Cochlear Implantation in Adults

A Systematic Review and Meta-analysis

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**Importance:** Sensorineural hearing loss is the third leading cause of years lived with disability worldwide. Cochlear implants may provide a viable alternative to hearing aids for this type of hearing loss. The Coverage and Analysis Group at the Centers for Medicare & Medicaid Services was interested in an evaluation of recently published literature on this topic. In addition, this meta-analysis is to our knowledge the first to evaluate quality-of-life (QOL) outcomes in adults with cochlear implants.

**Objective:** To evaluate the communication-related outcomes and health-related QOL outcomes after unilateral or bilateral cochlear implantation in adults with sensorineural hearing loss.

**Data Sources:** MEDLINE, Cochrane Central Register of Controlled Trials, Scopus, and previous reports from January 1, 2004, through May 31, 2012.

**Study Selection:** Published studies of adult patients undergoing unilateral or bilateral procedures with multi-channel cochlear implants and assessments using open-set sentence tests, multisyllable word tests, or QOL measures.

**Data Extraction:** Five researchers extracted information on population characteristics, outcomes of interest, and study design and assessed the studies for risk of bias. Discrepancies were resolved by consensus.

**Results:** A total of 42 studies met the inclusion criteria. Most unilateral implant studies showed a statistically significant improvement in mean speech scores as measured by open-set sentence or multisyllable word tests; meta-analysis revealed a significant improvement in QOL after unilateral implantation. Results from studies assessing bilateral implantation showed improvement in communication-related outcomes compared with unilateral implantation and additional improvements in sound localization compared with unilateral device use or implantation only. Based on a few studies, the QOL outcomes varied across tests after bilateral implantation.

**Conclusions and Relevance:** Unilateral cochlear implants provide improved hearing and significantly improve QOL, and improvements in sound localization are noted for bilateral implantation. Future studies of longer duration, higher-quality reporting, and large databases or registries of patients with long-term follow-up data are needed to yield stronger evidence.


Sensorineural hearing loss is the third leading cause of years lived with disability worldwide, according to the World Health Organization, and approximately 36 million adults in the United States report some degree of hearing loss. This type of hearing loss is usually permanent, occurs gradually, and becomes worse with increasing age, with clinical manifestations typically appearing during the fifth and sixth decades of life. Unlike routine eye examinations, screening for hearing loss among adults may not be performed regularly during primary care visits, and referrals for in-depth testing are uncommon, with poor follow-up rates and poor adherence to recommended treatment after screening.

Cochlear implants replace the function of hair cells that are no longer able to generate electrical impulses in response to sound. Therefore, these devices may provide a viable alternative to hearing aids among adults with sensorineural hearing loss because they bypass damaged hair cells by transmitting the electrical impulses directly to the acoustic nerve.

The Coverage and Analysis Group at the Centers for Medicare & Medicaid Services was interested in an evaluation of recently published literature on the effectiveness of cochlear implantation. There-
fore, the Agency for Healthcare Research and Quality (AHRQ) commissioned the Tufts Evidence-Based Practice Center to conduct a systematic review evaluating the comparative effectiveness of unilateral and bilateral cochlear implants in adult patients (≥18 years of age) with bilateral sensorineural hearing loss. Specifically, our aim was to address the communication- and health-related quality-of-life (QOL) outcomes achieved after successful unilateral implantation or after successful simultaneous or sequential bilateral implantations.

METHODS

We adapted methods from the AHRQ Methods Reference Guide for Effectiveness and Comparative Effectiveness Reviews and the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) statement. The full technical report describes the methods in detail, including literature search strategies, and presents results and evidence tables. The report also includes an extensive review of preoperative characteristics associated with improved outcomes; we refer the interested reader to this review owing to the practical constraints of presenting those results herein. For this report, we focused on the following 2 questions:

1. What communication- and health-related QOL outcomes are achieved in adults who undergo unilateral cochlear implantation?
2. What communication- and health-related QOL outcomes are gained from the use of bilateral compared with unilateral cochlear implants?

DATA SOURCES AND STUDY SELECTION

We searched MEDLINE, the Cochrane Central Register of Controlled Trials, and Scopus from January 1, 2004, through May 31, 2012, for studies of adults with bilateral sensorineural hearing loss who underwent cochlear implantation. We reviewed studies included in the national coverage decision memorandum published by the Centers for Medicare & Medicaid Services in 2005 and in the United Kingdom’s National Institute for Health and Clinical Excellence systematic review for cochlear implants to identify studies published before 2004 and eligible studies suggested by the peer reviewers of the full AHRQ technical report. We combined search terms or medical subject heading terms for sensorineural hearing loss and terms relevant to cochlear implantation (eg, hearing loss, sensorineural, deafness, and cochlear implant). We limited our search to primary studies of adults that were published in peer-reviewed journals. No language restriction was applied. We screened abstracts and retrieved full-text articles of the potentially relevant abstracts; we then rescreened these articles for possible inclusion.

STUDY ELIGIBILITY CRITERIA

We included studies of adults (≥18 years of age) with sensorineural hearing loss who had undergone unilateral or bilateral implantation with a multichannel cochlear device as the primary intervention. Concurrent use of hearing aids was permissible for inclusion, as well as use of cochlear implants of any coding strategy—the program used by the implant to interpret various aspects of incoming sound, such as pitch and loudness. Eligible studies must have included any of the following comparisons of interest: unilateral cochlear implantation compared with hearing aids in 1 or both ears, postoperative compared with preoperative outcomes, and bilateral compared with unilateral cochlear implantation (external cohort) or with either ear undergoing unilateral implantation (within subjects). Our outcomes of interest included communication- and health-related QOL outcomes. Eligible communication-related outcomes included evaluation of speech perception with open-set sentence tests and 2-syllable or multisyllable words tests, and health-related QOL outcomes included generic and hearing-specific measures. For bilateral implantation specifically, we also included outcomes of sound localization and binaural processing capabilities or improvements.

We included studies of any design and of any US Food and Drug Administration–approved device manufacturer. Consistent with the technical report, articles were included only if their study population consisted of a total of 30 or more patients for unilateral implantation or 10 or more patients for bilateral implantation. The sample size threshold of 30 was based on a consideration of the trade-off between potential information gain and practical considerations. During abstract screening, we lowered this threshold to 10 for studies of bilateral implantation owing to the small number of studies in this more recent body of literature.

We excluded studies of children and adults in which data were not separately available for adults only. Studies of brainstem implants, middle ear implants, or bone-anchored hearing aids for any type of hearing loss were excluded. Also excluded were studies of music perception.

DATA EXTRACTION AND QUALITY ASSESSMENT

Five researchers (J.M.G., G.R., M.C., J. Lee, and M.R.) extracted the studies. Data from each study were collected by one researcher and confirmed by another. Discrepancies were discussed and resolved by consensus. We used a customized data extraction form to abstract information on population characteristics, outcomes of interest, and study design (eFigure; http://www.jamaoto.com). We assessed the risk of bias of each study on the basis of methodological attributes that included selection, performance, attrition, study design, recall bias, and selective outcome reporting. Results of studies rated as having a low risk of bias are considered valid. Studies rated as having a medium risk of bias are susceptible to some bias but not sufficiently to invalidate the results. The high risk of bias in the remaining studies may invalidate the results.

DATA SYNTHESIS OF QOL OUTCOMES FOR UNILATERAL IMPLANTATION

Meta-analysis was used to compare preimplantation and postimplantation QOL variables measured with cochlear implant-specific, hearing-specific, and generic tests in studies that provided sufficient data. When calculating the standardized effect size for each study, we assumed a correlation of 0.30 between preimplantation and postimplantation values to account for repeated measurement of QOL within each study. We then computed the Hedges’ g value, the bias-corrected standardized mean difference, and the corresponding standard error. To compute the overall mean effect size, we used an inverse-variance random-effects model that assumes the existence of no single true population effect and allows for random between-study variance in addition to sampling variability. Analyses were performed using commercially available software (Stata, version 11; StataCorp). For those studies that reported outcomes data in graph form only, the values were estimated using digitizing software (Engauge Digitizer, version 2.14; http://digitizer.sourceforge.net/).

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RESULTS

Our search identified 2042 citations, of which 1762 were excluded at the abstract level. Thus, we evaluated a total of 280 full-text articles according to the predefined inclusion criteria. We selected 45 articles reporting 42 unique studies, including 3 from the National Institute for Health and Clinical Excellence report (Figure 1). Assessment of risk of bias showed medium to high risk of bias across studies, and no study was rated as having a low risk of bias. Twenty-three articles were found to have a medium risk of bias owing to a lack of adjustment for confounders, poor reporting of eligibility criteria, or a lack of quantitative interpretations of results. Twenty-two articles were found to have a high risk of bias owing to risk of recall bias, not accounting for all participants, cross-sectional study design, a lack of adjustment for confounders, incomplete reporting of results, or very high dropout rates.

COMMUNICATION-RELATED OUTCOMES IN UNILATERAL IMPLANTATION

A total of 16 studies (published in 17 articles)11-27 were identified as assessing communication-related outcomes. These outcomes were measured by open-set sentence tests or 2-syllable or multisyllable word tests (Table 1) using the following 6 different tests: AzBio sentence lists24; Bamford-Kowal-Bench sentence test11,13,14; Central Institute for the Deaf sentence test18,29; the City University of New York (CUNY) sentence test12,16,19,20,25; the Hearing in Noise Test (HINT)12,13,17,20,21,23,24; and the Hochmair-Schultz-Moser sentence test.22,27

No studies reported a decrease in mean speech scores after implantation. All studies comparing outcomes before and after implantation reported statistically significant improvement in mean speech scores, except for five13,16,17,22,24 that reported a nonsignificant benefit. All studies assessed preimplantation vs postimplantation scores in patients receiving unilateral devices, except one21 that assessed unilateral cochlear implantation vs a hearing aid. All studies except 1 cross-sectional study15 followed up patients longitudinally.

Higher-quality studies with a medium risk of bias12,19,22,23,25,26 all showed consistently significant improvement in speech outcomes after compared with before implantation. Lower-quality studies with a high risk of bias revealed variable (significant and nonsignificant) improvement in speech outcomes.13,15,17,19,21,22,24,27

COMMUNICATION-RELATED OUTCOMES IN BILATERAL IMPLANTATION

We identified 15 studies (published in 19 articles) assessing communication-related health outcomes in patients who received bilateral cochlear implants simultaneously,28,30 sequentially,21,37-43 or both44,45 (Table 2). All but 2 studies26,33 of simultaneous bilateral implantation showed a statistically significant improvement in communication-related outcome scores compared with unilateral implantation; in most studies, unilateral implantation was tested by temporarily deactivating 1 implant. One study found a statistically significant improvement in the ear with poorer hearing but a nonsignificant improvement in the ear with better hearing.32 In the 5 studies21,37-40 in which patients received bilateral sequential implants, all patients showed statistically significant clinical improvement or no significant net change after the first implantation. For the 2 studies that examined patients undergoing simultaneous and sequential implantation as a single group, one44 found an improvement in speech perception compared with unilateral activation of either ear in noisy conditions, but in quiet conditions an improvement in speech recognition only in the ear with better hearing compared with the ear with poorer hearing. The other45 showed no significant difference between the bilateral and bimodal (unilateral implant plus hearing aid) groups. All but 1 study44 tested sound localization in quiet conditions and reported an overall improvement in sound localization ability compared with unilateral implantation or activation. The risk of bias varied from medium to high across studies.

QOL OUTCOMES IN UNILATERAL IMPLANTATION

Thirteen studies11,14,19,26,46-54 were identified as evaluating QOL outcomes in patients receiving unilateral implants. These studies varied in design; all but 2 (comparing patients with a cochlear implant and those eligible for but without a cochlear implant) compared QOL after and before implantation as assessed by any of 17 tests.
Implant-specific, and otologically relevant) (Table 1).

We found considerable heterogeneity in the cochlear implantation in all but 1 QOL domain (family climate) for each study showed significant improvement. A sensitivity analysis revealed a consistent improvement in QOL at 3-, 6-, and 12-month intervals.

### QOL OUTCOMES IN BILATERAL IMPLANTATION

Three studies assessed QOL in recipients of bilateral vs unilateral cochlear implants (across groups or within subjects). Two of these studies showed a significant benefit across 5 subscales of 3 different hearing-related QOL tests but no change in the subscales that assessed emotional QOL and aversion to sound in patients with simultaneous bilateral implantation. For sequential implantation, improvement in QOL was seen in assessment on a social-emotional-psychological subscale but a statistically significant decrease in a generic QOL outcome assessor that was mainly attributable to tinnitus in 2 participants. We did not perform a quantitative analysis...
Table 2. Results of Communication-Related Outcomes in Bilateral Implantation

<table>
<thead>
<tr>
<th>Source (Country)</th>
<th>Study Design and Length of Follow-up</th>
<th>Cochlear Implant, No. of Patients</th>
<th>Mean Age, y</th>
<th>Degree of Deafness</th>
<th>Comparator</th>
<th>Speech Outcome</th>
<th>Reported Change (P Value)</th>
<th>Other Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Simultaneous Implantation</strong></td>
<td></td>
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<tr>
<td>Buss et al.26 2008 (United States)</td>
<td>Cohort (P)</td>
<td>26</td>
<td>48</td>
<td>Severe to profound hearing loss</td>
<td>Within same subjects, either ear implant</td>
<td>CUNY in noise</td>
<td>Improvement in signal to noise ratio (NS)</td>
<td>Head shadow effect Binaural summation Binaural squelch</td>
</tr>
<tr>
<td>Grantham et al.27 2007 (United States)</td>
<td>Cohort (P)</td>
<td>1 y</td>
<td>57</td>
<td>Severe to profound hearing loss</td>
<td>Within same subjects, either ear implant</td>
<td>CUNY in noise</td>
<td>Improvement in signal to noise ratio (NS)</td>
<td>None</td>
</tr>
<tr>
<td>Dunn et al.28 2008 (United States)</td>
<td>Cross-sectional</td>
<td>66</td>
<td>54 At implantation</td>
<td>ND</td>
<td>Within same subjects, either ear implant</td>
<td>HINT in quiet</td>
<td>Improvement in bilateral scores (&lt;.05)</td>
<td>None</td>
</tr>
<tr>
<td>Dunn et al.29 2010 (United States)</td>
<td>Cross-sectional</td>
<td>30 Simultaneous, 30 unilateral</td>
<td>56</td>
<td>96- to 102-dB hearing loss</td>
<td>Unilateral implantation</td>
<td>Speech test</td>
<td>Improvement in bilateral scores (&lt;.01)</td>
<td>None</td>
</tr>
<tr>
<td>Koch et al.30 2009 (United States)</td>
<td>Cohort (P)</td>
<td>15</td>
<td>51</td>
<td>Severe to profound hearing loss</td>
<td>Within same subjects, either ear implant</td>
<td>HINT</td>
<td>Improvement in bilateral scores (&lt;.05)</td>
<td>None</td>
</tr>
<tr>
<td>Litovsky,31 2004 (United States)</td>
<td>Cohort (P)</td>
<td>3 mo</td>
<td>17</td>
<td>53</td>
<td>ND</td>
<td>BKB-SIN speech-in-babble task</td>
<td>Improvement in bilateral scores (&lt;.01)</td>
<td>Noise location</td>
</tr>
<tr>
<td>Litovsky et al.32 2006 (United States)</td>
<td>Cohort (P)</td>
<td>6 mo</td>
<td>37</td>
<td>54</td>
<td>Hearing thresholds from 70 dB to no response (postlinguistic)</td>
<td>BKB-SIN Overall HINT</td>
<td>Improvement in bilateral scores (&lt;.01)</td>
<td>None</td>
</tr>
<tr>
<td>Litovsky et al.33 2009 (United States)</td>
<td>Cohort (P)</td>
<td>6 mo</td>
<td>17</td>
<td>53</td>
<td>Severe to profound hearing loss</td>
<td>Within same subjects, either ear implant</td>
<td>BKB-SIN</td>
<td>Improvement in bilateral scores (&lt;.01)</td>
</tr>
<tr>
<td>Litovsky et al.34 2009 (United States)</td>
<td>Cohort (P)</td>
<td>1 y</td>
<td>27</td>
<td>45</td>
<td>Postlinguistic bilateral profound or total hearing loss</td>
<td>Within same subjects, either ear implant</td>
<td>Disyllabic words in noise and quiet</td>
<td>Significant improvement in bilateral vs unilateral at 6 and 12 mo</td>
</tr>
<tr>
<td>Mosnier et al.35 2009 (France)</td>
<td>Cohort (P)</td>
<td>22</td>
<td>46 At first implantation; 52 at second</td>
<td>Profound deafness</td>
<td>Within same subjects, either ear implant</td>
<td>BKB-SIN</td>
<td>Improvement in bilateral implant (&lt;.05)</td>
<td>None</td>
</tr>
<tr>
<td><strong>Sequential Implantation</strong></td>
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<tr>
<td>Gifford et al.36 2008 (United States)</td>
<td>Cross-sectional</td>
<td>13 (1 Simultaneous)</td>
<td>59.5</td>
<td>ND</td>
<td>Unilateral implant (external group) Bimodal</td>
<td>2Bio sentence lists BKB-SIN</td>
<td>All comparisons (NS)</td>
<td>None</td>
</tr>
<tr>
<td>Laske et al.37 2009 (Switzerland)</td>
<td>Cross-sectional</td>
<td>29 (2 Simultaneous)</td>
<td>31 At first implant</td>
<td>Severe to profound hearing loss</td>
<td>Within same subjects, either ear implant</td>
<td>OLSA in quiet</td>
<td>Bilateral vs better ear None implant (NS) Improvement vs poorer ear implant (&lt;.001)</td>
<td>None</td>
</tr>
<tr>
<td>Nopp et al.38 2004 (Austria)</td>
<td>Cross-sectional</td>
<td>18</td>
<td>44</td>
<td>Prelinguistic or postlinguistic deafness</td>
<td>Within same subjects, either ear implant</td>
<td>OLSA</td>
<td>Improvement in bilateral implant (&lt;.05)</td>
<td>Head shadow effect Binaural summation Binaural squelch</td>
</tr>
<tr>
<td>Ramden et al.39 2005 (United Kingdom)</td>
<td>Cohort (P)</td>
<td>31</td>
<td>57</td>
<td>103- to 108-dB hearing loss</td>
<td>Within same subjects, bilateral vs first ear implant</td>
<td>CUNY in noise and quiet</td>
<td>In quiet (NS) Improvement in noise (&lt;.001)</td>
<td>None</td>
</tr>
<tr>
<td>Verschuur et al.40 2005 (United Kingdom)</td>
<td>Cohort (P)</td>
<td>9 mo</td>
<td>20</td>
<td>61</td>
<td>Severe or profound deafness &lt;15 y in either ear</td>
<td>Within same subjects, either ear implant</td>
<td>Sound localization in the horizontal plane</td>
<td>Bilateral had marked improvement in localization compared with unilateral (&lt;.001)</td>
</tr>
<tr>
<td>Zeitler et al.41 2008 (United States)</td>
<td>Cohort (R)</td>
<td>ND for follow-up</td>
<td>22</td>
<td>46</td>
<td>At first implantation; 52 at second</td>
<td>Profound deafness</td>
<td>HINT in quiet BKB-SIN</td>
<td>Improvement in bilateral implant (&lt;.05)</td>
</tr>
</tbody>
</table>

**Abbreviations:** BKB-SIN, Bamford-Kowal-Bench Speech in Noise sentence test; CUNY, City University of New York sentence test; HINT, Hearing in Noise Test; HSM, Hochmair-Schulz-Moser test; ND, no data; NS, not statistically significant; OLSA, Oldenburg Sentence Test; P, prospective; R, retrospective; SNR, signal to noise ratio.

Study population was part of the population included in Ramsden et al.37

Study population was part of the population included in Summerfield et al.43
synthesis of these results because of heterogeneity in design between the studies.

In summary, unilateral cochlear implantation with or without the additional use of hearing aids was an effective method for improving speech perception and health-related QOL in adults with severe to profound sensorineural hearing loss in the studies assessed within this review. Compared with unilateral implantation, bilateral cochlear implantation provided added improvements in speech perception. These findings are consistent with the results of the National Institute for Health and Clinical Excellence guidelines, in particular the conclusion that speech perception and QOL improve with unilateral and bilateral implantation, especially in noisy conditions.

Overall results from published studies showed that unilateral implantation provided a benefit in terms of hearing-related outcomes and QOL. As shown in the meta-analysis that revealed a significant improvement in postoperative QOL, a patient whose QOL is affected negatively by sensorineural hearing loss may experience improved QOL from unilateral cochlear implantation. (This result should not be interpreted to imply that deafness necessarily diminishes QOL.) To our knowledge, this meta-analysis is the first to evaluate QOL in adults with cochlear implants. The QOL findings are of particular importance because they provide strong evidence of this patient-centered outcome. However, despite lowering the threshold of inclusion criteria to 10 patients per study of bilateral implantation, a limited number of studies assessed QOL outcomes after bilateral implantation; therefore, although generally showing improvement, results of QOL outcomes after bilateral implantation cannot be generalized appropriately. More studies may be warranted that examine the added improvement in QOL after a second implant or after simultaneous implantation.

Because a large number of different tests are in use, this heterogeneity in speech and hearing tests across studies creates difficulty in comparing their findings. Although this may reflect actual variation within clinical practice across the countries and centers identified during the review, specific conclusions are therefore more difficult to abstract, and a quantitative synthesis of speech-related results was infeasible. However, significant improvements in speech outcomes pervade the identified literature. Moreover, although indirect evidence of the effectiveness of bilateral vs unilateral implantation was...
less pronounced in terms of QOL than the evidence regarding unilateral implantation alone, we found consistent improvement across studies in sound localization with the addition of the second implant.

The strength of the results is based on a comprehensive search performed in obtaining them, the consistency of reported outcomes, and the large effect size of the meta-analysis. Limitations, although they may shape the way in which the results are interpreted, do not invalidate the results. All included studies were assessed as having a medium or a high risk of bias. Most studies had poor reporting of baseline and follow-up data, and very few studies adjusted for confounders in their analyses. In several studies, preoperative characteristics were recalled postoperatively, potentially causing recall bias in favor of the treatment. Some limitations also exist in the quantitative synthesis. Chiefly, our analysis is based on study-level data and not individual patient data. Because of heterogeneity in outcomes, we combined effects from studies after standardizing them to a dimensionless measure. When calculating the standardized effect size for each study, we assumed a correlation of 0.50 between pre- and postimplantation and postimplantation values because this correlation was not reported directly in the literature.

Finally, studies of longer follow-up are needed to assess additional benefits in terms of health-related QOL and the potential risks and benefits of bilateral cochlear implantation compared with unilateral implantation. Particularly in the case of sequential bilateral implants, a significant second-ear training effect evolves over time, and longer follow-up is essential to assess these ultimate results properly. Future studies of higher-quality reporting and large databases or registries of patients with long-term follow-up data are needed to yield stronger evidence. We acknowledge the significant challenges in obtaining funding for prospective studies that would generate the high levels of evidence that are desired, and we hope that the identification of this need will motivate funding sources to support future work.

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Author Contributions: Mr Gaylor and Drs Raman, Chung, Lee, and Lau had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. Study concept and design: Gaylor, Raman, Chung, Lee, and Lau. Acquisition of data: Gaylor, Raman, Chung, and Rao. Analysis and interpretation of data: Gaylor, Raman, Chung, and Poe. Drafting of the manuscript: Gaylor, Raman, and Lee. Critical revision of the manuscript for important intellectual content: Gaylor, Raman, Chung, Rao, Lau, and Poe. Statistical analysis: Raman. Obtained funding: Lau. Administrative, technical, and material support: Gaylor, Rao, Lau, and Poe. Study supervision: Lau.

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Online-Only Material: The eFigure is available at http://www.jamaoto.com.

Additional Contributions: Issa Dababneh, MD, MS, provided statistical advice and Jenny Lamont, MS, provided editing advice during manuscript preparation. Srila Sen, MA, provided editing advice and Marilyn Neault, PhD, CCC-A, provided technical advice during report preparation.

REFERENCES


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