Diagnostic Procedures for Catheter Malfunction in Programmable Implantable Intraperitoneal Insulin Infusion Devices

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OBJECTIVE — To evaluate the roles of *1*) abdominal radiography, *2*) a pressure diagnostic procedure (PDP) using a standardized diluent infusion into the catheter sideport, and 3) radiocontrast imaging of the catheter lumen as procedures for diagnosing catheter malfunction in diabetic patients implanted with a programmable intraperitoneal infusion device.

RESEARCH DESIGN AND METHODS — Sixteen type I diabetic patients implanted with Infusaid programmable intraperitoneal insulin pumps were studied. The ability of the above three procedures to assist diagnosis of catheter malfunction and distinguish between occlusion and catheter breakage was retrospectively analyzed. Glycated hemoglobin was measured to determine the clinical importance of catheter malfunctions and decreases in pump flow due to insulin aggregation in the pump chamber.

RESULTS — Mean glycated hemoglobin levels increased significantly from 8.0 ± 0.3 to 9.0 ± 0.4% ($P < 0.05$) before and after catheter malfunction, but not during pump flow slowdowns. Mean peak pressure during PDP was 1.96 ± 0.14 psi ($P < 0.01$ vs. normal) in reversibly occluded catheters and 1.86 ± 0.35 psi ($P < 0.05$ vs. normal) in broken catheters, compared with 1.32 ± 0.23 psi in normal catheters. Decay times during PDP were >50 s for both reversibly occluded and broken catheters ($P < 0.001$ vs. normal of 3.6 ± 0.82 s). Abdominal radiographs and sideport injections of contrast material were used to distinguish the types of broken catheters.

CONCLUSIONS — Catheter breakage and occlusion are complications in implantable insulin infusion systems and result in metabolic deterioration. The presence of a sideport allows pressure data and radiographic procedures to assist in determining the cause of catheter malfunction. A diagnostic algorithm was generated to improve efficiency in investigating catheter problems.

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PDP, pressure diagnostic procedure.

The use of programmable implantable infusion devices in the treatment of type I diabetes has been documented to be safe and effective (1–6). Of the three major components of these devices (the electromechanical pump, the insulin, and the catheter), the catheter is the most likely to develop a malfunction manifested by unexplained hyperglycemia (5–7). Catheter survival rates range from 88 to 94% at 1 year (3,5) to 72 to 87% at 2 years (2,5,7). Because insulin infusion catheters are prone to occlusion and these devices can also develop decreased insulin flow due to insulin aggregation in the pumping chamber, the use of a pump sideport access can be extremely useful. For catheter problems, the sideport permits direct access to the catheter lumen and serves as an exhaust after the direct infusion of sodium hydroxide into the pump chamber to dissolve insulin aggregates. Both techniques can be achieved by percutaneous needle insertion into the sideport. We have previously described detailed analyses of intraperitoneal catheter survival rates and the methods and interpretations of the use of a sideport-equipped programmable implantable insulin delivery pumping unit (3,5–7). We have also reported the insignificant role of the pumping unit and catheter problems in the generation of insulin antibodies in patients using implantable insulin delivery systems (8). This communication describes the clinical metabolic consequences of various catheter problems and various procedures that can be used to arrive at a diagnosis. We examined three procedures used in a coordinated way to evaluate catheter malfunction in patients with the Infusaid implantable infusion device: *1*) abdominal radiographs, *2*) a percutaneous catheter pressure diagnostic procedure via the sideport, and 3) roentgenographic catheter visualization after infusion of iso-osmotic contrast material via the sideport. Since the relative clinical importance of decreased insulin infusion rate by slowdown and catheter malfunc-

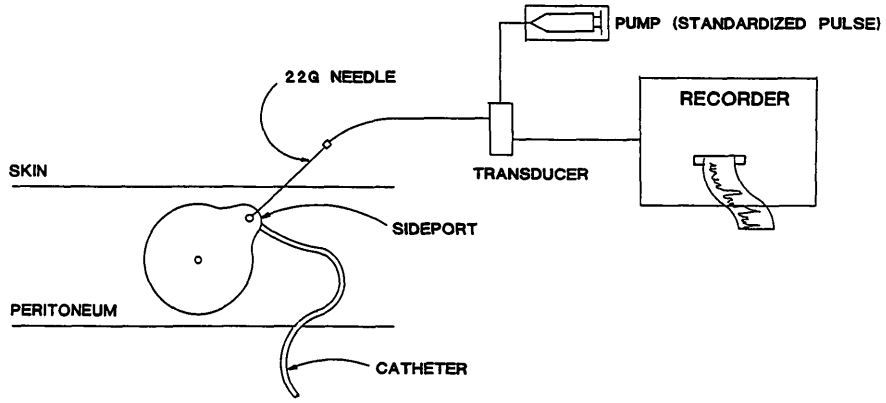

Figure 1—*PDP equipment, emphasizing the pressure connection between the catheter tip, sideport, and recorder.*

tions is unknown, both were clinically studied for their effects on diabetes metabolic control. Since catheter malfunction led to deterioration of metabolic control and pump slowdowns did not, a diagnostic algorithm was developed to expedite and facilitate the diagnosis and treatment of catheter malfunction.

RESEARCH DESIGN AND METHODS

— Sixteen type I, C-peptide–negative diabetic patients were included in this study, which was performed between 1989 and 1992. There were eight women and eight men, with an age range from 28 to 54 years (mean age 39 years). Patients did not have significant chronic diabetic complications, except for one patient with moderate renal insufficiency (serum creatinine 2–3 mg/dl). No patient had significant diabetic retinopathy requiring laser therapy. As part of an ongoing multicenter trial, all were implanted with a programmable insulin infusion system (Infusaid Model 1000, Norwood, MA) with delivery of insulin into the peritoneum. Patients were selected based on a prior history of adherence to an intensive insulin treatment medical plan. The success of these patients' adherence to intensive metabolic control has been previously reported in detail (1,4,6). Details of pump design and function have been published elsewhere (3,9). There is no pump-pressure patient alarm. The catheter design has been previously reported (3). In brief, the catheter is a bilaminar tube composed of silicone on the outside and polyethylene on the inside. All catheters were 28–35 cm in length and were in use from 1 month to 2 years. For this time period, catheter age does not appear to affect the results of catheter tests described below. Surfactant-stabilized, semisynthetic human insulin was used (Hoechst 21PH, 100 U/ml, Hoechst AG, Frankfurt, Germany). The patients were evaluated with monthly glycated hemoglobin levels measured by affinity chromatography (Isolab, Akron, OH; normal <6.9%). The study protocol was approved by the Institutional Review Board at the University of California, Irvine.

To assess catheter malfunction, three procedures were evaluated.

1. Standard abdominal anteroposterior and lateral radiographs were obtained to evaluate catheter position, especially at its exit from the pump housing. Visualization of the radiolucent catheter lumen throughout its entire length was also examined.
2. A pressure diagnostic procedure (PDP) was performed to record catheter function after a standardized diluting fluid infusion through the sideport (Fig. 1). This procedure has been previously validated and described in detail (3,7). In brief, after establishing a baseline pressure, a standardized infusion of diluent is given through the sideport while recording the pressure deflection using a pressure transducer (Daytronic Model 3270, Miamisburg, OH) and transducer dome (Disposadome, Telos, Upland, CA). Pressure calibration is performed using a water manometer at 0 and 1 m. A positive pressure deflection (normal 1.32 ± 0.23 psi, n = 66 evaluations in 16 patients over the duration of this study) followed by a return to baseline pressure indicates uninterrupted flow (Fig. 2*A*). Peak pressure is calculated from the highest point of positive deflection following diluent infusion, with 1 inch = 1 psi. $t_{1/2}$ decay time is determined by measuring the time in seconds for the pressure to decrease by 50% from its peak level following each bolus. An alteration of the pressure curve with a delayed or absent return to baseline (decay time >50 s) indicates catheter malfunction (Fig. 2*B*). If a malfunction is demonstrated, attempts are made to clear the catheter by a manual flush with diluting fluid (HOE 21PH diluent, Hoechst). If the flush is successful, normal waveforms (Fig. 2*A*) are observed following a repeat standardized diluent infusion.
3. Catheter integrity and patency are imaged by the infusion of iso-osmotic contrast dye (Isovue, Squibb, New Brunswick, NJ) through the sideport into the catheter via tubing connected to a three-way stopcock at the needle hub. Iso-osmotic dye was used to minimize renal complications. No renal abnormalities were observed. Radiolucency of the catheter lumen along its entire length before contrast infusion is examined (Fig. 3*A*), as well as the development of catheter lumen radiopacity along its entire length following contrast infusion (Fig. 3*B*). Intraperitoneal dye in the area of the catheter tip is also demonstrated (Fig. 3*B*).

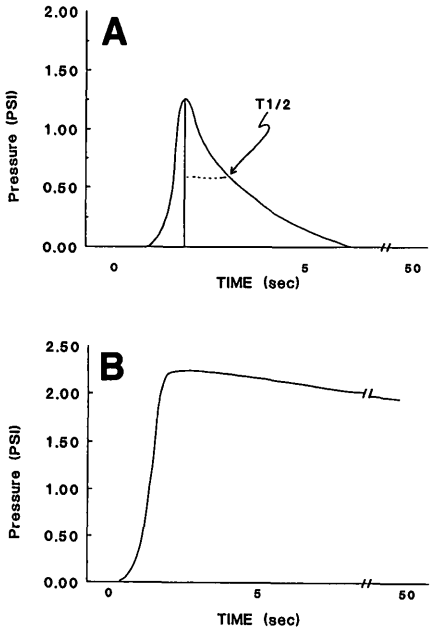

Figure 2—*PDP recording. A: normal pressure deflection following standardized bolus indicating normal pressure dynamics. $t_{1/2}$, the point of measurement of time after the standard injection. B: elevated peak pressure with a delayed return of the curve to the baseline (decay time >50 s) following the standard bolus. Results indicate catheter malfunction.*

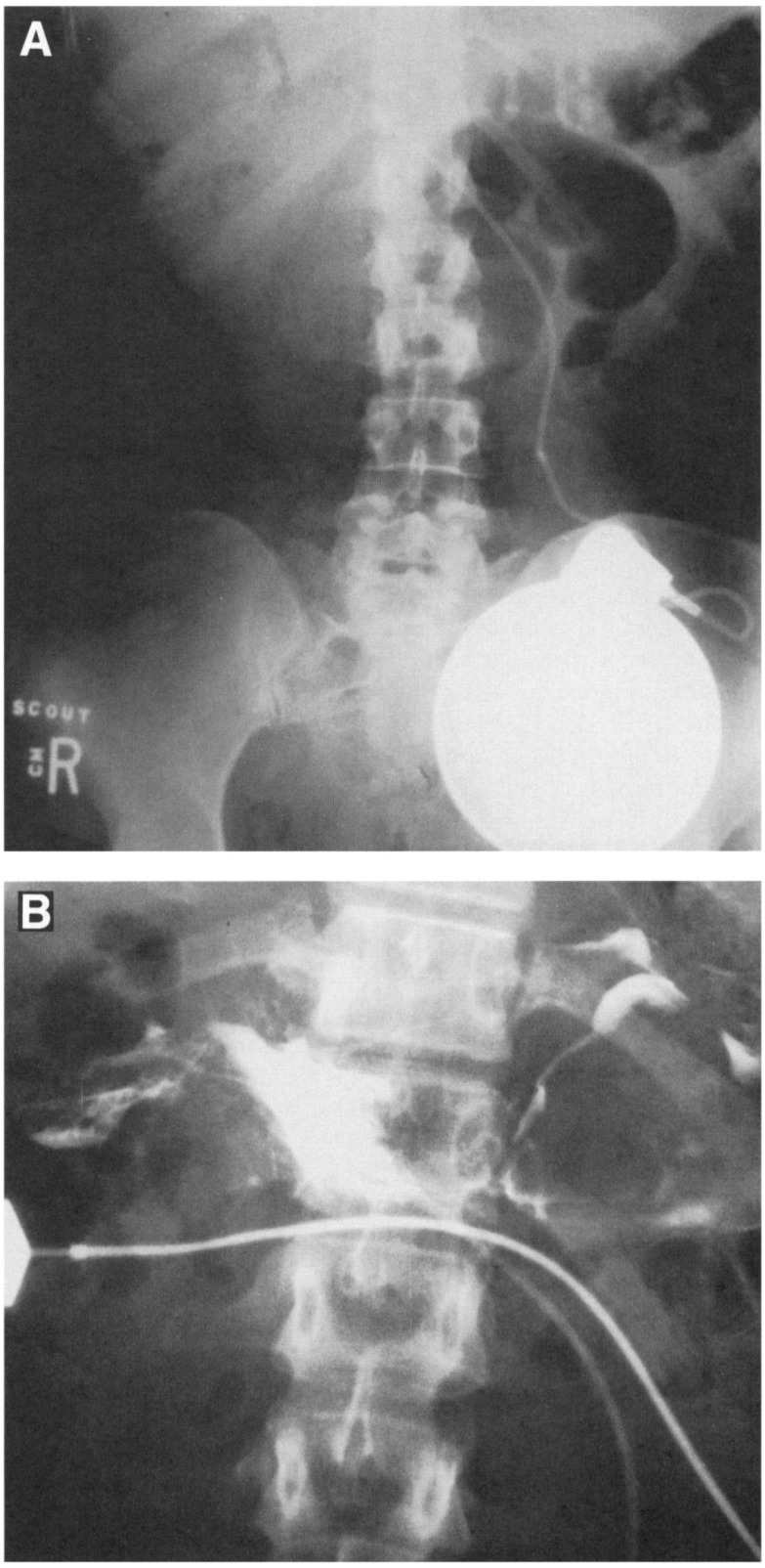

Figure 3—*Radiocontrast imaging. A: a radiolucency is noticed throughout the catheter lumen along its entire length before contrast has been infused. B: after the infusion of contrast material, radiopacity of the entire catheter lumen should be easily visualized.*

Slowdown of insulin flow is caused by aggregation of insulin in the pumping chamber. This is measured clinically by comparing the actual amount of residual insulin remaining in the pump reservoir during a refill procedure with the amount expected from the insulin-delivered calculation programmed into the pump electronic memory. An outpatient pump-chamber washing procedure is used to correct impaired insulin flow and has been previously described in detail (3). In brief, the actual:programmed insulin usage ratio is defined as the normalized flow. When the normalized flow is <0.8 and the catheter is functioning normally, the wash is performed. To wash, the pump reservoir is rinsed with sterile water followed by 0.1 N NaOH. The NaOH is then pumped through the system, draining from a needle inserted into the sideport. The NaOH is removed

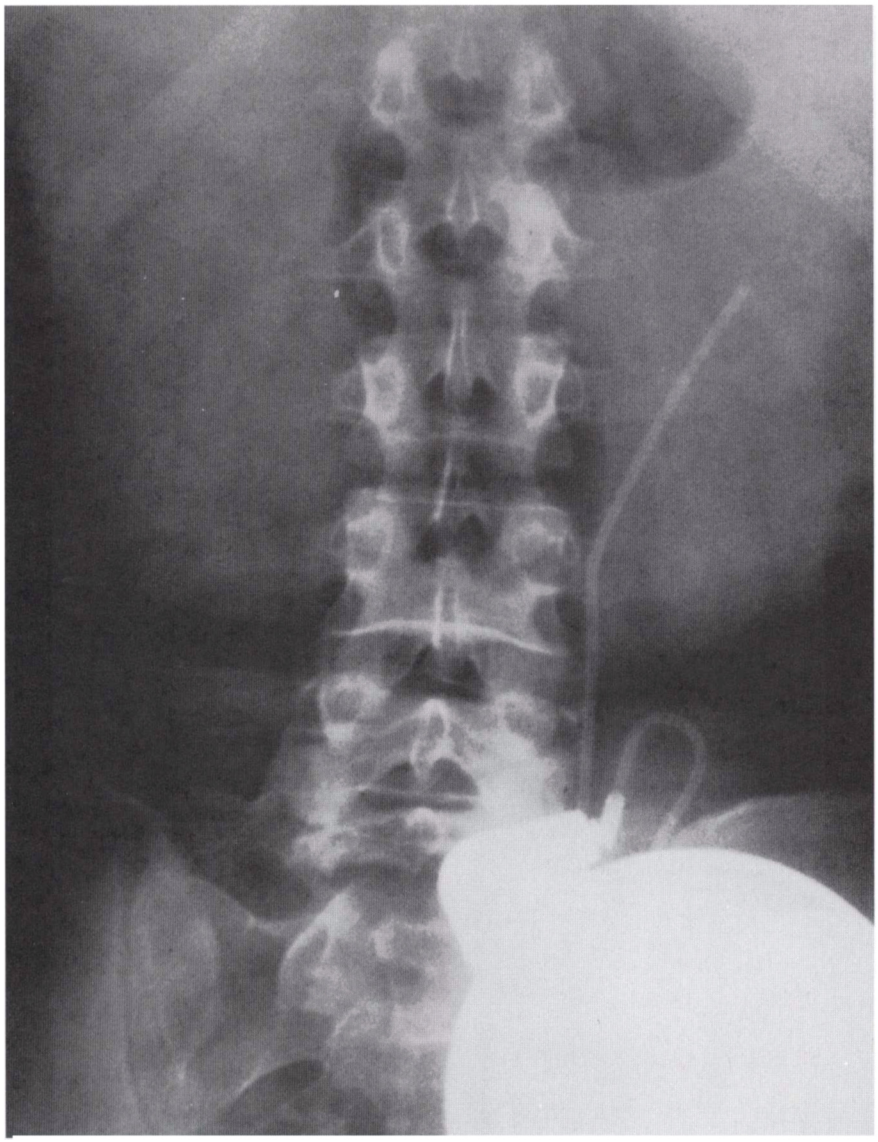

Figure 4—*Standard AP abdominal X ray. Abnormal angle linking catheter hub with pump clearly defining a broken catheter hub.*

from the pump by rinsing with sterile water and then diluent. All data are reported as means ± SE. Unpaired Student's *t* tests are used for comparisons.

RESULTS— To determine if catheter malfunction or pump slowdown created clinical deterioration of metabolic control, glycated hemoglobin levels were assessed before and after each event. During catheter malfunctions, mean glycated hemoglobin levels increased from 8.0 ± 0.3 to 9.0 ± 0.4% between the month before and 1 month after malfunction ($P < 0.05$, $n = 14$). The mean glycated hemoglobin level before pump slowdowns was 8.6 ± 0.2%, whereas the level was 8.9 ± 0.3% 1 month after the event (NS [$P < 0.07$], $n = 14$). Thus, catheter malfunction appeared more clinically relevant than pump slowdowns.

To establish if results of the PDP could distinguish between different causes of catheter malfunction, mean peak pressures and decay times were compared. The mean peak pressure in reversibly occluded catheters was 1.96 ± 0.14 psi ($n = 16$ evaluations in 16 patients) with a pressure curve $t_{1/2}$ decay time between 50 s and infinity.

These data contrast with a mean peak pressure of 1.32 ± 0.23 psi in normally functioning catheters ($P < 0.01$, $n = 66$ evaluations in 16 patients) and with a normal pressure curve decay $t_{1/2}$ of 3.6 ± 0.82 s ($P < 0.001$, $n = 66$). Irreversibly occluded catheters (n = six patients, seven events) do not permit $t_{1/2}$ decay time measurements. These catheters were all surgically replaced. During catheter malfunction associated with disruption of the catheter lumen (delamination; n = two patients, two events) or dislodgement of the catheter from the pumping device (n = three patients, three events), the $t_{1/2}$ decay time can be measured. For these latter two malfunctions, pre-flush measurements revealed a mean peak pressure of 1.86 ± 0.35 psi (n = nine evaluations in five patients) with a decay $t_{1/2}$ of infinity and a post-flush mean peak pressure of 1.33 ± 0.20 psi (NS vs. normal catheters) with a $t_{1/2}$ decay time of 5.3 ± 1.6 s (NS vs. normal catheters). These catheters were all surgically replaced after a diagnosis was made as described below.

Because peak pressure and $t_{1/2}$ decay times were similar in broken catheters and reversibly occluded catheters, both before and after flushing, abdominal radiographs and sideport injection of contrast material were used to differentiate between these two malfunctions. Abdominal radiographs also assisted in the diagnosis of one catheter's migration into the pump pocket. Breakage occurred in five catheters, three of which were broken at the catheter hub. Hub breakage is suspected on review of abdominal radiographs when the angle of linkage between the catheter and the pump is noted to be abnormal (Fig. 4). This can be confirmed if necessary by contrast infusion. Fracture of the catheter at its hub can lead to contrast material infusing into the pump pocket adjacent to the isodense pump

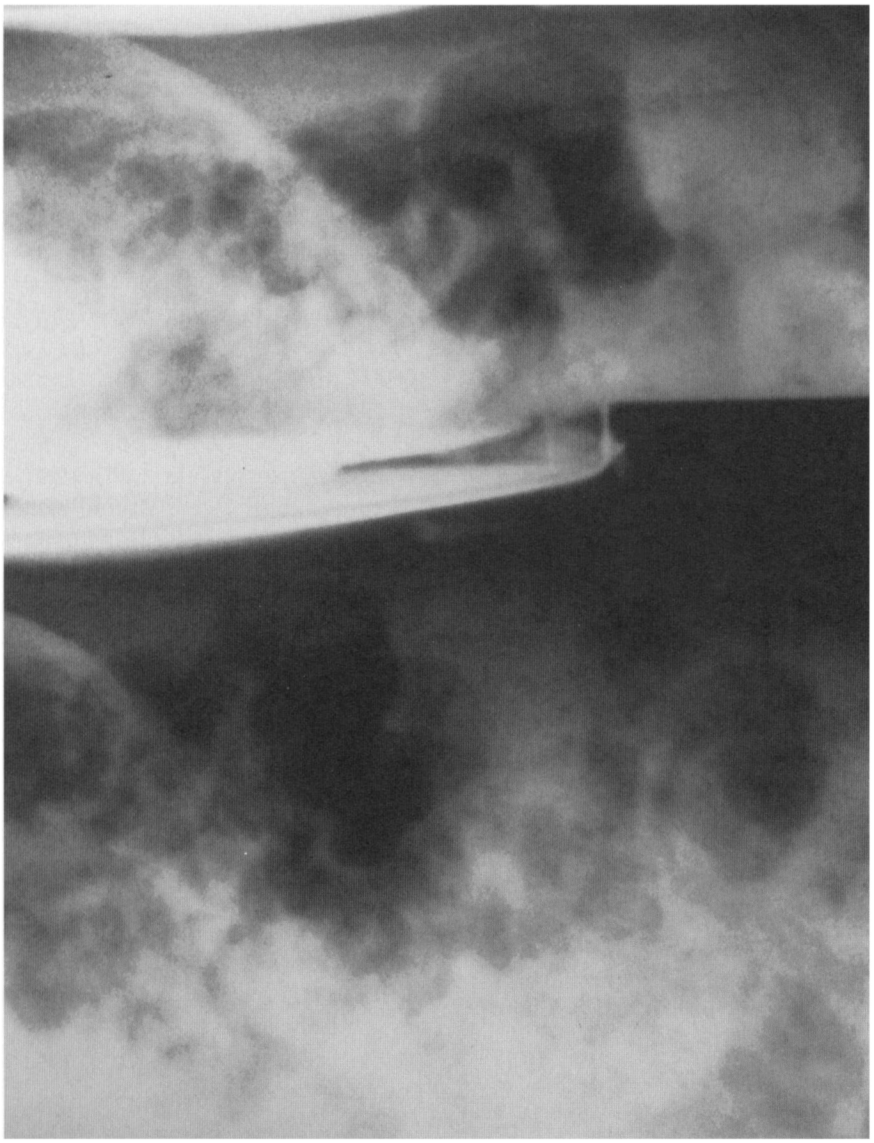

Figure 5—*Radiocontrast imaging. The upper part shows radiocontrast material collecting on the inferior surface of the pump. A similar radiopacity is noted in the lower part, showing contrast media in the pump pocket. Note the lumen of the catheter in the lower part, clearly showing radiolucency rather than being filled with contrast media.*

wall rather than through the catheter, making visualization of the infused contrast material difficult and suggesting improper placement of the needle into the sideport (Fig. 5). This occurred in one of our patients, but careful evaluation of the pump pocket revealed contrast. Excessive pressure requiring extreme manual pressure on the syringe plunger using smaller syringes (<10 cc) during infusion of diluent to release a catheter occlusion may lead to delamination of the catheter wall, necessitating surgical repair; this occurred in three of our patients, and a diagnosis only occurred after contrast infusion (Fig. 6). Radiopacity of the catheter lumen following contrast infusion is noted up to the point of delamination and breakage, at which point the lumen becomes radiolucent and contrast material spills into the peritoneum. Irreversible catheter occlusions typically occur at the catheter tip and have normal routine abdominal radiographs; however, contrast material is unable to be infused because of the occlusion. Thus, broken or delaminated catheters can be distinguished from reversibly or irreversibly occluded catheters.

All procedures were free of complications except for one episode of severe hypoglycemia 3 h after a PDP during the 1st year of this study. The patient recovered without complications.

CONCLUSIONS— The use of implantable pumps is likely to become widespread in the near future because of improvements in glycemic excursions (1,2,5–7) and major improvements in safety (4–6). Thus, the clinical relevance, diagnostic workup, and treatment strategies are important to understand. This study reports on each of these issues. We have confirmed the importance of the PDP in the assessment of catheter problems and have extended these data by the integration of routine abdominal X rays and contrast media X rays using the sideport to arrive at a more rapid diagnosis using a clinical-diagnostic algorithm. We have also described that catheter problems are more clinically relevant than pump slowdowns for overall metabolic control. Because of these observations, the diagnostic algorithm was generated to expedite the time to definitive diagnosis.

Broken catheters and catheter occlusions occurred in a significant number of patients and were associated with significant metabolic deterioration. We found more severe deterioration in glucose control with catheter malfunction than with pump slowdowns. The frequency of these events was described previously (3,5).

The PDP proved useful in distinguishing pump slowdowns from catheter malfunctions, because partial catheter occlusions result in decreased normalized flow as previously reported (3,5). The PDP alone is not successful in differenti-

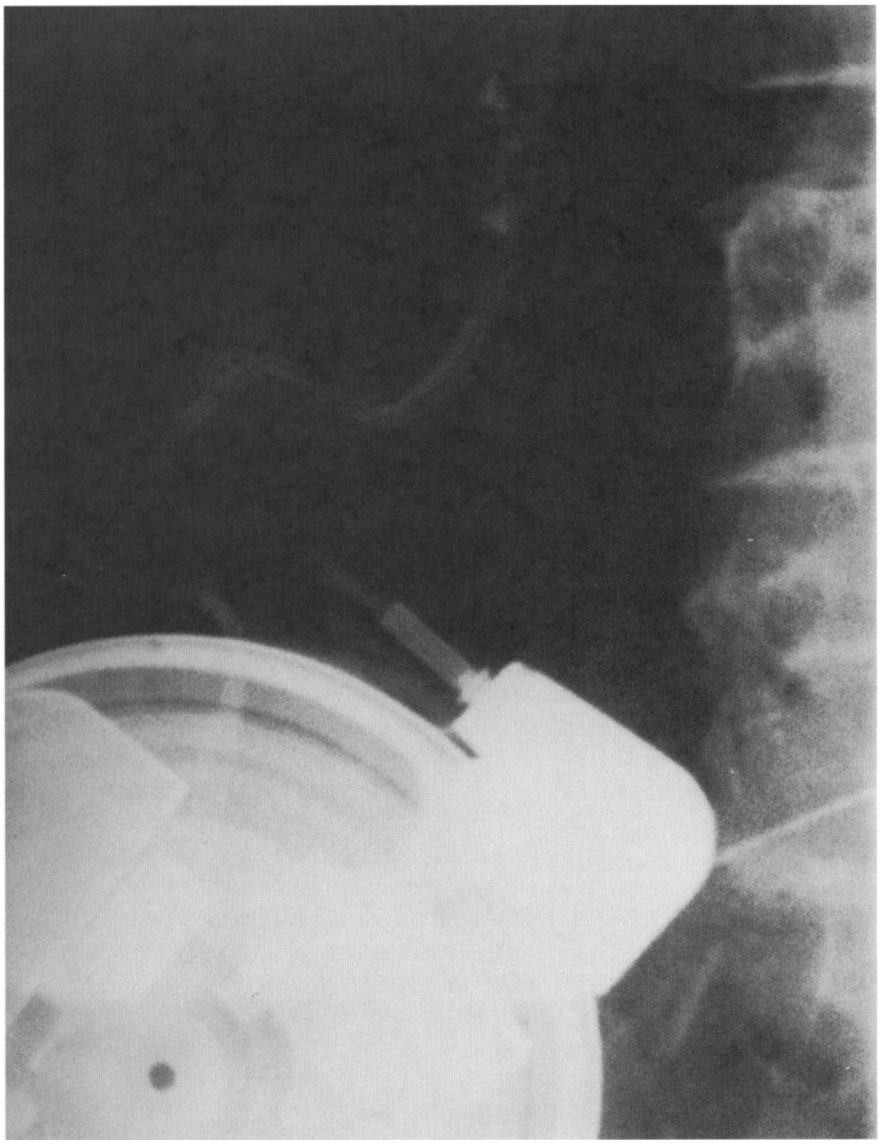

Figure 6—*Radiocontrast imaging. Note radiopacity of catheter lumen up to the point of catheter breakage where contrast material is extravasating from the catheter. Also note easily visible radiolucent catheter lumen distal to the delamination and leakage area. This is most easily observed with contrast material extravasating into the peritoneal space around the catheter approximately midway to the end of the catheter.*

ating between different causes of catheter malfunction. Catheter dislodgement or hub breakage and delamination, for example, produced similar peak pressures and decay times as did reversibly occluded catheters. Therefore, a diagnostic algorithm was developed to enhance the specificity of catheter malfunction evaluation (Fig. 7). Hub breaks in this device have been corrected by redesign of catheters. Initial assessment of a patient experiencing metabolic instability manifested by unexplained hyperglycemia is done with the PDP to rule out a catheter occlusion. If an occlusion is confirmed by PDP and is resolved by manual flushing, then no further workup is needed. This is the more frequent result. If an occlusion is not the correct diagnosis, then the patient will return within a short period (<1 month) with recurrent metabolic instability. At this time, an abdominal radiograph is performed before PDP to rule out catheter dislodgement or hub breakage. An abnormal radiograph necessitates open surgical repair. Failure to clear an occlusion during a PDP by manual flushing can be approached by laparoscopy to repair the catheter; if laparoscopy fails or is technically unfeasible, or if catheter breakage is present, an open surgical replacement of the catheter is performed.

A repeat PDP is indicated if the radiograph is normal, followed by contrast infusion into the sideport to evaluate catheter patency if a reversible catheter occlusion is suggested by PDP. Care must be taken during infusion of contrast material or diluent to avoid catheter rupture or delamination of the catheter lumen from excessive pressure; thus, we use syringes with sizes >5–10 ml for this procedure. Pressures up to 200 psi can be generated with 5-ml syringes and higher pressures with smaller syringes. Catheter breakage requires surgical repair and catheter replacement, whereas normal studies indicate the need to continue searching for alternative explanations for the patient's hyperglycemia.

In published studies, catheter malfunction has been the most common reason for explantation and has been responsible for the majority of surgical problems with pump use (3,5,9). Mechanisms proposed for catheter malfunction include physical disruption of the integrity of the catheter as well as catheter occlusion due to either fibrinous and cellular deposition intraluminally or at the catheter tip or by full or partial catheter encapsulation by omentum (3,5,9). The presence of a sideport allows not only improved diagnostic ability in determining the cause of reduced insulin flow, but also a means of manually reversing an occlusion. This is an improvement over other models lacking a sideport, where the more invasive laparoscopy and/or pump-pocket surgery are required. Without a

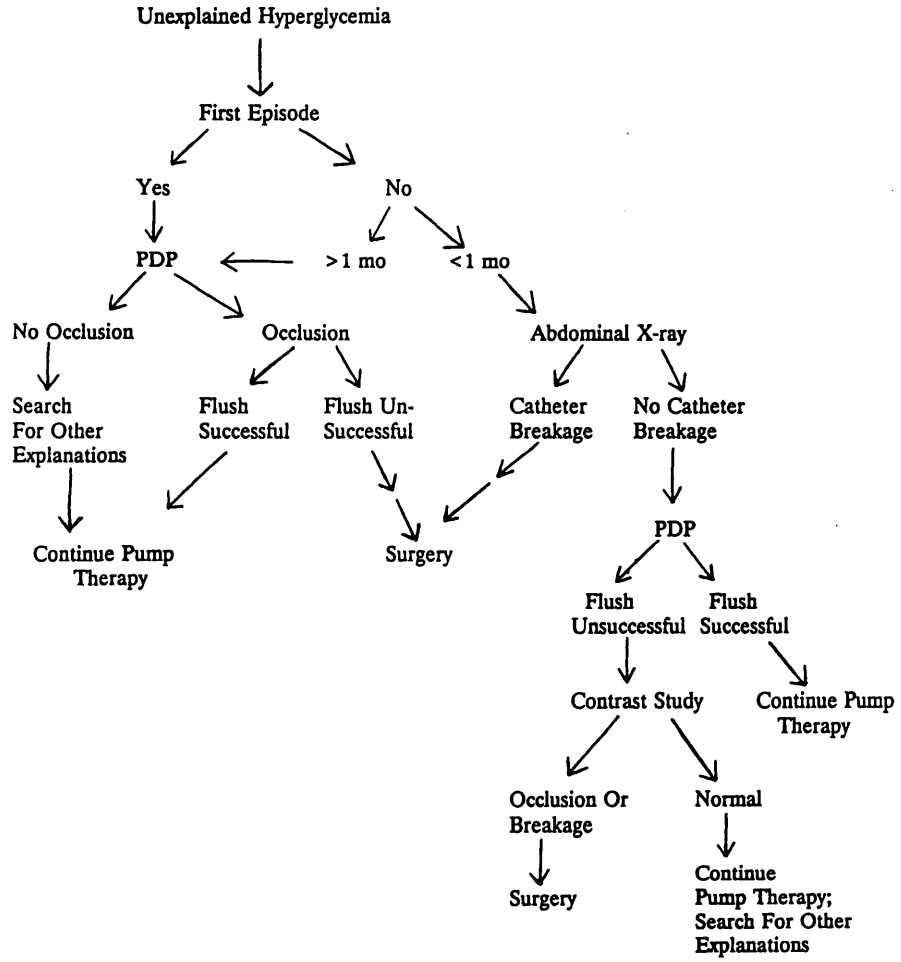

Figure 7—*Diagnostic algorithm used for evaluation of catheter malfunction and appropriate treatment.*

sideport, an unambiguous diagnosis of catheter problems is not published.

We therefore conclude that broken catheters and occlusions are not uncommon in implantable insulin infusion systems and, when present, tend to produce more metabolic deterioration than do pump slowdowns from insulin aggregation in the pump chamber. The pump model used contained a sideport, which allowed pressure data to be used along with radiographic methods to investigate catheter problems. This led to the generation of a diagnostic algorithm, which we feel will allow catheter malfunction to be most easily and efficiently evaluated, thus minimizing patient risk of metabolic deterioration.

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