ERRATUM

Open-loop deep brain stimulation for the treatment of epilepsy: a systematic review of clinical outcomes over the past decade (2008–present)


In the left column of Table 1, the first group named “Amygdala” was incorrect. This group should be “ANT” for “anterior nucleus of the thalamus.” Also, for the study by Krishna et al. (2016), the DBS response rate of 11/14 has been changed to 11/16 to reflect the original article. The corrected table appears on the following pages.

The article has been corrected online as of November 1, 2018.

Gillian Shasby
Director of Publications
Journal of Neurosurgery Publishing Group, Charlottesville, VA

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TABLE 1. Summary of literature review findings

<table>
<thead>
<tr>
<th>Target/Authors &amp; Year</th>
<th>Study Type</th>
<th>No. of Pts</th>
<th>Target</th>
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<td>ANT</td>
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<tr>
<td>Lim et al., 2008</td>
<td>CS</td>
<td>4</td>
<td>Bilat ANT</td>
<td>CS</td>
<td>2 yrs</td>
<td>50% (2/4)</td>
<td></td>
<td>1 pt developed asymptomatic hemorrhage; 1 pt developed erosion of extension wire through scalp, requiring surgical repair</td>
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<tr>
<td>Andrade et al., 2010</td>
<td>CS</td>
<td>1</td>
<td>ANT</td>
<td>CS</td>
<td>9.5–10 yrs</td>
<td>50% (1/2)</td>
<td>No changes in behavior or cognitive status</td>
<td>None described</td>
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<tr>
<td>Fisher et al., 2010</td>
<td>RCT</td>
<td>110</td>
<td>Bilat ANT</td>
<td>RCT</td>
<td>24 mos</td>
<td>53% (43/81)</td>
<td>Stimulated participants were more likely to report depression or memory impairment as adverse events during the blinded phase</td>
<td>12.7% of pts developed infections (7.3% stimulator pocket, 5.5% lead extensions, 1.8% bur hole), &amp; 8.2% required removal of hardware; 8.2% of pts required lead repositioning; 4.5% of pts developed asymptomatic hemorrhage; 1 participant developed status epilepticus associated w/ stimulation</td>
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<tr>
<td>Lee et al., 2012</td>
<td>CS</td>
<td>15</td>
<td>Bilat ANT</td>
<td>CS</td>
<td>24–67 mos</td>
<td>87% (13/15)</td>
<td></td>
<td>1 pt developed wound infection requiring explantation</td>
</tr>
<tr>
<td>Oh et al., 2012</td>
<td>CS</td>
<td>9</td>
<td>Bilat ANT</td>
<td>CS</td>
<td>Mean 15.9 mos</td>
<td>78% (7/9)</td>
<td>Improved performance in verbal fluency tasks &amp; delayed verbal memory after ANT DBS; improvement not correlated to Sz reduction. No significant changes in IQ, MMSE score, information processing, or executive function. No significant cognitive decline after DBS</td>
<td>None described</td>
</tr>
<tr>
<td>Penn et al., 2012</td>
<td>CR</td>
<td>1</td>
<td>Bilat ANT</td>
<td>CR</td>
<td>10 mos</td>
<td>NA</td>
<td></td>
<td>Pt developed Twiddler syndrome, requiring revision of IPG &amp; extension wires. After revision op, pt developed a wound infection requiring explantation</td>
</tr>
<tr>
<td>Hartikainen et al., 2014</td>
<td>CT</td>
<td>12</td>
<td>Bilat ANT</td>
<td>CT</td>
<td>NA</td>
<td>NA</td>
<td>ANT DBS stimulation increased the frequency of commission errors &amp; slowed reaction time in the presence of threat-related distractors</td>
<td>None described</td>
</tr>
<tr>
<td>Bucurenciu et al., 2015</td>
<td>CR</td>
<td>1</td>
<td>Bilat ANT</td>
<td>CR</td>
<td>11 mos</td>
<td>NA</td>
<td>Stimulation voltages &gt;3 V were associated w/ subclinical Szs in the anterior &amp; temporal regions</td>
<td>None described</td>
</tr>
</tbody>
</table>

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<th>Target/Authors &amp; Year</th>
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<td><strong>ANT (continued)</strong></td>
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<tr>
<td>Cukiert et al., 2015</td>
<td>CS 6</td>
<td>ANT</td>
<td>5 V; 130 Hz; 300 μsec; continuous</td>
<td>Up to 6 mos after battery depletion</td>
<td>100% (9/9)</td>
<td>1 pt did not experience increased Sz frequency after battery depletion; 5 pts experienced increased Sz frequency after battery depletion, 3 of whom had lower Sz frequency than at pre-DBS baseline, while 2 returned to pre-DBS baseline</td>
<td>None described</td>
<td></td>
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<tr>
<td>Piacentino et al., 2015</td>
<td>CS 6</td>
<td>ANT</td>
<td>4 V; 140 Hz; 90 μsec; not specified</td>
<td>24 mos</td>
<td>50% (3/6)</td>
<td>1 pt died 40 days postop due to a myocardial infarction (unrelated to op)</td>
<td>None described</td>
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<td>Salanova et al., 2015 (SANTE study w/ 5-yr FU)</td>
<td>CS 74</td>
<td>Bilat ANT</td>
<td>Not described</td>
<td>5 yrs</td>
<td>69% (51/74)</td>
<td>Significant improvement in neuropsychological testing at 5 yrs, specifically in attention, executive function, depression, tension/ anxiety, total mood disturbance, &amp; subjective cognitive function. Significant improvement in QOL (QOLIE-31) at 5 yrs</td>
<td>Implant site infection in 12.7% of pts; 9 required full/partial system explantation. Lead not w/in target in 8.2% of pts</td>
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<tr>
<td>Van Gompel et al., 2015</td>
<td>CS 2</td>
<td>Bilat ANT (stimulation) + bilat HCP (recording)</td>
<td>4 V; 7–8 Hz; 90 μsec; intermittent (0.4 on, 0.1 off) or continuous</td>
<td>12 wks</td>
<td>100% (2/2)</td>
<td>None described</td>
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<tr>
<td>Voges et al., 2015</td>
<td>CS 9</td>
<td>ANT</td>
<td>4 V; 145 Hz; 90 μsec; intermittent (1 on, 5 off)</td>
<td>1–21 mos</td>
<td>44% (4/9)</td>
<td>2 pts excluded because of technical artifacts; remaining 7 pts demonstrated DBS-related arousal w/ maximal voltage. At 5 V, DBS-related arousal occurred w/ 14.0%–67.0% of all DBS stimuli. Reduction of DBS voltage to btwn 1 &amp; 4 V led to decrease in DBS-related arousals to btwn 9.0% &amp; 33.0% of all stimuli. Reduction of nocturnal DBS voltages resulted in no worsening of Sz frequency &amp; incomplete/complete remission of neuropsychiatric symptoms</td>
<td>None described</td>
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<tr>
<td>Franco et al., 2016</td>
<td>CS 2</td>
<td>ANT</td>
<td>5 V; 145 Hz; 90 μsec; continuous</td>
<td>12–18 mos</td>
<td>100% (2/2)</td>
<td>Both pts experienced new-onset or worsening depressive symptoms after ANT DBS</td>
<td>None described</td>
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### TABLE 1. Summary of literature review findings

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<tr>
<td>Krishna et al., 2016</td>
<td>CS</td>
<td>16</td>
<td>ANT</td>
<td>2.4–7 V; &gt;100 Hz; 90 μsec; not specified</td>
<td>1–14 yrs (mean 4.3 ± 3.6)</td>
<td>69% (11/16)</td>
<td>1 pt developed a deep infection requiring explantation; 1 developed a superficial infection requiring wound revision; 1 experienced severe postop agitation requiring cessation of stimulation</td>
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<tr>
<td>Lehtimäki et al., 2016</td>
<td>CS</td>
<td>15</td>
<td>Bilat ANT</td>
<td>5 V; 140 Hz; 90 μsec; intermittent (1 on, 5 off)</td>
<td>5 yrs</td>
<td>67% (10/15)</td>
<td>None described</td>
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<tr>
<td>Sweeney-Reed et al., 2016</td>
<td>CS</td>
<td>8</td>
<td>Unilat/bilat ANT/DMNT</td>
<td>Not described</td>
<td>6 mos</td>
<td>50% (4/8)</td>
<td>None described</td>
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<tr>
<td>Lee et al., 2017</td>
<td>CR</td>
<td>1</td>
<td>Bilat ANT</td>
<td>8 V; 145 Hz; 120 μsec; continuous</td>
<td>45 days</td>
<td>NA</td>
<td>Immediate resolution of RSE after DBS placement &amp; stimulation; 100% decrease in GTCS &amp; “head nodding” events &amp; 90% decrease in staring episodes &amp; myoclonic jerks during FU</td>
<td>None described</td>
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<tr>
<td>Valentín et al., 2017</td>
<td>CS</td>
<td>1</td>
<td>Bilat ANT</td>
<td>Not described</td>
<td>12–48 mos</td>
<td>100% (1/1)</td>
<td>Pt w/ bilat ANT DBS developed increased aggression</td>
<td>None described</td>
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<td>Tröster et al., 2017 (SANTE trial w/ 7-yr FU)</td>
<td>RCT</td>
<td>67</td>
<td>Bilat ANT</td>
<td>Not described</td>
<td>7 yrs</td>
<td>NA</td>
<td>Stimulated participants were more likely to report depression or memory impairment as adverse events, but no objective cognitive decline or worsening of depression was observed in this group during the blinded phase. No overall cognitive decline or worsening of depression scores was observed 7 yrs into the open-label period. Self-reported depression &amp; memory impairment adverse events were not associated w/ reliable changes on objective neuropsychological measures or overall 7-yr neurobehavioral outcome</td>
<td>See Fisher et al., 2010\textsuperscript{15}</td>
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<td><strong>CMT</strong></td>
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<tr>
<td>Cukiert et al., 2009</td>
<td>CS</td>
<td>4</td>
<td>Bilat CMT</td>
<td>2 V; 130 Hz; 300 μsec; continuous</td>
<td>1–2 yrs</td>
<td>100% (4/4)</td>
<td>Clinically relevant increase in attention level in 4/4 pts after CMT DBS</td>
<td>None described</td>
</tr>
</tbody>
</table>

\textsuperscript{15} See Fisher et al., 2010
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<tr>
<td>Valentín et al., 2012</td>
<td>CR</td>
<td>1</td>
<td>Bilat CMT</td>
<td>5 V; 6 Hz; 90 μsec; continuous</td>
<td>6 mos</td>
<td>NA</td>
<td>Immediate resolution of tonic-clonic Szs &amp; epileptiform discharges after DBS placement &amp; stimulation. Further resolution of myoclonic jerks 4 wks after initiation of DBS</td>
<td>Electrodes explanted at 6 mos due to infection</td>
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<tr>
<td>Cukiert et al., 2015</td>
<td>CS</td>
<td>2</td>
<td>CMT</td>
<td>5 V; 130 Hz; 300 μsec; continuous</td>
<td>Up to 6 mos after battery depletion</td>
<td>100% (2/2)</td>
<td>1 pt did not experience increased Sz frequency after battery depletion; 1 pt experienced increased Sz frequency after battery depletion, but the frequency was lower than pre-DBS baseline</td>
<td>None described</td>
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<tr>
<td>Valentín et al., 2013</td>
<td>CT</td>
<td>11</td>
<td>Bilat CMT</td>
<td>5 V; 60–130 Hz; 90 μsec; continuous</td>
<td>12–66 mos</td>
<td>64% (7/11)</td>
<td></td>
<td>1 pt required device explantation because of infection; 1 experienced transient agraphia immediately after implantation</td>
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<tr>
<td>Son et al., 2016</td>
<td>CS</td>
<td>14</td>
<td>Unilat/bilat CMT</td>
<td>2.2 ± 0.41 V; 129.3 ± 2.7 Hz; 124.4 ± 23.0 μsec; continuous</td>
<td>9–25 mos</td>
<td>79% (11/14)</td>
<td>No correlation btwn calculated coordinates &amp; percentage of Sz reduction</td>
<td>1 pt required lead repositioning</td>
<td></td>
</tr>
<tr>
<td>Lehtimäki et al., 2017</td>
<td>CR</td>
<td>1</td>
<td>Bilat CMT</td>
<td>7 V; 180 Hz; 150 μsec; continuous</td>
<td>7 mos</td>
<td>NA</td>
<td>Resolution of RSE w/ high-frequency stimulation combined w/ S-ketamine infusion; RSE returned when stimulation switched from continuous to intermittent but resolved again w/ continuous stimulation; 2–4 focal Szs per mo on continuous stimulation (baseline frequency not noted)</td>
<td>None described</td>
<td></td>
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<tr>
<td>Valentín et al., 2017</td>
<td>CS</td>
<td>2</td>
<td>Bilat CMT</td>
<td>Not described</td>
<td>12–48 mos</td>
<td>50% (1/2)</td>
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<td><strong>HCP</strong></td>
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<tr>
<td>McLachlan et al., 2010</td>
<td>CT</td>
<td>2</td>
<td>Bilat HCP</td>
<td>0.5+ V; 185 Hz; 90 μsec; continuous</td>
<td>12 mos</td>
<td>NA</td>
<td>Subjective memory improvement in 1 pt during stimulation period</td>
<td>None described</td>
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<tr>
<td>Boex et al., 2011</td>
<td>CS</td>
<td>8</td>
<td>Unilat/bilat HCP/AMG</td>
<td>0.5–2 V; 130 Hz; 450 μsec; continuous</td>
<td>12–74 mos</td>
<td>75% (6/8)</td>
<td>Reversible memory impairments w/ high-voltage or quadripolar stimulation in 2 pts; otherwise, no significant neuropsychological outcomes</td>
<td>None described</td>
<td></td>
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<td>Target/Authors &amp; Year</td>
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<tr>
<td>Miatton et al., 2011</td>
<td>CS</td>
<td>10</td>
<td>Unilat/bilat HCP/AMG</td>
<td>1–2.5 V; 130 Hz; 450 μsec; continuous</td>
<td>6 mos</td>
<td>70% (7/10)</td>
<td>Pts w/ both unilat &amp; bilat HCP/AMG DBS reported significantly fewer somatic complaints &amp; feelings of insufficient mental/physical functioning. Unilat HCP/AMG DBS in dominant hemisphere was associated w/ significantly lower verbal IQ. No overall pattern of change in cognitive measures w/ DBS</td>
<td>None described</td>
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<tr>
<td>Bondallaz et al., 2013</td>
<td>CS</td>
<td>8</td>
<td>HCP</td>
<td>0.5–2 V; 130 Hz; 450 μsec; continuous</td>
<td>10–74 mos</td>
<td>75% (6/8)</td>
<td>1 pt required reimplantation of an electrode due to lead fracture</td>
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<tr>
<td>Vonck et al., 2013</td>
<td>CS</td>
<td>11</td>
<td>Unilat/bilat HCP/AMG</td>
<td>1–6 V; 130 Hz; 450 μsec; continuous +/- day/night cycling</td>
<td>67–120 mos</td>
<td>82% (9/11)</td>
<td>1 pt had asymptomatic intracranial hemorrhage; 1 pt required cable revision due to hardware failure; 1 pt required pulse generator removal due to local infection</td>
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<tr>
<td>Cukiert et al., 2014</td>
<td>CS</td>
<td>9</td>
<td>Unilat/bilat HCP</td>
<td>1–3.5 V; 130 Hz; 300 μsec; continuous</td>
<td>15–50 mos</td>
<td>78% (7/9)</td>
<td>1 pt required explantation due to infection related to trauma directly to the generator</td>
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<tr>
<td>Cukiert et al., 2015</td>
<td>CS</td>
<td>1</td>
<td></td>
<td>2 V; 130 Hz; 300 μsec; continuous</td>
<td>Up to 6 mos after battery depletion</td>
<td>100% (1/1)</td>
<td>Sz frequency increased after battery depletion but was lower than pre-DBS baseline</td>
<td>None described</td>
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<tr>
<td>Jin et al., 2016</td>
<td>CS</td>
<td>3</td>
<td>Bilat HCP</td>
<td>1–2.5 V; 130–170 Hz; 450 μsec; continuous</td>
<td>26–43 mos</td>
<td>100% (3/3)</td>
<td>No postop neuropsychological deterioration at 1 yr as measured by Wechsler Adult Intelligence Scale &amp; Wechsler Memory Scale</td>
<td>None described</td>
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<tr>
<td>Lim et al., 2016</td>
<td>CS</td>
<td>5</td>
<td>Unilat/bilat HCP</td>
<td>Low frequency: 1–6 V; 3–5 Hz; 90–120 μsec; intermittent (1 on, 5 off)</td>
<td>30–42 mos</td>
<td>60% (3/5)</td>
<td>None described</td>
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<tr>
<td>Cukiert et al., 2017</td>
<td>RCT</td>
<td>16</td>
<td>Unilat/bilat HCP</td>
<td>2 V; 130 Hz; 300 μsec; continuous</td>
<td>8 mos</td>
<td>87.5% (7/8)</td>
<td>2 pts presented w/ local wound erosions &amp; were treated successfully w/ antibiotics</td>
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</table>

Other

<table>
<thead>
<tr>
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<tr>
<td>Franzini et al., 2008</td>
<td>CS</td>
<td>4</td>
<td>Bilat pHyp</td>
<td>1.5–3.5 V; 185 Hz; 90 μsec; continuous</td>
<td>6 mos–5 yrs</td>
<td>75% (3/4)</td>
<td>2 pts who had significant behavior comorbidity before pHyp DBS experienced dramatic improvement in disruptive behavior</td>
<td>None described</td>
</tr>
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<tr>
<td>Wille et al., 2011</td>
<td>CS</td>
<td>5</td>
<td>Bilat SNr/STN ± bilat VIM</td>
<td>1–4 V; 100–160 Hz; 60–120 μsec; continuous</td>
<td>12–42 mos</td>
<td>NA</td>
<td>Improvement in HRQoL in 4/5 pts, predominantly in overall, energy/fatigue, &amp; emotional well-being domains</td>
<td>1 pt developed hardware failure due to unilat electrode dislocation</td>
</tr>
<tr>
<td>Capecci et al., 2012</td>
<td>CS</td>
<td>2</td>
<td>Bilat STN</td>
<td>2–3 V; 130 Hz; 60 μsec; continuous ± day/night cycling</td>
<td>12–48 mos</td>
<td>50% (1/2)</td>
<td>Both pts exhibited neuropsychological decline w/ DBS, including worsening attention, abulia, apathy, &amp; mood changes. No improvement in functional status or QOL noted in either case</td>
<td>None described</td>
</tr>
<tr>
<td>Koubeissi et al., 2013</td>
<td>CS</td>
<td>11</td>
<td>Fornix</td>
<td>8 mA/phase; 5Hz; 0.2 μsec; 4-hr sessions</td>
<td>48 hrs</td>
<td>NA</td>
<td>LFS of the fornix resulted in a significant increase in MMSE scores, mostly due to improvement in delayed recall scores</td>
<td>None described</td>
</tr>
<tr>
<td>Schmitt et al., 2014</td>
<td>CS</td>
<td>5</td>
<td>Bilat NAC + bilat ANT</td>
<td>5 V; 125 Hz; 90 μsec; intermittent (1 on, 5 off)</td>
<td>6 mos</td>
<td>40% (2/5)</td>
<td>No significant differences in neuropsychological measures at 6 mos: 1 pt experienced resolution of major depressive symptoms after NAC DBS &amp; 2 pts developed new-onset generalized anxiety disorder after DBS</td>
<td>None described</td>
</tr>
<tr>
<td>Benedetti-Isaac et al., 2015</td>
<td>CS</td>
<td>5</td>
<td>Bilat pHyp</td>
<td>3 V; 185 Hz; 90 μsec; intermittent (1 on, 5 off)</td>
<td>2 mos–4 yrs (mean 2.63 yrs)</td>
<td>100% (5/5)</td>
<td>None described</td>
<td></td>
</tr>
<tr>
<td>Kowski et al., 2015</td>
<td>CT</td>
<td>4</td>
<td>Bilat NAC + bilat ANT</td>
<td>5 V; 125 Hz; 90 μsec; intermittent (1 on, 5 off)</td>
<td>15 mos</td>
<td>75% (3/4)</td>
<td>None described</td>
<td>1 pt developed subcuteaneous infection requiring explantation &amp; reimplantation at a later date</td>
</tr>
</tbody>
</table>

AMG = amygdala; CR = case report; CS = case series; CT = crossover trial; CZi = caudal zone incerta; DMNT = dorsomedial nuclei of the thalamus; FU = follow-up; GTCS = generalized tonic-clonic seizure; HRQoL = health-related quality of life; IPG = implantable pulse generator; MMSE = Mini–Mental State Examination; NA = not available; NAC = nucleus accumbens; pHyp = posterior hypothalamus; Pt = patient; QOL = quality of life; QOLIE-31 = Quality of Life in Epilepsy Inventory-31; RCT = randomized controlled trial; RSE = refractory status epilepticus; SNr = substantia nigra pars reticulata; STN = subthalamic nucleus; Sz = seizure; VIM = ventral intermediate nucleus of the thalamus.