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A Pathologist's Perspective on Bone Marrow Aspiration and Biopsy: I. Performing a Bone Marrow Examination

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The bone marrow aspirate and biopsy is an important medical procedure for the diagnosis of hematologic malignancies and other diseases, and for the follow-up evaluation of patients undergoing chemotherapy, bone marrow transplantation, and other forms of medical therapy. During the procedure, liquid bone marrow is aspirated from the posterior iliac crest or sternum with a special needle, smeared on glass microscope slides by one of several techniques, and stained by the Wright-Giemsa or other techniques for microscopic examination. The bone marrow core biopsy is obtained from the posterior iliac crest with a Jamshidi or similar needle and processed in the same manner as other surgical specimens. Flow cytometric examination, cytochemical stains, cytogenetic and molecular analysis, and other diagnostic procedures can be performed on bone marrow aspirate material, while sections prepared from the bone marrow biopsy can be stained by the immunoperoxidase or other techniques. The bone marrow procedure can be performed with a minimum of discomfort to the patient if adequate local anesthesia is utilized. Pain, bleeding, and infection are rare complications of the bone marrow procedure performed at the posterior iliac crest, while death from cardiac tamponade has rarely occurred from the sternal bone marrow aspiration. The recent development of bone marrow biopsy needles with specially sharpened cutting edges and core-securing devices has reduced the discomfort of the procedure and improved the quality of the specimens obtained. J. Clin. Lab. Anal. 18:70–90, 2004.

Key words: bone marrow examination; bone marrow pathology; biopsy needle; diagnostic tests; anesthetics, local

INTRODUCTION

Peripheral blood examination and other routine laboratory assays do not always provide enough information for the diagnosis of hematologic disease. In some patients, direct microscopic examination of the bone marrow is required for confirmation of a suspected clinical diagnosis or for monitoring the course of medical therapy. Occasional patients also require bone marrow collection for special studies, such as cytogenetic analysis, flow cytometry, molecular studies, or microbiologic cultures. The osseous portion of human bone consists of irregular bony trabeculae separating spaces filled with fat cells, supporting connective tissue, and hematopoietic cells (1). During the bone marrow examination, bone marrow particles are aspirated and spread on slides, and a core of bone and marrow (trephine biopsy) is also obtained. The bone marrow aspirate preparations are valuable for differential cell counts and the evaluation of individual cell morphology, while the trephine biopsy is preferred for the evaluation of marrow cellularity, accurate determination of the number of megakaryocytes, and the detection of focal lesions such as lymphoma, granulomas, and metastatic carcinoma (2–8). Since the aspirate and biopsy provide complementary information, both specimens are routinely obtained. An experienced physician can usually perform a bone marrow examination with a minimum of pain and discomfort.

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HISTORY OF THE BONE MARROW EXAMINATION

Dr. John Dalrymple of Dublin, Ireland was among the first to perform microscopic examination of bone tissue in a pathologic disorder. In 1846, Dr. Dalrymple reviewed a bone specimen from Dr. William Macintyre's patient with multiple myeloma (9). Bone marrow sampling for pathologic diagnosis was first described in 1903 by G. Pianese, using trephination of the femur (10–12). A similar technique was reported by Ghedini of Genoa, Italy in 1908, and by Peabody in 1927 (13). The lack of active bone marrow in the tibia subsequently dissuaded many investigators, but in the 1920's Carley Paul Seyfarth and later Mikhail J. Arinkin demonstrated the value of sternal needle puncture as an excellent technique for obtaining diagnostic bone marrow aspirate specimens (12,14). In the early 1930's, Custer (15) described the diagnostic importance of biopsy imprints ("touch preparations") and histologic sections of sternal bone in addition to smear preparations. His technique was to remove a disc of the ventral sternal plate 1 cm in diameter, which required an elaborate intra-operative procedure. However, relatively few bone marrow biopsies were performed until 1958, when McFarland and Dameshek (16) reported a simpler technique using the Vim-Silverman biopsy needle. Later modifications of the Vim-Silverman needle by Westerman, Jensen, Jamshidi and Swain, Schaadt-Fischer and others made the procedure less painful, improved the biopsy retention rate, and resulted in larger core specimens (17–20). Recent advances in engineering have resulted in bone marrow biopsy needles with specially-shaped stylet and cannula tips for easier cortical bone penetration and internal core capturing devices to sever the biopsy and prevent core loss during needle withdraw (21,22).

INDICATIONS FOR THE BONE MARROW EXAMINATION

A bone marrow examination is a critical part of the evaluation of patients with a variety of hematopoietic and non-hematopoietic diseases (6,7,12,23,24) (Fig. 1). It is performed for diagnostic purposes in patients with splenomegaly, dysproteinemias, suspected lysosomal storage disease, an unexplained deficiency or excess of peripheral blood leukocytes or platelets, or the presence of immature or morphologically atypical cells in the peripheral blood. Anemic patients are seldom subject to bone marrow examinations unless the cause is not apparent after a variety of other laboratory assays have been performed, or the disease does not respond to appropriate therapy. The bone marrow examination may also be requested to obtain material for microbiologic culture in patients with unexplained fever ("fever of unknown origin"), HIV infection and AIDS, or other diseases, and to search for infectious organisms, neoplasms, granulomatous disease, or other lesions in these patients (25). In febrile patients with HIV infection, the bone marrow culture, histopathologic examination, and special stains will detect opportunistic mycobacterial or fungal infections in approximately 30–60% of cases (26–30). Bone marrow examination is also part of the staging process for newly diagnosed patients with lymphoproliferative diseases and certain non-hematopoietic malignancies such as neuroblastoma and other childhood tumors (24,31–34). Examination of the bone marrow is performed to determine the extent of marrow damage in patients exposed to radiation, drugs, chemicals, and other myelotoxic agents. Moreover, marrow evaluation is essential to determine the efficacy of treatment and to monitor the recovery process in patients undergoing bone marrow transplantation or marrow-ablative chemotherapy (35–39). Common indications for bone marrow aspiration and biopsy are listed in Table 1.

There are relatively few contraindications to the bone marrow procedure. Acquired or congenital coagulation factor deficiencies and other coagulation abnormalities are considered a contraindication by some physicians but not by others (7,40–42). Factor replacement therapy prior to the bone marrow examination and hospital observation for 24 hr after the procedure may be indicated in these patients (2,3,43). Patients receiving anticoagulants should have prothrombin time (PT) or activated partial thromboplastin time (aPTT) values

Table 1. Indications for bone marrow procedure

Major indication	Diseases
Disease diagnosis	Pancytopenia or unexplained anemia, leucopenia, or thrombocytopenia
	Acute leukemia
	Chronic leukemia
	Myelodysplastic syndrome
	Myeloproliferative disease
	Plasma cell dyscrasia
	Non-Hodgkin lymphoma
	Hodgkin lymphoma
	Aplastic anemia
	Fever of unknown origin
	Small cell tumors of childhood
	Mast cell disease
	Disseminated granulomatous disease
	Thrombotic thrombocytopenic purpura
	Primary amyloidosis
	Metabolic bone disease
Therapeutic follow-up	Chemotherapy/bone marrow transplantation for hematopoietic neoplasms or small cell tumors of childhood
	Treatment of isolated cytopenia

within the therapeutic range for warfarin or heparin (44). Isolated thrombocytopenia is not a contraindication to the bone marrow examination if the procedure is properly performed and technical difficulties are not encountered (43). However, platelet transfusions to increase the platelet count above 15×10^9/L is advisable in obese patients with severe thrombocytopenia (7). Other contraindications include infection or previous radiation therapy at the sample site and poor patient cooperation (42). Sternal bone marrow aspiration is completely contraindicated in patients with diseases associated with bone resorption, including multiple myeloma (45).

PERFORMING A BONE MARROW EXAMINATION

A successful bone marrow evaluation requires medical knowledge of the patient and the indication for the study. The following information should be obtained prior to performing a marrow study: 1) patient name; 2) patient age and gender; 3) patient location/requested time of examination; 4) primary diagnosis; 5) clinical indication(s) for examination; 6) allergies (especially to povidone iodine and lidocaine); 7) recent chemotherapy, radiation therapy, bone marrow transplantation, or blood transfusions; 8) dietary, racial, and family history; 9) medications (iron, B12/folate, G-CSF, aspirin, coumadin, heparin, antibiotics, etc.); 10) special studies requested (immunophenotypic analysis, cytogenetic analysis, culture, etc.); 11) special medical problems that may preclude procurement or written consent or complicate the procedure (i.e., unresponsive or mentally incompetent patient, adversity to medical procedures, anxiety, pain intolerance, disease or recent surgery involving the pelvic bone, hemophilia or other bleeding disorder, severe cardiac or pulmonary disease, morbid obesity, etc.); 12) name/pager number/telephone number of person requesting examination; and 13) name of attending physician.

The request for a bone marrow procedure should be validated by reviewing pertinent laboratory data, the patient's medical record, and a recent peripheral blood smear. It is not unusual for junior doctors to overlook a less invasive diagnostic procedure before requesting a bone marrow examination. For example, a CBC, serum iron studies, and a serum ferritin assay should be performed on a patient with suspected iron deficiency anemia, but a bone marrow examination would be an unusual request. If the request seems inappropriate, the requesting physician should be contacted for verification. Since the bone marrow examination is an invasive, expensive, and labor intensive procedure, some hospitals require a formal consultation from the hematology/oncology service to justify a request from another department. If the procedure is requested as part of a research protocol, a detailed list of the required specimens, specimen preparation directives, and transportation directions should be obtained. Arrangements for pain medication or other special patient needs should be made by the requesting physician prior to the arrival of the marrow procurement team. At a minimum, this should include an "as needed" (i.e., "PRN") medication order placed on the patient's chart.

Supplies and Equipment

Bone marrow procedures are performed in the clinic or at the bedside in most institutions so appropriate supplies and equipment must be carried to the site of the procedure. A compartmentalized plastic or wooden tray

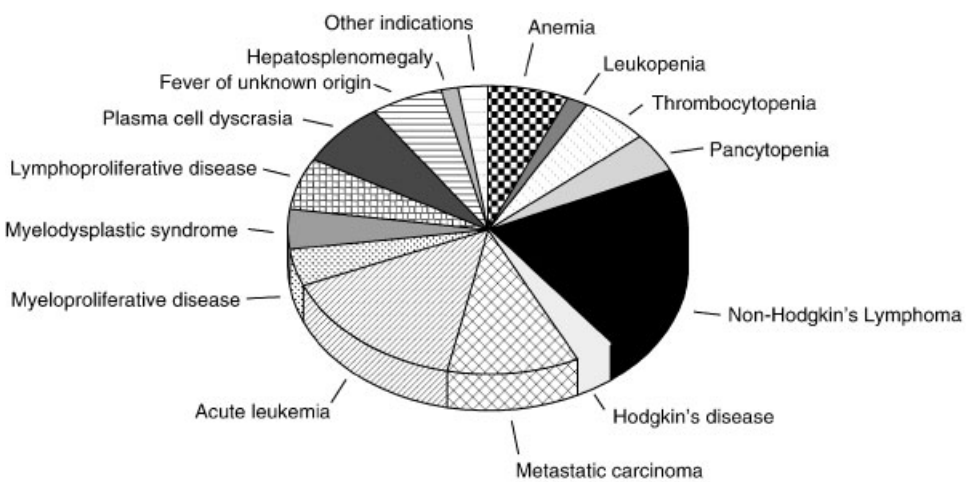

Fig. 1. Clinical indications for a bone marrow evaluation. Data from 286 bone marrow procedures performed at the Medical College of Virginia Hospitals, January–June, 1998.

Table 2. Equipment and supplies for bone marrow procurement

Purpose	Supplies and equipment
Obtaining written consent	Ballpoint pen
	Clipboard
	Patient consent forms
Site preparation	Alcohol prep pads, 2 ply, large
	Betadine (povidone iodine, 10%) swabsticks
	Ear speculum plastic tips
	Gauge sponges, 3×4 inch
	Impervious gowns
	Isopropyl alcohol swabsticks
	Latex gloves, examination, non-sterile
	Latex gloves, sterile
	Lidocaine hydrochloride, Injection, 1%, 20 mL vials
	Needles, 22 gauge, 1-1/2 inch
	Fenestrated drapes, sterile, small ($30' \times 30$ inch with 1-1/2 inch $\times$ 2 inch fenestration)
	Sodium bicarbonate solution, injection, USP, 8.4% (1 mEq/mL), 50 mL vials
	Sodium heparin, injection, 1000 USP Units/mL, 2 mL vials
	Spinal needles, 20 gauge, 3.5 inch
	Spinal needles, 20 gauge, 5 inch
	Sub-Q needles, 26 gauge, 5/8 inch
Marrow procurement	AZF fixative, 10 mL sealed, labeled containers
	Blank labels
	Bone marrow aspiration needles, 15 or 16 gauge, several lengths
	Bone marrow biopsy needles, several lengths, 8 and 11 gauge
	Disposable plastic syringes, sterile U 20 cc.
	Disposable plastic syringes, sterile, 10 cc.
	Disposable scalpel, 25 kGy (2.5 mrad)
	Green-top (sodium heparin) vacutainers
	Microscope slides, 1 inch $\times$ 3 inch, frosted
	Plastic bags, zip-lock
	Purple-top vacutainers
	Safety flow lancet
Wound care	Bandage scissors
	Elastic tape
	Transpore tape (3M)
Other supplies	Safety flow lancet

is often used for this propose, although a wheeled cart with a flat work surface for preparing the marrow slides is preferred by some groups. Adequate supplies to perform several bone marrow examinations should be carried, as well as any special tubes, preservative solutions, etc. The items typically carried in a bone marrow equipment tray are listed in Table 2. Information about commercial sources of bone marrow aspirate and biopsy needles are given in Table 3 (Fig. 2).

Meeting the Patient

The identification of the patient must be confirmed from a wrist band or identification card. The bone marrow team should be introduced to the patient. This team usually consists of a physician or physician's assistant assisted by a nurse or clinical laboratory scientist. In a teaching hospital, a resident physician may accompany the team to observe or perform part or all of the procedure under the physician's supervision. A basic description of the procedure must be presented verbally to the patient, the risks explained, and all questions answered completely. A handout such as that developed by O'Rourke (46) should be provided to the patient to reinforce the verbal description and provide additional information for post-procedure care. The patient should then be given the opportunity to sign a written consent form. Some patients are reluctant at first to grant consent and require further persuasion or time to consult with their family or physician. If the patient cannot provide written consent, it should be obtained from the next-of-kin. In the rare circumstance of an incapacitated patient without a family or legal guardian, a court order must be obtained. Under no circumstances should a bone marrow be obtained without written permission. Individuals performing a bone marrow procedure must also be thoroughly familiar with, and follow all institutional, policies regarding consent for medical procedures. Although the vast majority of patients do not require pharmacologic intervention other than local anesthesia, the procedure may need to be delayed until the proper type of sedation can be arranged. If needed, assistance should be requested from the nursing team. During the procedure, it is essential to minimize patient anxiety by establishing trust by being honest, providing accurate information in terms the patient can understand, ensuring comfort and privacy, and artfully concealing the contents of the bone marrow equipment tray (47–52).

Bedside Preparation

General considerations

Hematopoietically active bone marrow is distributed throughout the skeleton in children, but it is restricted to the axial bones of adults. The posterior iliac crest is the optimal location for marrow procurement for reasons of comfort, safety, and ease of performance, but alternative sites should be considered if the posterior iliac crest is diseased or inaccessible because of morbid obesity or inability to properly position the patient (53). Alternative sites include the anterior iliac crest (children and adults), sternum (adults only, aspiration only), and tibia (infants only). Sternal marrow aspiration should be considered only if other sites are unacceptable.

The optimal sequence to obtain marrow specimens is controversial. Procurement of the aspirate specimen prior to the trephine core can cause artifactual

Table 3. Commercial sources of bone marrow aspiration and biopsy needles in the United States

Company	Available Needles
Allegiance Healthcare Corporation McGaw Park, IL 60085 Telephone: 800-964-5227 http://www.allegiance.net/products/specpro/home.asp	Contoured Jamshidi (CJ) needles Disposable Jamshidi (DJ) needles Ergonomic Jamshidi (EJ) needles Iliac crest aspiration needles Illinois sternal/iliac aspiration/intraosseous infusion needles Pharmaseal bone marrow biopsy and aspiration trays
Dyna Medical Corp. 1-1025 Brough Street London, Ontario, N6A 3N5, CANADA Telephone: 800-268-1181 (Canada only)/519-642-0424 http://members.attcanada.ca/~dynabc/pg3.html	Goldenberg SNARECOIL bone marrow biopsy needle Extensive line of reusable aspiration and biopsy needles
Gallini U.S. Medical Devices 3574 Roger B. Chaffee, S.E. Grand Rapids, MI 49548 Telephone: 888-361-6941 http://gallinimedical.com/gallini/product/product.asp?sezione=oncology	BIOMID bone marrow biopsy needles ISAN and ACRI bone marrow biopsy needles BIOSYSTEM bone marrow biopsy needles with core-trapping device
Kendall Healthcare 15 Hampshire Street Mansfield, MA 02048 Telephone: 800-962-9888 http://www.kendallhq.com	Goldenberg SNARECOIL bone marrow biopsy needle Monoject bone marrow aspiration and biopsy needles Bone marrow procedure trays
Lee Medical Ltd. P.O. Box 24288 Minnaepolis, MN 55424 Telephone: 800-826-2360	Lee Lok bone marrow biopsy and harvest needle
Popper & Sons, Inc. 300 Denton Avenue P.O. Box 128 New Hyde Park, NY 11040 Telephone: 888-717-7677/516-248-0300/001.516.248.0300 http://www.popperandsons.com/needles/page3.asp?maincategory=needles&subcategory=procedure&grouping=biopsybonemarrow	Extensive line of reusable marrow needles
Ranfac Corporation 30 Doherty Avenue Avon, MA 02322 Telephone: 800-272-6322/508-588-4400 Fax: 508-584-8588 http://www.ranfac.com/hema.html	Goldenberg SNARECOIL bone marrow biopsy needle "I" type aspiration needle Ranfac bone marrow biopsy and aspiration tray Reusable bone marrow needles
Worldwide Medical Technologies 426 Main Street North P.O. Box 505 Woodbury, CT 06789-0505 Telephone: 877-783-5463/203-263-2579 E-mail: wwmt@wwmedtech.com http://www.wwmedtech.com/bm.htm	Core-Lock bone marrow biopsy systems "J" style coring needles "I" Style aspiration needles Marrow procedure trays

hypocellularity and contamination of the core with sinusoidal blood, a phenomenon referred to as "aspiration artifact" (54) (Fig. 3). However, the tissue trauma of the biopsy procedure releases thromboplastic substances that can compromise the quality of a subsequent marrow aspiration obtained from the same area (7,55). In spite of these considerations, many investigators feel that the sequence is unimportant, as long as different

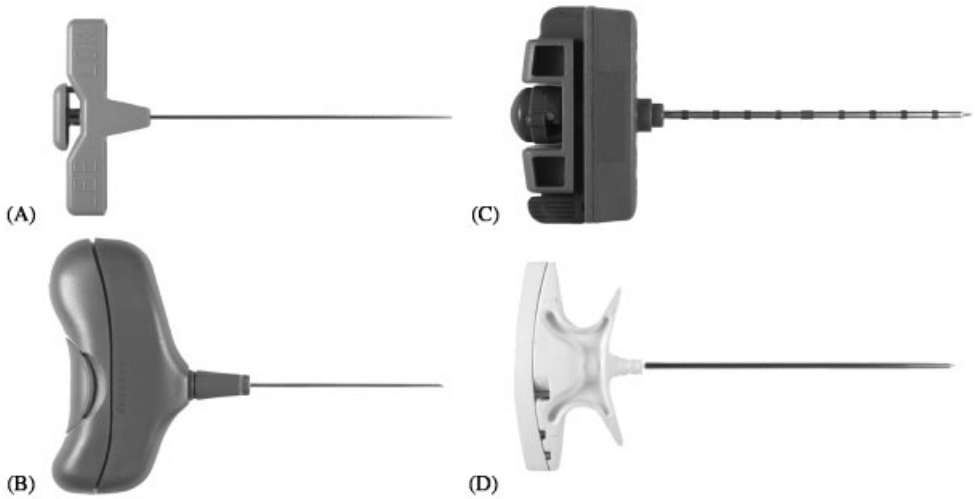

Fig. 2. Bone marrow aspiration and biopsy needles. **A:** Lee Lok bone marrow aspirate needle (Lee Medical Ltd., Minneapolis, MN); **B:** Iliac crest bone marrow aspiration needle with ergonomic handle (Allegiance Healthcare Corp., McGaw Park, IL); **C:** SNARECOIL bone marrow biopsy needle (Ranfac Corp., Avon, MA); **D:** Isan disposable needle for bone marrow biopsy (Gallini, Mirandola, Italy).

areas along the posterior iliac crest are sampled (45,56). Techniques for obtaining and preparing bone marrow specimens have been described by many authors (12,24,44,45,55,57–61).

Positioning the patient

Depending on the location of the procedure, the patient is positioned as in one of the following ways.

Posterior iliac crest (PIC). The patient is placed in a right or left lateral decubitus position with their knees flexed, a pillow under their head, and their eyes away. The posterior iliac crest may be used in patients over 1 year of age (2).

Anterior iliac crest (AIC). The patient is placed in a supine position, with their hips and knees flexed, and eyes averted away. This site is appropriate only in adults when the posterior iliac crest is inaccessible because of obesity, infection, injury, or inability to position the patient in the lateral decubitus position (59). The thick, hard cortical layer of the anterior iliac crest makes satisfactory specimens more difficult to obtain and the needle can enter the peritoneal cavity (59). In addition, needle biopsy of anterior superior iliac spine has been reported to be more painful and to produce samples of smaller length and area than biopsies of the posterior superior iliac spine (62).

Sternum. Supine position, head and eyes away, and light towel over face ''to keep things sterile'' and cover eyes. Sternal aspiration should be performed only if the posterior and anterior iliac crests are inaccessible or unsuitable for the procedure (63). Furthermore, sternal aspiration should be attempted only in adolescents and adults, since there is a higher incidence of serious complications in infants and children (2,59).

Tibia. Marrow aspiration from the anteromedial surface of the tibia is performed only in children less than 18 months of age (2,59). The tibia is an unsatisfactory site in older individuals because of variable cellularity and the hardness of the cortical bone (59).

A conversation should be begun with the patient and continued throughout the entire procedure. This is necessary to inform the patient about anticipated discomfort from the procedure, to assess the patient's feeling of pain, and to obtain early warnings of complications such as a vasovagal reaction.

Site preparation

Nonsterile latex ''examination'' gloves and an impervious plastic procedure gown or other protective clothing should be worn. The procedure site should be carefully palpated to identify anatomical landmarks and select the appropriate anatomic site for marrow procurement. To identify the chosen site after the area is cleaned with povidone-iodine soap, it should be first highlighted with an indelible pen or a shallow impression in the skin made with the tip of a plastic ear speculum. One of the following locations is chosen: PIC, upper or center portion of posterior superior iliac spine; AIC, center of prominence of anterior superior iliac

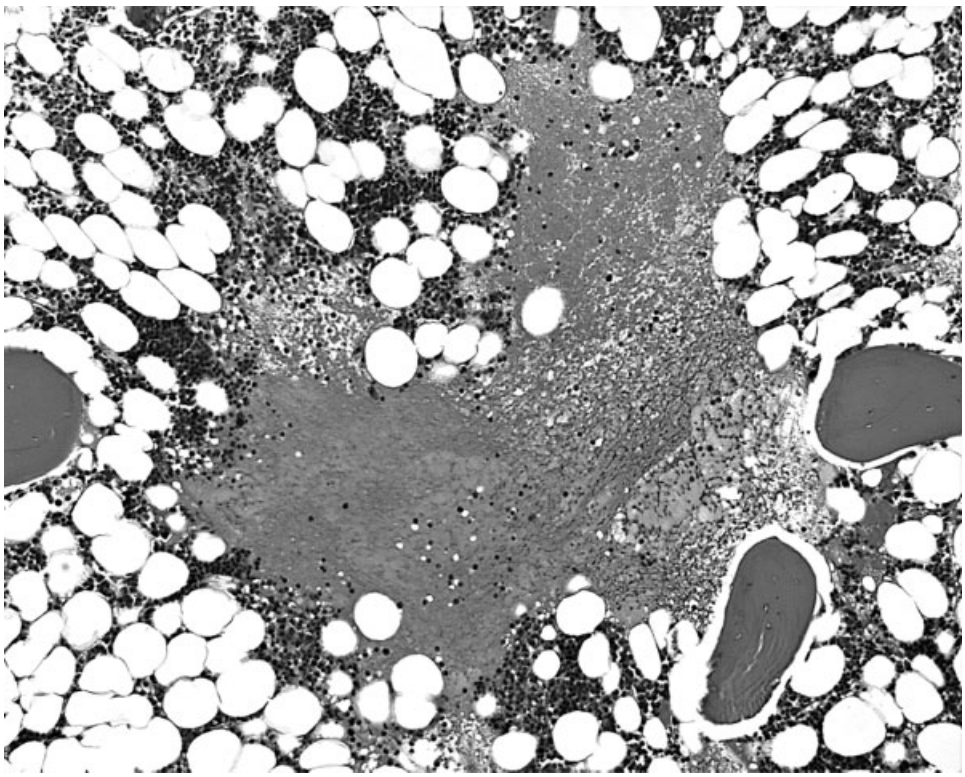

Fig. 3. Photomicrograph of bone marrow biopsy showing aspiration artifact. Note interstitial hemorrhage and marrow hypocellularity with preservation of surrounding tissue. Hematoxylin and eosin (400 × final magnification).

spine, just under lip of crest; or sternum, second intercostal space in midline.

The upper posterior superior iliac spine can be identified by a dimple in the skin at the lateral edge of the rhomboid of Michaelis (53) (Fig. 4). In obese patients where anatomic landmarks are not visible, the posterior superior iliac spine can usually be located by palpation with the thumb.

The skin surrounding the procedure site should be cleaned as follows:

1. Use three sterile disposable swabs soaked with 10% povidone-iodine solution (Betadine Solution, Purdue Frederick Co., Stamford, CT). For individuals allergic to iodine, chlorhexidine gluconate, 4% (Betasept Surgical Scrub, Purdue Frederick Co.) may be utilized.
2. Wash the skin in a circular motion beginning with the marked site and working outward approximately 4 inches with each of the swabs.
3. Remove the povidone-iodine from the center of the washed area with a single swipe of a sterile isopropyl alcohol-soaked swab.

Patients who were anxious at the beginning of the procedure are usually adapting well to the experience by this time, but the anxiety level increases in a few patients. Occasional patients may require conscious sedation to permit proper marrow procurement. Drugs commonly used for the bone marrow procedure are listed in Table 4.

Anxious patients who have an intravenous (IV) line in place can be given diazepam (''Valium'') by the assisting nurse or physician. This should be slowly hand-pushed (1 mg/min) into a rapidly running IV until the patient's speech is slurred (keep the patient talking!). This may require 5–20 mg of diazepam over 5–10 min. The patient usually falls asleep, but can be easily aroused. This sedation lasts 20 min to 2 hr and usually produces desirable amnesia for the procedure. Both diazepam and lorazepam have the advantage of inducing amnesia for the bone marrow procedure in many patients (64). The special problems of performing bone marrow procedures in children have been addressed by several authors (31,65–69).

The remainder of the marrow procurement process is performed under sterile conditions. The placement of a sterile drape with a fenestrated opening over the procurement site completes preparation of the site.

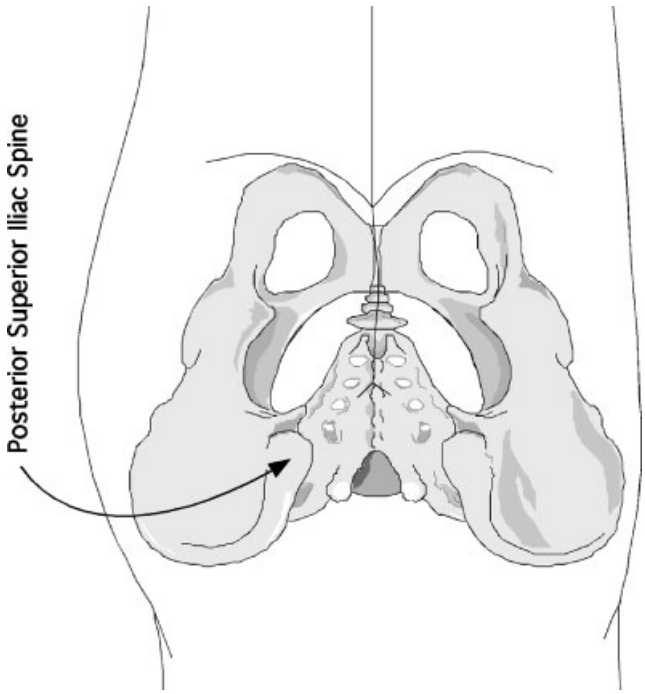

Fig. 4. Diagram of posterior pelvic bone illustrating the location of the spine of the posterior iliac crest (arrow).

Administering local anesthesia

A local anesthetic is used to numb the skin and periosteum at the site of marrow procurement. Lidocaine or a similar local anesthetic can be used, providing the patient has no history of an adverse reaction to the medication. Discomfort can be avoided during the remainder of the procedure if adequate time is taken to assure complete local anesthesia. During this process, 2 mL of sterile 8.4% sodium bicarbonate solution (1 mEq/mL) and 8 mL of sterile 1% lidocaine hydrochloride (Xylocaine, Astra Pharmaceuticals, Westborough, MA) are drawn into a 10 mL plastic syringe with a 22 gauge, 1-1/2 inch needle. The buffering of lidocaine with sodium bicarbonate reduces the burning pain caused by the acidic lidocaine solution. The 22 gauge needle is exchanged for a 5/8 inch, 26 gauge "sub-Q" needle, which is used to inject a small amount of buffered lidocaine solution intradermally to produce a small, 5–6 mm wheal (Fig. 5). The 26 gauge needle is then replaced by a 22 gauge needle, and the process is continued by pushing the needle slowly through the skin and subcutaneous tissue near the center of the papule until the surface of the periosteum is encountered. The thickness of the subcutaneous tissue and the depth to the periosteum is assessed for later reference. Approximately 2–5 mL of buffered lidocaine is used to anesthesize a roughly circular area of the periosteum approximately 1 cm in diameter. A 3-1/2 inch or 5 inch spinal needle is substituted for the 22 gauge needle in obese patients (Fig. 5). The adequacy of local anesthesia can be determined by gently probing the periosteum with the sharp point of the needle to make certain no sensitive areas remain. If sharp pain is experienced, the injection of an additional 1–2 mL of lidocaine may be required.

Adverse reactions of a neurologic, cardiovascular, and allergic nature can occur to lidocaine. The maximum recommended dose of lidocaine with epinephrine for healthy adults is approximately 7 mg/kg or

Table 4. Medications for pain and anxiety reduction during the bone marrow procedure

Agent	Route	Adult dosage[a]
Ativan (Lorazepam)	IM, IV, PO	0.044 mg/kg IM, IV 2–5 mg PO
Demerol (Merperidine)	IM	50–100 mg
Versed (Midazolam)	IM, IV	[b]
Vistaril (Hydroxyzene)	IM, PO	25–100 mg IM 50–100 mg PO
Valium (Diazepam)	IV, PO	

[a]Dosages vary with weight, age, etc., and should be adjusted to the individual patient and desired level of sedation.
[b]Midazolam may cause severe respiratory depression and should only be used in situations where heavy sedation is required. Consult PDR for current dosing recommendations.

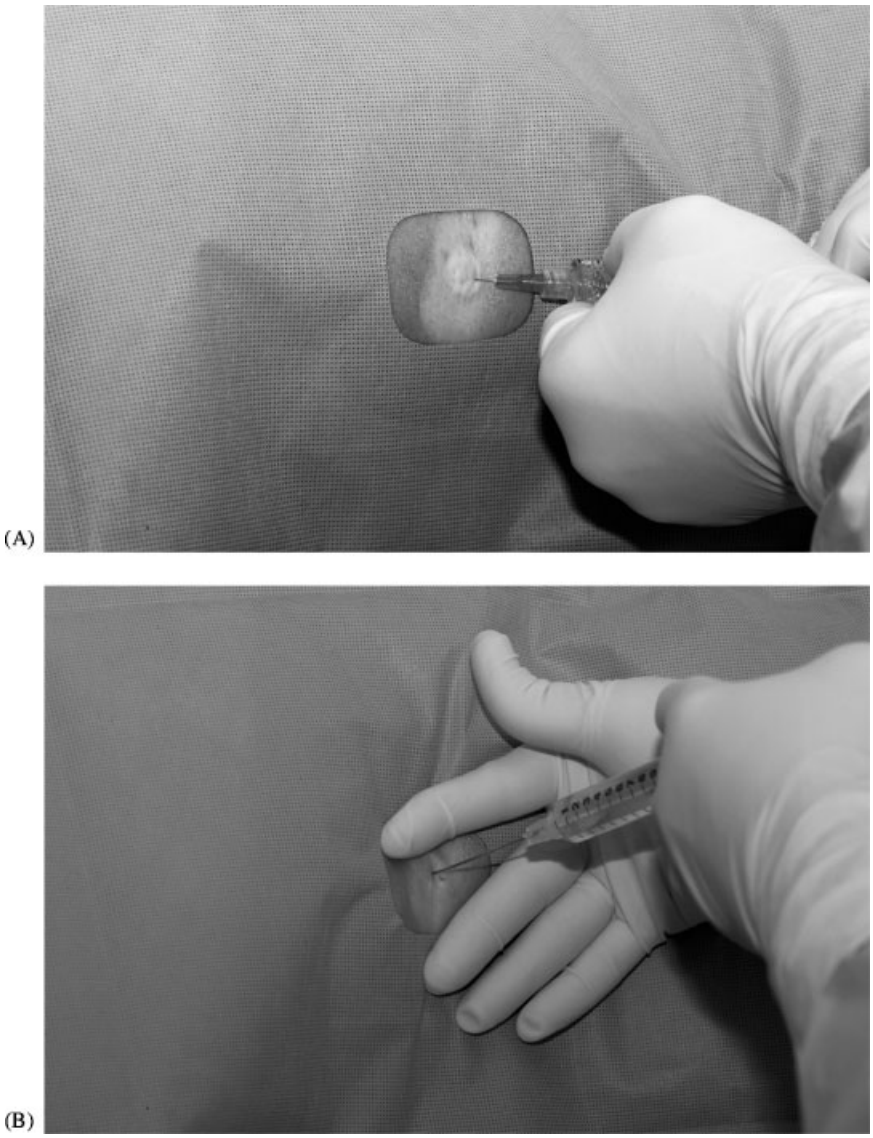

Fig. 5. Administering local anesthesia. **A:** Subcutaneous infiltration of 1% buffered lidocaine, using a 26-gauge needle; **B:** Infiltration of 1% lidocaine into the periosteum of the posterior iliac spine, using a 10 mL syringe with a 3-1/2 in. spinal needle.

500 mg total dose (50 mL of 1% lidocaine). Alternative local anesthetics can be used in patients who have a known hypersensitivity to lidocaine. These include chloroprocaine (Nesacaine, Astra Pharmaceuticals) and bupivacaine hydrochloride (Sensorcaine, Astra Pharmaceuticals). Another alternative in patients who are allergic to lidocaine is to administer methylprednisone (40 mg) and benadryl (50 mg) intravenously immediately prior to the injection of lidocaine, followed by oral prednisone (1 mg/kg) in two divided doses over 24 hr after the procedure (Saul Yanovich, M.D., personal communication). Since anaphylactic reactions can occur in patients without previous history of an allergic reaction, an emergency kit with an airway and injectable epinephrine and hydrocortisone should be available for immediate use (53).

Bone Marrow Aspiration Technique

The procurement of bone marrow aspiration and biopsy specimens is relatively easy to perform if the periosteum has been adequately anesthesized.

Marrow aspiration: AIC, PIC

A similar procedure is used for bone marrow aspiration from the posterior or anterior iliac crest. An amount of 1 or 2 10 mL plastic syringes are each filled with 1 mL sodium heparin solution, 100 USP Units/mL,

or other anticoagulant. Regardless of the purpose of the bone marrow study, it is best to obtain at least one sterile, anticoagulated tube of marrow aspirate for special studies such as microbiologic culture, immunophenotypic analysis, cytogenetic analysis, or molecular biology studies. This may eliminate the need for a subsequent marrow to obtain aspirate material for special studies if unexpected findings are encountered. After the special tubes are prepared, the desired marrow aspirate needle is *sterilely* obtained from the clinical laboratory scientist, the plastic guide and sternal guard removed, and the needle inspected for signs of manufacturing defects. The aspirate needle is held horizontally (for a patient in the lateral decubitus position) or vertically (if supine) with the index finger near the tip of the needle to control the depth of penetration. Many physicians advocate a 0.2 to 0.3 cm skin incision with a small scalpel blade to ease insertion of the needle, although an incision is not necessary if the obturator is sharp (63). The needle is then advanced with steady pressure and a slight twisting motion through the anesthetized skin and subcutaneous tissue at the center of the wheal to the periosteum of the posterior or anterior crest. The adequacy of anesthesia at that spot is determined by asking the patient, then the aspirate needle is gently advanced through the cortical bone by rotation and steady forward pressure. The consistency of the cortical bone is normally firm, but may be soft to very soft in elderly patients or patients with osteoporosis, multiple myeloma, renal failure, or multiple chemotherapy trials. The consistency of bone is very hard in patients with hyperostosis.

A sensation of decreased resistance usually indicates penetration of cortex and entry of the needle into the spongy cancellous bone. This causes a painful sensation in some patients. The needle is further advanced about 1 cm into the marrow cavity, and the stylet is unlocked and slowly removed. A 10 mL syringe is attached to the Luer-Lok™ (Becton, Dickinson and Co., Franklin Lakes, NJ) of the aspirate needle, the patient is warned of a possible unpleasant sensation, and the plunger of the syringe is vigorously pulled back to aspirate approximately 0.3 mL of bone marrow (Fig. 6). The syringe is quickly handed to the clinical laboratory scientist to prepare smears, and a finger is held over the needle opening to prevent further loss of bone marrow. The procurement of specimens larger than 0.3 mL dilutes the marrow with sinusoidal blood and can compromise the study. If marrow particles (''spicules'') are identified on the bone marrow smears, the extra marrow aspirates for special studies are then obtained. If marrow particles are not identified, the needle is advanced, with the stylet in place, to a slightly deeper location and the procedure is repeated. Aspiration at a different site should be attempted if the second attempt also fails to yield marrow particles. Aspiration with a 30 mL or 50 mL syringe may sometimes produce particles when aspiration with a 10 mL syringe is not successful. When an adequate marrow aspirate has been obtained, the aspiration needle is removed and pressure is applied to the procedure site with a sterile sponge until bleeding ceases.

A failure to aspirate fluid or obtain bone marrow particles when aspiration is performed is referred to as a ''dry tap.'' The most common cause of a dry tap is faulty positioning of the aspiration needle in the marrow cavity (1,59). In this event, the stylet is replaced in the bone marrow aspirate needle, the needle is further advanced, and a second aspirate specimen is obtained. Repeated dry taps may indicate the presence of aplastic anemia, myelofibrosis, hairy cell leukemia, Paget's disease, or a marrow densely packed with leukemia cells, metastatic tumor, or malignant lymphoma. The overall incidence of dry tap bone marrow aspirations is about 4–7% (59,70–73). A bone marrow biopsy is a mandatory procedure in the event of a dry tap to determine the nature of the pathologic process (71,74). Touch imprints of the bone marrow biopsy (see under ''Preparing bone marrow aspirate smears'') serve as an acceptable alternative to the bone marrow aspirate smears for morphologic evaluation when a dry tap is encountered. In addition, diagnostically useful smears can be prepared from the small quantity of material in the needle in about 80% of patients with a dry tap (75).

Marrow aspiration: sternum

Marrow aspiration from the sternum is usually performed only when the posterior and anterior iliac crests are diseased or inaccessible because of massive obesity. In addition to the rare, but very serious complication of entering the mediastinum during the procedure, the sternum is an unsuitable site for biopsy procurement and causes the most pain and patient apprehension (2). A site is chosen just to one side of the midline, at the level of the second or third interspace (2). If a sternal aspiration is necessary, an ''Illinois'' bone marrow aspirate needle with a sternal guard is used. The thickness of the subcutaneous is determined during the induction of local anesthesia, and the guard is adjusted so that only 5 mm further advancement is possible (3). The needle is held perpendicular to the skin, slowly advanced downward to the periosteum of the sternum, and then slowly rotated through the anterior table. A decrease in resistance usually indicates entry into marrow cavity. Further advancement of the needle is avoided in order to avoid penetration of the posterior table of the sternum. The sternum has a total thickness

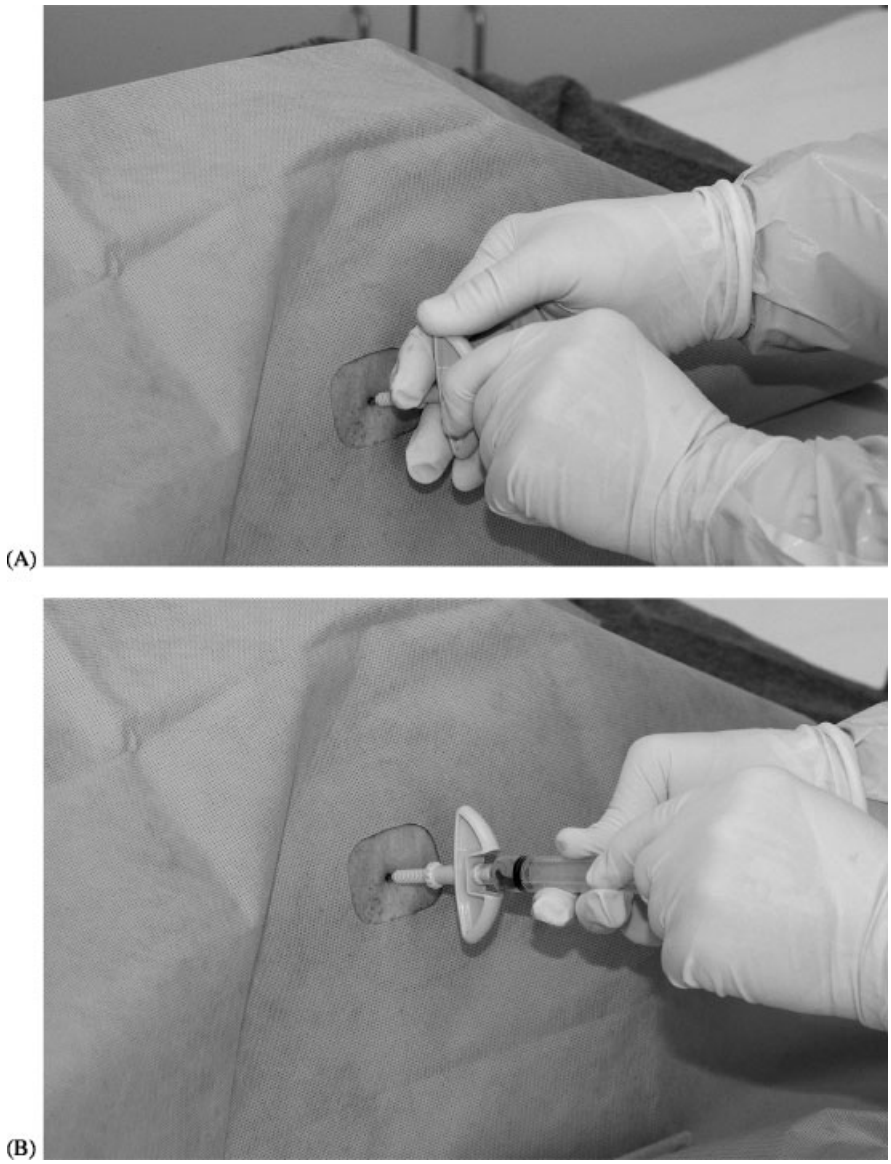

Fig. 6. Bone marrow aspiration. **A:** A 16 gauge Illinois sternal/Iliac aspiration needle has been placed into the marrow cavity. The obturator is being removed; **B:** The obturator of the Illinois sternal/iliac aspiration needle has been removed and a 10 mL syringe attached to the hub. Suction is being applied to the syringe, with successful aspiration of marrow.

of about 1 cm in the adult (1). The stylet is slowly removed, and the plunger is pulled back to aspirate approximately 0.5 mL of bone marrow. If the needle enters the mediastinum, fluid bubbles may appear in the syringe as the stylet is removed as the patient breathes.

Preparing bone marrow aspirate smears

Preparing quality aspirate smears is an essential part of the bone marrow procedure. Smears should be immediately prepared at the bedside from the first aspirated specimen (''first pull'') to ensure adequate particles and prevent contamination with peripheral blood. Aspirate smears must be prepared quickly, since freshly aspirated bone marrow tends to clot quickly. If smears cannot be prepared at the bedside, the aspirate material should be immediately placed into a tube containing EDTA anticoagulant (purple top) for smear preparation upon returning to the laboratory.

There are several ways to prepare an aspirate smear. The simplest is the traditional wedge technique used to make peripheral blood smears. A drop of bone marrow aspirate is placed at one end of a clean microscope slide, and a second clean microscope slide is used as the ''spreader slide.'' The spreader slide is held at a 30° angle, placed in front of the drop of bone marrow

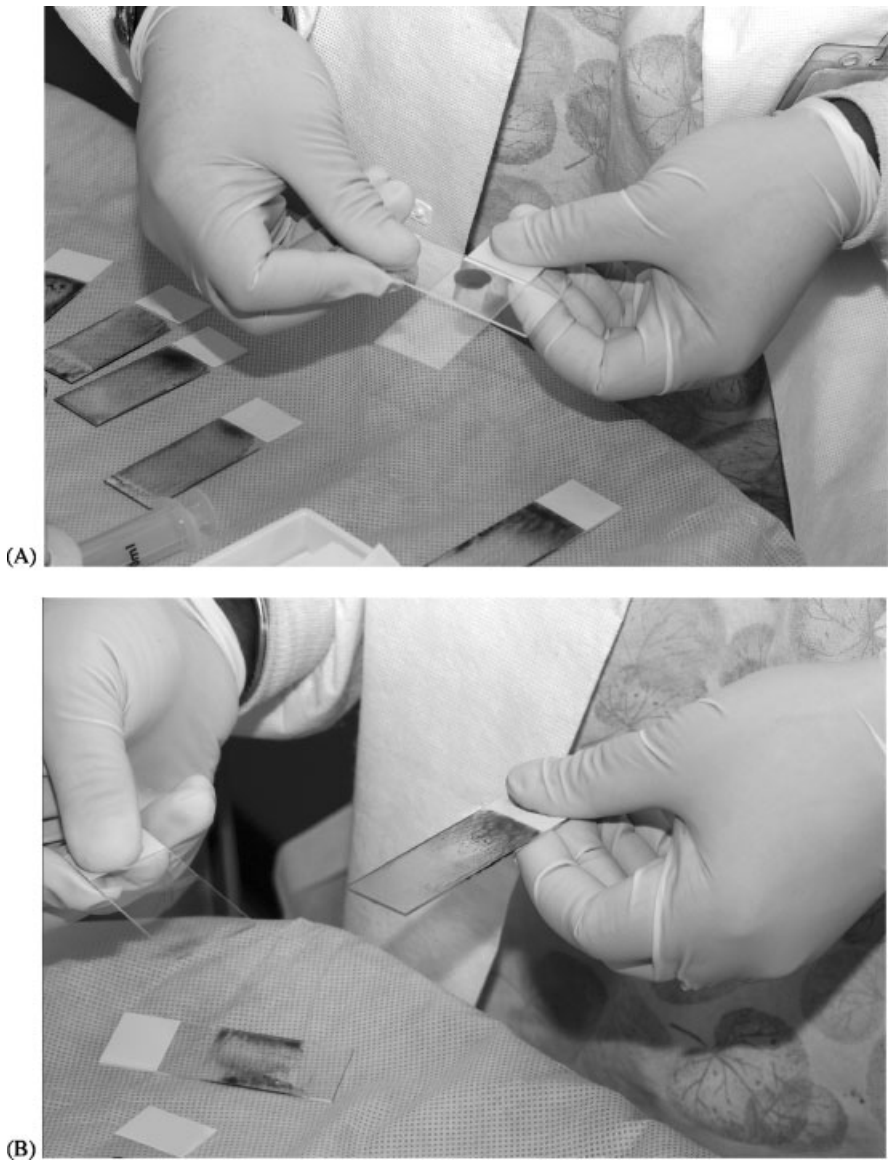

Fig. 7. Preparing aspiration smears. An experienced medical technologist is preparing smears from small drops of the bone marrow aspirate placed on glass microscope slides.

aspirate, and then pulled back until it touches the drop. The liquid is allowed to spread across the edge of the slide, which is then pushed forward at a 30° angle using a rapid, even motion. The smear should end in a particle-rich feathered edge (Figs. 7,8).

The particle crush method requires more experience to perform than the wedge preparation, but is superior for morphologic examination because it provides an "inside look" at the bone marrow particles, hematopoietic cells are more concentrated, and mast cells can be evaluated in the thick areas (53). In this technique, a small drop of aspirated marrow is placed at one end of a clean microscope slide. A second clean slide is held parallel to the first slide and directly over the drop of aspirate. With gentle pressure the second slide is pressed against the drop of aspirated marrow and pulled across the full length of the first slide to crush open and spread the marrow particles (Fig. 8). Coverslip smears may be prepared by the same technique, but the coverslips are more difficult to handle and more skill is required.

Coverslip preparations are relatively complex to prepare, but yield superior morphology (Fig. 8). In this technique, 1 to 2 mL of bone marrow aspirate from the first draw is placed into a Petri dish, which is tilted at a slight angle to drain off the blood and make marrow particles visible (60). One or two particles are aspirated into a Pasteur pipette and placed on a 22 × 22 mm cover glass. A second cover glass is placed diagonally

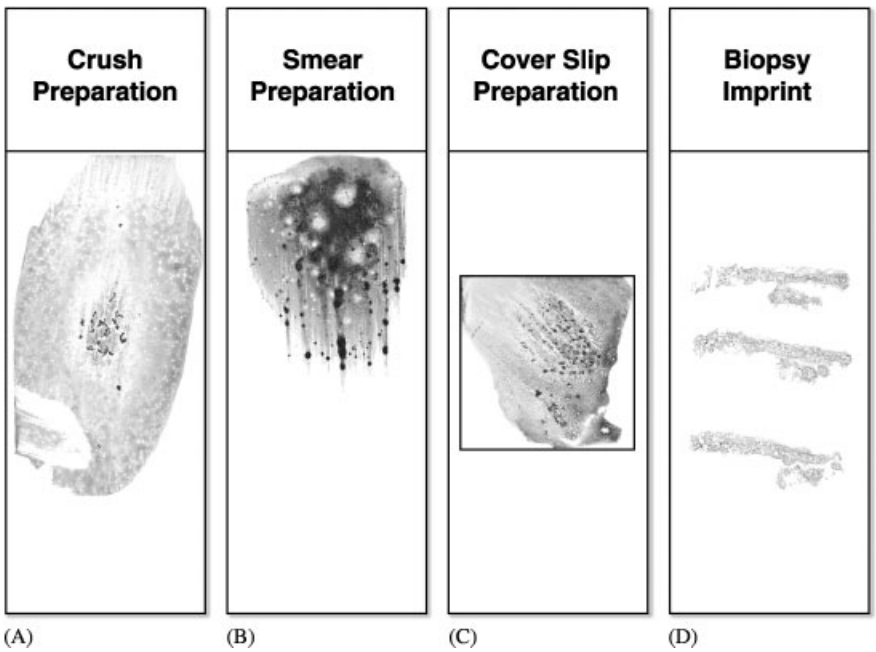

Fig. 8. Completed smears prepared from a bone marrow aspiration. **A:** Conventional "crush" preparation prepared with two glass microscope slides; **B:** "Smear" preparation; **C:** Coverslip preparation; **D:** Biopsy imprint ("touch preparation").

over the first, slight pressure is applied to gently crush the particles, and the two cover slips are gently pulled apart to produce smears (60). The cover slips are then placed in a clean, labeled Petri dish until they can be stained. The cover slip smears are manually stained using forceps to hold the cover slips during the staining process. As described above, smears from isolated particles can also be prepared with the use of glass microscope slides.

Particle "clot" sections are histologic sections of aspirated bone marrow material. The easiest clot section to prepare involves drawing a small amount of aspirate material into a plain syringe and allowing it to clot on its own. If the bone marrow aspirate does not clot, a small amount of thrombin solution should be added to the sample, drop by drop to initiate clotting. The disadvantage of this method is that the small aspirate particles are embedded in the clotted blood, sometimes making interpretation difficult. An alternate method of preparation by straining the specimen avoids this problem. In this modification of the technique originally described by Rywlin (41,53), a small amount of aspirate is placed into a collection tube containing EDTA at the bedside. Upon return to the laboratory, the anticoagulated material is poured into a tissue specimen bag. Any particles are trapped in the bag, while excess blood filters through. The particles are fixed in AZF or another fixative and submitted for processing, sectioning, and staining. Mark and Levin (76) found histologic sections prepared by this technique to be superior to the bone marrow biopsy for the detection of lymphoid nodules, nodular lymphoid hyperplasia, and lipid granuloma. The filtered blood remaining from the concentration procedure can be concentrated by centrifugation into four layers: fat and perivascular cells, plasma, myeloid-erythroid cells ("buffy coat"), and erythrocytes (55). The height of each layer can be measured to provide an estimate of the relative volume of each component layer. Smears prepared from the fat-perivascular and myeloid-erythroid layer are excellent for morphologic study since they are free of contaminating erythrocytes. In one study, the bone marrow buffy coat was also demonstrated superior to the bone marrow aspirate for the detection of acid-fast bacilli by the Ziehl-Neelsen technique (77). In neonates, bone marrow aspirate for clot section preparation can be obtained from the tibia using a 19 gauge needle (78). The value of clot sections in the diagnosis of focal bone marrow lesions, such as malignant lymphoma, granulomata, and metastatic cancer, has been well documented in the literature (79,80).

Biopsy imprint ("touch") preparations should be prepared from the bone marrow biopsy core if the aspirate specimen is devoid of particles or cannot be obtained. In this technique, the fresh core biopsy specimen is placed on a clean microscope slide. A second clean microscope slide is pressed very gently against the biopsy core and rolled slightly from side to side. Two or three microscope slides should be prepared with several imprints on each slide. During the

preparation of touch imprints, cells on the surface of the biopsy core stick to the microscope slides. The imprint slides can be stained by the Wright-Giemsa technique for morphologic evaluation or used for cytochemical analysis or immunoperoxidase staining. Several studies have demonstrated the value of biopsy imprint preparations in the detection of malignancy (81–86).

Bone Marrow Biopsy Technique

The Jamshidi needle, introduced in 1971, is most widely used for marrow biopsies at this time, although many other types of needles are available (18,19). The tip of the Jamshidi needle is tapered radially toward the cutting edge, allowing marrow tissue to freely enter the needle without clogging the tip (59). Recent innovations in bone marrow biopsy needle design have included tapered, specially-sharpened cutting edges to reduce pain and increase the efficiency of bone penetration, as well as core-securing devices to reduce damage to the core and decrease the chance of leaving the core in situ during specimen extraction (21,22,87).

The bone marrow biopsy is obtained through the same skin incision site used for the marrow aspiration, but the needle is angled differently from the aspirate needle in order to sample a different area. Due to the larger caliber of the bone marrow biopsy needle, more force is usually required than with the aspirate needle. In addition, some patients complain of an uncomfortable dull (''pressure'') sensation as the needle is advanced, which is not relieved by local anesthetic. Bone marrow biopsies are obtained from the PIC or AIC, but NEVER THE STERNUM! To perform the procedure, a bone marrow needle biopsy needle is *sterilely* obtained from the clinical laboratory scientist and inspected for bent, loose, or almost-broken parts. The obturator is reinserted and locked with a twist. Various types of bone marrow biopsy needles are pictured in Fig. 2.

The biopsy needle is held with the handle in the palm of the hand and the index finger tip on the shaft of the needle to control penetration. The needle is inserted through the skin puncture site, advanced with steady pressure to the periosteum, and twisted into the surface of the cortex of the bone (Fig. 9). The obturator is then removed from the needle. The tip of the needle is then pushed through the cortex while rotating with a ''back and forth'' motion. Decreased resistance usually indicates entry into marrow cavity. The needle is advanced 1–2 cm further with continued ''back and forth'' rotation. To determine the length of the biopsy specimen in the needle, the obturator can be carefully reinserted into the needle until resistance is encountered (Fig. 9). The biopsy core is broken off from the surrounding bone by vigorously rotating the needle 360 degrees several times while applying slight pressure. Decreased resistance to rotation usually indicates detachment of the core from the surrounding bone. If difficulty is encountered, the needle should be withdrawn slightly (2–3 mm, redirected at a new angle, and readvanced 2–3 mm with rotation to break off the biopsy core. The needle is carefully withdrawn with rotation through the bone, periosteum, and skin. A small blunt obturator is used to remove the biopsy core from the needle, while the needle is held vertically with the beveled (distal) end up and the hub approximately 2 cm above a clean glass microscope slide or piece of sterile gauze held by the nurse or clinical laboratory scientist (Fig. 9). The obturator is inserted into the distal end of the needle and the core biopsy is gently forced through the hub of the needle unto the glass slide. In patients with extremely dense bone, the tip of the beveled end of the needle may be bent during the biopsy procedure, making it difficult to insert the obturator. Several attempts may be necessary. Touch preparations of the biopsy should be obtained (Fig. 9).

As it is extracted from the needle, the trephine core should be inspected for adequacy and atypical features. A normal biopsy core is dark red with a fine white trabecular network. In patients with a markedly hypocellular bone marrow, the trabecular network remains, but reddish marrow is not visible. Cartilage is homogenous, white, and glistening, while cortical bone is white. A mottled appearance may indicate focal replacement with tumor or granulomas. Additional biopsy cores should be obtained if the specimen is inadequate in size or has an atypical gross appearance. Occasionally the biopsy core will remain in the skin incision as the needle is being withdrawn and can be removed with forceps. The creation of a gentle vacuum with an empty syringe inserted into the Luer-Lok of the biopsy needle as the needle is slowly withdrawn will sometimes result in a successful biopsy retrieval in a difficult patient.

There are no definitive criteria for the adequacy of a trephine biopsy. Most studies of multiple marrow sites have revealed marrow cellular content, cellular composition, and pathologic lesions to be relatively uniformly distributed throughout the hematopoietically active portions of bone. Therefore, most hematopathologists today consider an adequate sample from a single site acceptable for the evaluation of many diseases. However, additional biopsy cores may be required in patients with suspected ''focal'' lesions, such as malignant lymphoma, granulomatous inflammation, and metastatic carcinoma. If radiographic studies suggest unilateral disease, sampling from that side is favored. Research protocols may also dictate specific biopsy requirements. The bone marrow biopsy is

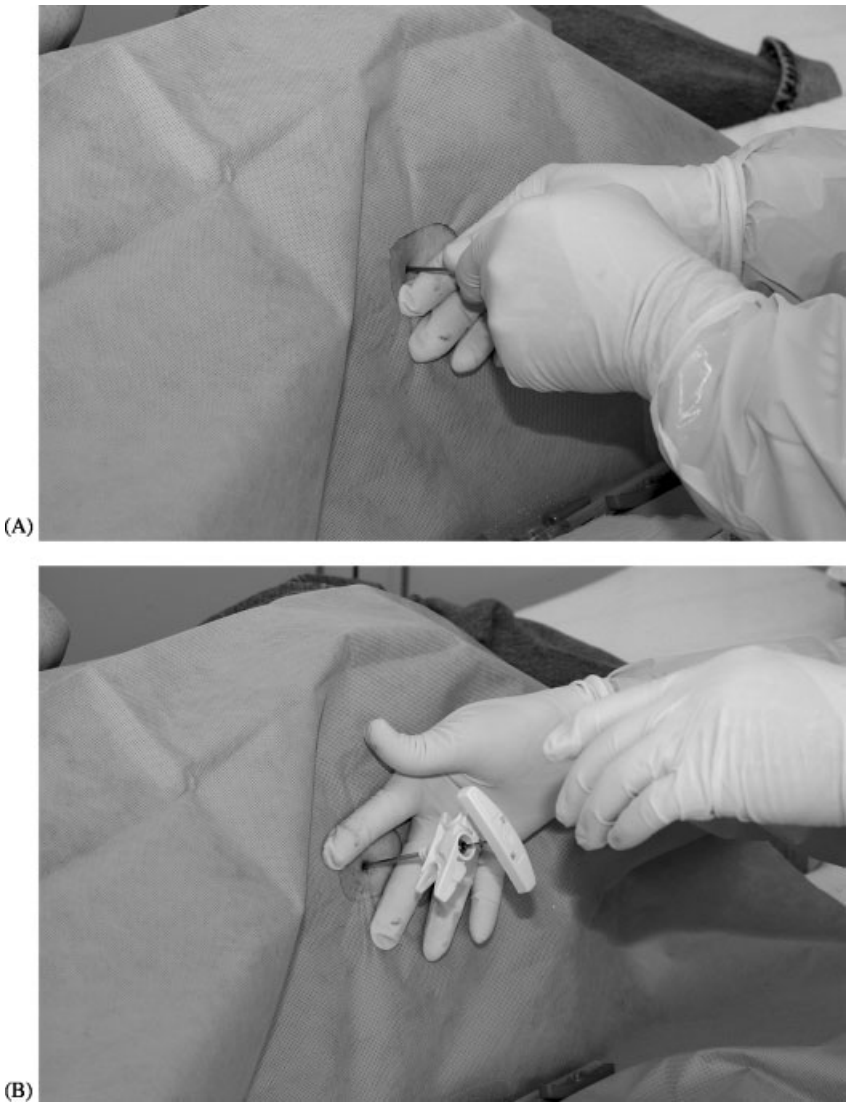

Fig. 9. Bone marrow biopsy. **A:** Inserting a 4″, 11 gauge, contoured Jamshidi bone marrow biopsy/aspiration needle into the posterior iliac crest for biopsy procurement; **B:** Determining length of biopsy core in needle by carefully reinserting obturator. Ideally, the core length should be 2 cm or greater; **C:** Delivery of biopsy core unto a glass microscope slide. The core has been forced through the hub of the needle using a small blunt obturator; **D:** Delivery of the biopsy core into a vial of AZF fixative following preparation of biopsy imprints. Biopsy imprints are prepared by gently touching a clean glass microscope slide to the biopsy core resting on another glass slide. Cells on the surface of the core stick to the clean slide, which is later stained by the Wright-Giemsa technique. Cytologic detail of the cells can be visualized and complements the aspirate and biopsy.

superior to the aspirate for the discovery of focal bone marrow lesions, although these procedures are complementary and both should be routinely performed (88–92).

The total length of the trephine biopsy core(s) obtained, the location and number of anatomic sites sampled, and the gauge of the biopsy needle are the major factors that determine the adequacy of a bone marrow biopsy examination. A total core length of 1.0 cm is considered adequate by some groups, while others require a longer core of 1.5 to 3 cm (17,20,55,58,59,93). Unfortunately, this subject is complicated by the time and technique of measurement, since the core may shrink by up to 25% during processing (7). A few investigators specifically studied the relationship between core length and pathologic findings. For example, Bishop et al. (94) evaluated marrow biopsies obtained for the detection of metastatic tumors, and found a post-processing core length of 1.2 cm (1.6 cm pre-processing) adequate for the detection of 90% of metastatic tumors. In children, 0.5 cm of well-preserved bone marrow was reported adequate for the detection of metastatic neuroblastoma (95–97). Jacobs (98), who evaluated more than 5,000 trephine biopsies, concluded that

Fig. 9. (*continued*).

a minimum of 3 cm of iliac bone is required for the demonstration of focal lesions.

Many studies have been undertaken to determine the sensitivity of unilateral or bilateral morphologic examination for the diagnosis of various bone marrow diseases. Although a consensus is difficult to reach due to differences in experimental methodology, all of these studies have revealed a higher incidence of disease incidence in bilateral vs. unilateral sampling for neuroblastoma and other childhood tumors (34,99), non-Hodgkin's lymphoma and other lymphoproliferative diseases (100–107), bronchogenic carcinomas (108), small-cell anaplastic carcinoma of the lung (109), and breast carcinoma (5,110). In a recent large study of 1,864 bilateral bone marrow biopsies, Wang et al. (111) concluded that bilateral bone marrow examinations are indicated for patients with non-Hodgkin's lymphoma, Hodgkin's lymphoma, carcinoma, and sarcoma, but not for the evaluation of acute or chronic leukemia, myelodysplasia, multiple myeloma, and other diseases. Flow cytometric analysis and cytogenetic analysis on ancillary aspirate did not provide adequate additional information to justify the collection of these specimens. In contrast, some physicians advocate the procurement of two biopsy cores from different directions through the same skin puncture over the two-site biopsy to obtain adequate tissue for evaluation and minimize patient discomfort (98). The recently developed 8 gauge bone marrow biopsy needles with core-securing devices may replace the conventional 11 gauge Jamshidi needle for the procurement of bone marrow biopsies in patients with focal lesions, since a large volume of bone marrow may be obtained with less patient discomfort (22). For comparison, a 2 cm bone marrow biopsy obtained

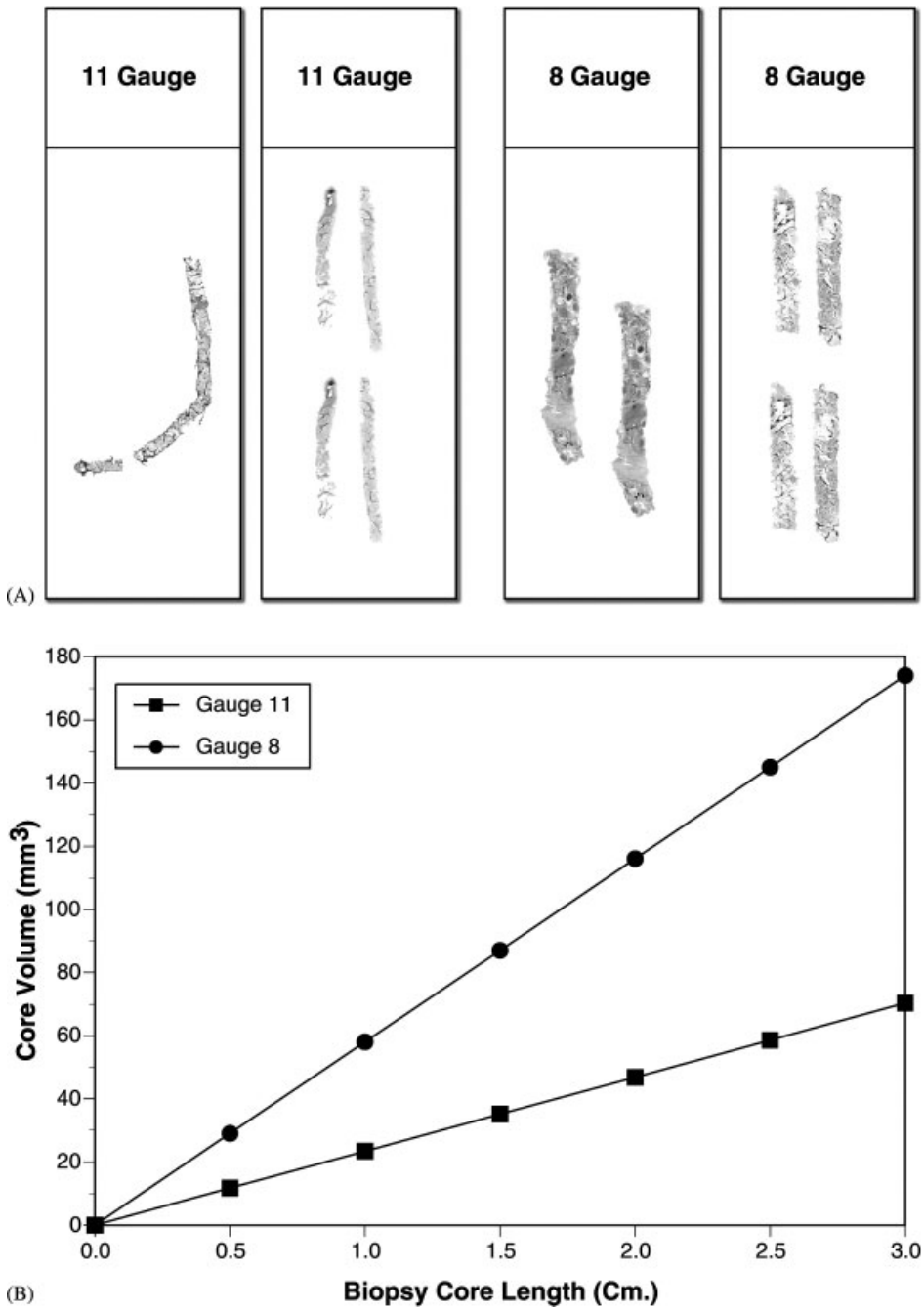

Fig. 10. Effect of bone marrow biopsy core length and needle diameter on total marrow tissue volume. Volume calculations were based on inner diameter of needle lumen (11 gauge = 0.068 in., 1.73 mm; 8 gauge = 0.107 in., 2.72 mm) using the mathematical formula volume = $\pi r^2 h$, where r is the radius and h the length of the core.

with an 8 gauge needle has a volume of approximately 116 mm^3, compared with 47 mm^3 for an 11 gauge needle (Fig. 10).

Post-Procedure Care

After procurement of the marrow specimens, bleeding must be stopped, the procedure site must be cleaned up, the needles properly disposed of in a sharps container, and a bandage is placed over the procedure site. Finally, a written description of the procedure must be placed in the patient's chart.

Post-procedure care in individuals without bleeding complications consists of placing a layer of sterile gauze over the skin puncture site, and applying firm pressure to the skin and underlying bone for approximately

1 min. The gauze is then removed, but further pressure is applied if bleeding is still encountered. The gauze and fenestrated drape are then removed and placed in a "sharps" waste container. The skin is carefully wiped with isopropyl-soaked swabs to completely remove the povidone-iodine. Residual povidone-iodine may cause itching and lead to a future allergic response. A gauze square is then doubled over the procedure site and covered with at least two pieces of elastic surgical tape approximately 2–3 inches in length. The patient is placed in a supine position with their weight concentrated over the wound for at least 30 min as a further precaution against bleeding (63). If unusual bleeding is encountered during a marrow procedure, pressure is applied until the bleeding stops, a pressure dressing is applied, and the patient is placed in a supine position for at least 1 hr (57). The procedure site may be slightly tender for several days. The patient is advised to contact their physician if swelling, marked tenderness, or bleeding is observed.

1. Carefully dispose of the syringes and needles in a "sharps" container.
2. Advise the patient's nurse or physician that you have completed the procedure and remind them to keep the patient supine for 30 min.
3. Place a note on the patient's chart. This is required for medicolegal and billing purposes, as well as to alert the patient care team to the performance of the procedure and any complications that were encountered. The contents and style of the note can vary according to personal style and hospital requirements.

COMPLICATIONS OF THE BONE MARROW PROCEDURE

The bone marrow examination is a safe procedure with a low risk of morbidity. Mortality is unusual in association with sternal marrow aspiration and extremely rare with bone marrow aspiration and biopsy of the iliac crest. Cardiac tamponade from laceration of the right ventricle or intrapericardial aorta was the cause of death in several reported cases of fatal sternal aspiration (53,112–117). Pulmonary bone marrow emboli, growth of a sternal tumor mass, and sternal-manubrial separation are other unique complications of sternal marrow aspiration (118,119). Hemorrhage is a rare complication of bone marrow aspiration and biopsy at any site, provided a small pressure dressing is applied to the biopsy site (53,120,121). Patients with osteoporosis, Paget's disease, and other bone diseases appear to have the greatest risk of bleeding complications. Fatal intra-abdominal hemorrhage was reported following bone marrow aspiration and biopsy in a patient with multiple myeloma (122). Retroperitoneal hemorrhage following bone marrow examination has also been reported in patients with osteoporosis/renal osteodystrophy and polycythemia vera (123–125). Breakage of the bone marrow needle or separation of the handle during insertion into the bone is a very rare complication of marrow procurement. If the needle fragment cannot be easily removed with a hemostat, the patient should be notified of the mishap and a surgical consultation obtained (53). Personally, we have observed rare patients who developed unilateral lower extremity numbness and weakness following the bone marrow examination, presumably from infiltration of the sacral nerve plexus. These patients were moderately obese, relatively intolerant of pain, and required extra lidocaine to induce local anesthesia. The symptomatology resolved without specific therapy.

SUMMARY AND FUTURE PROSPECTS

The bone marrow aspirate and biopsy are critical specimens for the diagnosis and monitoring of hematologic diseases. The posterior iliac crests are the preferred sites to obtain bone marrow for diagnostic purposes, since the pelvic bone has a large volume of bone marrow, there are no vital organs in close proximity, and most patients are most comfortable in the lateral decubitus position. During the bone marrow examination, liquid bone marrow is aspirated from the bone marrow cavity with a syringe, and a solid core of bone marrow is obtained with a special needle. Smears are prepared from the aspirated material and stained by the Wright-Giemsa technique for the evaluation of bone marrow cell morphology, while the bone marrow core is fixed, sectioned on microscope slides, and stained with the hematoxylin-and-eosin ("H&E") technique for assessment of cellularity and the presence of focal lesions such as malignant lymphoma, metastatic carcinoma, and granulomata. In some patients, aspirated bone marrow is also used for special procedures, including flow cytometric immunophenotypic analysis and cytogenetic analysis. The bone marrow aspirate smears can also be stained by cytochemical or immunohistochemical techniques, while immunohistochemical or other special stains are often performed on the bone marrow biopsy. Most patients tolerate the procedure well if adequate local anesthesia is performed by injecting lidocaine solution into the skin and over the periosteum of the procurement site. However, some patients require pre-medication to reduce anxiety over the procedure. Complications of the procedure are extremely rare if the procedure is properly performed and the patient possesses an adequate hemostatic

system. Bleeding, with the development of a subcutaneous hematoma, is the most common complication, usually in a patient with an unrecognized coagulopathy. Osteomyelitis, retroperitoneal hemorrhage, and other complications have been rarely reported. The recent development of bone marrow biopsy needles with internal snares to capture the bone marrow core is expected to reduce the discomfort of the procedure and increase specimen adequacy.

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