Ventriculoperitoneal (VP) shunts are known to perforate the gastrointestinal (GI) tract, the abdominal wall, and the bladder. The incidence of VP shunts perforating the GI tract has been reported to be between 0.1% and 0.7%.

If a shunt perforates the GI tract, it migrates most often caudally thereafter to protrude through the anal orifice, but has been reported to migrate upward and protrude through the oral cavity. Ventriculoperitoneal (VP) shunt perforations of the gastrointestinal tract

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OBJECT The purposes of this study were to evaluate the frequency with which children presented with ventriculoperitoneal (VP) shunt perforations of the gastrointestinal (GI) tract, to determine the type of shunts that caused the perforations, and to compare the stiffness of perforating catheters with the stiffness of catheters from other manufacturers.

METHODS Medical records were reviewed of 197 children who were admitted with VP shunt malfunction. Catheter stiffness was evaluated by measuring relative resistance to cross-sectional compression, resistance to column buckling, and elasticity in longitudinal bending. Catheter frictional force was measured per unit length.

RESULTS Six children were identified whose VP shunts had perforated the GI tract; 2 shunts subsequently protruded through the anal orifice, 1 protruded through the oral cavity, and 3 presented with subcutaneous abscesses that tracked upward from the intestine to the chest. All perforating shunts were Chhabra shunts. Catheter stiffness and resistance to bending were greatest with a Medtronic shunt catheter, intermediate with a Codman catheter, and least with a Chhabra catheter. Frictional force was greatest with a Chhabra catheter and least with a Medtronic catheter.

CONCLUSIONS The frequency of perforations by Chhabra shunts appears to be higher than the frequency associated with other shunts. The increased frequency does not correlate with their stiffness but may reflect their greater frictional forces.

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KEY WORDS ventriculoperitoneal shunts; perforations; extrusions; hydrocephalus; catheter

Methods
Data Collection
The neurosurgical database of BethanyKids at Kijabe Hospital, Kenya, was reviewed to identify children with pital with VP shunt perforations of the GI tract; 2) to determine the type of shunts that caused the perforations; and 3) to compare the stiffness of the perforating catheter brand with the stiffness of catheters from other manufacturers. It is particularly important that shunts not be prone to perforating tissues when they are used in developing countries, where recognition and treatment of shunt complications are considerably more difficult. Our hypotheses of this study were that Chhabra shunts are associated with GI perforations more frequently than shunts from other manufacturers, and that Chhabra shunts are associated with more GI perforations because they are stiffer than shunts from other manufacturers.

Abbreviations
GI = gastrointestinal; VP = ventriculoperitoneal; WBC = white blood cell.


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shunt complications, and of those, to identify children who presented with either visible shunt extrusions secondary to GI perforation or with abscesses secondary to migration of infection from a perforated bowel to a subcutaneous location. The type of shunts associated with perforations was identified. The study was approved by the Kijabe Hospital Institutional Review Board.

A search for the years 1990–2013 was conducted to identify articles selected with the search term, “ventriculoperitoneal shunt extrusion.” Nineteen publications were identified and from those, relevant data were collected, including age, etiology of hydrocephalus, shunt type, and time interval between shunt insertion and extrusion.

**Shunt Evaluation**

Mechanical properties of VP shunt tubing from Chhabra (G. Surgiwear Ltd), Medtronic small-diameter shunt tubing (Medtronic, Inc.), and Codman Bactiseal tubing (Codman Neuro) were evaluated (Fig. 1). All studies were conducted at room temperature, and the examiner was blinded to the tubing manufacturer. Relative stiffness of the tubing was evaluated by 3 methods: beam loading, longitudinal compression, and Euler buckling, and relative frictional force was measured.

Stiffness in longitudinal bending was evaluated using a simple beam method (Fig. 2c). In this method, 3.6-cm lengths of each tube were supported horizontally at one end while a weight (0.9 grams) was fixed to the opposite free end. Deformation was measured by photographing the weighted or loaded ends adjacent to a finely increment- ed rule (Fig. 3b). This procedure was repeated with each tube pressurized with a 36-cm water column (Fig. 3c).

Resistance to cross-sectional compression (Fig. 2a) was determined by applying increasing loads perpendicular to and across the width of the tubing with a MTS Criterion model C43 load frame tester fitted with a 150-N load cell. Each tube was compressed 0.021 mm/sec to one-half diameter by a horizontally oriented 2-mm-diameter rod lowered by the tester. Data acquisition hardware and software recorded load (in Newtons) versus tube compression distance (mm) at 0.01-second intervals.

Resistance to column buckling (Fig. 2b) or Euler defor- mation was also measured with the model C43 load frame tester. In this test, 2.9-cm lengths of tubing were fixed at each end and held vertically (Fig. 3a) during progressive axial loading.

Relative frictional force per unit length of tube was determined. Tubing under tension was compressed hori-zontally between 3-cm-long layers of fresh beef steak (to simulate the in vivo state). The end of the tube was pulled through the beef by a weighted line (17 g) and the average velocity was measured (Fig. 4).

**Results**

One hundred ninety-seven children who were admitted to Kijabe Hospital with shunt malfunction between January 2011 and April 2014 were included in this study. Two pediatric neurosurgeons at Kijabe Hospital were directly involved in or supervised all operations (including A.L.A.). More than 90% of the shunts with complications in this series were Chhabra shunts. Manufacturers of other shunts were often not reported in the operative notes.

Shunt insertion techniques were uniform, with the exception that abdominal trocars were used in approximate- ly 4% of cases. There was no variation in technique from one shunt type to another. Six (3%) of 197 children admitted with shunt malfunction were diagnosed with shunt perforations of the GI tract. All perforations were diag- nosed between January 2011 and April 2014. None of the GI perforations occurred within 1 month after shunt insertion, and none were associated with abdominal trocars. All shunts that caused perforations were Chhabra shunts.

None of the children had a prior history of abdominal symptoms or of abdominal surgery, other than their shunt insertion. After the GI perforations were treated,
subsequent reimplemented shunts were all Chhabra shunts. Children were followed up for at least 1 year after shunt replacement.

**Case 1**

A 7-month-old boy was admitted with shunt tubing protruding from his rectum for the previous 2 weeks. The shunt was divided in the retromastoid region distal to the Chhabra valve and all distal tubing was removed through the rectum; the ventricular catheter and valve were re-removed through the shunt insertion site. An external ventricular drain was inserted and the patient was treated with intravenous antibiotics. A new shunt was inserted into the peritoneal cavity 10 days later and no postoperative complications developed.

**Case 2**

An 18-month-old boy had a Chhabra VP shunt inserted at 3 months of age. The shunt was revised in another hospital 1 month before his admission to Kijabe Hospital. He was admitted with the shunt visible from his rectum for the previous 4 days. CSF obtained from the shunt before its removal had 2 white blood cells (WBCs). He was treated in the same manner as Case 1 and received intravenous antibiotics for 2 weeks. A new shunt was inserted into the peritoneal cavity 1 week thereafter and no postoperative complications developed.

**Case 3**

A 3-month-old girl was admitted with a 2-day history of irritability, retching, and vomiting. The distal end of her Chhabra shunt, which had been inserted at 10 days of age because of congenital hydrocephalus, was visible in the oral cavity. CSF from the shunt valve had 14 WBCs and a negative culture. The entire shunt was removed through a parietal scalp incision and an external ventricular drain was inserted. She was treated with intravenous antibiotics and a new shunt was inserted into the peritoneal cavity 2 weeks later, with no subsequent complications.

**Case 4**

A 2-year-old boy who had a Chhabra shunt inserted 1 year previously to treat recurrent CSF leaks after repair of a lumbar lipomeningocele presented with ulceration over the shunt in the midsternal region, with distal migration of the ventricular catheter and valve to that site. The shunt was removed in its entirety at that site, with the finding that the distal tubing was occluded with fecal matter. The ulceration was debrided and closed. The boy had no evidence of peritonitis and was discharged with no shunt after receiving 1 week of intravenous antibiotics.

**Case 5**

An 8-year-old girl who had undergone revision of a Chhabra VP shunt 1 year previously presented with pus draining over the shunt in the subclavicular region. The shunt was removed and its distal end was noted to be bile stained. A fistulogram demonstrated an enterocutaneous fistula. CSF culture grew *Escherichia coli*, *Enterobacter*, and *Klebsiella*. She was treated with intravenous antibiotics for 2 weeks, then a new contralateral shunt was inserted into the peritoneal cavity without complications.

**Case 6**

A 2-year-old boy with shunted hydrocephalus and malnutrition presented with a 2-month history of an exposed VP shunt on the scalp with ulceration in the subclavicular...
lar region. The shunt was removed in its entirety through the scalp incision and the distal portion of the abdominal catheter was noted to be bile stained. After shunt removal, bilious drainage was noted from the subclavicular wound. A fistulogram demonstrated an enterocutaneous fistula between a loop of small bowel and the subclavicular abscess. He was treated with dressing changes and antibiotics for 2 weeks then discharged. The fistula closed spontaneously 1 month after discharge. He did not return for follow-up but was reported to have no symptoms of hydrocephalus 9 months later. His case has been published.30

Table 1 summarizes the percentage relative-to-average stiffness performance of the 3 tubing brands. In beam loading, the elastic modulus of each tube was determined (Appendix); the weight of the tubing and water within (pressurized test) were accounted for in the calculations. Tubing 1 (Medtronic) was the stiffest in cross-sectional and longitudinal compression and the median and axial loading, while tubing 3 (Chhabra) was the least stiff. With pressurization by a water column, the relative stiffness of the 3 tubes was not significantly altered. Relative frictional force was significantly less for the Medtronic catheter than for the Codman and Chhabra catheters.

Patient data from the literature review are presented in Table 2. Of the 39 patients with shunt perforations, 24 prolapsed through the anal orifice, 5 through the oral cavity, and 4 through an intact abdominal wall. Two patients had trans-umbilical protrusion, 2 cervical, 1 lumbar, and 1 colonic perforation and protrusion. The shunt type associated with the perforation was noted by 9 of the 19 authors. Twenty-seven of the 39 perforating shunts were identified as Chhabra shunts; in 12 cases, the shunt brand was not mentioned.

Discussion

The incidence of VP shunts perforating the GI tract has been reported to be between 0.1% and 0.7%. In our series, 3% of 197 shunt complications were perforations of the GI tract by Chhabra shunts, a perforation frequency substantially higher than the frequency associated with other shunts. That high percentage of perforation has not been reported for shunts from other manufacturers and raised the possibility that perforations were related to stiffness of Chhabra shunts. Shunt characteristics that have been postulated as contributing to perforation of the GI tract, abdominal wall, or bladder include shunt stiffness, a sharp catheter end, and silicone allergy, but no factors are known to definitively increase the risk of GI perforations. Extremely malnourished children could theoretically be at increased risk, but the 6 children with perforations in this series were no more malnourished than other children in the series. Shunt type and/or brand has not been identified as a contributing factor, but in a review all of the 27 identified shunts associated with GI perforations or extrusions were Chhabra shunts, and all 6 of the cases in our experience were Chhabra shunts.

The laboratory results above do not support our hypothesis that Chhabra shunts are associated with an increased frequency of GI perforation because they are stiffer than other shunts, such as those from Medtronic and Codman. Medtronic shunt tubing was significantly stiffer than the Codman or Chhabra shunt tubing.

The resistance to bending was greatest for Medtronic tubing, which was not predicted, given that it has the smallest diameter. That result is primarily due to its material properties, rather than to its geometry. Codman and Chhabra tubing were of larger diameter and were expected to be stiffer because of a greater moment of area, a calculated property of a material based on its geometry used in the calculation of deflection; essentially, the more material located distally from the axis-of-deflection results in more stiffness in bending (see Appendix equation for “I”). However, their material is either more elastic or their greater

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Shunt Tube*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Manufacturer</td>
<td>Medtronic (US)</td>
</tr>
<tr>
<td>Outside diameter (mm)</td>
<td>2.16</td>
</tr>
<tr>
<td>Inside diameter (mm)</td>
<td>1.17</td>
</tr>
<tr>
<td>Color</td>
<td>White</td>
</tr>
<tr>
<td>Mass (g/cm)</td>
<td>0.035</td>
</tr>
<tr>
<td>Relative stiffness (%)</td>
<td>53</td>
</tr>
<tr>
<td>Beam loading</td>
<td>43</td>
</tr>
<tr>
<td>Pressurized to 36 cm H2O</td>
<td>66</td>
</tr>
<tr>
<td>Euler buckling</td>
<td>16</td>
</tr>
<tr>
<td>Relative frictional force (per length)</td>
<td>-76</td>
</tr>
</tbody>
</table>

* A negative sign indicates “less than” and a positive value indicates “greater than” the calculated average. In general, tube 1 was significantly stiffer than tubes 2 and 3. Tube 3 was the least stiff in all instances. In beam loading, pressurizing the tubes to 36 cm of water did not significantly change the relative stiffness. Tube 1 was significantly less affected by frictional forces and tube 3 was the most affected.
† Percentage values are relative to the calculated average.
diameter allows the thin-walled tube to flatten more during bending, affecting “I.” Their similar geometry can explain their equal resistance to Euler buckling; their greater diameter compared with Medtronic tubing also increases their relative stiffness in buckling. It was expected that with pressurization the stiffness of the tubes might be less dissimilar as the flattening effect would be impeded; however, that was not the case in the range of 36 cm of water.

We hypothesized that the stiffest tubing would be more likely to penetrate the GI tract or other tissues. Our tests, however, show that Chhabra tubing, the least stiff of the 3 tubings tested, is associated with these complications. Thus, factors other than stiffness apparently contribute. We considered that if shunt tubing became obstructed in vivo, the resultant stiffness might cause penetration; however, 5 of the 6 perforating shunts in our series were patent, and at 36 cm of pressurized water the additional stiffness was not significantly greater nor relatively dissimilar.

The frequency of Chhabra perforations may be related to the frictional force results noted above. Greater friction might keep the distal tubing at one location longer, e.g., on the side of a segment of transverse colon. Chhabra tubing had the greatest friction per unit length, and, when stiffened more so by CSF, it may become a slowly penetrating (or eroding) tubule. Phani has postulated that bowel perforation occurs when the shunt tip becomes adherent to the serosa of the bowel wall and the continuous waterhammer effect of CSF pulsations acts as a slow drilling mechanism.24 The greater frictional forces of Chhabra tubing may increase its likelihood of adhering in 1 site and subsequently perforating.

**Conclusions**

Chhabra shunts penetrated the GI tract in 3% of 197 patients with shunt malfunction treated at our hospital, a significantly higher rate of perforation than has been reported for other shunts. The perforations could not be related to shunt catheter stiffness but may be related to greater frictional forces associated with chronic contact of the distal catheter with intestine.

**Appendix**

E and I equations for beam deflection of tubing fixed and loaded at opposite ends:

\[
E = \frac{(3 \ w \ L^4 + 8 \ P \ L^3)}{(24 \ d \ I)}, \quad \text{and} \quad I = \frac{\pi (a^4 - b^4)}{4}
\]

in which “E” is the elastic modulus, “w” is mass per length of tubing.

**Table 2. Published cases of perforations of the GI tract by VP shunts**

<table>
<thead>
<tr>
<th>Authors &amp; Year</th>
<th>No. of Patients</th>
<th>Age, Sex</th>
<th>Hydrocephalus Etiology</th>
<th>Duration* (mos)</th>
<th>Shunt Type</th>
<th>Extrusion Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barkatullah et al., 2005</td>
<td>1</td>
<td>17 mos, F</td>
<td>Congenital</td>
<td>15</td>
<td>Chhabra</td>
<td>Trans-anal</td>
</tr>
<tr>
<td>Digray et al., 2000</td>
<td>1</td>
<td>2 yrs, —</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>Trans-anal</td>
</tr>
<tr>
<td>Ghritlaharey et al., 2012</td>
<td>6</td>
<td>0–12 yrs, M/F</td>
<td>Congenital/post-TB meningitis</td>
<td>3–60</td>
<td>Chhabra</td>
<td>5 trans-anal, 1 trans-umbilical</td>
</tr>
<tr>
<td>Gupta et al., 2012\textsuperscript{10}</td>
<td>1</td>
<td>4 yrs, M</td>
<td>Congenital</td>
<td>54</td>
<td>—</td>
<td>Per oral</td>
</tr>
<tr>
<td>Gupta et al., 2012\textsuperscript{11}</td>
<td>1</td>
<td>2 yrs, F</td>
<td>Congenital</td>
<td>4</td>
<td>—</td>
<td>Trans-anal</td>
</tr>
<tr>
<td>Hai et al., 2011</td>
<td>2</td>
<td>9 mos, M 3 yrs, M</td>
<td>Congenital</td>
<td>7</td>
<td>Chhabra</td>
<td>Trans-anal</td>
</tr>
<tr>
<td>Handa et al., 2007</td>
<td>2</td>
<td>18 mos, F 5 yrs, M</td>
<td>Post-meningitis</td>
<td>4</td>
<td>Chhabra</td>
<td>2 trans-anal</td>
</tr>
<tr>
<td>Kanojia et al., 2008</td>
<td>5</td>
<td>1–3 mos</td>
<td>—</td>
<td>3–6</td>
<td>Chhabra</td>
<td>Lumbar, 2 cervical, umbilicus, rectum</td>
</tr>
<tr>
<td>Kinasha et al., 2005</td>
<td>8</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>Chhabra</td>
<td>6 trans-anal, 2 trans-abdominal</td>
</tr>
<tr>
<td>Kothari et al., 2006</td>
<td>1</td>
<td>18 mos, M</td>
<td>Congenital</td>
<td>17</td>
<td>—</td>
<td>Per oral</td>
</tr>
<tr>
<td>Matsuoka et al., 2008</td>
<td>1</td>
<td>4 yrs, F</td>
<td>Congenital</td>
<td>48</td>
<td>—</td>
<td>Trans-anal</td>
</tr>
<tr>
<td>Murali &amp; Ravikumar, 2008</td>
<td>1</td>
<td>6 yrs, M</td>
<td>Congenital</td>
<td>66</td>
<td>—</td>
<td>Trans-oral</td>
</tr>
<tr>
<td>Odehade, 2007</td>
<td>1</td>
<td>15 mos, F</td>
<td>Hydrocephalus</td>
<td>6</td>
<td>Chhabra</td>
<td>Per oral</td>
</tr>
<tr>
<td>Panigrahi et al., 2012</td>
<td>2</td>
<td>7 mos, F 14 yrs, M</td>
<td>Posttraumatic</td>
<td>3</td>
<td>—</td>
<td>Via intact abdominal wall (both patients)</td>
</tr>
<tr>
<td>Phani, 2013</td>
<td>1</td>
<td>9 mos, F</td>
<td>Congenital</td>
<td>7</td>
<td>Chhabra</td>
<td>Trans-anal</td>
</tr>
<tr>
<td>Sharma et al., 2006</td>
<td>1</td>
<td>3 yrs, M</td>
<td>Post-TB meningitis</td>
<td>12</td>
<td>Chhabra</td>
<td>Trans-anal</td>
</tr>
<tr>
<td>Sridhar &amp; Karmarkar, 2009</td>
<td>1</td>
<td>8 mos, F</td>
<td>Post-meningitis</td>
<td>6</td>
<td>—</td>
<td>Per oral</td>
</tr>
<tr>
<td>Waluza &amp; Borgstein, 2005</td>
<td>2</td>
<td>Mean age 3 mos†</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>Trans-anal</td>
</tr>
<tr>
<td>Zhou et al., 2007</td>
<td>1</td>
<td>1.5 yrs, M</td>
<td>Associated w/ occipital meningocele</td>
<td>10</td>
<td>Silastic</td>
<td>Transverse colon</td>
</tr>
</tbody>
</table>

TB = tuberculosis/tuberculous; — = not mentioned or data not provided.

* Duration = interval between shunt insertion and time of extrusion.
† Ages are 15 years and below.
ing, “L” is length of tubing, “P” is end load, “δ” is deflection, “I” is moment of area, “a” is outside diameter, and “b” is inside diameter.

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Conception and design: Albright, Thiong’o. Acquisition of data: all authors. Analysis and interpretation of data: Albright. Drafting the article: all authors. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the article: all authors. Critically revising the article: all authors. Analysis and interpretation of data: Albright. Conception and design: Albright, Thiong’o. Acquisition of data: all authors. Analysis and interpretation of data: Albright. Reviewed submitted version of manuscript: all authors. Approved the article: all authors. Critical appraisal of review of manuscript: all authors. Critical appraisal of final version of manuscript: all authors. Approved the article: all authors. Reviewed the article: all authors. Critical appraisal of review of manuscript: all authors. Critical appraisal of final version of manuscript: all authors. Approved the article: all authors. Critical appraisal of final version of manuscript: all authors. Approved the article: all authors.

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