Internal and external fixation techniques have been described for realignment and arthrodesis of Charcot midfoot deformity. There currently is no consensus on the optimal method of surgical reconstruction. This systematic review compared the clinical results of surgical realignment with internal and external fixation, specifically in regard to return to functional ambulation, ulcer occurrence, nonunion, extremity amputation, unplanned further surgery, deep infection, wound healing problems, peri- or intraoperative fractures, and total cases with any complication. A search of multiple databases for all relevant articles published from January 1, 1990, to March 22, 2014, was performed. A logistic regression model evaluated each of the outcomes and its association with the type of fixation method. The odds of returning to functional ambulation were 25% higher for internal fixation (odds ratio [OR], 1.259). Internal fixation had a 42% reduced rate of ulcer occurrence (OR, 0.578). External fixation was 8 times more likely to develop radiographic nonunion than internal fixation (OR, 8.2). Internal fixation resulted in a 1.5-fold increase in extremity amputation (OR, 1.488), a 2-fold increase in deep infection (OR, 2.068), a 3.4-fold increase in wound healing complications (OR, 3.405), and a 1.5-fold increase in the total number of cases experiencing any complication (OR, 1.525). This was associated with a 20% increase in the need for unplanned further surgery with internal fixation (OR, 1.221). Although internal fixation may decrease the risk of nonunion and increase return to functional ambulation, it had a higher rate of overall complications than external fixation for realignment and arthrodesis of Charcot midfoot deformity. [Orthopedics. 2016; 39(4):e595-e601.]
medullary cannulated screws, and solid intramedullary fusion bolts. External fixation typically is achieved with unilateral fixators, ring fixators, or hybrid fixators incorporating both types. There currently is no consensus on the optimal method of surgical correction, as each technique has strengths and weaknesses. An absence in the literature of systematic reviews comparing the 2 methods provided the motivation for this review.

This systematic review compared internal fixation and external fixation in midfoot arthrodesis for Charcot neuroarthropathy with regard to specific outcome measures: return to functional ambulation, postoperative ulceration, nonunion, extremity amputation, unplanned need for further surgery, deep infection, wound healing problems, peri- or intraoperative fractures, and total complication rate.

**Materials and Methods**

**Study Selection**

Searches of PubMed, MEDLINE, Embase, and the Cochrane Database of Systematic Reviews were performed for articles published from January 1, 1990, to March 22, 2014, using the search terms Charcot, diabetes, arthropathy, neuroarthropathy, internal fixation, external fixation, or Ilizarov. The reference lists of the retrieved articles were reviewed manually for any additional studies that met inclusion criteria.

**Eligibility**

To meet the criteria for inclusion, a study must have reported on: (1) patients with Charcot arthropathy of the midfoot secondary to diabetes mellitus who underwent Lisfranc or Chopart joint arthrodesis, (2) surgical treatment with either internal or external fixation, and (3) outcomes of interest. Articles were excluded from review when they met any of the following criteria: (1) studies in which surgery was performed for other causes of midfoot deformity, such as posttraumatic arthritis, (2) studies using a surgical technique that combined the use of both internal and external fixation, and (3) studies that reported on Charcot arthropathy and surgery at the ankle joint, where midfoot cases could not be extracted and analyzed separately.

Involvement of the hindfoot was neither an inclusion nor exclusion criterion (ie, as long as the midfoot was involved, patients also could have undergone surgery at the subtalar joint, calcaneocuboid joint, and the talonavicular joint, but not the ankle joint). All study designs were considered, and there were no restrictions based on language or country in which the study was performed. Duplicate data on the same patient population were excluded to avoid counting patients more than one time.

**Quality Assessment of the Literature**

The quality of each study selected for inclusion was evaluated using MacDermid’s Structured Effectiveness Quality Evaluation Scale (SEQES) and by the level of evidence criteria. The SEQES contains 24 items each scored from 0 to 2 based on adherence to specific criteria. Two independent reviewers (D.J.L., J.S.) scored each study using the specific descriptors provided in MacDermid’s original paper to limit subjectivity and variance between reviewers. Consensus was reached using MacDermid’s adjudication process. Each study was assigned a cumulative score (out of 48) to rank the study as low (scores 1-16), moderate (scores 17-32), or high quality (scores 33-48). 7

**Data Extraction**

The literature search was conducted independently by 2 reviewers (D.J.L., J.S.). Abstracts of eligible studies were reviewed, and relevant manuscripts were read in full. Each reviewer (D.J.L., J.S.) independently extracted the data and entered them into a standardized data-extraction form. Any differences were resolved by discussion until consensus was reached. In studies that included some patients without midfoot involvement but where these patients could be excluded on an individual basis, data were extracted for only those cases that involved the midfoot, with or without hindfoot involvement. Cases involving the ankle joint were excluded.

**Outcome Measures**

Outcomes of interest included: return to functional ambulation, postoperative ulcer occurrence, radiographic nonunion, extremity amputation, unplanned further surgery, deep infection, wound healing problems, peri- or intraoperative fractures, and total cases with any complication. Significant heterogeneity in the reporting of outcomes across the studies required the use of standardized definitions for each of the parameters examined.

**Return to Functional Ambulation.** This was defined as the ability to ambulate after surgery, with or without assistive devices and with or without special diabetic footwear. This excluded amputees or those who died prior to returning to functional ambulation, but included those who returned to functional ambulation then later died for unrelated causes.

**Ulcer Occurrence.** This was defined as the presence of any ulcer located in either the plantar midfoot or at a site other than the midfoot at any point during the follow-up period.

**Radiographic Nonunion.** This was defined as occurrence of any failure of solid bony union at any fusion or osteotomy site. A fibrous union was included as a nonunion, even if it was functionally stable.

**Extremity Amputation.** This was defined as any major amputation of the operative extremity, excluding toe amputations.

**Unplanned Further Surgery.** This was defined as the occurrence of any unplanned further surgery for any indication, not including amputation. These included incision and drainage for infection, management of wound complications (eg, skin grafting or delayed closure), revision...
of fixation, hardware removal including in-office procedures, and management of postoperative fractures.

**Deep Infection.** This was defined as the presence of any postoperative infection (e.g., osteomyelitis), not including superficial incision site infection or pin-tract infection.

**Wound Healing Problems.** This was defined as any wound dehiscence, skin sloughing, or other wound healing issues.

**Peri- or Intraoperative Fractures.** This was defined as any fracture occurring during the procedure or during the immediate postoperative period.

**Total Cases With Any Complication.** This was defined as the total number of cases with any complication.

### Statistical Analysis

A mixed-effects logistic regression analysis was used to account for the significant heterogeneity across the different studies. This model evaluated each of the outcomes described above and its association with the type of fixation method (internal vs external). The response was defined as the presence or absence of a specific outcome or individual complication event and entered into the model as the number of events (report of number with a given outcome) divided by the number of study participants. This formed the basis for the unweighted analyses. Logistic regression was used to estimate the odds ratio (OR) with 95% confidence intervals (CIs) for individual parameters.

In addition, each study was weighted by its sample size to investigate possible changes in the OR, under the assumption that those studies with a larger number of observations reflected greater experience among practitioners with a procedure and might provide a more appropriate estimate of the outcomes of interest. In fact, the weighted OR, rather than the unweighted incidence rates, likely provide the most accurate description of the differences between the 2 interventions with respect to individual parameters. All analyses were performed using SAS version 9.3 software (SAS Institute Inc, Cary, North Carolina) on a Windows 7 (Microsoft, Redmond, Washington) platform.

### RESULTS

#### Studies and Baseline Patient Characteristics

The initial search yielded 184 references. A review of the bibliographies of the obtained articles produced 12 additional studies. After stringent inclusion and exclusion criteria were applied, 11 studies were determined to meet the criteria (Figure). The characteristics of the included studies are summarized in Table 1.

All of the articles were published between 1996 and 2014. The majority of studies were conducted at single centers in the United States and Europe. All 11 studies represented Level IV evidence (case series or case reports), with 10 studies using a retrospective design and 1 study using a prospective design.

None of the studies directly compared internal and external fixation techniques. Of the 11 studies, 8 (73%) reported on internal fixation and 3 (27%) reported on external fixation. A total of 88 feet in 85 patients underwent internal fixation and 38 feet in 38 patients underwent external fixation for realignment of midfoot Charcot deformity. The studies on internal fixation used interfragmentary screws (n=1), plate and screws or screws alone (n=2), intramedullary cannulated screws (n=2), and the solid intramedullary fusion bolt (n=3). The studies on external fixation used monoplanar external fixators (n=2) and ring external fixators (n=1). Mean length of follow-up was 37.4 and 23.1
months for internal and external fixation, respectively.

**Specific Outcome Measures**

Results of statistical analysis and specific outcome measures are reported in Table 2, which includes the unweighted incidence rates in each treatment group, as well as the unweighted and weighted OR, 95% CI, and P values. Although P values are reported for the weighted analyses, it should be understood that significance is an artifact of the weighting scheme and serves to highlight differences between the techniques.

**Return to Functional Ambulation**

Ten studies reported the return to functional ambulation (7 internal fixation studies and 3 external fixation studies). The rate of return to functional ambulation was 25% higher for the internal fixation group, although this difference was not statistically significant in the weighted analysis (OR, 1.259; P=.9766).

**Ulcer Occurrence**

All 11 of the studies reported the total number of cases with any ulcer occurrence. The rate of ulcer occurrence was 8% (range, 0-18.2%) in the internal fixation group and 15.8% (range, 0-18.2%) in the external fixation group. The internal fixation group had a 42% reduced rate for ulcer occurrence, which was significant in the weighted analysis (OR, 0.578; P<.0001).

**Radiographic Nonunion**

Eight studies reported the radiographic nonunion rate (6 internal fixation studies and 2 external fixation studies). The rate of radiographic nonunion was 15.1% (range, 0-27.3%) in the internal fixation group and 58.3% (range, 0-63.6%) in the external fixation group. Taking the inverse of the OR (reversing the group comparison), external fixation was approximately 8 times more likely to result in nonunion than internal fixation (OR, 8.197 for the weighted analysis; OR, 7.874 for the unweighted analysis); this difference was significant in the unweighted analysis (P=.002).

**Extremity Amputation**

All 11 of the studies reported the rate of major extremity amputation. The rate of extremity amputation was 5.6% (range, 0-28.6%) in the internal fixation group and 2.6% (range, 0-3.8%) in the external fixation group. The OR suggested an almost 50% greater likelihood of extremity amputation for the internal fixation group, although this difference was not statistically significant in the weighted analysis (OR, 1.488; P=.0972).

**Unplanned Further Surgery**

All 11 of the studies reported the rate of unplanned further surgery. The rate

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**Table 1**

<table>
<thead>
<tr>
<th>Study (Year)</th>
<th>Design</th>
<th>Method of Fixation</th>
<th>No. of Feet</th>
<th>Mean Patient Age, y</th>
<th>Mean Follow-up, mo</th>
<th>Setting</th>
<th>No. of Surgeons</th>
<th>Level of Evidence</th>
<th>SEQES Score (0-48)</th>
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<td>Internal fixation</td>
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<td></td>
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<tr>
<td>Early and Hansen&lt;sup&gt;a&lt;/sup&gt; (1996)</td>
<td>Case series</td>
<td>IFS</td>
<td>17</td>
<td>58</td>
<td>29</td>
<td>Single site</td>
<td>1</td>
<td>IV</td>
<td>21</td>
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<td>Simon et al&lt;sup&gt;13&lt;/sup&gt; (2000)</td>
<td>Case series</td>
<td>P&amp;S</td>
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<td>41</td>
<td>Single site</td>
<td>1</td>
<td>IV</td>
<td>31</td>
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<td>Screws</td>
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<td>20</td>
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<tr>
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<td>55</td>
<td>42</td>
<td>Single site</td>
<td>1</td>
<td>IV</td>
<td>25</td>
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<tr>
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<td>ICS</td>
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<td>Wiewiorski et al&lt;sup&gt;16&lt;/sup&gt; (2013)</td>
<td>Case series</td>
<td>SIFB</td>
<td>8</td>
<td>63</td>
<td>27</td>
<td>Single site</td>
<td>NA</td>
<td>IV</td>
<td>22</td>
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<td>24</td>
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<td>Sticha et al&lt;sup&gt;14&lt;/sup&gt; (1996)</td>
<td>Case report</td>
<td>Monoplanar EF</td>
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<td>Monoplanar EF</td>
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</table>

Abbreviations: EF, external fixation; ICS, intramedullary cannulated screws; IFS, interfragmentary screws; NA, not available; P&S, plate and screws; SEQES, Structured Effectiveness Quality Evaluation Scale; SIFB, solid intramedullary fusion bolt.
of unplanned further surgery was 21.6% (range, 0-45.5%) in the internal fixation group and 15.8% (range, 0-23.1%) in the external fixation group. The OR suggested a 20% increase for the internal fixation group with respect to unplanned further surgery, although this difference did not reach statistical significance in the weighted analysis (OR, 1.221; \( P=0.0715 \)).

**Deep Infection**

Nine studies reported the rate of deep infection (7 internal fixation studies and 2 external fixation studies). The rate of deep infection was 9.4% (range, 0-42.9%) in the internal fixation group and 3.7% (range, 0-3.8%) in the external fixation group. Those in the internal fixation group were twice as likely to report deep infection as those in the external fixation group; this difference was significant in the weighted analysis (OR, 1.524; \( P=0.013 \)).

**Wound Healing Problems**

Six studies reported the rate of wound healing problems (4 internal fixation studies and 2 external fixation studies). The rate of wound healing problems was 12.2% (range, 0-28.6%) in the internal fixation group and 3.7% (range, 0-3.8%) in the external fixation group. The OR showed a 3.4-fold increase for the internal fixation group, which was significant in the weighted analysis (OR, 3.405; \( P<0.0001 \)).

**Peri- or Intraoperative Fractures**

Five studies reported the rate of peri- or intraoperative fractures (3 internal fixation studies and 2 external fixation studies). The rate of peri- or intraoperative fractures was 10.9% (range, 5.9%-14.3%) in the internal fixation group and 7.4% (range, 0-7.7%) in the external fixation group. There was a 50% increased odds of fractures for the internal fixation group, which was significant in the weighted analysis (OR, 1.478; \( P=0.0324 \)).

**Total Number of Cases With Any Complication**

All 11 of the studies reported the total number of cases with any complication. The rate of total cases with any complication was 44.3% (range, 0-63.6%) in the internal fixation group and 42.1% (range, 0-72.7%) in the external fixation group. The internal fixation group reported a 50% increased odds of complications, which was significant in the weighted analysis (OR, 1.525; \( P<0.0001 \)).

**DISCUSSION**

The optimal surgical reconstruction of Charcot midfoot arthropathy remains an issue of debate. Internal and external fixation techniques have been described for midfoot Charcot deformities, but the lack of comparative studies makes it difficult to advocate one technique over the other. This is the first systematic review comparing the short-term (mean follow-up, 35.7 months) outcomes of internal vs external fixation for Charcot midfoot arthropathy. Because all of the available literature that formed the basis of this review comprised nonrandomized, noncontrolled, predominantly retrospective case series with significant heterogeneity, these findings should be interpreted with caution. However, this review highlights important differences between the 2 techniques that reflect their individual strengths and weaknesses.

Internal fixation arthrodesis has been used effectively for the stabilization of...
the reconstructed Charcot foot.\textsuperscript{4,8} Traditional approaches to internal fixation using pins, plates, and screws have been described.\textsuperscript{9,17–19} More recently, the use of intramedullary cannulated screws has emerged as a potentially superior method of correcting Charcot midfoot deformity. According to the present study, patients undergoing internal fixation experienced a 42\% risk reduction of any postoperative ulcer formation compared with external fixation. These included both recurrent midfoot plantar ulcers as well as new ulcers on the operative foot at a site other than the midfoot. Although this finding raises the possibility that internal fixation may better maintain the reduction compared with external fixation, it also could reflect less severe deformity of the internal fixation patient group. Unfortunately, none of the external fixation studies classified the severity of bony deformity, and even among the internal fixation studies, heterogeneous classification schemes were used. This was a limitation of the systematic review and underlines the need to perform studies in patients with similar degrees of Charcot deformity.

These data also suggest that internal fixation may reduce the risk of radiographic nonunion by up to 90\% compared with external fixation. However, this result is based on a small number of studies, and there is literature to suggest that a nonunion may still provide sufficient stability to produce a successful clinical outcome.\textsuperscript{20,21} Notably, there was a trend toward greater return to functional ambulation with internal fixation, which may be a more reliable marker of functional outcome. Unfortunately, most external fixation studies did not report the maintenance of plantigrade correction after surgery, which would yield further insight into the durability of both procedures.

Despite favorable results with internal fixation, there are important limitations associated with this technique. Plates require significant soft tissue dissection with a long incision and wide exposure, and intramedullary cannulated screws are vulnerable to breakage with progressive weight bearing. This analysis demonstrated a 50\% increased risk of peri- or intraoperative fracture for patients treated with internal fixation compared with external fixation. To avoid the complication of screw breakage, several authors recently reported the use of a solid-core intramedullary bolt to better tolerate the tensile and compressive forces in the midfoot region.\textsuperscript{5,16} Although they did not observe screw breakage, Eschler et al\textsuperscript{6} and Wiewiorski et al\textsuperscript{16} reported fixation failure with solid intramedullary fusion bolts in the form of screw migration in 2 (28.6\%) of 7 and 3 (37.5\%) of 8 cases, respectively.

In addition to the risk of hardware failure, the present review showed that patients undergoing internal fixation had a 1.5-fold increase in extremity amputation, a 2-fold increase in deep infection, a 3.4-fold increase in wound healing complications, and a 1.5-fold increase in the total number of patients experiencing any complication compared with external fixation. There was a trend toward more unplanned further surgeries in the internal fixation group, presumably to address these complications.

External fixation has gained favor in recent years as a solution for surgical reconstruction of Charcot midfoot arthropathy. Unlike internal fixation, external fixation does not depend on good bone quality and minimizes the amount of soft tissue dissection needed for stabilization.\textsuperscript{20,22} The versatile design of ring fixation also allows for multiplanar correction in the postoperative period.\textsuperscript{11,23,24} Finally, its percutaneous application allows it to be used in the presence of active infection and osteomyelitis where internal fixation would be contraindicated. Pinzur et al\textsuperscript{23} reported good results with ring external fixation in patients with Charcot foot complicated by osteomyelitis: at a minimum of 1-year follow-up, 58 of 73 patients were free of infection, and only 3 patients required amputation (for either unresolved infection or bony instability).

The most common complication of external fixation is pin-tract infection. Although none of the included studies on external fixation reported on pin-tract infections, other studies of Charcot arthropathy outside of the midfoot report an incidence ranging from 45\% to 80\%.\textsuperscript{5,22,24–26} Cooper\textsuperscript{20} reported pin-track infection in 7 of 83 patients (8.4\%), whereas Rogers et al\textsuperscript{27} reported a number of pin-related complications, including pin-track infection (33.3\%), pin breakage (26.7\%), and soft tissue injury (60\%). In addition, the cosmetic appearance of the foot is less affected by internal fixation than it is by formal external fixation.\textsuperscript{28,29} The technical difficulty of frame application also may be a challenge for the surgeon. These are important drawbacks that may limit the appeal of external fixation.

Brodsky\textsuperscript{2} classified Charcot neuroarthropathy based on anatomic location and identified the tarsometatarsal joint (type 1) as the most common region of involvement, representing approximately 60\% of cases. The current analysis focused on the midfoot with or without hindfoot involvement and excluded cases involving the ankle joint. This is a strength of the current review, as neuropathic changes at the ankle lead to different deformities than those at the midfoot and therefore entail a separate and distinct course of management.\textsuperscript{1,3}

This systematic review was limited by the quality of the included studies. There were no randomized controlled studies in the literature, and only findings from uncontrolled case series or case reports (Level IV) could be reported; all but one of these case series were retrospective. This was reflected in the SEQES scale, a subjective measure of literature quality, which found all of the included studies to be of moderate quality (mean SEQES score 23.5 of 48). In addition, there was significant heterogeneity in baseline patient populations, severity of Charcot deformity, surgical technique, and reporting of outcomes among the included studies.
Thus, this review highlights the need for uniform outcomes reporting and randomized, controlled, prospective trials to facilitate formal comparisons between techniques.

**Conclusion**

This systematic review justifies the use of external fixation as an alternative to internal fixation for surgical reconstruction of the Charcot foot. Although internal fixation may decrease the risk of nonunion and increase return to functional ambulation, it may result in significantly more complications than external fixation. External fixation was associated with a higher rate of ulceration but resulted in fewer cases with any complication, including a decreased risk of extremity amputation, deep infection, wound healing problems, peri- or intraoperative fractures, and the need for unplanned further surgery. Randomized controlled trials ultimately will be required to formally compare the 2 methods of surgical stabilization.

**References**