OBJECTIVE: Dehydration is a significant threat to the health of children worldwide and a major cause of death in resource-scarce settings. Although multiple studies have revealed that oral and intravenous (IV) methods for rehydration in nonsevere dehydration are nearly equally effective, little is known about effectiveness beyond these 2 techniques. With this systematic review we analyzed the effectiveness of nonoral and nonintravenous methods of rehydration.

METHODS: The Medline, Cochrane, Global Health, Embase, and CINAHL (Cumulative Index to Nursing and Allied Health Literature) databases were searched for articles on intraosseous (IO), nasogastric (NG), intraperitoneal (IP), subcutaneous (hypodermoclysis), and rectal (prococlysis) rehydration through December 2009. Only human pediatric studies that included data on the effectiveness or complications of these methods were included.

RESULTS: The search identified 38 articles that met the inclusion criteria: 12 articles on NG, 16 on IO, 7 on IP, 3 on subcutaneous, and none on rectal rehydration. NG rehydration was as effective as IV rehydration for moderate-to-severe dehydration. IO rehydration was effective and easy to obtain, although only 1 randomized trial was identified. IP rehydration had some benefit for moderate dehydration, although none of the trials had control groups. Limited data were available on subcutaneous rehydration, and only 1 case series showed benefit.

CONCLUSIONS: NG rehydration should be considered second-line therapy, after oral rehydration, particularly in resource-limited environments. IO rehydration seems to be an effective alternative when IV access is not readily obtainable. Additional evidence is needed before IP and subcutaneous rehydration can be endorsed. Pediatrics 2011; 127:e748–e757

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KEY WORDS: dehydration, critically ill children, diarrhea, international child health, intravenous rehydration

ABBREVIATIONS: IV—intravenous
NG—nasogastric
IO—intraosseous
IP—intraperitoneal
ORS—oral rehydration solution
NS—normal saline

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Dehydration is one of the most common problems confronting ill children worldwide. It is closely tied to many of the leading causes of childhood mortality, including diarrheal illnesses, acute respiratory infections, malaria, and malnutrition. The United Nations Children’s Fund has estimated that 1.7 million children per year die from diarrheal dehydration alone. It is well established that when available and tolerated, oral rehydration is the preferred method of rehydration. It is as effective as intravenous (IV) rehydration in mild and moderate dehydration and is more readily available and affordable. However, for some patients oral rehydration is not possible because of unwillingness or inability to drink, severity of illness, or comorbidities. In resource-scarce settings, sterile supplies needed to secure and maintain IV access are often absent. Even if supplies are available, children in the developing world frequently present with such severe dehydration that intravascular access is technically challenging or impossible.

Because oral and IV rehydration are not feasible for all children, it is important for clinicians to have alternative methods of rehydration available to them. Numerous alternative methods have been used. Nasogastric (NG) rehydration uses the intestinal system just as oral rehydration does. Proctoclysis relies on the absorption of fluids through the rectal mucosa. Intraperitoneal (IP) fluid administration uses bone marrow as a direct access to the intravascular circulation. Hypodermoclysis, or subcutaneous fluid administration, and intraperitoneal (IP) rehydration both rely on indirect absorption into the circulation. The relative effectiveness of these methods for acute rehydration is unclear. Some, such as NG and IO rehydration, are used today at the discretion of the practitioner. Others are not widely used.

The aim of this review was to examine the literature on the effectiveness, benefits, and risks of alternative (i.e., nonoral and non-IV) techniques for pediatric rehydration. Techniques examined included NG, IO, IP, subcutaneous, and proctoclysis rehydration.

METHODS
A literature search was conducted in 5 databases: Medline, Cochrane, Global Health, Embase, and CINAHL (Cumulative Index to Nursing and Allied Health Literature). The following text search terms and Medical Subject Headings were used: rehydration; dehydration; hydration; fluid therapy; and injection, in combination with any of NG, IO, IP, subcutaneous, hypodermoclysis, or proctoclysis. The searches were limited to articles written in English and concerning human studies. The searches were not restricted by dates of publication and included all articles through the completion of the search in December 2009. In addition to the articles identified through this search, key references from included articles were also examined.

The identified articles were manually sorted to include patients younger than 18 years. If studies had both pediatric and adult populations, they were included only if they had listed the results separately for the pediatric patients. Adult studies were excluded, because much of the adult data on alternative rehydration methods, such as subcutaneous rehydration, come from geriatric and palliative care literature. These patients have different physiology and goals of care from children with acute dehydration. Case reports and consensus-based guidelines were eligible for inclusion, whereas articles that were opinion-based were excluded. Articles in which a technique but not its effectiveness was described were also excluded. However, articles in which a complication of a method was described, regardless of reference to effectiveness, were included to allow an assessment of risks and benefits. The search strategy is outlined in Fig 1. The selection of articles was initially conducted by 1 author; when an article was felt to be borderline for inclusion or exclusion, it was examined by 2 or more authors, and a consensus on inclusion or exclusion was reached. Given the limited literature on this subject, articles that met the above-listed inclusion criteria were not excluded on the basis of the quality of their methods, but assessment of the differences in methodology was incorporated into the text of the review to allow the reader to weigh the quality of the literature.

RESULTS
The initial search strategy identified 1436 articles. A significant number of these articles were excluded, because they focused solely on adult populations. In addition, many studies did not relate to dehydration or hypovolemia. After manual review of the titles and available abstracts of these articles, the list was narrowed to 82 articles. Subsequent review of the full text of these articles identified 38 articles that met all inclusion criteria: 3 on subcutaneous rehydration, 12 on NG rehydration, 7 on IP rehydration, 16 on IO rehydration, and none on proctoclysis.

NG Rehydration
Twelve articles about NG hydration met the inclusion criteria for our review. Of these studies, 5 were randomized controlled trials, 4 of which compared NG to IV rehydration and 1 of which compared different solutions for NG rehydration. The remaining articles included cohort studies, case series, retrospective chart reviews, and consensus-panel statements. The articles reviewed suggested that NG rehy-
dration is effective in cases of moderate and severe dehydration.

The 4 randomized trials that compared NG to IV rehydration are summarized in Table 1. In all 4 studies, NG rehydration had efficacy similar to that of IV rehydration, although different end points and protocols were used in each study. NG rehydration failed in 2% of all patients (4 of 211 total) for reasons detailed in Table 1. These patients were switched to IV rehydration.

Several case series also supported the effectiveness of NG rehydration. In 2000, a prospective study of 4131 children with acute diarrhea and severe dehydration, defined as at least a 10% weight loss, supported NG rehydration. In these children, 3537 (88%) had a rapid response to fluids, 316 (8%) needed prolonged hydration, and 147 (4%) needed admission to the hospital. It is unclear if children admitted to the hospital were given IV rehydration.

Smaller case series also supported the effectiveness of NG rehydration. In 2 studies focused on children with moderate dehydration, most patients experienced clinical improvement with NG rehydration, although 4 of 47 patients (9%) in the 2 studies needed to be switched to IV rehydration. Two other case series revealed benefits with NG rehydration consistent with those in other studies, although neither the level of dehydration nor the rehydration protocol that was followed were specified.

Finally, one consensus guideline on the management of diarrhea with or without vomiting addressed NG rehydration. It was developed by using a Delphi consensus process after a systematic literature review. The panel recommended NG rehydration over IV rehydration for patients in whom oral rehydration had failed.

Complications from NG rehydration were infrequent. One study found that emesis was more common in patients with gastroenteritis who were given NG rehydration compared with IV rehydration. One patient developed meteorism, or excessive gas accumulation in the gastrointestinal tract, and was successfully switched to IV rehydration. In a study on adverse events in patients with NG tubes for rehydration, reported adverse effects included multiple insertions in 34%, sore throat in 13%, coughing in 16%, negligible epistaxis in 3%, and need for mittens in nearly 75% of the patients. However, in this study, data on adverse events were collected from only 26% of the eligible patients. There was only 1 aspiration event in any of the included studies, and after review of the chart in that case, the authors concluded that it was unclear if the recorded event was aspiration or misplacement.

**10 Rehydration**

Sixteen articles addressed IO infusions. One was a randomized controlled trial, 12 were case reports, and 3 were case series. Of the 12 case reports, 10 described the efficacy of IO infusion and 2 described complications.

The randomized controlled trial compared IV to IO hydration in severely de-
# TABLE 1 Randomized Controlled Trials in Which IV and NG Rehydration Were Compared

<table>
<thead>
<tr>
<th>Author (Year)</th>
<th>Population</th>
<th>Infusion Fluids</th>
<th>End Points</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gremse4 (1995)</td>
<td>2–24 mo old; 24 patients; moderate dehydration; developed country</td>
<td>NG: Rehydralyte (ORS), volume to replace fluid deficit over 6 h; IV: D5½NS, volume not specified</td>
<td>Weight; intakes and outputs; frequency and volume of vomiting and diarrhea; duration of hospitalization; serum electrolyte levels</td>
<td>Rehydration successful in 11 of 12 patients receiving NG rehydration; failed for 1 patient because of persistent vomiting; Patients in the NG group had formula introduced sooner (at discretion of attending) and had shorter hospitalizations; No complications of NG placement; most frequent IV complication was IV infiltration (patients needed an average of 1.9 IV catheters)</td>
</tr>
<tr>
<td>Hidayat et al5 (1988)</td>
<td>1–59 mo old; 75 patients; severe dehydration; developing country; at study onset, the NG group had a similar duration of illness to the IV group, but fewer episodes of vomiting per day</td>
<td>NG: WHO standard ORS; IV: lactated Ringer’s solution, 40 mL/kg × 1 h, then 30 mL/kg × 1 h, then 20 mL/kg × 2 h</td>
<td>Weight; hourly assessment of degree of dehydration; 4-h assessment of degree of hydration</td>
<td>No differences in rates of successful rehydration, recurrence of dehydration, mean hospital stay, or duration of vomiting; Rehydration succeeded for 33 of 36 children in the NG group (failed for 2 patients because of persistent vomiting and for 1 because of meteorism, or excessive gas accumulation in the gastrointestinal tract) and 37 of 39 children in the IV group (failed for 1 because of persistent vomiting and for 1 because of seizures); differences were not statistically significant</td>
</tr>
<tr>
<td>Nager and Wang6 (2002)</td>
<td>3–36 mo old; 90 children; moderate dehydration; emergency department patients; developed country</td>
<td>50 mL/kg of Pedialyte by NG tube or NS by IV line over 3 h, then switched to oral fluids</td>
<td>Vital signs; general clinical state; capillary refill; change in weight; change in serum electrolyte levels; urine chemistries; urine specific gravity; telephone follow-up; return-visit rates</td>
<td>No difference in discharge rates, clinical condition at follow-up, or number of return visits; both groups gained weight, although those in the NG group gained less as a percentage of body weight (2.2% vs 3.6%); IV placement failed more frequently than NG placement (61% vs 4% mean per-case failure rate)</td>
</tr>
<tr>
<td>Varavithya et al7 (1978)</td>
<td>4–17 mo old; males; 22 children; moderate dehydration; developing country</td>
<td>150 mL/kg per d (10–20 mL/kg per h × 2 h, then a constant rate over 22 h); NG: bedside ORS; IV: D5½NS</td>
<td>Weight; blood and urine samples; plasma specific gravity</td>
<td>Similar weight gain, oral intake, and improvement in laboratory test results between groups; sodium and osmolarity returned to normal without complications in both groups</td>
</tr>
</tbody>
</table>

All studies were of children with acute dehydration secondary to vomiting or diarrhea. Gremse4 and Nager and Wang6 included children for whom an oral challenge had failed. In all articles, moderate dehydration was estimated to be 5% to 10%. Nager and Wang6 and Varavithya et al7 both defined signs of moderate dehydration as tachycardia, decreased skin turgor, sunken fontanelles and eyes, dry mucous membranes, delayed capillary refill, and normal or listless mental status. Severe dehydration was defined by Hidayat et al5 by using World Health Organization criteria and was estimated to be >10% dehydration. These criteria included lethargy or unconsciousness, very decreased skin turgor, very dry mucous membranes, no tears, and very sunken eyes. Gremse4 did not specify how the degree of dehydration was estimated. Exclusion criteria varied between studies. Hidayat et al5 excluded patients with meteorism, or excessive gas accumulation, complications (not defined), and a nonpalpable pulse; Gremse4 excluded shock, sepsis, ileus, seizures, metabolic disease, intestinal obstruction, and chronic disease; Nager and Wang6 excluded children with severe dehydration, shock, intractable vomiting, underlying diseases, or suspected other acute etiology (such as appendicitis, malrotation, or meningitis); and Varavithya et al7 did not list any exclusion criteria. D5NS indicates 5% dextrose NS; D5½NS, 5% dextrose 0.5% NS; D5¼NS, 5% dextrose 0.3% NS; WHO, World Health Organization.

* The Nager and Wang6 study initially enrolled 96 patients; 3 were withdrawn because of continued emesis that required hospital admission (2 IV, 1 NG); 1 was withdrawn because of intussusception, and 2 were withdrawn after they were found to have severe dehydration in retrospect (both in the IV group).
hydrated children with acute gastroenteritis. Sixty children received a 20 to 30 mL/kg normal saline (NS) bolus by IO or IV routes, followed by identical protocols regarding the reintroduction of oral fluids. End points included time to placement, stabilization of vital signs, correction of dehydration, and complications. There was no difference in efficacy of rehydration or correction of laboratory abnormalities between the groups. However, IO placement was significantly faster (67 vs 129 seconds) and more reliable (IV lines failed to be placed within 5 minutes in 33% of the patients in the IV group, versus no failures in the IO group). IO needles were successfully placed in those patients in the IV group in whom IV placement had failed; it is unclear in which group these patients were subsequently analyzed. There were no short-term complications in either group, although the study lacked long-term follow-up.

Results of another study of 22 children aged 1.5 to 10 months with shock further supported the efficacy of IO fluids for rehydration. Children had an IO line placed either immediately if they had gasping respirations or after 2 to 3 failed IV-line-placement attempts. Twenty-one of 22 patients (95.5%) had improvement in their circulatory state with fluids, blood, and medications given through the IO route. Sixteen (73%) of the patients ultimately survived. The only patient with no response to fluids was apneic and bradycardic on arrival. It is important to note that in all patients, IO access was obtained by using a standard 18-gauge butterfly needle rather than an IO-specific needle.

Four case reports focused on IO-fluid resuscitation in patients with burns. A total of 6 patients (age range: 17 days to 3 years) were included in these reports. All 6 children were successfully initially resuscitated with IO fluid, and 2 continued to receive IO fluids for 48 hours. One child died from smoke inhalation 2 days after the initial resuscitation.

Two case reports involved fluids given through the IO route during cardiac arrest. One child was successfully resuscitated after receiving lactated Ringer’s solution and multiple vasoactive medications. The other child did not survive, but a femoral vein puncture above the site of the IO infusion produced diluted blood that appeared to be mixed with saline, which provided evidence that the IO-infused saline had reached the intravascular space.

Two additional case reports on hypovolemic patients who were resuscitated with IO access reported successful outcomes. One was a 5-year-old patient with diabetic ketoacidosis and an estimated 10% fluid deficit. The initial 14 hours of the resuscitation were accomplished via the IO route and produced clinical improvement. The other was a 7-month-old infant who had dehydration caused by vomiting and was successfully resuscitated with NS through a spinal needle inserted into the tibia. In both cases, initial attempts at IV access had been unsuccessful.

Several articles addressed IO use in neonates. In 1 study, 27 neonates in the ICU who had unsuccessful attempts at routine means of access had IO needles inserted for resuscitation. All patients had an IO catheter inserted in less than 2 minutes and were successfully initially resuscitated through the IO route with volume expanders and medications. However, 44% of the patients later died of underlying disease. Two case reports described successful use of IO infusions in neonates: 1 in a 38-day-old preterm infant who weighed 800 g and another in a 10-day-old infant with dehydra
TABLE 2 Articles on Intraperitoneal Rehydration

<table>
<thead>
<tr>
<th>Author (Year)</th>
<th>Population</th>
<th>Study Protocol</th>
<th>End Points</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agusto-Odutola (1971)</td>
<td>15 patients; 3–23 mo old; moderate dehydration</td>
<td>55 mL/kg IP bolus of NS with potassium</td>
<td>Clinical rehydration; serum electrolytes; hemoglobin; PCV, urea; plasma osmolarity</td>
<td>14 patients (93%) improved and were discharged within 24 h; 1 patient died; postmortem examination showed no complications from IP infusion; Improvements in electrolyte levels were seen by 2 h after infusion</td>
</tr>
<tr>
<td>Carter (1953)</td>
<td>96 children; ages not given; patients in whom “death appeared inevitable”</td>
<td>IP bolus of D2.5NS; volume was not standardized</td>
<td>Rate of absorption (which was assumed to be proportional to clinical hydration state and physical examination)</td>
<td>Rate of absorption was very good in 15 cases, good in 34, fair in 15, and poor in 6; remainder of patients were not accounted for; the total number of deaths was not listed; 20 postmortem examinations were performed</td>
</tr>
<tr>
<td>Mahalanabis et al (1970)</td>
<td>26 patients; 7 mo to 6 y old; moderate-to-severe dehydration</td>
<td>4 patients given only IP fluids: 70–100 mL/kg IP lactated Ringer’s solution bolus; 22 patients given IV fluids for 1–3 h, then 50–70 mL/kg IP lactated Ringer’s solution bolus</td>
<td>Clinical state; weight; plasma specific gravity; pH; CO₂</td>
<td>IP-only group: all 4 children were initially normotensive and all were successfully treated; IV-followed-by-IP group: children had lower blood pressures at admission to the study and 19 (88%) of the children were successfully treated; 88.3% were fully rehydrated after 8 h; 3.6% had no response to IP fluids and required IV rehydration; Significant increase in weight and decrease in diarrhea was seen 8 h after initial infusion</td>
</tr>
<tr>
<td>Noerasid et al (1975)</td>
<td>56 children; 2–18 mo old; moderate dehydration</td>
<td>40 mL/kg IP bolus of 2 parts NS, one part D5 at 0 and 4 h;</td>
<td>Weight; vital signs; degree of dehydration; frequency of vomiting and diarrhea; urine output; leukocyte count; serum electrolyte levels</td>
<td>Clinical rehydration; serum electrolyte levels</td>
</tr>
<tr>
<td>Ransome-Kuti et al (1969)</td>
<td>105 children; 91 included in the analysis; 3 mo to 4 y old; mild-to-severe dehydration</td>
<td>11.4 mL/kg bolus of IP fluids in 1 of 5 compositions</td>
<td>Clinical improvement, defined as: ability to tolerate oral fluids, improved level of consciousness, absence of tachycardia and hypotension, improved skin turgor, moist mucous membranes</td>
<td>14 patients with severe dehydration were excluded from the analysis after they deteriorated and needed IV fluids; 74.7% of the remaining children were able to be discharged within 24 h; 11 patients died, 7 were moderately or severely dehydrated, 4 had pneumonia and malnutrition</td>
</tr>
<tr>
<td>VanRooyen et al (1985)</td>
<td>14 children; 4 mo to 15 y old; significant dehydration; patients for whom oral therapy and IV placement failed</td>
<td>80 mL/kg IP bolus of ½NS</td>
<td>Clinical improvement defined as: ability to tolerate oral fluids, improved level of consciousness, absence of tachycardia and hypotension, improved skin turgor, moist mucous membranes</td>
<td>13 children improved (93%); 1 died within 24 h</td>
</tr>
<tr>
<td>Wenzel and Phillips (1971)</td>
<td>4 children; 5–10 y old; moderate dehydration</td>
<td>Bolus amount not specified</td>
<td>State of hydration, stool output; urinary output</td>
<td>No child had improvement in clinical dehydration or stool or urine output after 4 h; all were given IV or oral rehydration and recovered; did not specify if other children were successfully treated</td>
</tr>
</tbody>
</table>

Definitions on the degree of dehydration varied between studies: Agusto-Odutola and Ransome-Kuti et al both used 1952 criteria from the Medical Research Council that defined moderate dehydration as a 5% to 10% decrease in body weight associated with restlessness, decreased skin turgor, cool skin, sunken eyes and anterior fontanelle, dry mucous membranes, and a pulse of 160 to 180 beats/minute. Severe dehydration was defined as >10% weight loss, with semi-coma, worsened signs of the above, and a pulse of >180 beats per minute. VanRooyen et al defined “significant dehydration” as decreased level of consciousness, dry mucous membranes, poor skin turgor or tenting, and tachycardia or hypotension. Noerasid et al, Wenzel and Phillips, and Mahalanabis et al did not provide criteria for their dehydration classifications, although Wenzel and Phillips noted that all of their patients had tachycardia and poor skin turgor. Carter did not discuss the degree of dehydration but included patients in whom “death appeared inevitable.” PCV indicates packed cell volume; D5, 5% dextrose; D2.5NS, 2.5% dextrose NS; ½NS, 0.5% NS.

recovered without incident (ref 38 and M. J. VanRooyen, MD, MPH, personal e-mail communication, March 18, 2010). Meteorism was seen in 9 of 56 patients (16%) in 1 case series. The authors of this study also noted a slight increase in average leukocyte count (from 8.4 to 11.7) and temperature (from 37.7 to 38.2°C) after infusion. Of 20 postmortem examinations performed after IP transfusion, there was 1 child with peritonitis that was...
found on autopsy. However, it was attributed to dysentery causing multiple full-thickness ulcerations of the distal ileum with one site of perforation 2 inches from the peritoneal infusion site.\textsuperscript{34}

**Subcutaneous Rehydration (Hypodermoclysis)**

Three studies met the inclusion criteria for subcutaneous rehydration. One was a series of 51 patients with mild or moderate dehydration treated with subcutaneous fluid infusion assisted by a hyaluronidase enzyme. Patients were given an initial bolus of 20 mL/kg isotonic fluid over 1 hour, followed by further fluid if needed. Forty-three patients (84.3%) were rehydrated through subcutaneous fluid in the emergency department. An additional 5 patients (10%) were reported as successfully rehydrated (judged to have been “clinically rehydrated primarily through the subcutaneous route”\textsuperscript{40}). It is unclear if they were given any other forms of rehydration.

The other 2 publications about subcutaneous rehydration date back to the 1960s. One was a case series of 4 patients with significant metabolic abnormalities who were transferred to a pediatric center after failing to improve with subcutaneous fluids. All 4 patients later improved with IV fluids, and the author concluded that the subcutaneous fluids were ineffective and worsened the symptoms.\textsuperscript{41} However, the volume of subcutaneous fluid given to each patient was not indicated, and the author provided no reasons for postulating that subcutaneous fluid worsened the patients’ conditions rather than the natural disease course. The other publication was a case report of a 5-month-old child with pneumonia who was given an unspecified amount of subcutaneous NS with 5% dextrose. Three days later the patient developed oliguria and edema, which were attributed to the subcutaneous infusion.\textsuperscript{42}

In the case series of 51 patients, 1 serious adverse event (cellulitis) was reported. Most patients had pain on the infusion of hyaluronidase, but two-thirds of them had no pain with fluid infusion.\textsuperscript{40}

**Proctoclysis**

There were no studies on proctoclysis that met the inclusion criteria. Only 3 studies on proctoclysis were identified in our literature search: 2 studies were of adults, and 1 failed to meet our study inclusion criteria because it was opinion-based rather than empirically driven.

**DISCUSSION**

Dehydration threatens the lives of at least 2 million children annually.\textsuperscript{1} The effectiveness of oral and IV rehydration has been well established, although at times neither is available, effective, or possible. In this review we examined the data on alternative methods of rehydration.

NG rehydration for moderate and severe dehydration is supported by the results of several randomized controlled trials. The data have suggested that NG hydration is safe and effective. Despite this fact, it is not as widely used as it could be.\textsuperscript{43} Larger studies may be needed to determine if the benefits of oral rehydration can be replicated with NG rehydration.\textsuperscript{44} Furthermore, although not one of our primary areas of interest, limited data suggest that compared with IV rehydration, NG rehydration results in shorter hospital stays and cost savings of as much as $115 per case in a developed country.\textsuperscript{2,15} It is important to note that, unlike IV infusion, NG infusion does not require sterile fluids but can rely on standard ORS, which makes it a more accessible technique in low-resource environments.

With the exception of NG rehydration, the quality of evidence behind other methods of hydration is poor. The quality of data on IO infusions was not as robust as expected, given its widespread use as a rescue technique for intravascular access. Our literature search identified only 1 randomized trial of IO versus IV access. The results of this study and other published reports support IO infusions as effective and easy to obtain. In addition, multiple resuscitation guidelines recommend IO access in cases of shock when IV access cannot be obtained quickly. Our review has demonstrated that IO access in infants can be achieved with needles that are not specifically designed for IO cannulation, such as 18-gauge butterfly needles\textsuperscript{13} or spinal needles.\textsuperscript{25} The quality of evidence on IP rehydration is not as robust as would be desired. Multiple case series have shown that IP hydration is effective in moderately dehydrated patients, although the results in severely dehydrated populations have been mixed. In addition, there have been no comparative studies on IP rehydration. Therefore, until further evidence is obtained, IP rehydration can only be recommended when oral, NG, IV, and IO rehydration either fail or are not available.

The quality of evidence on subcutaneous rehydration is also poor. The authors of 2 older case reports warned against subcutaneous rehydration but without clear justification. Only 1 case series supported its use. However, this case series was small and designed to test a specific medication as an adjunct. As such, its results may not be generalizable. Literature on rehydration of adults has suggested that subcutaneous rehydration may be administered without hyaluronidase, although the effect on absorption is unclear.\textsuperscript{45} Although data on subcutaneous rehydration in the adult palliative
care literature suggest some benefit, more research in the pediatric population is required before its use can be endorsed.46,47

Serious complications were uncommon in all of the methods we analyzed. Infection, which is a theoretical complication of all methods of rehydration, was infrequent. One case of cellulitis was reported after subcutaneous infusion.40 Low rates of osteomyelitis (1%) were reported from a 1946 series of IO infusions,32 and pooled data from adult and pediatric patients from 1942 to 1977 revealed osteomyelitis rates of 0.6%.48 More recent data from children were not available, but infection rates would likely be lower given improvements in sterile technique. The 1 case of peritonitis in a patient with IP infusion was not felt to be attributable to the infusion but to the underlying disease. Two other serious events were identified: a possible aspiration in a patient who was receiving NG rehydration and 2 cases of compartment syndrome in patients who were receiving IO infusions. Although previous studies have shown that oral rehydration has fewer complications than IV rehydration,44 we did not analyze the frequency of these adverse events in our review. As such, it is not possible to compare the frequency of complications with NG, IO, IP, or subcutaneous rehydration to those of IV or oral treatment.

Overall, the data support a role for NG rehydration as an alternative to IV rehydration when patients are unable to be rehydrated orally. IV access can be used when NG rehydration fails, and IO access can be used if an IV line is not quickly obtainable. It is important to note that specialized techniques for intravascular access, including central vein catheterization and neonatal umbilical vein catheterization, were not reviewed here but remain available to the clinician. If none of the above-mentioned techniques are successful or safely available, IP rehydration and subcutaneous rehydration can be used as life-saving measures, although the data supporting their use are limited.

The articles summarized here include data from resource-poor and resource-rich environments. As such, the results are applicable to either setting. However, they are likely to be particularly relevant to clinicians who work in resource-limited settings, where limited supplies necessitate flexible treatment plans. In these situations, supplies such as sterile fluids or tubing may be limited, which makes techniques such as NG rehydration with ORS more accessible. In addition, NG rehydration can be accomplished by parents using a syringe, which frees up limited nursing resources. In other situations, training or experience with IV cannulation may be limited. Methods such as IO, subcutaneous, or IP rehydration may represent life-saving alternatives if IV access cannot be obtained.

The results of our review are limited by several factors. Our search terms, although broad, focused on hydration and may have missed patients in shock, severe trauma, or cardiac arrest. We also limited our data to human pediatric studies and required an outcome measure or complication be documented. In particular, the limited number of studies on IO infusions may have been a result of these limitations, because the IO literature may focus more on emergent resuscitation. Our data are also limited by the different inclusion criteria, protocols, and primary end points in each study. Even the definitions of degree of dehydration varied from article to article. These factors made it difficult to group studies or perform any quantitative analysis. In addition, the sample size for most of the studies we identified was small. Even for the randomized controlled trials that compared IV to NG rehydration, sample sizes were less than 100 patients. This number may have been too small to detect a small difference in effectiveness or adverse events between techniques. The largest studies identified had no comparison groups. Finally, our review focused on the effectiveness of these techniques, but we did not consider the paucity of data on the relative discomfort experienced by patients undergoing each procedure.

CONCLUSIONS

Dehydration is a common presenting condition of children worldwide and plays a significant role in many of the leading causes of mortality in children younger than 5 years. Various methods of pediatric rehydration are available to the clinician, each with its unique utility and limitations. In settings with limited material and human resources, it is helpful to have a clear understanding of alternative rehydration methods.

Despite limited data, the results of this review provide an evidence-based approach to the hydration of a child. Oral rehydration remains the preferred route for rehydration. When oral rehydration is not possible, our review suggests that NG and IV rehydration have similar outcomes. Each method may have its unique role and advantages in different circumstances. At this time, IO rehydration is the next-best method supported by the existing literature. Additional evidence is still needed regarding IP, subcutaneous rehydration, and proctoclysis, but clinicians who work in resource-limited settings may wish to also consider these alternative methods when all other options fail or are not feasible.


Alternative Rehydration Methods: A Systematic Review and Lessons for Resource-Limited Care
Shada Rouhani, Laura Meloney, Roy Ahn, Brett D. Nelson and Thomas F. Burke
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