures

**Empirical antimicrobial therapy**
- Vancomycin i.v. PLUS
- Ceftriaxone or cefepime i.v.

- No ventriculitis / meningitis / abscess
- No dysfunction
- No erosion (intact skin and gut)

**AND**
- Early infection

**AND**
- Microorganisms known to be susceptible to anti-biofilm antibiotics

**Shunt retention or immediate reinsertion possible**

12 weeks anti-biofilm treatment
(usually 2 weeks i.v., then 10 weeks oral treatment)

**Adapt antimicrobial treatment to culture results**

**Remove** shunt, treat infection, intercurrent EVD if necessary

Reinsert shunt once infection is cleared, usually **after 7-21 days**
(dependent on: microorganism, extent of infection, CSF results)

CSF: Cerebrospinal fluid
EVD: external ventricular drainage

**Yes**

**No**
External ventricular drains (EVD)-associated infections

Ventriculitis, meningitis, exit site infection
- Fever, headache, decrease in GCS, neck stiffness, vomiting

- Median EVD indwelling time: **7 days** (range, 1-39 days)
- Occurrence of infection: median **6 days** after implantation (range, 1-17 days)

- 23% presented within 10 days after EVD removal
- Mostly coagulase-negative staphylococci

EVD-associated infections: Microbiology, CSF leukocytes (n=48)

Detection of microorganism: 37/48 (77%)

<table>
<thead>
<tr>
<th>Table 4</th>
<th>Microbiology of 48 episodes of EVD-associated infections.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Causing microorganisms</td>
<td>n = 48</td>
</tr>
<tr>
<td>Monomicrobial infection</td>
<td></td>
</tr>
<tr>
<td>Coagulase-negative staphylococci</td>
<td>17 (63)</td>
</tr>
<tr>
<td>Propionibacterium acnes</td>
<td>4 (15)</td>
</tr>
<tr>
<td>Staphylococcus aureus</td>
<td>3 (11)</td>
</tr>
<tr>
<td>Other</td>
<td>3 (11)</td>
</tr>
<tr>
<td>Polymicrobial infection</td>
<td>10 (21)</td>
</tr>
<tr>
<td>Culture-negative infection</td>
<td>11 (23)</td>
</tr>
</tbody>
</table>
Proposed algorithm for the management of suspected EVD-associated infections

Febrile patient with EVD

CSF purulent?

- Yes
  - >300×10⁶ cells/l, serum/CSF glucose ratio <0.5, CSF lactate >2.1 mmol/l
  - Immediately start antimicrobial treatment
    - Vancomycin i.v. PLUS
    - Ceftriaxone or cefepime i.v. (according to local surveillance data)
  - Adapt treatment to culture results; treatment duration 7-21 days (dependent on: microorganism, extent of infection, CSF results)

- No
  - Rule out contamination and colonization
    - If infection suspected: Increased cell index* and EVD in situ > 3 days
      - EVD replacement mainly
        - *S. aureus*, gram-negative and Candida infections
        - Inadequate response to treatment

- No
  - CSF gram stain: gram-positive bacteria (mostly staphylococci)

* Cell index: Leukocyte/erythrocyte ratio in CSF vs. leukocyte/erythrocyte ratio in blood

Questions concerning EVD management

- Daily CSF sampling – not recommended
- Prophylactic EVD exchange – not recommended
  - Increased risk of infection by regular system manipulation
- Rifampin therapy in EVD-associated infections – not recommended
  - Rifampin later needed in case of definitive VP-shunt (curative therapy)
  - Change of microbiome and emergence of rifampin-resistance
- Antibiotic-impregnated catheters (rifampin, clindamycin) - not recommended
  - Emergence of rifampin resistance

Neurostimulator-associated infections
<table>
<thead>
<tr>
<th>Indications</th>
<th>Spinal cord stimulator (SCS)</th>
<th>Deep brain stimulator (DBS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chronic refractory pain, stool incontinence</td>
<td>Movement disorders (Parkinson’s disease, dystonia), refractory pain</td>
<td></td>
</tr>
<tr>
<td>Infection rate</td>
<td>5% (2.5-14%) 38%</td>
<td>5.6% (0-15%) 52%</td>
</tr>
<tr>
<td>Most common pathogens</td>
<td><em>S. aureus</em>, coagulase-negative staphylococci, <em>P. aeruginosa</em></td>
<td><em>S. aureus</em>, coagulase-negative staphylococci, <em>P. acnes</em></td>
</tr>
</tbody>
</table>

- Epidural abscess
- Rarely lead infection
- Brain abscess
- Meningitis
- Wire/wire extender infection
- >50% pocket infection

**References:**
- Follett K. *Anesthesiology* 2004; 100:1582–94.
- Kumar K. *Neuromodulation* 2014;17:22–35.
### Treatment of DBS- and SCS-associated infections

- Surgical debridement and soft tissue coverage
- Implant retention/immediate reimplantation possible if:
  - Early infection (for implant retention)
  - Microorganism known, susceptible to anti-biofilm antibiotics
  - No brain/epidural abscess

<table>
<thead>
<tr>
<th>Clinical situation</th>
<th>Deep brain/spinal cord stimulator</th>
<th>Antibiotic therapy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pocket infection</td>
<td>Change generator (and implantation site), keep wires and leads</td>
<td></td>
</tr>
<tr>
<td>Extracranial wire infection</td>
<td>Keep generator and leads, debride wound, change wires, lead extenders or connector sites</td>
<td>12 weeks anti-biofilm antibiotic treatment</td>
</tr>
<tr>
<td>DBS/SCS removed (no difficult to treat microorganisms)</td>
<td>Reimplantation immediate (1-stage exchange)</td>
<td></td>
</tr>
<tr>
<td>DBS/SCS removed (no difficult to treat microorganisms)</td>
<td>Reimplantation delayed (2-stage exchange), after 2-6 weeks</td>
<td></td>
</tr>
</tbody>
</table>

Conclusions

- If implant in situ → treat as biofilm infections
  - Always combination of surgery and anti-biofilm therapy

- In case of infection: Interdisciplinary management
  - Microbiologist, neurosurgeon, ID specialist

- Adhere to treatment algorithms to achieve high treatment success (cure rates >90% possible)
  - Improved diagnostic with sonication of implants
  - Efficient strategy to cure infections without implant removal or 1-stage implant exchange
Neurological implants

Craniotomy/bone flap
Cranioplasty
Deep brain stimulator
Ventriculo-peritoneal shunt
Spinal cord stimulator
External ventricular drainage
Ventriculo-atrial shunt

Thank you for your attention

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