特集　小児領域における非血管系*Interventional Radiology*最近の進歩

1. (Mostly) Non-Vascular Intervention in Children: An overview

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Abstract

The 1970's and 1980's were a period of rapid development and growth of interventional radiology in the pediatric population. During this time the types and numbers of procedures grew and the pediatric interventionalist became an active member of the physician team actively caring for children. Many new procedures were introduced and equipment developed and was modified for use in children of all ages and sizes. As a result of these advances in the 1970's and 1980's the case load increased dramatically. Since 1990 this trend has intensified and the case load has increased again by approximately threefold and we are now performing almost 3000 procedures per year. This increased demand has also been accompanied by an increasing case complexity e.g. biliary drainage and dilatation. The result is that the pediatric interventionalist is now involved in caring for extremely ill children with complex medical and surgical problems. In addition to the growth in inpatient procedures there has been a simultaneous and dramatic increase in the number of procedures performed in the outpatient setting.

It has become clear that the increasing utilization of the pediatric interventional services and angiography/interventional suite has several advantages including: shorter hospital stays, lower intensity post procedural nursing care, and less post procedural discomfort and problems when compared to comparable open surgical procedures. In addition to these advantages to the child there is a lower financial cost to the institution. Thus, it is likely that this trend towards interventional (minimally invasive) therapy will continue and intensify in the future. The purpose of this review is to present and overview of some of the newer and important non-vascular interventions and selected vascular interventions being performed in the pediatric population.

Key words : Interventional procedures, Infants and children, Gastrointestinal tract

Percutaneous feeding techniques

Adequate nutrition is essential for normal growth and development. In children with chronic illnesses or those unwilling or unable to take in adequate calories and/or other essential food stuffs e.g. malabsorption, short gut syndrome, growth will stop or proceed at an abnormal rate. In order for these children to thrive, nutritional supplementation is necessary. In children with normal digestive function it is preferable to utilize the gastrointestinal (GI) track for feeding to avoid hyperalimentation and its complications. To accomplish the goal of maintaining normal nutritional status in the face of short term or long term nutritional deprivation, several strategies may be enlisted and tailored to the individual's need. In our practice chil-

dren who are expected to require short term nutritional support (for approximately 6 weeks or less) are advised to get their nutrition by either peripheral intravenous alimentation, nasogastric (NG) tube, nasojejunal (NJ) tube feeding or combinations of these techniques. However, when longer periods of nutritional support are anticipated percutaneous gastrostomy (PG) or percutaneous gastrojejunostomy (PGJ) is recommended.

In 1837 Egeberg[1] first proposed the operative gastrostomy. However, it was not until 1876 that Verneuil performed the first successful surgical gastrostomy (SG) in a human[2]. Since then a number of surgical techniques have been described. In 1897 the surgical technique was modified by Stamm[3]. It is this technique that has become today's standard. The indications for SG have progressive increased. As a result the SG has become one of the most commonly performed operations in the pediatric population and is central to the care of critically ill and nutritionally deprived children of all ages[4~6].

An alternative to SG did not appear until 1979, over 100 years after the initial operation performed by Verneuil. In 1979 Sacks and Glotzer[7] introduced the idea for percutaneous gastrostomy (PG) with the publication of two cases of fluoroscopically guided placement of a gastric feeding tube through a healed SG site. Shortly thereafter, Gauderer, Ponsky, and Izant[8] described and popularized the percutaneous endoscopic gastrostomy (PEG). In the short time since the introduction of the PEG it has become a popular and successful alternative to the SG. In 1981 Preshaw[9] followed by Sacks and colleagues in 1983[10] modified the PEG technique so that a PG could be inserted under fluoroscopic guidance (FPG). Over the next few years a plethora of reports appeared that documented successful endoscopic[11~16] and fluoroscopically[17~22] guided placement of gastrostomy tubes in adults. However, little had been written about the safety and efficacy of the percutaneous technique in children until 1986 when Keller and associates[23] reported PG insertion in a single child. In 1988 Towbin and colleagues[24] described the antegrade approach for PG and PGJ insertion and reported the first large series of children receiving these de-

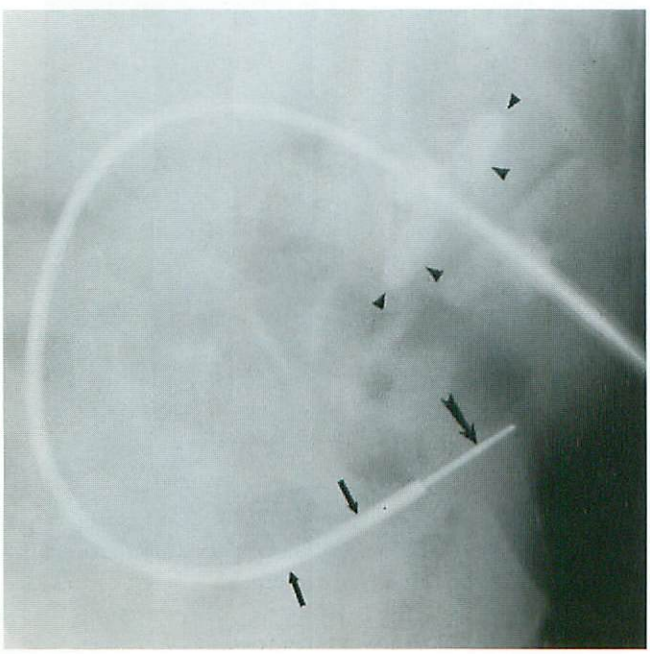


Fig.1
Percutaneous gastrojejunostomy tube: a 14F antegrade gastrostomy with a triangular retention disc (Ross) is within the stomach(arrowheads). A modified 8F jejunostomy (arrows) (Frederick Miller, Cook Inc.) is inserted coaxially over a guidewire (large arrow).

vices (**Fig.1**). Since that time numerous reports have been published confirming the safety and utility of the antegrade and retrograde PG and PGJ in children[25~29]. Regardless of the route of insertion selected the percutaneous approach is highly successful and well suited to large segments of the pediatric population.

The percutaneous techniques have demonstrated numerous advantages over the operative approach for gastrostomy tube insertion. In most instances a PG can be inserted under local anesthesia and intravenous sedation avoiding general anesthesia, decreasing overall procedure time, resulting in a shorter hospital stay. Also, a PG is more flexible allowing for easier conversion to a gastrojejunostomy, has a lower complication rate, and is less expensive. As a result of these numerous advantages the percutaneous approach has become the preferred method for tube placement in many situations. Whether the retrograde or antegrade route is chosen, the high likelihood of success (84~100%) and low rate of major (2~5%) and minor (12~16%) complications compares favorably with the operative approach[30~31].

In 1984, Gauderer, Picha, and Izant reported the initial experience with the gastrostomy button (GB)[32]. The GB is a simple, skin level, non-refluxing gastrostomy device and is a substitute for conventional gastrostomy tubes. The intended use was for replacement of gastrostomy tubes in patients with established tracks which had been inserted surgically or endoscopically. Shortly after its introduction, other reports appeared supporting the use of the GB and stressing the positive features of the device and the high level of patient satisfaction[55~59]. Since that time, the use of GBs for long term nutritional support has grown tremendously and the GB is now an important device for individuals who require prolonged

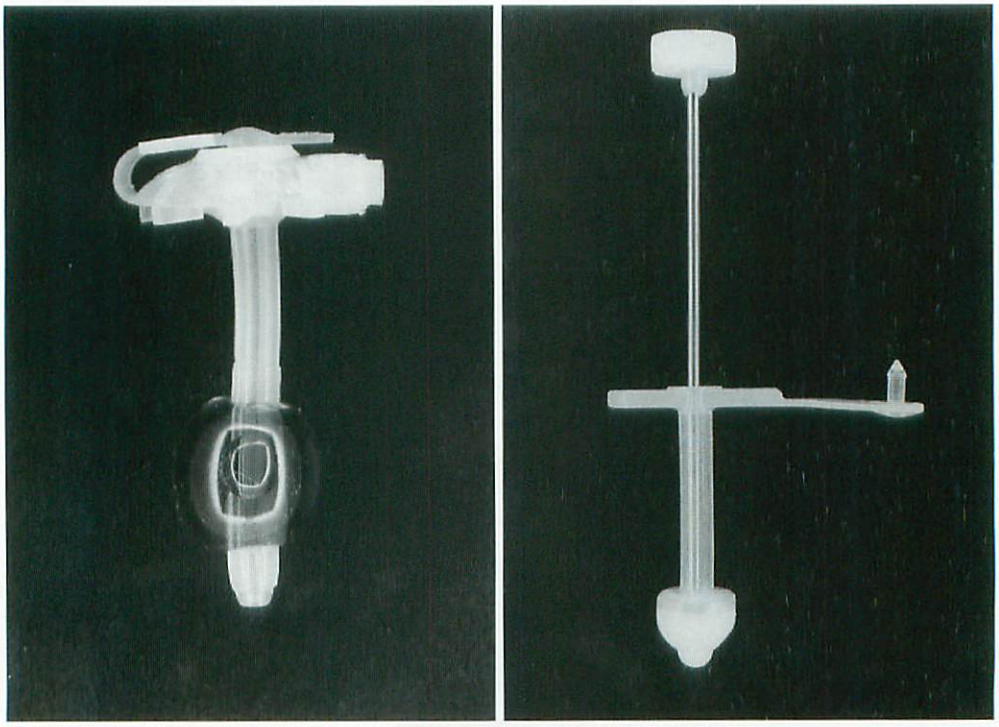


Fig.2 Gastrostomy buttons, The two types of buttons are shown.
a: Balloon retention.
b: Mushroom tip with stylet. Balloon type easier to insert/remove. Mushroom type more stable.

gastrostomy feeding but who do not require jejunostomy feeding (**Fig.2**). This subgroup of children are not candidates for GBs.

It is likely that the area of percutaneous feeding will continue to evolve with minimally invasive techniques replacing open surgery in most cases.

Percutaneous cecostomy

Fecal incontinence is estimated to effect at least 3 million people in the United States. However, most forms of therapy have been unsatisfactory. Dietary modification, the use of suppositories, small volume enemas, and biofeedback techniques have all shown limited results. In children fecal incontinence is a condition encountered in all age groups but is often the result of spinal dysraphism. Other etiologies including trauma, colorectal or spinal surgery may also lead to fecal soiling. To date, the most effective and predictable method for management of these children is using a large volume enema. This allows for complete emptying of the colon minimalizing the possibility of unpredicted and humiliating bowel evacuation[36]. Although effective, large volume enemas do not always result in control of fecal incontinence due to the lack of patient compliance. In addition, children with paresis or paralysis of limbs and/or trunk are unable to perform the procedure without aid. As a result of these problems Malone and colleagues devised an operation, the appendicocecostomy to ease the performance and increase the effectiveness of an antegrade enema[37]. Since then other operative approaches have been developed. However, the complication rate and the need for an opened procedure has limited the acceptance of this approach.

In 1996 Shandling, Chait, and Richards reported a pilot study using percutaneous cecostomy for treatment of children with fecal incontinence[38]. This interventional method is a creative modification of other percutaneous methods developed in the 1980's for the insertion of a percutaneous techniques. A subsequent report by Chait and colleagues gives us the first look at midterm results of this treatment method, its complications, safety and effectiveness[39]. It now appears that a percutaneous cecostomy is an effective way to deliver an antegrade enema for the purpose of achieving fecal continence and independent living.

Hepatobiliary techniques

Ultrasound, computed tomography, MRI, and nuclear medicine studies are sensitive modalities for the detection of biliary dilatation and can demonstrate hepatobiliary pathology. To date, the standard for imaging ductal anatomy has been percutaneous transhepatic cholangiography(PTC) although in the near future MRCP(magnetic resonance cholangiopancreatography) may replace diagnostic PTC in the pediatric population. Endoscopic retrograde cholangiopancreatography (ERCP) is used when imaging of both the biliary and pancreatic ducts is needed. However, ERCP has only a 70~90% success rate in demonstrating the intrahepatic bile ducts[40~43] as compared to PTC. Also, PTC is successful in determining the site of obstruction in 95~100% of cases and the etiology of the obstruction in 90~96% of patients with dilated intrahepatic bile ducts[43~45]. In contrast, ERCP is more technically difficult to perform in children, is not available in all hospitals, and is up to four times as expensive as PTC. Thus, fine-needle PTC is the safest and most accurate test to differentiate intrahepatic from extrahepatic cholestasis. In combination with percutaneous biliary dilatation and external stenting these techniques have enabled minimally invasive therapies to be applied to children with complex biliary pathology, especially in post operative patients with hepatic transplants. These techniques are well described in both adults and children. Therefore,

attention will be given in the following paragraphs to newer hepatobiliary interventions.

Transhepatic central line placement

Since its introduction in 1989 the safety and efficacy of percutaneous central line placement in adult and pediatric patients by interventional radiologists using image-guided techniques has been well documented[45~50]. The advantages of the percutaneous technique include a high success rate because of the ability to use imaging guidance for needle and guidewire placement, prompt recognition of catheter malposition with the ability to easily reposition the catheter properly, relatively instantaneous identification of complications, lower costs relative to surgically-placed central lines, and the ability to provide viable alternatives for placement of central lines in patients in whom standard routes are no longer available. In 1991, Kaufman, et al, reported insertion of a central catheter via the transhepatic approach[51]. We have adapted this technique for insertion of central venous catheters and placement of large-bore dialysis catheters[52].

Vascular access into the inferior vena cava is accomplished using either general anesthesia, intubation with subsequent paralysis and sedation, or intravenous sedation and local anesthesia. The latter is preferred whenever possible. Hepatic vein access is accomplished using real-time ultrasound guidance. A biopsy guide is fitted to the ultrasound transducer and a Chiba needle or sheathed needle is guided into the most vertical (usually right) hepatic vein. With the needle in place a guidewire (usually a glidewire) is maneuvered into the right atrium and the track is dilated so that a peel-away sheath can be inserted. After the catheter length is measured using a guidewire a double lumen 5～7F tunneled catheter or port is inserted (**Fig.3**). If phoresis or dialysis is necessary a large bore(7～11.5F) catheter is substituted for the central line using the same technique.

We have found this approach to be life saving in many situations. The technique is safe even in children who are coagulopathic. In all cases when the central catheter or large bore catheter is removed the

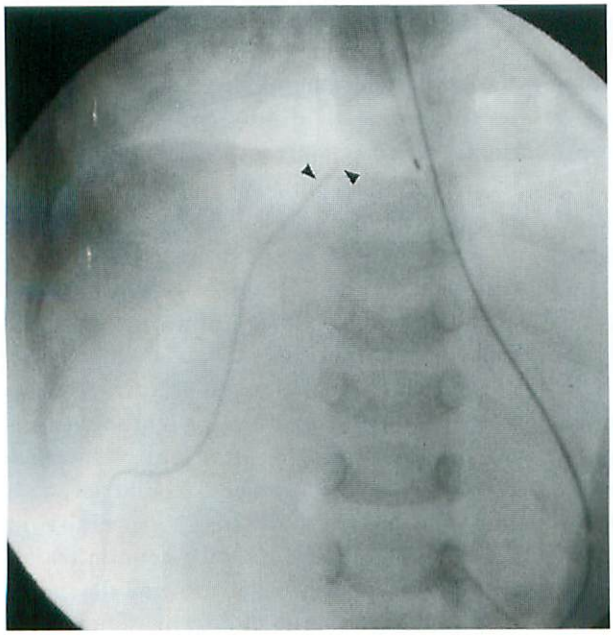


Fig.3
Child with biliary atresia with occluded central veins. Venous access acheived by transhepatic puncture of hepatic vein under US guidance. C-line tip at base of right atrium (arrowhead).

track is embolized with gelfoam pledgets or coils in order to achieve hemostasis.

Transjugular liver biopsy

The importance of diagnostic liver biopsy in the management of pediatric patients with severe liver disease or liver transplants is well-recognized[53]. Unfortunately, subgroups of children are at risk for serious bleeding and are not candidates for the conventional transhepatic biopsies. The first transjugular liver biopsy was performed in a human patient in 1967 by Weiner et al[54]. Several large series have since been reported which confirm the safety and usefulness of the transjugular approach in the adult population[55~58]. The theory behind this technique is that any bleeding associated with the biopsy will be directly into the vascular space and cause no hemodynamic problems. In 1992, Furuya et al. demonstrated that the transjugular was safe and effective in children[57]. This was confirmed by Bergey and colleagues in 1998.

In patients with severe coagulopathy and/or massive ascites and possibly children with segmental liver transplants the standard transcutaneous approach is contraindicated. Depending on operator preference two approaches may be considered: the transjugular and the transhepatic with post-procedural track embolization. In our practice the transhepatic route with subsequent track embolization is chosen when the child has a near normal or partially correctable coagulapathy with the PT, PTT, and platelet values near normal. In children with significant uncorrectable coagulopathies or platelet level below 30,000 the transjugular route is preferred (**Fig.4**). Despite the disadvantages of increased procedure time, smaller and/or fragmented core biopsy samples, higher cost, and the need for more highly trained personnel when compared to percutaneous liver biopsy, transvenous (transjugular or transfemoral) liver biopsy offers an effective and safe technique to obtain liver tissue for diagnostic purposes in this high-risk patient population. The transjugular approach may also be useful in this same group of patients when there is a need to measure

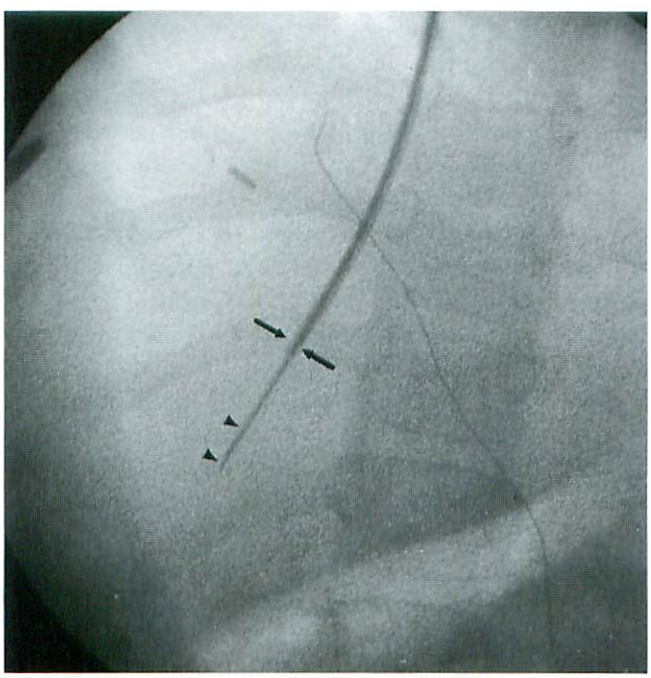


Fig.4
10-year-old female status post liver transplantation with an uncorrectable coagulopathy and abnormal liver function tests. Transjugular liver biopsy using a Quick-Core transjugular biopsy needle (Cook, Inc., Bloomington, IN). Guide sheath in proximal middle hepatic vein (arrows) with biopsy needle deployed. (arrowhead)

hepatic vein wedge pressures and/or perform an hepatic venogram for diagnostic purposes. Other less common reasons to use the transjugular approach include failed conventional percutaneous liver biopsy, massive obesity, small, cirrhotic liver and situations in which excessive bleeding may occur as a result of percutaneous biopsy, such as suspected vascular tumor.

One of the main contraindications to transjugular biopsy is a medically unstable child. Another significant contraindication is occlusion of any of the veins which need to be traversed in order to perform the biopsy, such as the internal jugular veins, SVC or hepatic veins in the case of the transjugular approach, or the femoral veins, IVC or hepatic veins in the case of the transfemoral approach. Careful ultrasound examination of these patients is obviously mandatory.

Prior to the procedure PT, PTT, Hgb, Hct and platelets values are routinely obtained. If necessary, blood products are administered either prior to or during the procedure. One or two units of PRBC's are ordered in the event of a serious bleeding complication. Since infectious complications are very rare, prophylactic antibiotics are not routinely given.

In most cases general anesthesia is selected because of the need for the patient to remain motionless and maintain a relatively uncomfortable position for 1～2 hours. Ultrasound examination of the liver is performed to evaluate the IVC, hepatic veins, and overall hepatic size and thickness. The right internal jugular vein is the preferred entry site. If the right internal jugular vein is occluded or otherwise not suitable for access, the left internal jugular vein or a femoral vein may be used. These alternative sites make the procedure more complicated technically. Using real-time US guidance, an 18 gauge needle is inserted into the jugular vein using Seldinger technique. The needle is exchanged for a 5F JB-1 catheter over a guidewire. Under fluoroscopic guidance the wire and catheter are manipulated into the right hepatic vein. The JB-1 catheter is then exchanged for a long 7F or 9F vascular sheath. The sheath is advanced 3 or 4 ㎝ into the right hepatic vein which keeps it in a relatively posterior position, hopefully with enough intervening hepatic parenchyma to be a safe distance from the anterior liver capsule. An hepatic venogram is then performed. Following the venogram the wire is removed and a 7F Colapinto metal sheath is placed into the hepatic vein via the vascular sheath already in position. The Colapinto sheath is advanced so that the tip is protruding from the distal end of the vascular sheath by approximately 1 ㎝. An 18 gauge Cook Quick-core biopsy needle is advanced until the tip of the needle is at the end of the sheath. The sheath is then rotated anteriorly and the biopsy needle advanced so that the tip protrudes from the end of the sheath by approximately 0.5 ㎝. A biopsy is then taken. A maximum of three passes are made to minimize the potential of post operative complications. Once the biopsy has been obtained the Colapinto sheath is removed. Prior to removing the sheath a post-biopsy contrast injection is done to check for capsular perforation, which occurs in approximately 3.5% of cases[58], although clinically significant bleeding has been reported in only 0.35 % of cases. If extravasation is identified the needle track may be embolized with Gelfoam (Upjohn Co., Kalamazoo, MI) or metal coils. Transjugular biopsy successfully obtains adequate liver tissue in greater then 95% of patients[52,58]. Failed attempts at transjugular biopsy are uncommon, but when they do occur they are usually related to difficult anatomy preventing puncture of the internal jugular vein, preventing cannulation of the hepatic veins, or retrieval of an adequate volume liver tissue[56,58]. In patients with small, hard, cirrhotic livers not only is

there a lower success rate in obtaining adequate liver tissue, but the risk of perforating the liver capsule with its attendant bleeding complications is higher. A routine post-biopsy chest Xray is taken in all children to access for complications.

New procedures

Osteoid osteoma was initially described by Jaffe in 1935[59]. This benign bone tumor is the third most common primary benign bone tumor in children behind osteochondroma and non-ossifying fibroma in frequency. It is found in 11% of cases and occurs 2~3 times more frequently in males. The lesion is most often diagnosed in patients ranging from 5~24 years of age. Interestingly, it is uncommon in the preschool age group accounting for only 3% of all osteoid osteoma cases[60]. Although the long bones are the most common site of involvement, any bone can be effected. The most commonly involved bones include the femur, tibia, humerus, and lumbar spine. In most patients pain is the initial symptom which is often more intense at night. In 30~75% of cases the discomfort is relieved by salicylates, however, both tylenol and ibuprophin may be effective. Local tenderness is also usually present upon palpation.

Plain skeletal radiographs usually reveal a small, sharply defined, eccentric, round to oval lytic lesion with reactive bone. Its characteristic feature is a hyperdensed nidus made up of spongy hypervascular focus up to 1.5 ㎝ in diameter. In 80~90% of cases the lesion is located within the cortex. Generally there is thick laminar periosteal new bone formation adjacent to the lesion. Interestingly, periosteal reaction is often minimal or absent when lesions are located in the metaphysis especially in the femoral neck. In young children (<5 years) and those with atypical symptoms other diagnoses may be considered clinically including; osteomyelitis, neuromuscular disease, and Legg-Calve-Perthes disease to name a few.

Although in a small number of cases the symptoms may gradually disappear over long period of time, the only curative approach is complete operative removal. Traditionally, a wide surgical excision is necessary to remove the lesion and reduce the potential for recurrence. This approach has been required because of the inability to directly visualize the tumor nidus at the time of surgery. More recently CT guided insertion of a Kirschner wire into the lesion has also shown to be effective for accurate intraoperative localization. Unfortunately, these methods are imperfect and incomplete resection still occurs.

For years CT scans have been utilized to diagnose a wide variety of benign and malignant bone tumors and to plan and guide percutaneous bone biopsy and surgical procedures. Thus, it is logical to use CT to identify the nidus of an osteoid osteoma, identify a safe route for its treatment, and to guide REMOVAL using a precision technique. Additionally, CT has the advantage over surgical removal of being able to accurately guide the tumor removal in real-time with interval imaging and immediately know if the lesion has been completely removed.

In 1989, Doyle and King described 2 patients in whom osteoid osteomas were removed percutaneously[61]. In 1990, Voto and colleagues using a freehand technique successfully excised 7 of 9 lesions using CT guidance[62]. In 1995, Towbin and associates reported a coaxial approach for CT guided removal[63]. These authors stressed that this method enhanced precision and flexibility in route planning. Since that time Rosenthal and colleagues have reported ablation of the nidus using a radio frequency coagulation technique[64]. There have now been several reports validating this approach towards removal of these benign bone tumors and it appears that CT guided removal may be the preferred

approach in many instances.

No special patient preparation is required. The procedure is performed as an outpatient whenever possible. The child is kept NPO as per hospital policy prior to the procedure. All children are begun on antibiotics and maintained on the drug the drugs for at least 3 days after the osteoid osteoma is removed. It is our preference to perform all CT guided removals under general anesthesia. Children with osteoid osteomas less than 2 cms in length and in an readily accessible location are scheduled for approximately 2 hours. Patients with large tumors, multiple lesions, and/or those in unusual or difficult locations require more time to remove. We have found that the use of power tools will shorten the procedural time as much a 50% and is especially useful for removal of larger lesions and those with marked periosteal thickening.

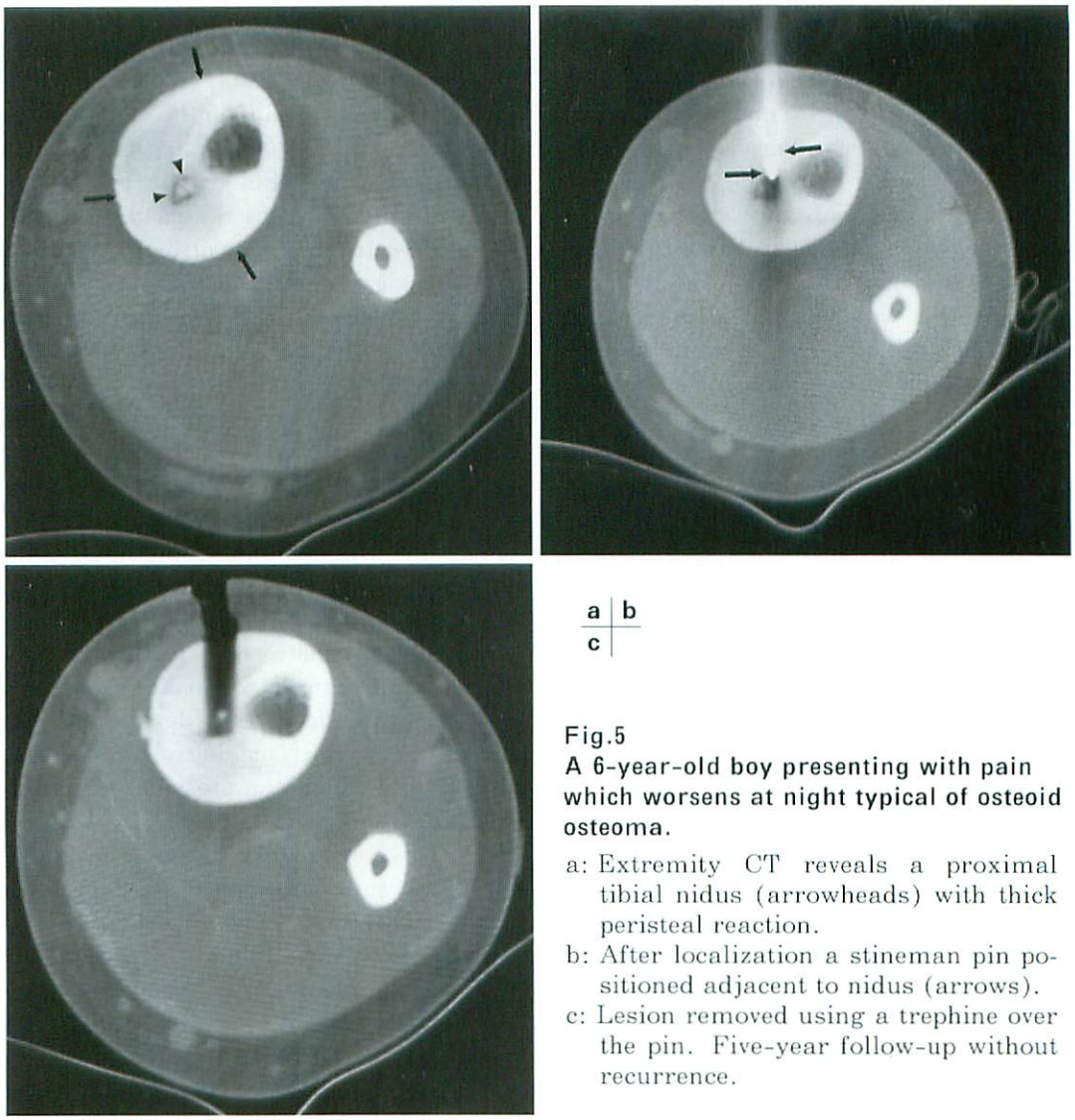
If a prior CT is not available or has not been performed it is important to obtain a high quality examination to confirmation the diagnosis, measure the size of the lesion, and plan the safest and easiest route to approach the lesion. On the day of percutaneous removal a limited CT is performed through the region of interest and the skin entry site is marked with indelible ink. Care is taken to avoid the vicinity of a nerve or vascular structure. Skin preparation is accomplished using a combination of betadine solution and alcohol. A small (approximately 5㎜) incision is made using a #11 scalpel blade and the incision is bluntly dissected to the bony surface. A pin or K-wire is inserted via the skin incision and directed towards the center of the lesion. Once the pin/wire is centered over the lesion and confirmed by it is hammered into the bone with a metal mallet until the pin/K-wire leading edge is adjacent or through the lesion. A core of bone including the lesion is then removed using a trephine of appropriate size. In order to remove the osteoid osteoma completely the track should pass through the back wall for a distance approximately 1.5 times the diameter of the lesion. When the track is of desired length both the pin/wire and trephine may be removed within bloc. The specimen is then removed from the needle and sent to pathology for review (**Fig.5**).

After the lesion is removed another limited CT is performed to confirm the total removal. Regardless of whether or not some sclerotic margins of the wall remain the track and tumor cavity is aggressively scrapped using angled curettes. After recovery from anesthesia the child is discharged to home with the instructions for non weight bearing for about 6 weeks. The patient is asked to return for examination in about two weeks and is actively followed for 6 to 8 weeks. It is gratifying to know that in most instances the child is pain free immediately after completion of the procedure and has limited post procedural discomfort.

In most cases minor analgesia with tylenol, ibuprophen or aspirin is all that is necessary. Occasionally, a narcotic analgesic is needed for a few days but this is the exception to the rule. The antibiotic coverage is maintained for a total of 5 days and discontinued unless an infectious complication arises.

Tracheal stenting

Stenting of the tracheobronchial tree is now feasible for the treatment of strictures involving the pediatric airway. In 1974, Montgomery reported the use of silicone stents[65]. Since that time several types of plastic stents have been used for the treatment of tracheobronchial stenoses[68]. Metallic stents were developed for treatment of vascular stenoses. However, it quickly has become evident that these devices could be used to treat strictures involving other sites. In 1986, Wallace and colleagues reported the usefulness of expandable metal stents for treatment of



a | b
c

Fig.5
A 6-year-old boy presenting with pain which worsens at night typical of osteoid osteoma.

a: Extremity CT reveals a proximal tibial nidus (arrowheads) with thick peristeal reaction.
b: After localization a stineman pin positioned adjacent to nidus (arrows).
c: Lesion removed using a trephine over the pin. Five-year follow-up without recurrence.

stenoses following tracheobronchial reconstruction[67]. Since then, several groups have described the successful placement of metallic stents for treatment of a variety of conditions. When an airway stenosis is identified there are a variety of therapeutic options available for their treatment. Bronchoscopy with dilation, laser therapy, endobronchial resection, fluoroscopically guided balloon dilation, and stenting all may be helpful depending on the clinical setting. The relative indications for each therapeutic approach changes with technical advances. At the current time surgical resection of an airway stricture is recommended whenever possible. However, surgery is not always feasible because of; the location of the stenosis, post operative recurrence(s), and a child who is not a surgical candidate due to the severity of underlying disease, or an uncorrectable coagulopathy. Thus, in these settings balloon dilatation with or without stenting may be a life saving procedure. The risks and technical limitations of surgical resection and tracheo-

bronchial reconstruction make the use of stents and other techniques appealing for management of these difficult patients. The use of stents represents an advance in the management of otherwise inoperable patients.

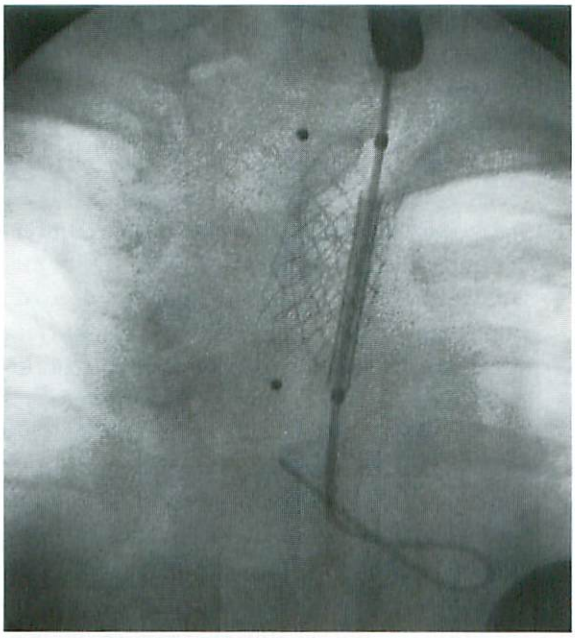
Silicone stents were initially designed for use as T-tubes and were modified for use in other areas. Today the Dumon stent is most widely used silicone endoprosthesis[66]. Silicone stents were first to be used in the airway and offer several advantages. Silicone stents are easily inserted and can be modified into a variety of shapes and lengths and are generally well tolerated. They are efficacious for treatment of inflammatory and malignant strictures. The plastic prevents ingrowth of granulation tissue and tumor into the tracheal or bronchial lumen although there is tissue growth between the stent and airway wall. Perhaps the biggest advantage of this material is its ease of removal. Unfortunately, disadvantages also exist and tend to outweigh the advantages. Silicone stents are a non-tapered, high-friction material. Its construction makes it difficult to position in individuals with tight strictures. In addition, plastic stents are prone to displacement and expulsion from the airway and must be carefully sutured in place. In addition, the stents have relatively thick wall and narrow lumens and are apt to obstruct with mucus and other secretions. This is especially problematic in children with smaller airways. Since these stents are solid they interfere with normal mucociliary action and clearance of secretions and require constant pulmonary toilet. Also, because of it construction the silicone stent cannot be used if a lesion crosses a bronchial oriface since it would result in obstruction of a lung segment. Thus, when used silicone stents tend to be a short term solution.

Metallic stents have several advantages over silicone stents especially their low profile, expandability, flexibility, and the ability to be covered via epithelialization. Regardless of type metal stents have thinner walls with significantly larger inner diameters than equivalent sized silicone stents. Metallic stents are low profile and easily inserted across a stricture without significant trauma. Because of their open mesh design metal stents can be placed across a brachial origin without obstructing it. Finally, metallic stents are more stable and are less likely to dislodge. These physical characteristics reduce the amount of specialized care required after stent placement.

In spite of the positive features of metal stents disadvantages do exist. In general, metal stents can be deployed accurately. However, on occasion they may be inadvertently malpositioned. If this occurs, repositioning may be difficult or impossible. Also, the open mesh design does not protect against tissue ingrowth into the lumen and stent compression. Perhaps covered stents will help in some situations, however, no experience is available to answer this question. In the long term if the stent is no longer needed or it is causing problems, it may be difficult or impossible to remove. Although stent removal is not recommended, Filler and colleagues have removed 11 of 30 stents in a pediatric population[68]. They report that removal using a twisting and withdrawal can be accomplished in less that 30 seconds so that significant airway obstruction does not occur. A small amount of mucosal bleeding is noted in all cases which stopped spontaneously in a few minutes. These authors did note that one child died at attempted stent removal because it was welded into the tracheal wall by fibrous reaction. Nashef and associates describe removal of Gianturco stents as a process similar to rolling spaghetti on a fork, but much more difficult and time consuming[69]. Others have removed Palmaz and wallstents by cutting them

with lasers to affect removal. Thus, although some stents have been removed it is clear that the current generation of stents are intended to be permanent. Therefore, it may be the best strategy to avoid removal whenever possible.

Airway obstruction unresponsive to medical or surgical therapy is the indication for stent placement in childhood (**Fig.6**). The most common conditions requiring stent insertion are malacia, stricture, and airway compression. The list of indications for which placement of a stent may be efficacious in the pediatric population seems to be growing. In general, in spite of the allure of this therapeutic option, the long term effect of stenting an airway in a growing child is still unknown. Thus at this time, it is my feeling that stent placement should be reserved for treatment of conditions that are not responding to conventional forms of management.



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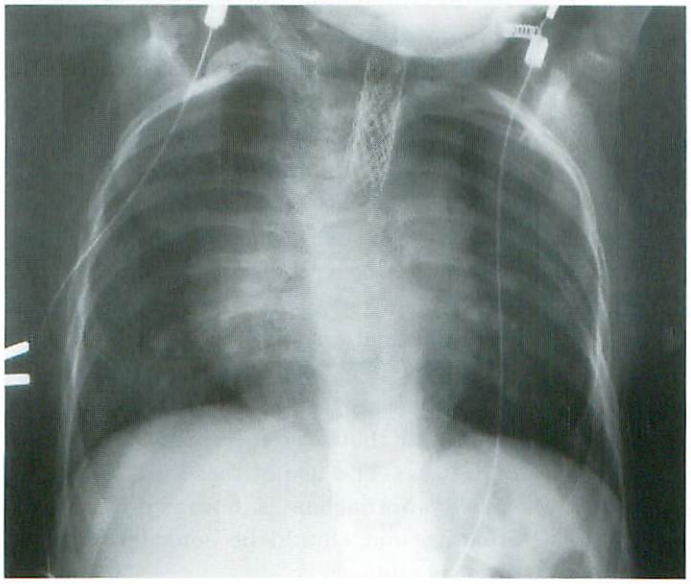

b

Fig.6
2-year-old male with congenital heart disease and severe tracheomalacia secondary to extrinsic compression from high aortic arch.
Failed aortopexy. Ventilator dependent until stent inserted. A second Palmaz stent being positioned (a). Both stents in position (b).

Although in time it may be shown that stenting of a child's airway is safe, effective, and the approach of choice it is probably wise at this time to take a conservative view until more information becomes available. Having said this, it has already become obvious that tracheobronchial stenting may be life saving in certain situations and may be offered to patients whose conditions are not amenable to surgery.

The preliminary results of tracheobronchial stenting[58,69] suggests the long term results of airway stenting depends upon the underlying etiology of the stricture. In patients with narrowing secondary to fibrosis, those with tracheobronchomalacia or extrinsic compression stenting is an excellent therapeutic option. However, children with fibroinflammatory disease with active inflammation and proliferation of granulation tissue usually have poor results. These patients have a high incidence of restenosis which may necessitate stent removal. In these individuals it is may be best to delay insertion of a metallic stent until the inflammation subsides if possible. If stenting is necessary during this acute phase a silicone stent could be initially placed until the inflammation subsides since this type of stent does not allow ingrowth of granulation tissue. Later a metallic stent can be inserted if needed. It appears that placement of a metal stent for treatment of an airway stricture can be accomplished safely and effectively in the vast majority of cases.

Contraindications to the placement of a stent in the airway of a child are difficult to elucidate at this time due to the lack of experience with this technique. However, patients with a breach in the integrity of an airway wall may be more prone to stent erosion and secondary complications. Children with the combination of a mucosal proliferative process and a tracheobronchial stricture have a high risk of recurrent strictures. Thus, in these children placement of a metallic stent may be a relative contraindication. In this subgroup medical therapy, a silicone or covered metal stent may be preferable.

Serious complications from stents have been reported including massive fatal hemoptysis resulting from penetration of a Gianturco Z stent into a pulmonary artery and development of a brachiocephalic-tracheal fistula[70]. In my opinion, Gianturco Z stents with hooks should be used with extreme caution in the tracheobronchial tree of children.

Today one of the most difficult questions to answer is whether to use a stent in a growing airway. There are no long term studies in children available to assess the effect of a stent on the circumferential and longitudinal growth of the airway. Thus, it seems prudent to avoid stent insertion especially those devices that might be more likely to tether or injure a growing tracheobronchial tree. It is currently our practice to select only those children who have severe symptoms and who have failed conventional therapy before considering insertion of a metallic stent. In these severely affected children with tracheobronchial strictures balloon dilation is the initial therapy of choice. Balloon dilation will be repeated if restenosis occurs as long as PTA relieves the child's symptoms. Stenting is utilized if PTA is unsuccessful in alleviating symptoms or symptomatic restenosis occurs rapidly. In the rare child with tracheomalacia who is ventilator dependant primary stenting is the procedure of choice.

Interventional procedures appears to have application in virtually all areas of the body. The pediatric interventionalist now plays an important role in the diagnosis and therapy of children of all ages and sizes. The use of these minimally invasive approaches is both safe and cost effective and should be considered whenever possible.

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References

1) Walker LG Jr : L. L. Staton, and the first successful gastrostomy in America. Surg Gyn and Obst 1984 ; 158 : 387–388.
2) Verneuil A : Observation de gastrostomie pratiquee avec succes pour um retrecessment icatriciel infranchis-sable de l'oesophage. Bulletin Aced Med Paris, 1976 ; 25 : 1023–1038.
3) Ashcroft and Holder : Chapter 24-Lesions of the stomach. Pediatric Surgery (2ed) 289–304, Ed by Dudgeon, DL, W.B. Saunders Company, 1983.
4) Gauderer MWL : Gastrostomy techniques and devices. Surg Clin North Amer 1992 ; 72 : 1285–1299.
5) Flake AW, Shopene C, Ziegler MM : Antireflux gastrointestinal surgery in the neurologically handicapped child. Pediatr Surg Int 1991 ; 6 : 92–94.
6) Torosian MH, Rombeau JL : Feeding by tube enterostomy. Surg Gynecol Obstet 1980 ; 150 : 918–927.
7) Sacks BA, Glotzer DJ : Percutaneous reestablishment of feeding gastrostomies. Surgery 1979 ; 85 : 575–576.
8) Gauderer MWL, Ponsky JL, Izant RJ Jr : Gastrostomy without laparotomy : A percutaneous endoscopic technique. J Ped Surg 1980 ; 15 : 872–875.
9) Preshaw RM : A percutaneous method for inserting a feeding gastrostomy tube. Surg Gyn and Obst 1981 ; 152 : 659–660.
10) Sacks BA, Vines HS, Palestrant AM, et al : A non-operative technique for establishment of a gastrostomy in the dog. Invest Radiol 1983 ; 18 : 485–487.
11) Stellato JA, Gauderer MWL : Percutaneous endoscopic gastrostomy in the cancer patient. The American Surg 1988 ; 54 : 419–422.
12) Ponsky JL, Gauderer MWL, Stellato JA : Percutaneous endoscopic gastrostomy. Arch Surg 1983 ; 118 : 913–914.
13) Kirby DF, Craig RM, Tsang TK, et al : Percutaneous endoscopic gastrostomies : A prospective evaluation and review of the literature. JPEN 1986 ; 10 : 155–159.
14) Cappell MS, Godil A : A multicenter case controlled study of percutaneous endoscopic gastrostomy in HIV-seropositive patients. Am J Gastroenterol 1993 ; 88 : 2059–2066.
15) Hull MA, Rowlings J, Murray FE, et al : Audit of long-term enteral nutrition by percutaneous endoscopic gastrostomy. Lancet 1993, 341 : 869–871.
16) Wollman BS, D'Agostino HB, Nalus-Wigle JR, et al : Radiologic, endoscopic and surgical gastrostomy : An institutional evaluation and meta-analysis of the literature. Radiology 1995 ; 97 : 699–704.
17) Will JS, Oglesby JT : Percutaneous gastrostomy. Radiology 1983 ; 149 : 449–453.
18) Ho CS, Gray RR, Goldfinger M, et al : Percutaneous gastrostomy for enteral feeding. Radiology 1985 ; 156 : 349–351.
19) Gray RR, St Louis EL, Grosman H : Percutaneous gastrostomy and gastrojejunostomy. Brit J Radiol 1987 ; 60 : 1067–1070.
20) VanSonnenberg E, Wittich GR, Cabrerea OR, et al : Percutaneous gastrostomy and gastroenterostomy : 2. Clinical experience. AJR 1986 : 581–586.
21) O'Keeffe F, Carrasco CH, Charnsangavej C, et al : Percutaneous drainage and feeding gastrostomies in 100 patients. Radiology 1989 ; 172 : 341–343.
22) Hicks ME, Surratt RS, Picus D, et al : Fluoroscopically guided gastrostomy and gastroenterostomy analysis of 158 consecutive cases. AJR 1990 ; 154 : 725–728.
23) Keller MS, Lai S, Wagner DK : Percutaneous gastrostomy in a child. Radiology 1986 ; 160 : 261–262.
24) Towbin RB, Ball WS Jr, Bisset GA III : Percutaneous gastrostomy and gastrojejunostomy in children : Antegrade approach. Radiology 1988 ; 168 : 473–476.
25) Garel L : Pediatric gastrostomy and gastrojejunostomy. Semin Interv Radiol 1991 ; 8 : 210–213.
26) Cory DA, Fitzgerald JF, Cohen MD : Percutaneous non-endoscopic gastrostomy in children. AJR 1988 ; 151 : 995–997.
27) Malden ES, Hicks ME, Picus D, et al : Fluoroscopically guided percutaneous gastrostomy in children. JVIR 1992 ; 3 : 673–677.

28) King SJ, Chait PG, Daneman A, et al : Retrograde percutaneous gastrostomy : A prospective study in 57 children. Pediatr Radiol 1993 ; 23 : 23–25.
29) Towbin RB, Chait P : Percutaneous Feeding Techniques. Semin Interven Radiol 1991 ; 8 : 214–216.
30) Galat SA, Gerig KD, Porter JA, et al : Management of premature removal of the percutaneous gastrostomy. Ann Surg 1990 ; 56 : 733–736.
31) Shallman RW, Norfuct RG, Hardache JM : Percutaneous endoscopic gastrostomy feeding tube migration in the abdominal wall, Gastrointest Endos 1988 ; 34 : 367–368.
32) Gauderer MWL, Picha GH, Izant RJ Jr : The gastrostomy "button" : A simple, skin level, non-refluxing device for long-term enteral feedings. J Pediatr Surg 1984 ; 19 : 803–805.
33) Gauderer ML, Olsen MM, Stellato TA, et al : Feeding gastrostomy buttons : Experience and recommendations. J Pediatr Surg 1988 ; 23 : 24–28.
34) Foutch PG, Talbert GA, Gaines JA, et al : The gastrostomy button : A prospective assessment of the safety, success and spectrum of use. Gastrointest Endosc 1989 ; 35 : 41–44.
35) Al-Malki T, Langer JC, Thompson V, et al : A prospective evaluation of the button gastrostomy in children. CJS 1991 ; 34 : 247–250.
36) Blair GK, Djonlic K, Fraser GC, et al : The bowel management tube : An effective means for controlling fecal incontinence. J Pediatr Surg 1992 ; 27 : 1269–1272.
37) Malone PS, Ransley PG, Kiely EM : Preliminary report : The antegrade continence enema. Lancet 1990 ; 336 : 1217–1218.
38) Shandling B, Chait PG, Richards HF : Percutaneous cecostomy : A new techniqe in the management of fecal incontinence. J Pediatr Surg 1996 ; 31 : 534–537.
39) Chait PG, Shandling B, Richards H, et al : Percutaneous cecostomy : A prospective study of the treatment of fecal incontinence in children : Radiol 1997 ; 203 : 621–624.
40) Kullman E, Borch K, Tarpila E, et al : Endoscopic retrograde cholangiopancreatography (ERCP) in patients with jaundice and suspected biliary obstruction. ACTA Chir Scand 1984 ; 150 : 657–663.
41) Tobin RS, Vogelzang RL, Gore RM, et al : A comparative study of computed tomography and ERCP in pancreaticobiliary disease. CT : The Journal of Computed Tomography 1987 ; 11 : 261–266.
42) Jander HP, Galbraith J, Aldrete JS : Percutaneous transhepatic cholangiography using the Chiba needle : Comparison with retrograde pancreatocholecystography. Southern Medical Journal 1980 ; 73(4) : 415–421.
43) Juttijudata P, Palavatana C, Chiemchaisri C, et al : The accuracy of percutaneous transhepatic cholangiography (P.T.C.) Using the Chiba needle in the diagnosis of level and cause of cholestasis. Australasian Radiology 1986 ; Vol. XXX(1).
44) Cronan JJ : The imaging of biliary obstruction. Seminars in Ultrasound, CT, and MR 1984 ; 5(4) : 376–398.
45) Juttijudata P, Palavatana C, Chiemchaisri C, et al : Percutaneous transhepatic cholangiography with the Chiba needle in patients with biliary calculi. Radiology 1983 ; 146 : 643–645.
46) Johnson LJ, Mauro MA, Jaques PF : Radiologic placement of Hickman catheters. Radiol 1980 ; 170 : 1007–1009.
47) Hull JE, Hunter CS, Luiken GA : The Groshong catheter : Initial experience and early results of image-guided placement. Radiol 1992 ; 85 : 803–807.
48) Fernando C, Jurarsky L, Yedlicka J, et al : Subclavian central venous catheter insertion : Angiointerventional technique. Semin in Intervent Radiol 1991 ; 8 : 78–81.
49) Cockburn JF, Eynon CA, Virji N, et al : Insertion of Hickman central venous catheters by using angiographic techniques in patients with hematologic disorders. AJR 1992 ; 159 : 121–124.
50) Goutail-Flaud MF, Sfez M, Berg A, et al : Central venous catheter-related complications in newborns and infants : A 587-case survey. J Pediatr Surg 1991 ; 26 : 645–650.
51) Kaufman JA, Greenfield AJ, Fitzpatrick GF : Transhepatic cannulation of the in-

ferior vena cava. JVIR 1991 ; 2 : 331-334.
52) Bergey E, Sane S, Kaye , et al : Pediatric transvenous liver biopsy. JVIR 1998 ; 9 : 829-832.
53) Walker WA, Krivit W, Sharp HL : Needle biopsy of the liver in infancy and childhood. Pediatr 1967 ; 40 : 946-950.
54) Weiner M, Hanafee WN : A review of transjugular cholangiography. Radiol Clin North Am 1970 ; 8 : 53-68.
55) Lebrec D, Goldfarb G, Degott C, et al : Transvenous liver biopsy : An experience based on 1000 hepatic tissue sampling with this procedure. Gastroenterology 1982 ; 82 : 338-340.
56) Little AF, Zajko AB, Orons PD : Transjugular liver biopsy : A prospective study in 43 patients with the quick-core biopsy needle. J Vasc Interv Radiol 1996 ; 7 : 127-131.
57) Furuya KN, Burrows PE, Phillips MJ, et al : Transjugular liver biopsy in children. Hepatology 1992 ; 15 : 1036-1042.
58) McAffee JH, Keeffe EB, Lee RG, et al : Transjugular liver biopsy. Hepatology 1992 ; 15 : 726-732.
59) Jaffe HL : Osteoid osteoma : A benign osteoblastic tumor composed of osteoid and atypical bone. Arch Surg 1935 ; 31 : 709-728.
60) Kaweblum M, Lehman WB, Bash J, et al : Grant AD. Clin Orthop and Related Research 1993 ; 296 : 218-224.
61) Doyle T, King K : Percutaneous removal of osteoid osteoma using CT control. Clin Radiol 1989 ; 40 : 514-517.
62) Voto SJ, Cook AJ, Weiner DS, et al : Treatment of osteoid osteoma by computed tomography by guided excision in the pediatric patient. J Pediatr Orthop 1990 ; 10 : 510-513.
63) Towbin R, Kaye R, Meza MP, et al : Osteoid osteoma : Percutaneous Excision using a CT-guided coaxial technique. AJR 1995 ; 164 : 945-949.
64) Rosenthal D, Hornicek F, Wolfe M, et al : Percutaneous radiofrequency coagulation of osteoid osteoma compared with operative treatment. J Bone and Joint Surg 1998 ; 80-A(6) : 815-821.
65) Montgomery WW : Silicone tracheal T-tube. Ann Otol Rhinol Laryngol 1974 ; 83 : 71-75.
66) Dumon JF : A dedicated tracheobronchial stent. Chest 1990 ; 97 : 328-332.
67) Wallace MJ, Charnsangavej C, Ogawa K, et al : Tracheobronchial tree : Expandable metallic stents used in experimental and clinical application. Radiology 1986 ; 158 : 309-312.
68) Filler RM, Forte V, Chait P : Tracheobronchial stenting for the treatment of airway obstruction. J Pediatr Surg 1998 ; 33 : 304-311.
69) Nashef SAM, Dromer C, Velly J, et al : Expanding wire stents in benign tracheobronchial disease : Indications and complications. Ann Thorac Surg 1992 ; 54 : 937-940.
70) Maynar M, Lopez L, Gorriz E, et al : Massive brachiocephalic artery bleeding due to Gianturco tracheal stent. JVIR 1993 ; 4 : 289-291.