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SEVENTH EDITION

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FOREWORD FOR THE SEVENTH EDITION

Who would have thought when the first edition of *Operative Hand Surgery* was published in 1982 that nearly three and a half decades later we would be publishing the seventh edition and the book would be sold in more than 50 countries? The success of this book has been due to three main factors: (1) Careful selection of experienced authors with recognized expertise who are willing to invest the huge time and energy commitment that it takes to write an outstanding chapter (and people who are willing to make that commitment are becoming increasingly difficult to recruit); (2) meticulous dissection and critique of each chapter by the editors, another job that requires a mammoth expenditure of hours; and (3) the worldwide explosion of interest in hand surgery and the blossoming of national hand societies throughout the world (56 at last count). In 1982, we were fortunate to be at the right place at the right time.

A huge debt of gratitude is due to the contributors of the seventh edition, who made the decision to write a chapter, which demanded that they forego more pleasurable or financially productive pursuits. I am especially grateful to Scott Wolfe, who picked up the mantle of editor-in-chief and has devoted the time and effort necessary to oversee and direct the last two editions. He has more than justified the confidence we had in choosing him for this job over many other equally qualified hand surgeons. To my good friends and former practice partners, Bob Hotchkiss and Chris Pederson, I cannot thank you enough for what you have done to stick with this book through several editions. Over many years, we have laughed, we have cried, and we have anguished together over the peaks and valleys of bringing to life this large body of work. And to the new editors, Scott Kozin and Mark Cohen, I extend my appreciation for their commitment to this demanding process. Your only reward will be knowing that someone, somewhere will benefit from your efforts.

One other person deserves credit that is long overdue. Lewis Reines was president of the American division of Churchill Livingstone in the late 1970s, and *Operative Hand Surgery* was his idea. I had wanted to do a small book on some topic in hand surgery, but Lew said, "No, do the big book." This text would never have come into being without his foresight, encouragement, and expert guidance during those early years.

David P. Green, MD
San Antonio, TX
September 2016

PREFACE

"See one, do one, teach one" was the mantra of our past generation of surgical mentors. This rubric was emblematic of a surgical apprenticeship style of learning that had been effective for centuries. But implicit in this approach is a trial and error mentality that may only have worked in a day of lower expectations and a more narrow understanding of disease. The last half century has witnessed an explosion of technological advancements, increased scientific knowledge base, and surgical complexity, coupled with parallel changes in health care financing, regulation, and work hour restrictions that challenge our ability to teach effectively.

The average adult learner requires not one, but *seven* exposures to learn a new concept, and retention becomes even more difficult if the learning occurs over a short, intense study period. Similarly, psychological theory holds that it may take as many as 10,000 repetitions to master a technique or a skill. How then can a medical student, or even an accomplished surgeon, master a surgical reconstruction of a disorder that he or she may only see twice in a career? Benjamin Franklin quipped, "Experience keeps a dear school, but fools will learn in no other." Experience alone is not a panacea, however, as one can practice and engrain incorrect techniques. Experience should be accompanied by feedback and reinforcement, such that when skill acquisition is accompanied by reading, learning, and coaching, repetition will lead to mastery.

Enter *Green's Operative Hand Surgery*, a concept that was introduced 35 years and six editions ago, and one that has remained the backbone of hand surgical learning since. David Green invited recognized masters of specific hand surgical techniques to pool their talents to create an enduring resource of expert techniques, a synthesis of current publications and novel research, and the hugely successful guide to success: the *Author's Preferred Technique.* In this book, you can immerse yourself in concise tutorials of what works and what doesn't, learn the evidence and the anecdotes that contribute to success, and enlist the surgical mentoring of nearly a hundred recognized experts in hand surgery. The electronic version of *Green's Operative Hand Surgery,* available at ExpertConsult.com, does not simply duplicate the written content but expands on it, with volumes of illustrative cases, an expert classroom of 60 video techniques, classic chapters from archived editions, and regular online updates of emerging techniques that promise to change the landscape of tomorrow's hand surgery. Through the intensely dedicated work of its five editors, *Green's* can sharpen the skills of hand surgeons worldwide and excite present and future students of hand surgery. Welcome to *Green's Operative Hand Surgery*, seventh edition.

Scott W. Wolfe, MD

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Publishing a multimedia reference of this magnitude requires an enormous team effort and unanimity of purpose. I'd first like to thank Dave Green for his confidence in entrusting his brainchild with me and for giving me the amazing opportunity to expand our hand educational borders across the globe. On behalf of our readership, a huge shout-out to our expert authors for their countless hours away from family and work, their exquisite attention to the details and principles of *Operative Hand Surgery*, and their dedication to education. Many of our authors wrote their chapters single-handedly, which, in the spirit of the inaugural edition of *Green's*, gives our readers firsthand exposure to their thoughts, tips, and techniques. What may be less apparent is the luster given to each chapter by our incredible editorial team, whose proficiency and dedication make *Green's* the foundational resource of hand surgery. I am indebted to my trusted colleagues Bob Hotchkiss and Chris Pederson, who have devoted their expertise in microsurgery and elbow reconstruction for more than twenty years and five editions to hone these gems to perfection. We are incredibly fortunate to have attracted Scott Kozin, a thought leader in pediatrics and congenital hand, to complete a comprehensive revision of our pediatric section in the sixth edition. With the seventh edition, I'm delighted to welcome longtime friend and colleague Mark Cohen, also a prolific writer and exemplary educator, as our newest associate editor. Special thanks as well to Jonathan Isaacs and David Dennison, whose innovative ideas and commitment will make the electronic version of *Green's Operative Hand Surgery* a true living, interactive, and fully accessible bridge between the print editions.

I'd particularly like to thank the outstanding staff of Elsevier for assuring the highest quality print and online publications. From its inception six years ago, the content strategy team of Don Scholz, Helene Caprari, and Dolores Meloni have sculpted the first fully integrated print and online edition to ensure that *Green's* is available where you are. I'm indebted to my go-to person and content strategist Maureen Iannuzzi, who choreographed the entire production from its start to its launch, gently coaxing, convincing, and cajoling our writers and editors across the finish line. Special thanks to our illustrator, Wendy Beth Jackelow, for bringing these pages to life with abundant new color drawings, and to our project manager, Kate Mannix, for transforming our concepts and documents into the published multimedia finale.

Most importantly, I want to thank my family: my incredible children, William, Elizabeth, and Christian, for giving me free passes for too many weekends holed up in the office; and most of all, my wife Missy: my best friend, historian, and trusted advisor, whose sacrifice, patience, and wisdom inspired me to complete this work.

Scott W. Wolfe, MD

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CONTENTS

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VIDEO CONTENTS

1

Anesthesia

Elaine Yang

Acknowledgments: The author wishes to recognize the work of previous authors Drs. Lauren Fisher and Michael Gordon for their contributions to Green's Operative Hand Surgery *and to this manuscript.*

There are several techniques for providing anesthesia for hand surgery. This chapter provides an overview, illustrating both the risks and benefits of each. General anesthesia will be briefly discussed and regional techniques will be addressed, as well as the unique role that regional anesthesia plays in both operative anesthesia and postoperative analgesia for hand surgery.

GENERAL ANESTHESIA

General anesthesia has long been the technique of choice for surgical procedures, using either traditional endotracheal intubation or the newer laryngeal mask airway. Considered fast and reliable, it is the standard of care at many institutions. Unfortunately, it also has its share of complications, because the systemic administration of medication can cause derangements of other organ systems, including the brain, the heart, the lungs, the airways, and the gastric, endocrine, and renal systems. General anesthesia often calls for airway manipulation, which causes additional associated complications ranging from minor sore throat and hoarseness to more feared, serious complications, including laryngospasm, aspiration, or failed airway. These serious complications are relatively rare; more prevalent are the minor complications of nausea and vomiting, grogginess, or pain requiring further treatment.[47]

REGIONAL ANESTHESIA

Regional anesthesia is the anesthetic of choice at our institution and is especially suited to upper extremity surgery, as most patients are ambulatory. For inpatients, regional anesthesia is associated with less time spent in the recovery room, improved pain control, lower opiate consumption, and less nausea and vomiting.[46] Regional blockade can be used alone as an intraoperative anesthetic or as a supplement to general anesthesia.

Contraindications

Absolute Contraindications

The two absolute contraindications to regional anesthesia are (1) patient refusal and (2) infection at the site of needle insertion. Often patients refuse regional anesthesia because they have been inadequately educated preoperatively or are misinformed about it. However, many common fears regarding regional anesthesia can be dispelled with a forthright discussion.[115] For instance, patient surveys reveal concerns regarding discomfort during needle placement or awareness of the surgical procedure.[28] These concerns are easily allayed with adequate premedication and sedation. In fact, a regional technique would be advantageous to the patient wishing to minimize sedation and remain awake.

Relative Contraindications

Need for Assessing Postoperative Nerve Status or Compartment Syndrome. Because a successful block hinders motor and sensory conduction, nerve testing in the immediate postoperative period is not possible. Therefore, if an immediate postoperative assessment of nerve function is required, a regional block should not be used.

Fear of masking postoperative compartment syndrome is another relative contraindication to regional anesthesia. Compartment syndrome is diagnosed from both the subjective history and objective findings, especially compartment pressure measurements.[49] Pain in the postoperative period is estimated to precede changes in neurovascular status by 7.3 hours but can be masked by the use of nerve blockade provided for analgesia. Even more confusing, there are also reported cases of compartment syndrome being masked by intravenous (IV) morphine administration during patient-controlled analgesia.[118] Concern for the development of compartment syndrome should be conveyed prior to the start of the case and a plan for postoperative pain control determined at that time. Appropriate vigilance is needed and measurement of compartment pressures mandatory if suspicion for increased compartment pressures exists.

Aggravating a Preexisting Nerve Injury. Another concern is the possibility that regional nerve blockade will incite further nerve injury (double-crush phenomenon) in patients with preexisting nerve injury or paresthesias.[13,83] While this is an understandable concern, experience has shown that regional nerve blockade remains an appropriate option for patients undergoing uncomplicated procedures such as ulnar nerve transposition[50] and the vast majority of elective upper extremity operations.

At our institution, most surgeons and anesthesiologists, in consultation with the patient, opt for the use of regional nerve blockade, even in cases of existing nerve injury or dysfunction. The demonstrated safety of newer techniques (described in the following) and benefit of pain control outweigh the unlikely risk of nerve injury. It is important to discuss the advantages and disadvantages with the patient, allowing him or her to participate in decision making, especially when nerve dysfunction preexists. For patients who appear to fear further nerve injury, we often opt to use general anesthesia with local anesthesia at the surgical site in order to avoid adding a perceived risk and uncertainty to the fears of an already anxious patient.

Anticoagulation Therapy. A relative concern among regional anesthesiologists is performing regional blockade in patients who are taking anticoagulants. More and more patients presenting for surgery are already taking anticoagulants for treatment of underlying coronary artery disease, atrial fibrillation, or cerebrovascular disease or for prevention or treatment of deep venous thrombosis. An injury or even the stress of surgery itself, along with a prothrombotic tissue insult, places anticoagulated patients at risk for development of postoperative deep and superficial venous thrombosis and leads many practitioners to prescribe antithrombotic measures to prevent its occurrence.[90]

Regional neuraxial (spinal or epidural) anesthesia does not contribute to venous thrombosis in patients not receiving anticoagulation therapy and, in fact, has been shown to reduce the rate of blood clots following lower extremity and abdominal surgery, though this advantage has been minimized in recent years with the advent of aggressive and risk-appropriate thromboprophylaxis.[93] Postulated mechanisms include sympathetic blockade leading to improved blood flow and decreased sympathetic stimulation, as well as a direct antithrombotic effect of the local anesthetic solution. However, neuraxial regional anesthesia is contraindicated in the fully anticoagulated patient, given the risk of epidural hematoma and subsequent devastating neural injury. Performance of deep plexus blocks in this setting, though, remains practitioner-dependent. Although few case reports exist of retroperitoneal hematoma following deep lumbar plexus blockade in anticoagulated patients, the relative safety of this technique was confirmed in a large study of 670 patients who underwent continuous lumbar plexus blockade while anticoagulated with warfarin.[15]

In the anticoagulated patient, a perivascular brachial plexus nerve block has the potential to cause excessive bleeding. Yet, several case reports document the safety of peripheral nerve block in the anticoagulated patient, particularly when it is placed under ultrasound guidance.[31] Despite these reassuring findings, the most recent published regional anesthesia guidelines advocate applying the same recommendations for neuraxial anesthesia to patients undergoing deep plexus or perivascular nerve blocks.[54] Patients who have incomplete reversal of their anticoagulation or who possess mild derangements of their coagulation panel for unclear reasons must be approached on a case-by-case basis, and the risks and benefits must be discussed thoroughly with the patient.

Bilateral Procedures. Although there may be instances in which regional anesthesia could be used for bilateral procedures, there are many risks, and it should be avoided if possible. The risk of drug toxicity is higher because the dose must be nearly doubled. Using a lower amount to avoid toxicity raises the probability of block failure.[33] The type of block also influences the risk. Interscalene nerve block commonly results in phrenic nerve paralysis,[111] so bilateral interscalene nerve block is contraindicated because of the risk of respiratory failure. Even supraclavicular blockade has an estimated associated risk of diaphragmatic paralysis of around 50%[81]; this risk, compounding the associated risk of pneumothorax, makes supraclavicular blockade an unreasonable technique for bilateral regional blockade. A safer alternative may be combining techniques of proximal and distal blockade or performing the blocks using low-volume, short-acting local anesthetics in sequence (i.e., performing the block on the second limb only upon completion of the first limb).[33,53]

Relative Indications

Microvascular Surgery Patients

Regional anesthesia with the use of long-acting blocks or continuous/prolonged infusion for digital reimplantation and free flaps is discussed in a later chapter. Continuous sympathetic blockade causes vasodilation and improves blood flow to the digit at risk and reduces neurogenically mediated vasospasm.[105] Improved pain control at the graft site via an effective nerve block also reduces pain-induced sympathetic-mediated vasospasm.[120] While peripheral nerve blockade has been shown to be a safe and effective anesthetic option, it is still unclear whether continuous nerve blockade indeed results in improved graft survival.[105]

Patients with scleroderma undergoing digital sympathectomy and vascular reconstruction also benefit from prolonged anesthetic blockade.[113]

Finally, patients with complex regional pain syndrome who undergo corrective surgery are also likely to benefit from effective prolonged regional anesthesia.[25]

Pediatric Patients

Anesthesia for pediatric patients depends greatly on the age and maturity of the child and the experience of the anesthesiologist. Many techniques combine general anesthesia for the surgical procedure itself with regional anesthesia for postoperative pain control. Many practitioners are comfortable placing blocks in anesthetized children, especially under ultrasound guidance, though the dose of anesthetic agent and the anatomy must be carefully considered.[72] Regional anesthetic technique has been demonstrated to be an effective form of postoperative pain control in children with very low rates of complications[87] and it has opioid-sparing effects. A long-term study looking at the use of continuous peripheral nerve catheters in pediatric patients shows this to be a safe and effective way to provide prolonged analgesia for this population of patients.[45]

Pregnant Patients

While elective procedures are generally not performed during pregnancy, circumstances that require surgery may present.

When possible, a local or regional technique should be used to minimize the effects on maternal physiology as well as reduce the possible pharmacologic exposure of the developing fetus. Ideally, surgical procedures should be deferred to the second trimester to minimize exposure of the fetus to teratogens during the critical period of organogenesis (15 to 56 days) and also limit the risks of preterm labor more prevalent in the third trimester.[55]

An anesthetic plan must provide safe anesthesia for both the mother and the fetus. When surgery is unavoidable in a previable fetus, the American College of Obstetricians recommends monitoring the fetal heart rate by Doppler ultrasound before and after surgery. With regard to a viable fetus, fetal heart rate and contraction monitoring should occur before, during, and after the procedure. The patient should have given consent for emergency cesarean section, and obstetric staff should be on standby in the event of fetal distress.[89]

The pregnant patient has an increased cardiac output, increased minute ventilation, increased risk for gastric aspiration, and increased upper airway edema, which can increase the risk of failed intubation. Fetal safety generally relates to avoidance of teratogenicity, avoidance of fetal asphyxia, and avoidance of preterm labor. While randomized controlled trials examining teratogenicity are not ethically or clinically feasible, local anesthetics, volatile agents, induction agents, muscle relaxants, and opioids are not considered teratogenic when used in clinical concentrations when normal maternal physiology is maintained. Nitrous oxide is probably best avoided given its effects on DNA synthesis and its teratogenic effects in animals.[39]

Patients With Rheumatoid Arthritis

Patients with rheumatoid arthritis are especially suitable candidates for regional anesthesia for upper limb surgery as it decreases the need for airway manipulation and blunts the stress response to surgery. Patients with deformity associated with advanced rheumatoid arthritis require careful positioning on the operating room table to avoid injury to other areas of the body.

This patient population often carries a high potential for airway complications owing to cervical spine immobility, paradoxic atlantoaxial instability, temporomandibular joint ankylosis, and cricoarytenoid arthritis,[96] all of which make endotracheal intubation difficult. Additionally, many rheumatoid patients are maintained on antirheumatic drugs and systemic corticosteroids, which have the potential for causing immunosuppression and a decreased neuroendocrine stress response. Patients consuming at least 20 mg of prednisone a day for more than 3 weeks are considered at significant risk for hypothalamic-pituitary-adrenal suppression.[2] These patients may be considered for stress dose steroid coverage depending on the invasiveness and stress of the procedure, and steroid treatment should be provided in the event of refractory hypotension.

Advantages and Disadvantages (Box 1.1)

A common concern regarding regional anesthesia is the question of whether the block will work. Success depends on the experience and confidence of the practitioner performing the block. At our orthopedic hospital, more than 6300 upper extremity blocks are performed annually, and we are able to achieve a surgical level of anesthesia in 94% to 98% of patients.[71,70]

BOX 1.1 Factors Limiting Use of Regional Anesthesia

In spite of the advantages of regional anesthesia, several factors may prevent its use. Each of these problems can be overcome with appropriate planning.

- Time constraints
- Anesthesiologist's lack of familiarity with the procedure
- Patient's fear of anesthesia failure
- Concern about complications
- Patient's desire to be completely unaware during the procedure

While regional blockade can effectively anesthetize the upper extremity and surgical site, this does not ensure patient comfort. Patients asked to lie motionless on a hard operating room bed might be apt to move to relieve discomfort in the back or knees, therefore disturbing the operative field. We place pillows to support the head and under the knees to reduce low-back strain. Even with adequate motor and sensory blockade, some patients will experience vibration or proprioception, and even vague sensations of pressure in the operative limb. Adequate anxiolysis and sedation will minimize the sensation. Access to the airway should be maintained during surgery in case the block is inadequate or other problems ensue. If the patient's position, such as lying prone, precludes this access intraoperatively, preoperative securing of the airway may be needed.

Duration of the neural blockade is variable, anywhere from 45 minutes to 24 hours after a single injection. The duration can be extended using a peripheral nerve catheter for continuous local anesthetic administration. Catheters have been successfully inserted along various levels of the brachial plexus depending on the desired location of blockade, from above the clavicle, such as interscalene and supraclavicular locations, to below the clavicle, such as infraclavicular and axillary locations.[95] Catheters can be maintained to provide continuous-flow or patient-controlled analgesia for hospitalized patients, and many centers have started home catheter programs for their outpatient population.

Prolonged regional anesthetic blockade provides improved pain relief during immediate postoperative physical therapy, and does not necessarily preclude active participation. In a study comparing continuous patient-controlled perineural infusion with 0.2% ropivacaine with patient-controlled IV narcotic infusion following arthroscopic rotator cuff repair, regional anesthesia techniques resulted in decreased use of supplementary analgesics and had a comparable incidence of motor weakness as did IV patient-controlled analgesia.[101]

The advantages of regional nerve block have been well demonstrated in the ambulatory surgery population. These advantages include lower pain scores, decreased nausea and vomiting, and shorter stays in the postanesthesia care unit.[57,95,101] While these effects are considerable in the immediate postoperative period, studies are ongoing to demonstrate a long-term outcome difference between the different types of anesthetics.[58,103] Evidence supports the finding that in patients undergoing repair of displaced distal radius fracture, regional anesthesia offers decreased pain and improved functional outcomes at 3 and 6 months.[27]

TABLE 1.1 Characteristics of Commonly Used Drugs

Generic Name (Trade Name)	CONCENTRATION (g/dL) Infiltration	Nerve Block	Maximum Dose (mg/kg)*	Approximate Duration
Procaine (Novocain)	0.75	1.5-3	10-14	45-90 min, short-acting
Chloroprocaine (Nesacaine)	0.75	1.5-3	12-15	
Lidocaine (Xylocaine)	0.5	1-2	8-11	1.5-3 hr, medium-duration
Mepivacaine (Carbocaine)	0.5	1-2	8-11	
Tetracaine (Pontocaine)	0.05	0.15-0.2	2	
Bupivacaine (Marcaine)	0.25	0.25-0.5	2.5-3.5	3-10 hr, long-acting
Ropivacaine (Naropin)	0.25	0.25-0.5	2.5-3.5	

*Higher doses with the use of 1:200,000 epinephrine.

BOX 1.2 Prevention of Systemic Toxicity

- Avoid intravascular injection.
- Use epinephrine to slow systemic absorption.
- Use benzodiazepine as a premedication.
- Use ultrasound guidance to fractionate the dose.

Equipment and Pharmacologic Requirements

Medications commonly used in regional anesthesia are listed in Table 1.1.

Regional anesthesia may be administered in a designated block room or preoperative area, in addition to in the operating room. It is crucial to have available appropriate monitoring and resuscitation equipment, including airway management supplies and resuscitative medication, should an acute complication arise. High-flow oxygen, airway management equipment, and suction capability are crucial for emergency airway management in the event of seizure or high or total spinal block. Medications including inotropes, anticholinergics, and vasopressors should be immediately available to treat symptomatic arrhythmias, bradycardias, and hypotensive episodes. Other available medications should include benzodiazepines or propofol to treat seizures and an intralipid to treat bupivacaine-induced cardiovascular collapse (Box 1.2).[4]

Local Anesthetic Additives

In recent years, the use of additives in local anesthetics to increase efficacy and onset of block, as well as overall block duration, has been readily investigated.[5] Historically, sodium bicarbonate has been used to increase onset of sensory and motor blockade in epidural anesthesia through alkalinization of the molecule, thereby facilitating its passage across lipid membranes. When used perineurally, this advantage appears to be more unpredictable for certain types of blocks and may not be clinically significant.[18] Epinephrine, on the other hand, remains one of the most popular adjuncts for prolonging the effect of short- and intermediate-acting local anesthetics by decreasing systemic uptake of the local anesthetic through vasoconstriction. It is also an excellent marker for detection of intravascular injection. The advantage of epinephrine as an adjunctive in long-acting local anesthetic peripheral nerve blocks is not as apparent, especially when juxtaposed with concerns of neurotoxicity in at-risk patients.[114]

Dexamethasone is another additive that has gained popularity in recent years because of its ability to significantly prolong peripheral nerve blockade. Through its proposed ability to inhibit nociceptive C-fibers, dexamethasone has been used with both short- and long-acting local anesthetics in upper extremity surgeries with some success, though recent randomized trials and meta-analyses suggest that this effect can be achieved just as well via IV administration, which has a well-characterized safety profile.[22,24] While investigations into concerns for neurotoxicity with dexamethasone have not yielded conclusive results, we recommend that care be taken when using this adjunct in patients with preexisting nerve injuries.

Alpha-2 selective adrenergic agonists such as clonidine and dexmedetomidine have an analgesic benefit when added to local anesthetics for peripheral blocks.[38,88] By inhibiting current channels that facilitate neurons to return to normal resting potential from a hyperpolarized state, clonidine and dexmedetomidine selectively disable C-fiber neurons from generating subsequent action potentials, resulting in analgesia. The disadvantages of using these additives include dose-dependent systemic effects of sedation, bradycardia, and hypotension.

Opioid agonists such as tramadol and buprenorphine are also used as additives to local anesthetics.[3,9] Tramadol, which acts as a weak mu-opioid agonist while stimulating serotonin release and inhibiting reuptake of norepinephrine, prolongs blockade when given perineurally but does not reliably have a clear advantage over IV or intramuscular administration.[59,61] Buprenorphine, on the other hand, has a fairly consistent record of prolonging block duration and reducing postoperative analgesia when given perineurally, an effect not related to systemic absorption of the drug. The mechanism of action of buprenorphine is an ability to inhibit voltage-gated sodium channels in a fashion similar to local anesthetics.[67] Further studies are needed to elucidate any potential neurotoxic effects of this adjunct.

Finally, additives such as ketamine, midazolam, and magnesium, while showing some promise, do not have an adequately characterized safety profile to be recommended as routine additives to local anesthetics at this time.[64-66]

Historical Techniques

Regional nerve blockade is essentially the deposition of local anesthetic near a nerve. Historically, nerve blocks were blind techniques, performed on the basis of known anatomic relationships to superficial landmarks. Practitioners noted that patients would report paresthesias as the needle advanced, leading to development of the paresthesia technique. This technique required a cooperative and conscious patient capable of providing verbal feedback, as the anesthetic practitioner would intentionally attempt to elicit a paresthesia as a means of nerve localization. Others began experimenting with the use of a nerve stimulator, applying a low-current electrical impulse through the needle near a nerve to stimulate muscle contraction.[14] Studies were unable to demonstrate outcome differences.[85] Though it was hoped that nerve localization using nerve stimulation would decrease actual needle-to-nerve contact, reducing nerve injury, a randomized prospective trial comparing the two techniques was unable to determine a difference in postoperative neurologic symptoms.[69] An advantage of the development of the nerve stimulator was decreased reliance on patient feedback and, therefore, the ability to perform the technique on sedated or even anesthetized patients.

Ultrasound was next used to improve needle placement by means of a portable device in the operating room or holding area. Ultrasound allows visualization of anatomic structures, blood vessels, and nerves, as well as of the advancement of a needle and the distribution of local anesthetic.[60] With satisfactory visualization of target structures, this technique does not require patient feedback and can be used safely after the patient has been given sedation or even general anesthesia.[78] However, when target structures are deep, needle visualization can be difficult; in such cases, it is a standard of safety to engage patient feedback whenever possible. Several studies have demonstrated improved onset and decreased dosing requirements compared with traditional techniques.[76,107] A recent metaanalysis of 16 randomized controlled trials showed that ultrasound decreased the incidence of complete hemidiaphragmatic paresis and vascular punctures and was more likely to result in a successful brachial plexus block when compared with the nerve stimulation technique.[119] Despite these benefits, ultrasound-guided blocks do not appear to decrease the incidence of neurologic injury.[71,119] Certainly, this is an area in need of further study and review as we attempt to maximize results while minimizing risks of complications for our patients.

Continuous Peripheral Nerve Catheters

The use of continuous peripheral nerve catheters has gained favor both in the inpatient setting and the outpatient setting. As mentioned before, the advantages include time-extended, opioid-sparing, and site-specific analgesia with only minimal side effects.[12] Disadvantages include increased anesthesia performance time, dislodgement or malplacement of the catheter leading to ineffective analgesia, and infection.[56] Rarely, brachial plexus peripheral nerve catheters have led to epidural and even intrathecal blockade.[40,112] The incidence of brachial plexus catheter failure on postoperative day 1 is between 19% and 26%.[1] The rate of dislodgement is low (<5%) but is directly correlated with the length of time the catheter has been in place and the extent of upper extremity movement.[74] Though there appears to be a modest clinical benefit to the use of nerve-stimulating catheters over nonstimulating catheters to confirm tip placement, this advantage has been largely minimized by ultrasound guidance.[79] In contrast to epidural catheters, the choice of end-orifice versus multiple-orifice catheters in continuous peripheral nerve blocks does not affect analgesic quality.[35]

Once the patient is at home, peripheral nerve infusion pumps for ambulatory surgery patients are safe and effective for extending the duration of nerve blocks from hours to days. In a study of ambulatory patients comparing general anesthesia with single-shot interscalene nerve blocks with continuous interscalene blocks for 48 hours, during which time the patients went home, the catheter group had lower pain scores both at 48 hours and at 1 week.[95] Rare complications include respiratory compromise in proximal brachial plexus catheters (interscalene and supraclavicular blocks) due to ipsilateral diaphragmatic paralysis, technical problems involving the infusion pump leading to dosing inconsistency, infection due to the indwelling catheter, and catheter coiling leading to block failure or catheter retention.[56] Evidence supports the use of these catheters in children as well as adults.[45]

Minimum Effective Volume

In recent years, efforts to determine the minimum effective volume (MEV) of local anesthetic required to produce an adequate operative and postoperative anesthetic have been made in order to reduce the dose-dependent side effects and the risk of neurotoxicity and systemic absorption without sacrificing time to onset of block and overall duration of effective analgesia. These efforts have been helped enormously by the use of ultrasound. For the upper extremity, low local anesthetic volumes have been established for interscalene blocks and axillary blocks using ultrasound guidance. Although the absolute effect of type and concentration of local anesthetic on minimal volume is not yet elucidated, the MEV to elicit an interscalene blockade that is 90% to 95% successful ranges as low as less than 1 mL.[29,76] Reducing the anesthetic volume in interscalene blocks has the potential advantage of reducing the incidence of hemidiaphragmatic paresis.[92] For axillary blocks, the 90% to 95% MEV averages 1 to 2 mL per nerve.[30,42] On the contrary, the 90% to 95% MEV for supraclavicular and infraclavicular blocks averages above 30 mL.[108,109] We postulate that this discrepancy in the latter blocks may be related to increased variations in injection techniques and anatomy.

Elderly patients generally require lower local anesthetic volumes, an effect likely related to a decrease in the cross-sectional area of the brachial plexus as we age.[84] Similarly, diabetic patients are more likely to have a successful supraclavicular block than their nondiabetic counterparts for a given local anesthetic dose.[41] The authors postulate that this is due either to an increased sensitivity of diabetic nerve fibers to local anesthetic, inadvertent intraneural penetration due to decreased ability to elicit paresthesias, or a preexisting neuropathy leading to decreased sensation to surgical stimulation. Surprisingly, although associated with a higher performance difficulty, an increased body mass index does not necessitate an increased local anesthetic volume.[44,100]

In general, in the absence of additives, decreasing the dose of local anesthetic either by volume or concentration in the peripheral block results in a reduction of block duration and decreases the time until the patient first requires an analgesic.[36,99] Despite the advantage of decreasing dose-dependent complications and reducing neurotoxicity, our goal in establishing the MEV should always be juxtaposed with the surgical procedure, the patient's particular risk factors, and the expected postoperative pain. In the end, it is also important to remember that the MEV for any given block is heavily influenced by the practitioner and his or her ability to deposit local anesthetic optimally.

Specific Blocks

The goal of regional anesthesia for upper extremity surgery is to provide anesthesia in the localized area of surgery, taking into account other potential painful stimuli, including positioning and the application of a tourniquet. There are many different approaches to nerve blockade, all involving nerves encompassed in the brachial plexus and providing sensory and motor innervation to the upper extremity. The brachial plexus is formed by the ventral rami of C5-T1, occasionally with small contributions by C4 and T2 (Figure 1.1).

There are multiple approaches to blockade of the brachial plexus, beginning proximally with the interscalene approach and continuing distally with the supraclavicular, infraclavicular, axillary, and midhumeral approaches at the terminal branches. The uniting concept is the existence of a sheath encompassing the neurovascular bundle extending from the deep cervical fascia to slightly beyond the borders of the axilla.[32]

Interscalene Block

The interscalene block is the most proximal approach, performed as the brachial plexus courses in the groove between the anterior and middle scalene muscles, traditionally at the level of the cricoid cartilage (Figure 1.2).[117] This block is well suited for procedures of the shoulder, the lateral two thirds of the clavicle, and the proximal humerus. Advantages of this block include rapid and reliable blockade of the shoulder region, as well as relative ease of landmark palpation. Disadvantages of this block traditionally include incomplete coverage of the inferior trunk of the plexus; hence, insufficient anesthesia of the ulnar distribution makes it an unreliable block for forearm or hand procedures. The interscalene block commonly causes transient ipsilateral diaphragmatic paralysis and ipsilateral Horner syndrome because of the proximity of the phrenic nerve and the cervical sympathetic ganglion, respectively. Rare but serious complications include permanent phrenic nerve palsy and cervical epidural and total spinal blockade.[68]

Supraclavicular Block

A supraclavicular approach to the brachial plexus provides profound anesthesia for the entire arm, making it an appropriate block for most upper extremity procedures. Past approaches have used surface landmarks, generally lateral to the lateral border of the sternocleidomastoid muscle and superior to the clavicle, considering the first rib as the safety margin for the cupola of the lung.[63] Proximity to the brachial plexus was

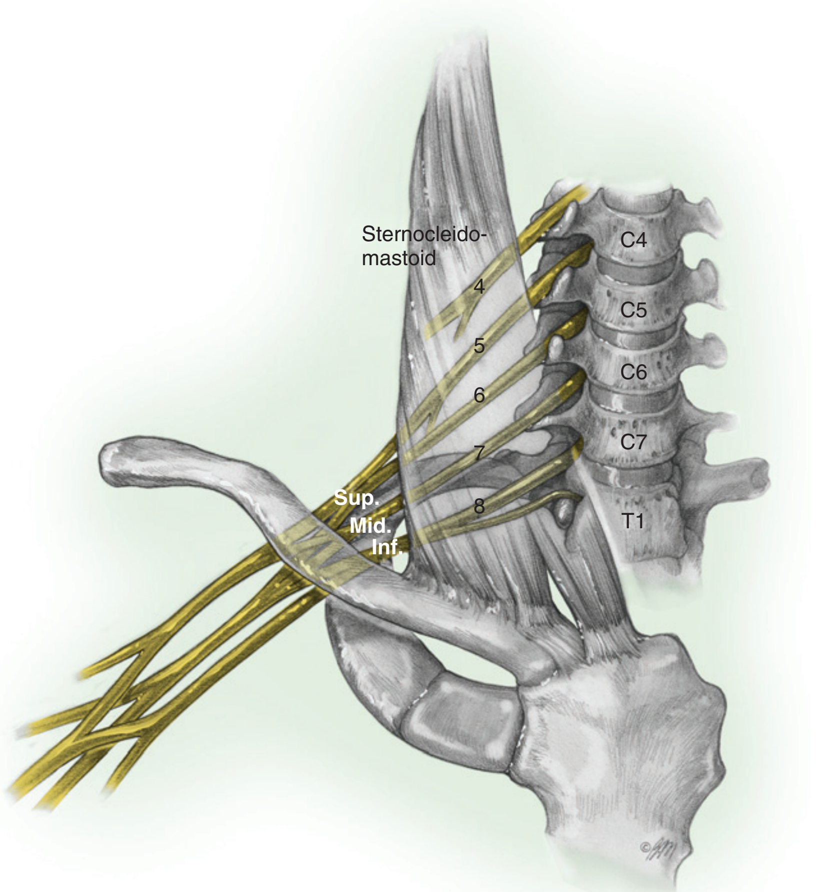

FIGURE 1.1 Brachial plexus, showing the relationship of the roots, trunks, divisions, and cords to bony landmarks. *Inf.*, Inferior; *Mid.*, middle; *Sup.*, superior. (Copyright Elizabeth Martin.)

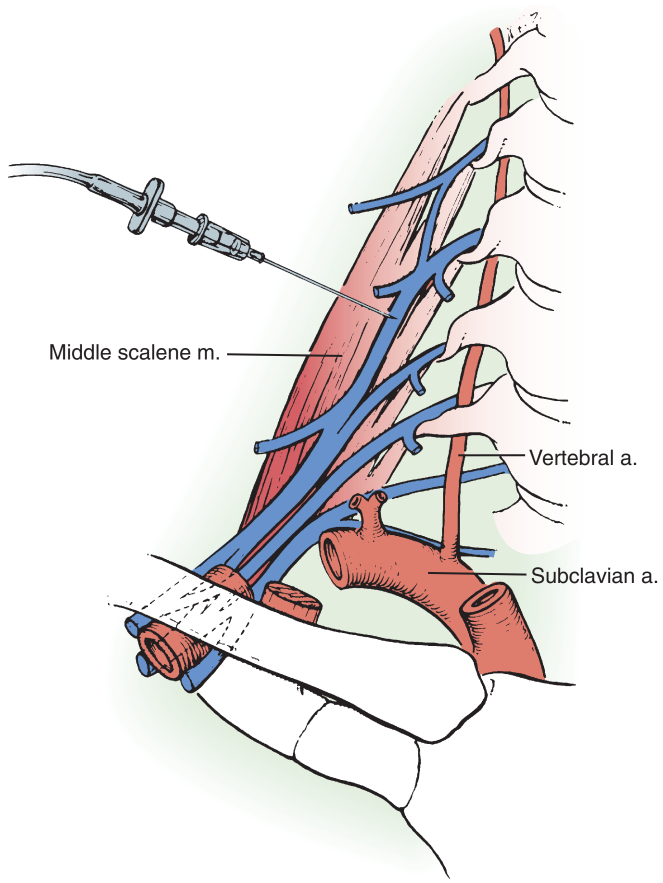

FIGURE 1.2 Interscalene technique. (From Winnie AP: Regional anesthesia. *Surg Clin North Am* 55:861–892, 1975.)

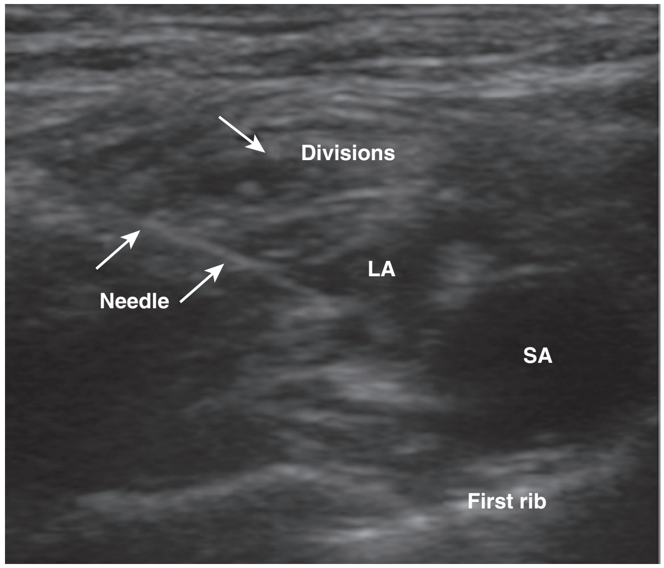

FIGURE 1.3 Ultrasound-guided supraclavicular nerve block. The brachial plexus is approached at the level of the divisions; the needle is entering the view from the lateral aspect at the top left of the screen. The pulsations of the subclavian artery (*SA*) are visualized, as is the spread of local anesthetic (*LA*).

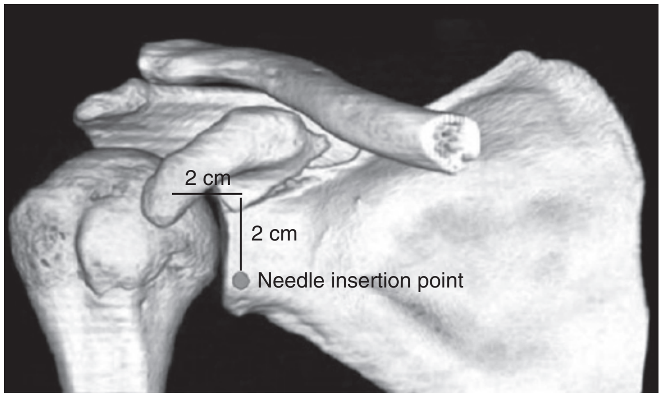

FIGURE 1.4 Landmarks for infraclavicular block.

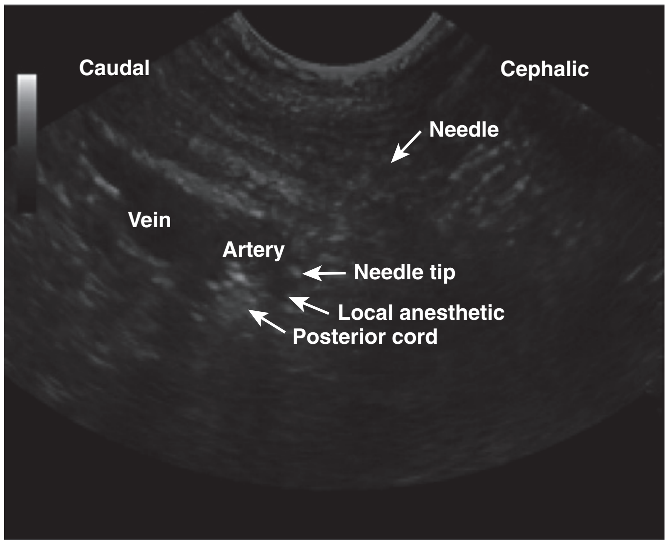

FIGURE 1.5 Ultrasound-guided infraclavicular nerve block; note the perivascular spread of local anesthetic.

determined using either paresthesia or nerve stimulator techniques.[34] Concern regarding the risk for pneumothorax with traditional techniques (estimated at 1% to 4%) led to the development of an ultrasound-guided technique for supraclavicular brachial plexus blockade (Figure 1.3).[60,116] Ultrasound guidance allows the practitioner to visualize the first rib and the border of the pleura, thereby being able to watch the approach of the needle to help ensure an appropriate distance from these vulnerable structures.[102] Advantages include a compact formation of the plexus at this level and resultant dense blockade of the entire upper extremity. Disadvantages include the remote risk of pneumothorax, suprascapular nerve palsy,[26] and potential for slower block onset.

Infraclavicular Block

The infraclavicular (or coracoid) approach is more distal still, at the level of the cords as they course circumferentially around the subclavian artery, providing dense anesthesia to the entire arm to the fingers. This block does not adequately anesthetize the shoulder but has become the block of choice at our institution for elbow, wrist, and hand surgery. Initial techniques of the infraclavicular block based needle placement on anatomic landmarks and nerve localization with a nerve stimulator,[91] but more recent approaches favor an ultrasound approach (Figures 1.4 and 1.5).[97] The consistent anatomic relationship between the cords and the vascular structures makes it a predictable and reliable block to perform under ultrasound guidance. The lower anatomic location of this block makes it unlikely to encounter phrenic blockade and therefore makes it a more appropriate block for bilateral procedures. Disadvantages include pneumothorax, a risk minimized by performing the block more laterally along the clavicle,[11] and the concern that if the subclavian artery is accidentally punctured in the infraclavicular approach, subsequent compression of the area to tamponade bleeding is difficult.

Axillary Block

The axillary block, the most distal of the brachial plexus blocks before the nerves leave the sheath and divide into their terminal branches, is perhaps one of the oldest and most traditional regional blocks for hand and wrist surgery. Various guidance techniques are described, including ultrasound, anatomic (either transarterial or paresthesia), or nerve stimulator techniques. All begin with palpation of the axillary nerve in the apex of the axilla, with consideration of the reliable anatomic relationship of the nerves to this arterial landmark (Figure 1.6). Because the musculocutaneous nerve frequently leaves the sheath proximal to the intended insertion point of this block, frequently a supplemental injection into the body of the coracobrachialis muscle is needed, especially if a forearm tourniquet is planned. This can be done easily with a blind technique as well as with ultrasound guidance, as the nerve is commonly found in the fascial plane between the coracobrachialis muscle and the biceps. A 2013 Cochrane Database Review showed that a multiple-injection technique led to more effective anesthesia than a single- or double-injection technique; however, no difference in other outcomes could be found.[16] Major risks for this block are largely related to the close proximity of the axillary artery. Risks for minor bruising and tenderness run higher with transarterial techniques, although the risk of hematoma is lower, reported from 0.2%[104] to 8%.[62] Another concern relating to the high vascularity of this area is local anesthetic toxicity related to either intraarterial injection or rapid systemic absorption after injection near an arterial puncture. Rates of systemic toxicity are around 0.2%.[104] Although the end results of these incidental complications were minor and without lasting effect, at our institution the axillary approach to the brachial plexus has largely been replaced by the ultrasound-guided infraclavicular block because of the latter's reliability and low incidence of side effects and the availability of ultrasound at our facility. At other institutions, the axillary plexus block is widely used as the preferred technique for lower arm procedures.

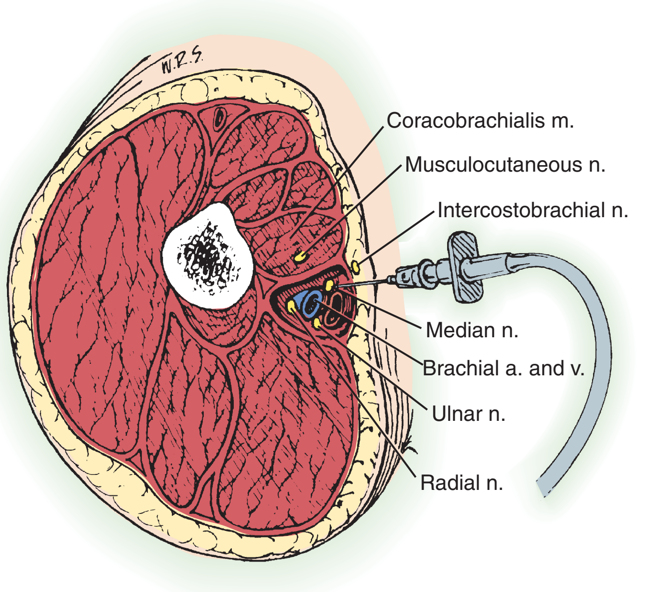

FIGURE 1.6 Cross-sectional view of the axillary nerve block. (From Winnie AP: Regional anesthesia. *Surg Clin North Am* 55:861–892, 1975.)

Supplementary Blocks

Elbow Block

The intercostobrachial nerve arises from T1-T3 and travels superiorly to provide cutaneous sensory innervation to the medial and posterior upper arm.[82] Because this innervation is not part of the brachial plexus, additional blockade in the form of a field block is used for surgery around the medial aspect of the elbow. Subcutaneous distribution of 5 to 10 mL of local anesthetic along the distal portion of the axillary crease will effectively anesthetize this cutaneous distribution.

Blocks around the elbow are rarely performed as a primary technique because the overlap and variation of nerve distribution would necessitate multiple injections in order to obtain anesthesia of a given area. Blocks around the elbow are mainly used to supplement incomplete brachial plexus nerve blockade. While blocks are often performed blindly using bony landmarks, it is also possible to perform blocks based on eliciting paresthesias or nerve stimulation. The median, radial, and ulnar nerves are individually visualized using ultrasound as they course from the elbow to the wrist.[75]

The median nerve may be blocked as it courses posteromedial to the brachial artery superior to the antecubital crease. The nerve is typically blocked using 5 to 10 mL of local anesthetic injected slightly superior to a line connecting the epicondyles. This block can be accomplished using a blind, landmark-based technique, by eliciting paresthesias, or by using a nerve stimulator.

The radial nerve can be blocked 3 to 4 cm above the lateral epicondyle, close to the distal head of the humerus. After the lateral intramuscular septum has been pierced, paresthesias or a nerve stimulator can be used to localize the nerve. An injection of 5 to 10 mL of local anesthetic will provide an adequate nerve block in this location.

The ulnar nerve is largely missed in interscalene blocks, so supplementation is often necessary to obtain complete anesthesia of the arm. The nerve is usually blocked as it runs behind the medial epicondyle. Injection of 3 to 5 mL of local anesthetic is made between the olecranon and the medial epicondyle. Caution must be used to avoid compressing the nerve, because it runs near the bony landmarks.[94]

Wrist Block

Hand surgeons frequently use wrist blocks to produce anesthesia for surgery or supplement plexus nerve blocks. Wrist blocks are relatively simple and reliable to perform based on external landmarks. The nerve supply of the extrinsic muscles of the hand is preserved, thus allowing the patient to move the fingers of the hand, but the intrinsic muscles are paralyzed. Whereas

FIGURE 1.7 Surface anatomy for median nerve block at the wrist. (Reproduced with permission from Chung KC, editor: *Operative Techniques: Hand and Wrist Surgery*, Philadelphia, 2008, Saunders, p 5.)

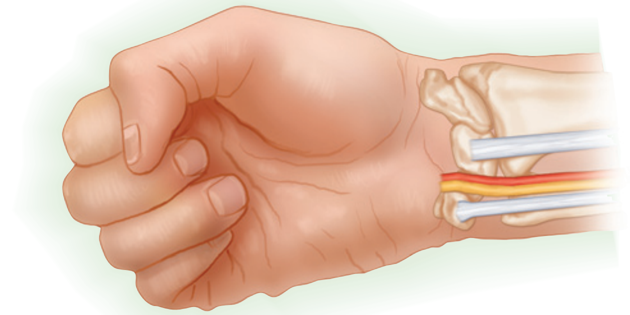

FIGURE 1.8 Surface anatomy for ulnar nerve block at the wrist. (Reproduced with permission from Chung KC, editor: *Operative Techniques: Hand and Wrist Surgery*, Philadelphia, 2008, Saunders, p 6.)

this can be an advantage in a cooperative patient, it is a potential disadvantage and distraction in an uncooperative patient. Additionally, the need for a forearm tourniquet limits the duration of surgery to 20 to 30 minutes in most instances. These blocks are especially efficacious for carpal tunnel release.[23,110]

The median nerve can be blocked as it courses between the palmaris longus and flexor carpi radialis tendons (Figure 1.7). A 1.5-cm, 25-gauge needle is inserted at the level of the ulnar styloid process or the proximal crease of the wrist. In the absence of the palmaris longus tendon, the needle is inserted on the ulnar side of the flexor carpi radialis tendon. After penetration through the flexor retinaculum at a depth of approximately 1 cm, 5 mL of local anesthetic is injected. Injecting 1 mL of local anesthetic above the retinaculum as the needle is withdrawn can block a superficial palmar branch supplying the skin over the thenar eminence.[21,94]

The ulnar nerve is blocked at the wrist at either the radial or the ulnar side of the flexor carpi ulnaris tendon (Figure 1.8). The ulnar approach is preferred so as to avoid intravascular injection, given the location of the ulnar artery on the radial side of the tendon. At the level of the distal ulna, the needle is introduced on the dorsal ulnar side of the flexor carpi ulnaris. Subsequent injection of 5 mL of local anesthetic under the flexor carpi ulnaris will result in anesthesia of this distribution. Additional subcutaneous infiltration of the dorsal ulnar area of the wrist ensures adequate blockade of the dorsal cutaneous branch of the ulnar nerve.[21]

The radial nerve is superficial and divided into branches running in the subcutaneous fat at the level of the radial styloid process (Figure 1.9). It may be blocked using 5 to 10 mL of local

FIGURE 1.9 Surface anatomy for radial nerve block at the wrist. (Reproduced with permission from Chung KC, editor: *Operative Techniques: Hand and Wrist Surgery*. Philadelphia, 2008, Saunders, p 7).

anesthetic injected in a subcutaneous field block at the level of the radial styloid. Initial injection is made using 2 to 3 mL of local anesthetic just lateral to the radial artery at the level of the proximal wrist crease. The needle is then redirected and advanced with subcutaneous injection of 5 to 7 mL of local anesthetic across the proximal border of the snuffbox to the midpoint of the dorsal wrist. Several injections may be necessary to follow the curvature of the wrist and block the many superficial branches.[94]

Digital Block

As the most distal innervation of the hand, four nerve branches—two dorsal and two volar—run along the sides of each digit to supply each digit (Figure 1.10). There are three main recommended approaches for performing digital nerve block—transthecal, transmetacarpal, and subcutaneous. A circumferential ring block along the base of the digit is not recommended because the subsequent pressure can result in gangrene.

Transthecal digital nerve block uses the flexor tendon sheath for anesthetic infusion. At the level of the palmar digital crease, the needle enters the flexor tendon sheath until bony contact is made (Figure 1.11). The needle is then withdrawn slowly until the local anesthetic solution is injected easily into the potential space between the periosteum and the flexor tendon. Two milliliters of local anesthetic is used for digital anesthesia. Advantages of this approach include a single injection and rapid onset[52]; however, patients often complain of prolonged discomfort in the finger after this technique.[73]

Transmetacarpal block is performed at the level of the distal palmar crease. The insertion site is approximately 1 cm proximal to the metacarpophalangeal joint, traditionally on the volar side of the hand (Figure 1.12), though some favor entering the thinner dorsal side for patient comfort. Two milliliters of local anesthetic injected on one side of the metacarpal neck effectively anesthetizes the common digital nerve supplying the finger.[98]

Subcutaneous digital nerve block is accomplished at the level of the distal palmar crease. The needle is inserted vertically into each side of the flexor tendon sheath, and 2 mL of local

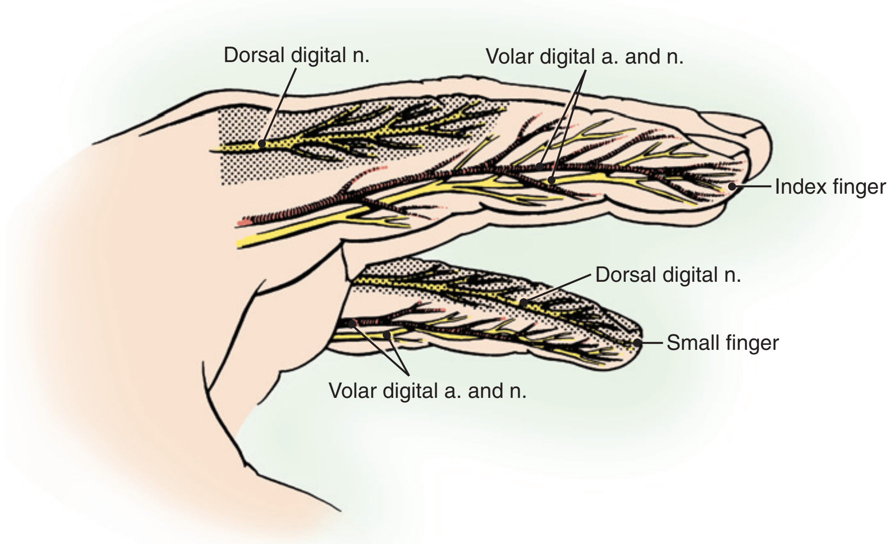

FIGURE 1.10 Relationship and distribution of the digital nerves. Note that in the small finger, the dorsal digital nerve extends to the top of the digit; in the median nerve distribution, the volar nerve supplies the dorsum of the digit distal to the proximal interphalangeal joint. (Copyright Elizabeth Martin.)

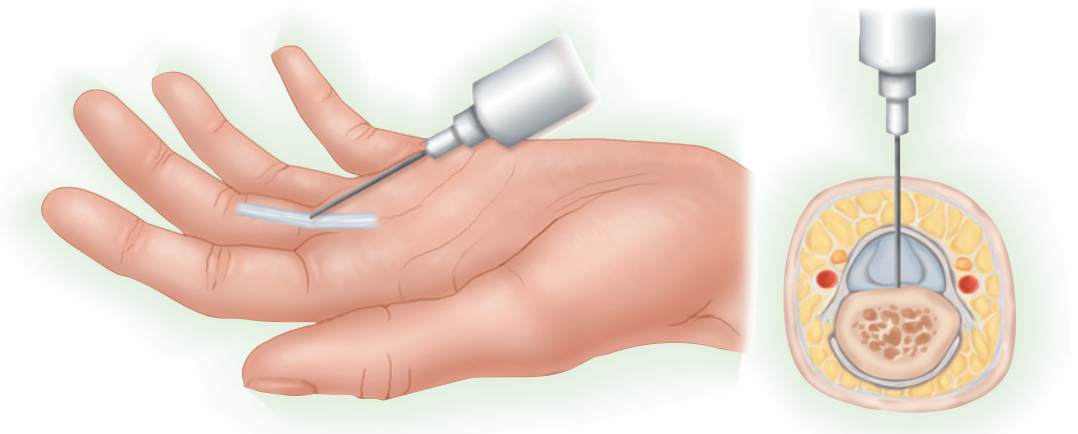

FIGURE 1.11 Transthecal digital nerve block. (Reproduced with permission from Chung KC, editor: *Operative Techniques: Hand and Wrist Surgery*. Philadelphia, 2008, Saunders, p 13.)

anesthetic is injected at each location (Figure 1.13). Alternatively, injection can be made just proximal to the web of the finger using a 1.5-cm, 25-gauge needle, creating a skin wheal superficial to the extensor hood to block the dorsal nerve. The needle is then advanced toward the palm and an additional 1-mL injection is made just under the skin on the volar side to anesthetize the volar digital nerve. The needle is then withdrawn to the skin and redirected toward the opposite side of the finger to place a superficial skin wheal, and the process is repeated on that side. Care must be taken to use small volumes of local anesthetic to avoid creating a circumferential ring. In recent years, clinicians have moved away from the traditional two injections method to a single injection method due to improved patient comfort. With this technique, 2 to 3 mL of local anesthetic are deposited into the subcutaneous space at the middle point of the palmar digital crease.

Use of Epinephrine in Digital Nerve Blockade. Long-standing debate has taken place about the use of epinephrine in digital nerve blocks because of concern regarding vasoconstriction to the digit and subsequent ischemia and necrosis. Several studies and reviews have addressed this issue; Chowdhry and colleagues published a retrospective review in 2010 that reported no adverse events involving digital gangrene in 1111 patients.[19] The authors concluded that the use of local anesthetic with the addition of epinephrine was safe in digital nerve blockade, enabling improved hemostasis and decreasing the need for tourniquet placement.[19]

Intravenous Regional Block

Intravenous regional block, or Bier block, was one of the first techniques of regional blockade, introduced in 1908.[20] Bier block can be used for brief surgical procedures or manipulation of the distal upper extremity. Advantages of this technique include ease of use and rapid onset of anesthesia; disadvantages include the necessity of using a pneumatic tourniquet and the lack of postoperative analgesia.

This technique involves placement of an IV catheter in the dorsum of the hand, followed by exsanguination of the upper

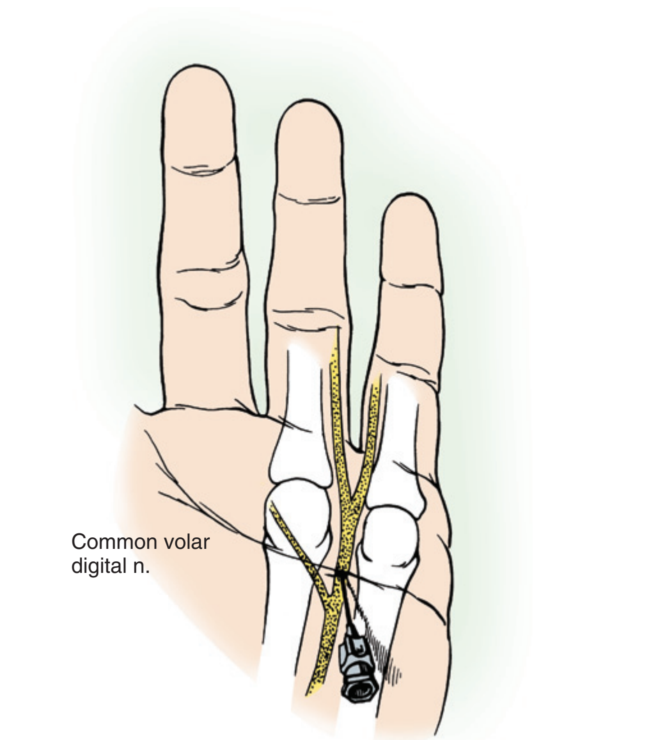

FIGURE 1.12 Transmetacarpal digital nerve block. (Copyright Elizabeth Martin.)

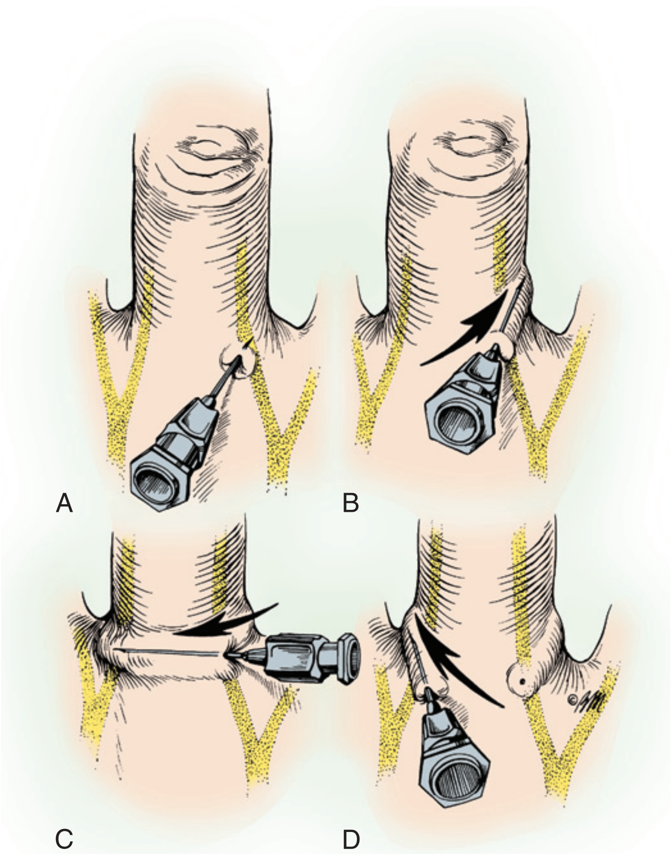

FIGURE 1.13 Subcutaneous digital nerve block. **A,** The needle is inserted along one side of the flexor tendon sheath to block the volar nerve **(B)**. **C,** The dorsal digital nerve is anesthetized with a superficial skin wheal. **D,** The opposite volar nerve is blocked using the same technique. Care is taken to ensure that local anesthetic is not injected fully circumferentially around the finger. (Copyright Elizabeth Martin.)

extremity and inflation of a pneumatic tourniquet. Subsequent injection of local anesthetic into the venous system by means of the IV catheter results in rapid and profound sensory blockade. Plain lidocaine 0.5% in a dose of 3 mg/kg is the typical agent of choice, which results in a volume of 40 mL for the average adult.[20] Other agents such as prilocaine may be used instead[43]; however, bupivacaine is contraindicated in Bier block because of potential cardiac toxicity. While not well studied, additives such as acetaminophen, magnesium, narcotics, and vecuronium have been used in an effort to increase onset and efficacy of the Bier block while reducing the total local anesthetic volume needed to achieve adequate anesthesia.[77]

Contraindications include crush injuries or compound fractures in which the venous system may be interrupted or the extremity difficult to exsanguinate. Bier block is also contraindicated in patients in whom tourniquet use is contraindicated, in patients with local skin infections or cellulitis, or in those with a convincing allergy to local anesthetics. Another limitation to the use of a Bier block is duration of tourniquet application; patients tend to complain of tourniquet pain after 30 minutes. Adding a second distal tourniquet allows prolongation of the block; after tourniquet pain is experienced with the proximal tourniquet, the distal tourniquet is inflated. By using this double-tourniquet technique, the tourniquet time is prolonged up to 1 hour.[86]

Complications associated with Bier block are mainly related to drug effects of the local anesthetic, especially if there is mechanical tourniquet failure leading to early deflation of the cuff. It is recommended that the cuff stay inflated for 20 to 30 minutes after injection in order to minimize local anesthetic effects, particularly on the cardiovascular and respiratory systems.[43] Using incremental deflation, inflation, and deflation again allows for gradual release of the local anesthetic from the isolated limb. Additional complications can arise from the use of the pneumatic tourniquet, including but not limited to ischemic and mechanical crush injuries.

❖ AUTHOR'S PREFERRED METHOD OF TREATMENT: Regional Anesthesia

For surgery of the upper extremity, regional anesthesia is our standard method. Regional anesthesia is associated with decreased morbidity and shorter stays in the postanesthesia care unit.[46,57,95,101]

Our preferred blocks for regional anesthesia of the upper extremity are ultrasound-guided supraclavicular and infraclavicular blocks. They are often faster to perform in less experienced hands, have a faster onset, and allow smaller anesthetic volumes to be used.[76,106,107] Each year nearly 5000 supraclavicular and infraclavicular blocks are performed at our institution. Of these 5000, all but a few are done with ultrasound guidance. This method has proven to be very safe, rapid, and highly successful at anesthetizing the upper extremity.

The type of ultrasound-guided block chosen depends on the surgery involved. For surgery from the shoulder to the elbow and occasionally from the elbow to the hand, the block of choice at our institution is the ultrasound-guided supraclavicular block. For surgery on the more distal upper extremity, the block of choice is most frequently the ultrasound-guided infraclavicular block.

The technique for perivascular blocks involves an in-plane view of the needle at its point of entry just under the skin to its location near the plexus. The needle choice is probably less critical, although we use short-bevel, noninsulated needles, which are more echogenic. In placing the block, our goal is to keep needle movement to a minimum, thereby decreasing the chance for needle-to-nerve trauma. For the supraclavicular block, the needle is placed just inferoposterolateral to the plexus, as in “eight ball in the corner pocket” (see Figure 1.3).[102] The preferred position of the infraclavicular block is the 6 o’clock location relative to the subclavian artery (see Figure 1.4). The goal is to get close to the nerve (plexus or cord) without actually coming into contact with it. Once the fascial plane adjacent to the nerve is reached, a small amount of local anesthetic is injected. The anesthetic will hydrodissect the area and demonstrate local filling in the desired location of the nerve. Again, needle movement is kept to a minimum while injecting the full dose of local anesthetic. We find these locations to be reliable in accomplishing whole-plexus blocks while minimizing needle-to-nerve contact and trauma.

Complications

Neurapraxia (Box 1.3)

Incidence. Temporary postoperative paresthesia, or temporary sensory or motor deficit, is relatively uncommon. Injury can result from needle trauma, local anesthetic irritation, patient positioning, tourniquet compression, or surgical manipulation, to name a few of the confounding variables. Studies attempting to elucidate the relationship between neural anatomy and nerve injury, mainly correlating epineural and intraneural injections with neurologic sequelae, have been largely inconclusive.[17] The majority of these postoperative neuropathies resolve by 4 weeks, and the incidence of prolonged or permanent neurologic deficit is exceedingly rare. Certain patient risk factors have been identified that may increase the risk of neurologic injury after peripheral nerve blockade. These include old age, the use of chemotherapy, and the presence of diabetes mellitus, cervical myelopathy, multiple sclerosis, vascular disease, and any other preexisting neuropathies.[6] A review of recent literature shows the incidence of temporary neurologic complications after peripheral regional anesthesia to be 3% to 8% and of permanent nerve injury as defined by the presence of symptoms after 6 months to be between 0.04% and 0.6%.[7,37] Interestingly, the use of ultrasound guidance rather than the nerve-stimulator technique has not led to a decrease in the incidence of neurologic complications after peripheral nerve blockade.[7,37,80]

Management (Figure 1.14)***.*** It is often the surgeon who discovers the existence of residual neurapraxia postoperatively. Management of the patient’s concerns and the suspected injury requires thorough communication between the surgeon, anesthesiologist, and patient. A thorough history and physical examination are needed to determine the duration and types of symptoms and the vascular integrity, dermatomal distribution, and correlated motor or sensory deficit. It is important to investigate other confounding factors such as postoperative pain, immobility, edema, positioning, and casting or dressings.

We recommend dividing the findings into minor or major deficits. Minor deficits include positional paresthesias, defined as changes in temperature or light touch sensation without loss of motor function. Sometimes a burning sensation in a dermatomal distribution is present. For minor deficits, reassurance that the deficit will likely resolve in a few weeks will likely allay the patient’s anxiety. It is important to closely follow the patient to ensure resolution of symptoms, provide reassurance, and allow early detection of a more serious problem or the need for referral to a neurologist.

Major deficits, such as complete or nearly complete palsy, should prompt early neurologic or neurosurgical consultation, which may be able to guide further diagnostic testing and treatment. If compression is suspected, ultrasound or magnetic resonance imaging should be performed to localize the lesion, followed by prompt surgical decompression.[6] Pain medication should be provided to prevent nerve sensitization and the potential for a complex regional pain syndrome. Nerve conduction studies (NCSs) can detect the presence of a lesion in myelinated nerves. However, because the nerves that transmit pain sensation are mostly unmyelinated nerves, NCSs are inconclusive when the only symptom is pain. A decrease in conduction velocity indicates myelin damage, whereas a decrease in amplitude indicates axonal damage. NCSs can show a lesion 1 to 2 days after injury. If the initial NCS is normal, the patient likely has a neurapraxia that should resolve with time and should be followed clinically, with the NCS repeated if symptoms persist or worsen. If the initial NCS is abnormal, electromyography (EMG) is indicated to find the exact anatomic location of the injury within the plexus. Because EMG changes appear 2 to 4 weeks following injury, many centers choose to perform an initial EMG at the same time as the NCS to obtain a baseline of preexisting nerve damage. Ideally, EMG should then be performed 2 to 4 weeks after injury because delaying it beyond 4 weeks may complicate the picture owing to reinnervation. EMG analysis will indicate the location of the nerve injury and may be able to pinpoint the likely cause.[48]

Allergy and Sepsis

Local anesthetics are categorized into two groups, esters and amides, based on their chemical structure. Esters are rapidly metabolized by plasma pseudocholinesterase, while amides are metabolized intracellularly by the liver. True allergic responses to local anesthetics are rare,[8,10] and often a history of a tachycardic response to added epinephrine can be elicited. True allergies are more likely to be due to the ester group, although some patients have a history of allergy to the preservative methylparaben, which is added to multidose vials of amide anesthetic. There is no evidence for cross-reactivity between the two groups, attributable to the different chemical structures.

Any injection through the skin raises concerns for infection, and regional nerve blockade is no exception. Aseptic technique is recommended, including thorough hand washing and skin

BOX 1.3 Neurologic Complications

- Neurologic complications can occur after regional or general anesthesia.
- Use of ultrasound does not appear to minimize this risk.
- The mechanisms of injury are sometimes obscure.
- With appropriate precautions the frequency of nerve injury after nerve blocks is quite low.

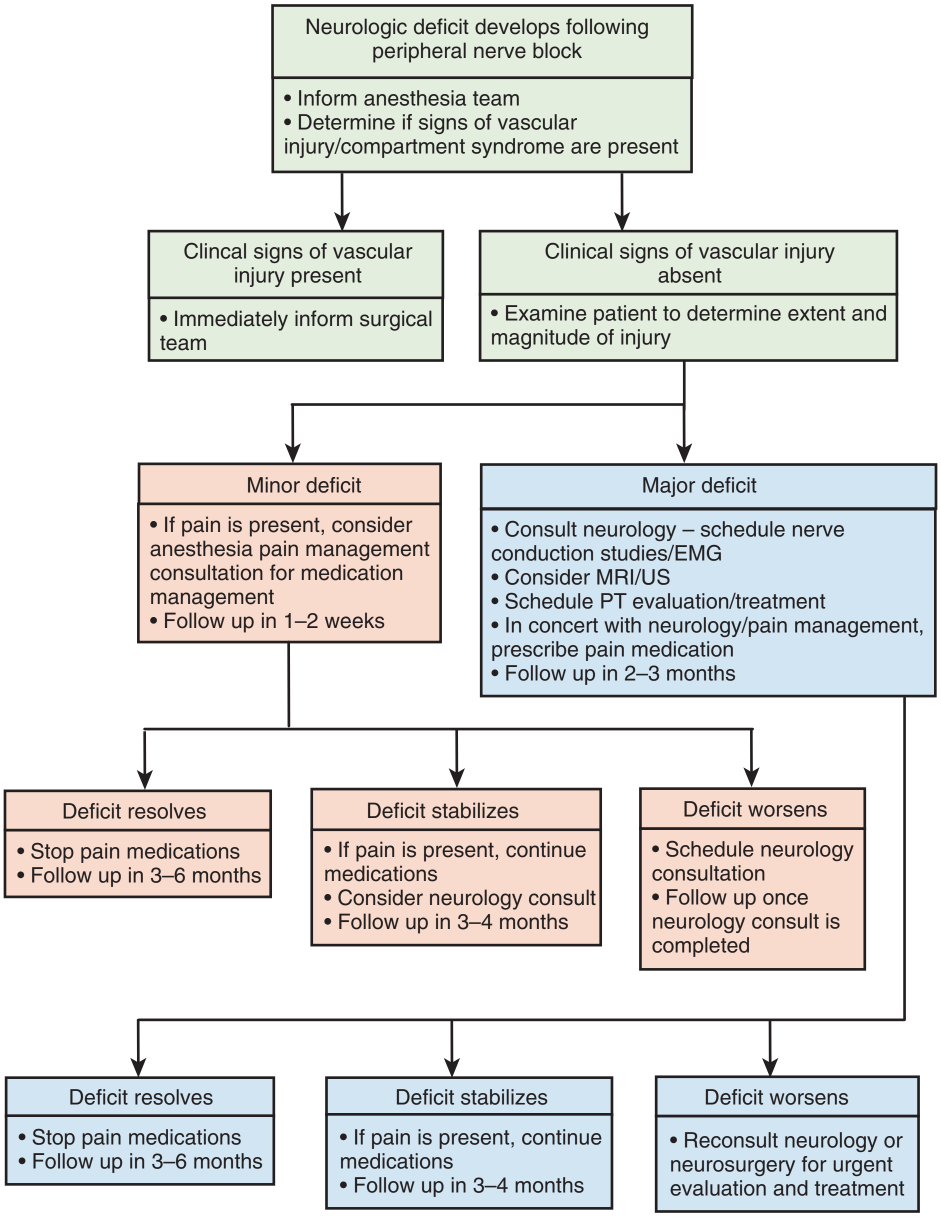

FIGURE 1.14 Management of neurologic deficit following peripheral nerve block. (Reproduced and modified with permission from Hadzic A, editor: *Textbook of Regional Anesthesia and Acute Pain Management*, New York, 2007, McGraw-Hill, p 989.)

cleansing with either povidone-iodine solution or chlorhexidine.[51] The rate of infection is exceptionally low for single-shot techniques, though sporadic case reports can be found in the literature. It is established that indwelling catheters have the potential for colonization; however, the rate of clinical infection, which positively correlates with catheter duration, is negligible.[51]

CRITICAL POINTS *Regional Anesthesia*

- Regional anesthesia for upper extremity surgery may improve the control of postoperative pain, lower opiate consumption, decrease nausea and vomiting, and decrease the hospital stay.
- Among the regional anesthesia techniques of nerve stimulator–guided, paresthesia-guided, or ultrasound-guided nerve block, there is no demonstrated improvement in outcome with any particular technique. However, ultrasound-guided blocks have been shown to improve onset and decrease dosage requirements compared with traditional techniques.
- Absolute contraindications to regional anesthesia are infection at the site of injection and patient refusal. Patient refusal often stems from fear of the unknown, which can be dispelled with a forthright discussion and promise of adequate sedation prior to administering the block.
- The use of additives to local anesthetics can prolong block duration and analgesia while reducing overall local anesthetic dose, but agents should be chosen judiciously to avoid neurotoxicity.
- Continuous peripheral nerve catheters are safe and effective for extending opioid-sparing, site-specific analgesia for adult and pediatric patients in both the inpatient and outpatient settings.
- The incidence of temporary postoperative paresthesias is between 3% and 8%; of that number, most resolve within 4 weeks.
- Prolonged neurapraxias are extremely rare, with an incidence of between 0.04% and 0.6%. In the event of a neurapraxia, a coordinated effort between the anesthesiologist and surgeon is required, as well as thorough communication with the patient. Often, early neurologic consultation will help with further diagnosis and treatment.

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2

Acute Infections of the Hand

Milan V. Stevanovic and Frances Sharpe

GENERAL PRINCIPLES

Hippocrates' principles for the treatment of hand infections are fundamentally valid today. Wounds were kept clean with frequent changes of wine-soaked dressings. Dressings were kept loose "so as not to intercept the pus, but to allow it to flow away freely."[44] Coupled with these early principles is the pioneering work of Dr. Alan Kanavel, a Chicago general surgeon who treated hand infections in the preantibiotic era. Much of our current understanding of the pathogenesis and treatment of hand infections must be credited to his extensive dissections and innovative injection studies. Through these studies, he demonstrated the potential spaces of the hand and the pathogenesis of infection. From this data, he developed the surgical principles that remain the cornerstone of modern treatment of hand infections.[75]

Hand infections can result in severe disabilities, including stiffness, contracture, and amputation. These complications have been significantly reduced through the introduction of antibiotic therapy in conjunction with surgical treatment. Although antibiotics have dramatically reduced the morbidity associated with hand infections, their use does not supplant the need for expedient and proper surgical intervention. Several factors influence the outcome of hand infections. These include the location of the infection, infecting organism, timing of treatment, adequacy of surgical drainage, efficacy of antibiotics, and health status and immunocompetence of the host. In the words of one of the preeminent United States public health officials, Dr. Charles V. Chapin: "As it takes two to quarrel, so it takes two to make a disease, the microbe and the host."

Host factors play a determining role in the severity and duration of infection. Many medical conditions reduce host defenses. Malnutrition, alcoholism, autoimmune diseases, chronic corticosteroid use, hepatitis, and human immunodeficiency virus (HIV) infection are some of the comorbidities to be considered. The most prevalent disease with associated immunosuppression is diabetes mellitus, which affects up to 11% of the adult population of the United States.[140]

Early and superficial infections may respond to nonsurgical management. However, most acute infections of the hand represent surgical emergencies. Swelling and edema associated with an infection result in increased tissue pressure and can cause ischemia and tissue necrosis by a process resembling compartment syndrome.[139] Furthermore, toxins produced by the offending pathogen can cause vascular thrombosis and tissue death. Patients with necrotizing fasciitis and gas gangrene need *immediate* surgical care.

Types of Infections

Cellulitis is an infection of the subcutaneous tissue, which is often diffuse and can be associated with lymphangitis. It is caused by a single organism, usually *Staphylococcus aureus* or β-hemolytic *Streptococcus*. Lymphangitic streaking is more commonly seen with β-hemolytic streptococcal infections. It generally has a more distal nidus and spreads proximally. It is a non–pus-forming infection and as such is initially treated nonsurgically. If the cellulitis is not responding to intravenous therapy over 12 to 24 hours, this often suggests the formation of pus (*abscess*) and more serious infection. Even in the absence of abscess formation, cellulitis associated with significant swelling resolves more quickly with surgical decompression. Cellulitis often requires hospital admission and close monitoring for response to antibiotic therapy. A specific type of staphylococcal infection is the *staphylococcal scalded skin syndrome*, primarily a disease of young children that results from an exfoliative toxin-producing staphylococcal organism.[85,120] A high index of suspicion and early differentiation of this process from other skin conditions are important to treatment outcome. Although this syndrome is extremely rare in adults, it is associated with a high mortality rate, usually because of serious underlying illness, such as kidney failure or immunosuppression.[120] Detection of the exfoliative toxin is required for diagnosis. New immunologic methods allow for more rapid detection.[81] Prompt antibiotic therapy and local wound care are the mainstays of management. *Necrotizing fasciitis* is a serious life-threatening infection that may initially resemble cellulitis. Although purulence is not present, a watery discharge often described as "dishwater-like fluid" may be seen superficial to the fascia. Most other hand infections are generally pus forming and are discussed in detail throughout the chapter.

The most common infecting organisms are *Staphylococcus* and *Streptococcus* species, with staphylococcal organisms predominating. Many infections, especially those associated with bite wounds, those associated with gross contamination, or those seen in diabetics, are often caused by mixed species. *Pasteurella multocida* should be considered in most animal bites, and both streptococcal species and *Eikenella corrodens* should be considered in human bite wounds. Anaerobic infection is less common but should be considered more frequently in diabetics or intravenous drug users. Empirical antibiotic therapy should be tailored toward the most likely offending pathogen. The local prevalence of antibiotic-resistant organisms should be considered when starting empirical treatment. An infectious disease specialist is valuable in patient management because he or she is most familiar with the hospital-specific patterns of antibiotic resistance, can direct antibiotic therapy, and can follow outpatient intravenous therapy.

Methicillin-Resistant *Staphylococcus aureus* Infections

The increasing incidence of infection with methicillin-resistant *S. aureus* (MRSA) has been recognized throughout the surgical as well as infectious disease literature. A strain of *S. aureus* resistant to methicillin was mentioned in reports from the United Kingdom in 1961. This strain was soon identified worldwide and was associated with hospital-acquired infections (HA-MRSA).[113] Only a handful of successful HA-MRSA clones are responsible for the majority of infections, and different clones dominate in different geographic locations.[87] However, MRSA infections have been increasingly identified as community-acquired infections (CA-MRSA). There are unique microbiologic and genetic properties distinguishing the hospital-acquired and community-acquired strains. A community-acquired infection is defined as occurring in patients with MRSA identified by culture who have no history of a hospital or medical facility stay within the past year, who have no history of dialysis or surgery occurring within the past year, and in whom no indwelling catheters are present.

CA-MRSA is now the predominant strain in hand infections, found in up to 60% of *S. aureus* infections.[20,25,72,114] The majority of CA-MRSA infections in the United States have been caused by a single clone (USA300). One of the distinguishing features in CA-MRSA is the frequent gene sequence encoding for Panton-Valentine leukocidin (PVL), a potent toxin that leads to the characteristic tissue necrosis commonly seen in the clinical setting.

MRSA infections frequently have a characteristic appearance of a dermonecrotic skin lesion (Figure 2.1). They are often mislabeled as "spider bites" due to their dermonecrotic appearance and may not receive appropriate antibiotic therapy.[160] More recently, we have not seen the extensive tissue necrosis with MRSA infections that we have in the past. Empirical treatment of hand infections has also changed to address potential MRSA infections.[25,41,70,116] Successful treatment requires surgical débridement with excision of necrotic tissue in conjunction with appropriate antibiotic therapy.

Nosocomial Infections

The hand is a very well-vascularized region, making it less vulnerable to postoperative infection than other anatomic sites. *S. aureus* is the most common pathogen in clean surgical procedures.[21,46,141] The use of perioperative intravenous antibiotics within 1 hour preceding surgery has greatly reduced the incidence of postsurgical infections in general orthopedic practice.[27] However, the role of perioperative antibiotics in elective

FIGURE 2.1 Characteristic appearance of MRSA infection with central skin necrosis and surrounding erythema. Purulence is not always present. Soft tissue necrosis is often more extensive than would be expected from a localized infection. (Copyright courtesy of Milan Stevanovic and Frances Sharpe.)

hand surgery is less clear. Several studies suggest that for soft tissue procedures of less than 2 hours' duration, the routine use of prophylactic antibiotics is not indicated.[19,40,64,128,154] Ultimately, the whole patient must be considered. Prophylactic antibiotics in patients with joint arthroplasties are recommended to protect the prosthesis more than to prevent surgical site infection. Patients with an altered immune response may have a potentially greater benefit from prophylactic antibiotics than an immunocompetent host. For surgical procedures that involve exposure of the bone or joint or those involving implants, we routinely give intravenous prophylaxis.*

Patient Evaluation

Clinical examination remains the hallmark of diagnosis in hand infections. Pain (dolor), and increased temperature (calor), with or without erythema (rubor), and tenderness remain the prime features of hand infection. Temperature elevation is inconsistent. Abnormalities of the white blood cell (WBC) count and C-reactive protein (CRP) level are uncommon features of a hand infection. In one study, these were normal in

*Editor's note (DPG): I strongly disagree with the practice of giving "prophylactic" antibiotics for all clean bone and joint cases in the wrist and hand. This is not only unnecessary but harmful in the long term, creating superresistant bacteria. In my practice, I do not administer perioperative antibiotics in clean, elective cases unless there is a specific indication to do so. Unfortunately, many orthopedic surgeons give antibiotics indiscriminately purely as a defensive measure, fearing that if the patient does get an infection and no antibiotics were given, a plaintiff's attorney will cite this as inappropriate care. In addition, many hospital policies now require the routine administration of preoperative antibiotics.

75% of patients. The erythrocyte sedimentation rate (ESR) was slightly more useful, with elevation of the ESR found in 50% of patients.[68]

The initial evaluation and management in the emergency department should include a thorough medical history, assessment of risk factors for immunocompromise, and evaluation of tetanus immunization status. Appropriate tetanus prophylaxis should be administered based on immunization history and time of the last booster shot. Tetanus immune globulin (TIG; HyperTET®) and tetanus toxoid booster are given if the patient has not had a series of tetanus immunizations. Clinical evaluation of the affected extremity should include examination for fluctuance, warmth, edema, redness, tenderness, and lymphangitis or lymphadenopathy. Areas of cellulitis should be marked on the skin so that progression or regression of the infectious process can be monitored; if an open draining wound is present, a specimen should be sent for aerobic and anaerobic culture. Blood cultures should be taken in febrile patients. Blood should be drawn for a complete blood cell count (CBC), ESR, CRP, electrolytes, and random blood glucose measurements. Hand infection may be the first presenting complaint of undiagnosed diabetes. Radiographs are obtained to evaluate for the presence of a foreign body, gas within the soft tissues, underlying fracture, septic joint, or osteomyelitis.

When a patient presents with an area of fluctuance, this should be provisionally treated with aspiration or decompression until formal surgical débridement is performed. The fluid should be sent for culture. For patients who do not clearly have an abscess, aspiration may be useful to identify a deep pyogenic infection. Swollen painful joints should be aspirated with caution. The site of aspiration should not be over an area of cellulitis, so as not to seed the joint with bacteria. The aspirated fluid should be sent for culture. Joint fluid analysis with cell count, glucose, and protein levels can be obtained if an adequate specimen is available. If the joint aspirate is not clearly pyogenic and there are not other indicators of infection, antibiotics are withheld. Nonsteroidal antiinflammatory drugs (NSAIDs) may be given to both treat the patient and help distinguish between an inflammatory process and sepsis. If the presentation is suggestive of an inflammatory process, antibiotics are withheld while the response to NSAIDs is observed. When infection is suggested, empirical antibiotic therapy should be started in the emergency department after a culture specimen has been obtained.

Differentiating between an infectious process and an inflammatory process, especially pseudogout, can be difficult. The suspicion of one process over the other depends on many factors, including the patient's history, the presence of underlying diseases, and the clinical presentation. When to withhold antibiotic therapy can be a diagnostic challenge, and the use of antibiotics in some circumstances may be done more to treat the physician's anxiety than the patient's disease. Overnight observation in the hospital while antibiotics are withheld allows the disease process to be closely monitored and allows treatment to be changed if the anticipated improvement is not evident with NSAID therapy alone. When the level of suspicion for an infectious process is low, a corticosteroid dose pack (Medrol DosePak™) may be used. The patient is reevaluated in 24 to 48 hours. The importance of seeing the patient again within 48 hours cannot be overstated. If the process is noninfectious, the symptoms will be nearly resolved. It may take years to develop the clinical experience to recognize these different processes, and even the experienced eye can mistake these two conditions.

Patients with severe infections such as necrotizing fasciitis or gas gangrene or who are immunocompromised, including diabetics, should be immediately treated with broad-spectrum antibiotic therapy and emergent surgical intervention.

Treatment Principles

Surgical drainage should be done through a large incision. The incision should be planned so that it can be extended proximally or distally. Longitudinal incisions across a flexion crease should be avoided.

Excision of all necrotic tissue is imperative for infection control. In the 1800s, Louis Pasteur noted that it is the environment and not the bacterium that allows the propagation of infection. Cultures and surgical pathologic reports should be obtained. Fungal and mycobacterial organisms are slow growing and may be more rapidly identified by staining techniques. Most wounds can be left open, with moist gauze covering the exposed surfaces. Alternatively, large wounds can be managed with a negative-pressure sponge dressing. In an acute infection, these should be changed in 48 hours. Small wounds with a tendency to heal quickly should be kept open with a gauze wick. Multiple débridements may be necessary to control infection. Amputation may be necessary to eradicate infection. Functional results may be improved by amputation of a stiff, contracted, and painful digit. In cases of severe infection such as necrotizing fasciitis or gas gangrene, amputation may be a life-saving procedure.

Postoperatively, loose soft dressings are applied. A short period of immobilization for 24 to 48 hours with a splint may afford some pain relief to the patient. Early mobilization in the first 24 hours, under the guidance of a hand therapist, reduces edema, stiffness, and contracture associated with severe hand infections.

Empirical antibiotic therapy may be started after cultures have been obtained. In the case of cellulitis, where local cultures cannot be obtained, blood cultures may identify an organism and should if possible be obtained prior to initiating antibiotic therapy. The specific empirical therapy should be based on the most commonly encountered organisms for the type of infection being treated. The patient history, such as being exposed to an aquatic or a farm environment or being bitten by an animal, may help tailor the specific treatment to the patient. The relative prevalence of MRSA is increasing in many communities, and empirical treatment for MRSA is now commonplace. An infectious disease specialist is invaluable in guiding antibiotic recommendations for both specific infections and for resistant organisms that may be relatively prevalent in one's community. Table 2.1 lists general antibiotic recommendations for common infections. Dosages should be adjusted for the patient's age, weight, renal function, and allergic status. The duration of therapy depends on the clinical response to treatment, the location and depth of the infection, and the patient's immune status. The use of peripherally inserted central venous catheters (PICC lines) can be a valuable method of providing outpatient parenteral therapy, but it comes with a risk of upper extremity venous thrombosis.

CRITICAL POINTS *Treatment Principles*

Surgical Setup and Incision
- Tourniquet control
- Elevation (not elastic) to exsanguinate the limb
- Surgical incisions long and extensile
- Planned to minimize exposure of blood vessels, nerves, or tendons
- Avoid longitudinal incisions across flexion creases

Débridement
- Excision of all necrotic tissue

Specimens
- Obtain culture specimens from the periphery of an abscess cavity
- Gram-stained smear, aerobic and anaerobic cultures
- Tissue and/or fluid to pathology department and request fungal and mycobacteria stains

Irrigation
- Copious irrigation to reduce bacterial load

Wound Management
- Wounds should be left open
- Negative-pressure dressings should be used
- Do not be overly eager for immediate wound closure
- Delayed primary wound closure or healing by secondary intention

Postoperative Care
- Frequent dressing changes for open wounds
- Dressing changes every other day for negative-pressure wound care
- Early motion to reduce the incidence of tendon adhesions and stiff joints
- Multiple débridements may be needed to control infection
- Amputation may be necessary to eradicate infection
- Empirical antibiotic therapy based on most common organisms and patient history
- Infectious disease consultation for antibiotic recommendations and management very helpful

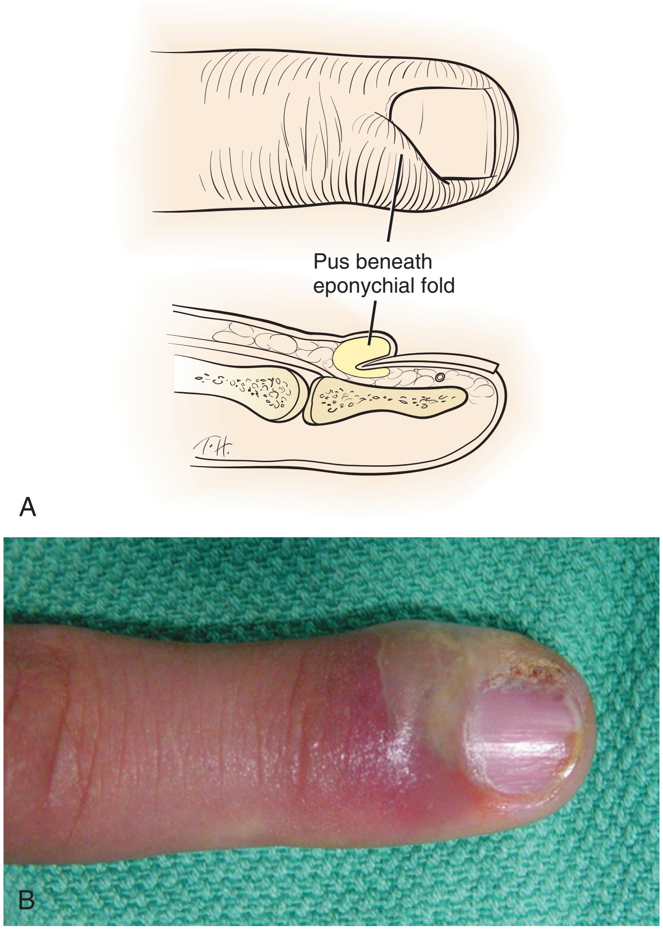


FIGURE 2.2 **A**, Inflamed paronychium and eponychium shown with pus extending below the eponychial fold. **B**, Clinical appearance of a purulent paronychium with partial involvement of the eponychium. (Copyright courtesy of Milan Stevanovic and Frances Sharpe.)

SPECIFIC TYPES OF COMMON HAND INFECTIONS

Acute Paronychia

Paronychia is the most common infection in the hand.[127] It is generally treated by primary care physicians, although refractory cases are often seen by the hand surgeon. Acute paronychia involves the soft tissue fold around the fingernail. It usually results from the bacterial inoculation of the paronychia tissue by a sliver of nail or hangnail, by a manicure instrument, or through nail biting. The disruption of the barrier between the nail fold and the nail plate allows the introduction of bacteria into the tissue bordering the nail (Figure 2.2). Although most paronychias are mixed infections, the most common infecting organism is *S. aureus*.

Clinical Presentation and Preoperative Evaluation

Erythema, swelling, and tenderness immediately adjacent to the nail are the hallmarks of the early clinical presentation. If left untreated, an abscess may form along the nail fold. The abscess may extend below the nail plate, either partially or completely, or it can track volarly into the pulp space. Because of the continuity of the nail fold with the eponychial tissue overlying the base of the nail, the infection can extend into this region and may continue around to the fold on the opposite side of the fingernail. This unusual occurrence is called a "runaround infection." Infection involving the entire eponychium, as well as one lateral fold, is known as an *eponychia*. An eponychia is usually manifested as a collection of pus beneath the proximal portion of the nail in the region of the lunula. It is rare to see both lateral folds and the dorsal tissue infected in the same digit.

Radiographs and laboratory examination are not necessary in uncomplicated cases with early clinical findings. However, patients who have not responded to initial treatment or who present with significant swelling or abscess should be evaluated for underlying systemic diseases such as diabetes. The patient's history and examination will direct the need for wound cultures for atypical organisms, radiographs to evaluate for a foreign body or osteomyelitis, and laboratory evaluation. Patients who do not respond to empirical therapy with a first-generation cephalosporin may also have CA-MRSA infection and may respond to a change in antibiotic therapy.

Pertinent Anatomy

The nail complex consists of the nail bed, nail plate, and perionychium. The nail bed, which lies below the plate, consists of

TABLE 2.1 Antibiotic Recommendations for Common Infections

Infection Type	Most Common Organism	Other Considerations	Initial Antibiotic Therapy
Cellulitis	*Staphylococcus, Streptococcus*	Antibiotic synergy for streptococcal infections with clindamycin	First-generation cephalosporin or penicillin (for *Streptococcus* only)
Abscess (e.g., paronychia, felon, deep space infections)	*Staphylococcus aureus*	Methicillin-resistant *S. aureus* (MRSA) is common now in the community; start therapy for MRSA empirically and change to nafcillin or first-generation cephalosporin if infection is methicillin sensitive	**IV:** Vancomycin or clindamycin for inpatients Linezolid or tigecycline if unable to tolerate vancomycin **Oral:** Trimethoprim/sulfamethoxazole (Bactrim), clindamycin, or doxycycline
Flexor tenosynovitis	*Staphylococcus, S. aureus,* anaerobes	Polymicrobial infections have worse prognosis. Consider multimodal therapy as initial treatment until culture results are available, especially in immunocompromised patients	**IV:** Ampicillin/sulbactam (Unasyn) plus cefoxitin (second-generation cephalosporin) **Oral:** Amoxicillin/clavulanate (Augmentin) If pencillin allergic: Fluoroquinolone (ciprofloxacin or other) plus clindamycin
Pyarthrosis	*Staphylococcus*	Requires parenteral therapy MRSA is common now in the community; start therapy for MRSA empirically and change to nafcillin or first-generation cephalosporin if infection is methicillin sensitive Consider coverage for *Neisseria gonorrheae* in sexually active patients	**IV:** Vancomycin Add ceftriaxone for *N. gonorrheae* coverage Presumptive treatment for MRSA until cultures are available; then change to antibiotic appropriate to organism with the least side effect profile
Human bite	*Staphylococcus, Streptococcus, Eikenella corrodens,* anaerobes		**IV:** Ampicillin/sulbactam (Unasyn) plus cefoxitin **Oral:** Amoxicillin/clavulanate (Augmentin) If pencillin allergic: Fluoroquinolone (ciprofloxacin) plus clindamycin Alternative: Third-generation cephalosporin plus anaerobic coverage with clindamycin or metronidazole **Note:** Quinolones not indicated in children
Animal bites	*Pasteurella multocida, Staphylococcus, Streptococcus*		**IV:** Ampicillin/sulbactam (Unasyn) plus cefoxitin **Oral:** Amoxicillin/clavulanate (Augmentin) If pencillin allergic: Fluoroquinolone plus clindamycin Alternative: Third-generation cephalosporin plus anaerobic coverage with clindamycin or metronidazole **Note:** Quinolones not indicated in children
Suspected CA-MRSA (community-acquired MRSA)		Suspected based on clinical appearance and relative frequency of CA-MRSA seen in community	**IV:** Vancomycin or clindamycin **Oral:** Trimethoprim/sulfamethoxazole (Bactrim), clindamycin
Suspected HA-MRSA (hospital-acquired MRSA)			**IV:** Vancomycin, linezolid, or daptomycin
Necrotizing fasciitis	*Streptococcus* or polymicrobial infection	Treat both until organisms identified	Broad-spectrum beta-lactam (piperacillin/tazobactam; imipenem) plus vancomycin (for MRSA) plus clindamycin (for synergy for *Streptococcus pyogenes*)
Gas in soft tissues	*Clostridium. perfringens* (gas gangrene), polymicrobial infections (anaerobic and facultative anaerobes)	Intravenous drug abusers and diabetics more often have polymicrobial infections; often, gas in the soft tissues	High-dose penicillin plus clindamycin Broad-spectrum beta-lactam (piperacillin/tazobactam; imipenem) plus vancomycin (for MRSA) plus clindamycin (for synergy for *S. pyogenes*)

the germinal and sterile matrices. The germinal matrix is responsible for the majority of nail growth. The proximal portion of the nail sits below the nail fold. The border tissue surrounding the nail is the perionychium. The eponychium is the thin layer of tissue extending from the nail wall onto the nail plate. The hyponychium is the mass of keratin just distal to the sterile matrix, below the distal nail plate. This area of the nail complex is highly resistant to infection.

Treatment Options

In the very early stages, this infection can be treated by soaks in a warm solution, systemic oral antibiotics, and rest of the affected part. If there is a superficial abscess, treatment can be carried out with local anesthesia and should consist of elevation of the cuticle away from the nail plate in the area of erythema and opening the thin layer of tissue over the abscess with a sharp blade directed away from the nail bed and matrix. Drainage of

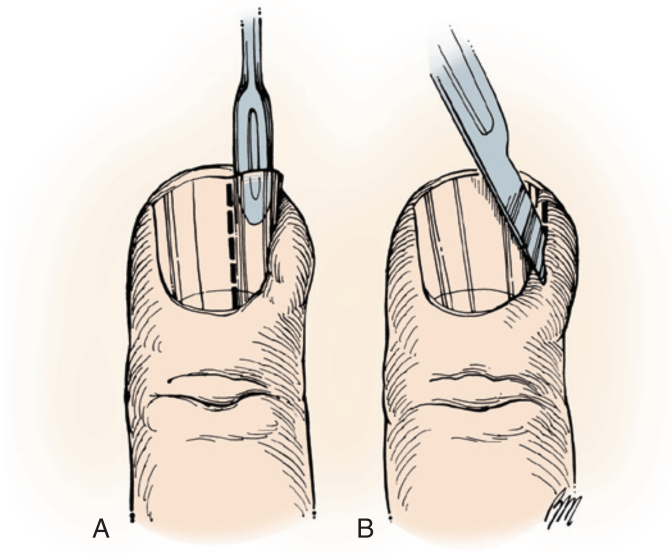


FIGURE 2.3 **A**, Elevation and removal of one fourth of the nail to decompress the perionychium. **B**, Incision of the perionychial fold with the blade directed away from the nail bed and matrix.

the abscess is performed where the abscess most nearly approaches the surface (Figure 2.3). The patient is counseled regarding high-risk activities, such as nail biting and manicures.

More extensive infection requires individualized treatment based on the extent of the lesion. Surgical decompression is best carried out under digital block anesthesia at the level of the metacarpal head with plain lidocaine. If the perionychial fold and the adjacent part of the eponychium are involved, the perionychium and skin adjacent to the nail fold are released. If the perionychial infection tracks volarly and involves the pulp, the incision should be deep enough to fully drain the abscess and allow evaluation of bone involvement of the distal phalanx. Infection that travels below the nail plate requires removal of a portion of the nail. If the entire nail matrix is involved, then the entire nail is removed. Purulence below the nail plate can cause pressure on the germinal matrix, resulting in ischemia of the germinal matrix and temporary or permanent arrest of nail growth.

Operative Methods. The peronychial sulcus is elevated from the nail gently by a flat, blunt instrument such as the flat portion of a malleable or metal probe or a Freer elevator. Sharp incision may be used as well. The incision is directed away from the nail bed to avoid injury to the nail bed and subsequent growth abnormality. The incision may be extended proximally along the nail fold, as far proximally as is necessary (Figure 2.4, *A* and *B*). It is generally sufficient to carry the incision only to the proximal edge of the nail, but it may extend as far proximally as the distal interphalangeal (DIP) joint.

When abscess or fluctuance is found below the eponychium and a single incision does not adequately expose or decompress the involved tissues, a parallel incision along the opposite nail fold is made, allowing the eponychium and nail fold to be elevated and reflected above the nail plate (see Figure 2.4, *C* through *E*).

When the abscess extends below the nail plate, a portion of the nail plate should be removed. The amount and location of nail removal depend on the location and extent of involvement below the nail. If the area of fluctuance lies adjacent to the perionychium, a flat blunt probe or Freer elevator is used to separate the affected portion of the nail plate from the nail bed. The nail plate is then cut with a small scissors and removed. In the rare case where the eponychium is infected and pus is present only below the proximal portion of the nail, the eponychium and nail plate are elevated through a single or double incision. The proximal third of the nail plate is carefully removed. Only when the nail is entirely separated from the underlying matrix is it necessary to remove the entire nail plate. After decompression, the area of abscess is irrigated. The wound is left open with a small thin piece of gauze that allows the wound to stay open and drain.

❖ AUTHORS' PREFERRED METHOD OF TREATMENT

No one treatment should be used exclusively, because there are cases in which each is applicable. We prefer to treat early infections nonsurgically with oral antibiotics and soaks two to three times per day in a solution of warm water and povidone-iodine at a ratio of 10 parts water to 1 part povidone-iodine. If the patient is allergic to topical povidone-iodine, warm normal saline may be used. Antibiotic treatment should cover *S. aureus*.

CRITICAL POINTS *Acute Paronychia*

Indication

- Perionychial or eponychial infection with abscess

Preoperative Evaluation

- None required in healthy individual with acute infection
- Laboratory evaluation in diabetics or immunocompromised patients
- Radiographs if long-standing infection or no improvement with conventional therapy

Pearls

- Careful evaluation for infection residing below the nail plate or in finger pulp

Technical Point

- Incise with blade facing away from nail bed to reduce risk of injury to matrix.

Pitfalls

- Misdiagnosis as herpetic whitlow (see section on herpetic whitlow)
- Failure to recognize underlying osteomyelitis
- Underlying systemic illness or atypical organism leading to refractory infection

Postoperative Care

- Seven to ten days of oral antibiotics
- Daily soaks in dilute povidone-iodine solution
- Early finger range of motion

Surgical treatment depends on the location and extent of the perionychial infection. Generally, we release along the perionychial sulcus, extending proximally to the level of the nail base. Double incisions are reserved for more extensive eponychial involvement, or when removal of the proximal portion of the nail is planned. Removal of any portion of the nail is done only when the area of abscess extends below the nail plate. Removal of the entire nail is necessary only when the entire nail plate is separated from the nail matrix by abscess.

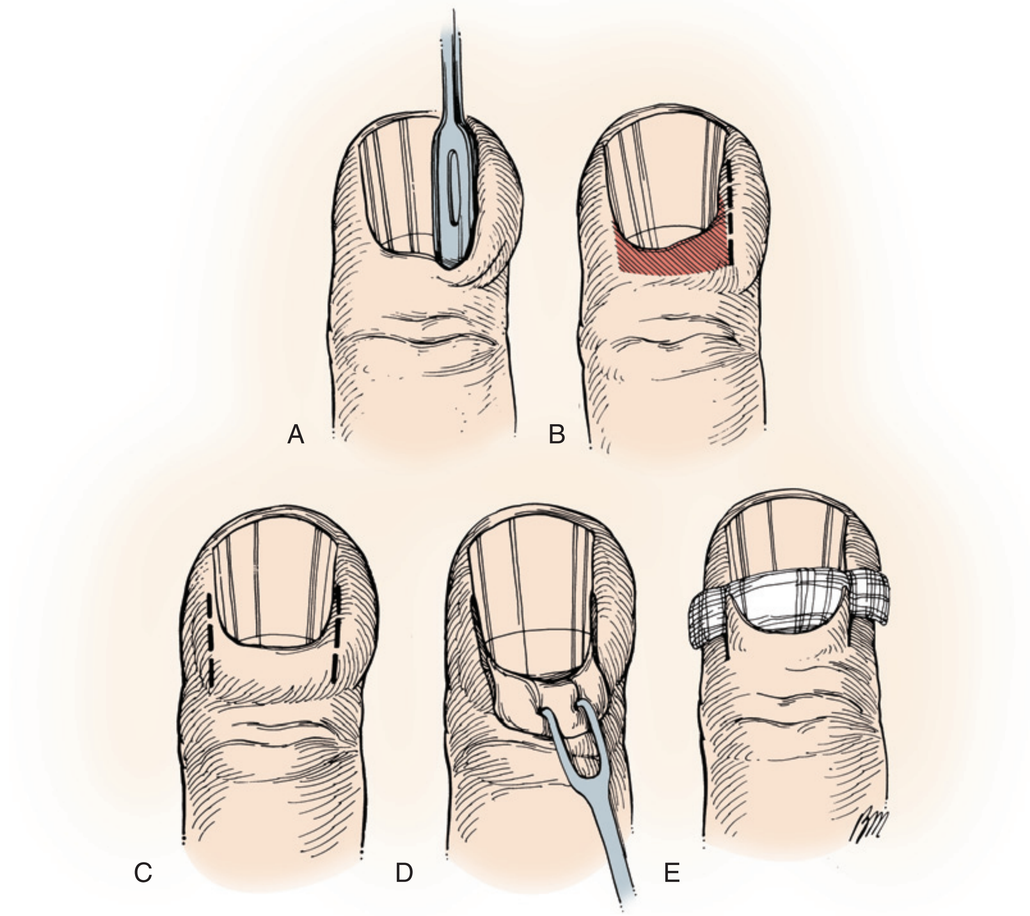


FIGURE 2.4 **A**, Elevation of the eponychial fold with a flat probe to expose the base of the nail. **B**, Placement of an incision to drain the paronychia and elevate the eponychial fold for excision of the proximal third of the nail. **C** to **E**, Incisions and procedure for elevating the entire eponychial fold with excision of the proximal third of the nail. A gauze pack prevents premature closure of the cavity.

Postoperative Management and Expectations

Postoperatively, the patient is given oral antibiotics for 7 to 10 days, depending on the severity of the infection. Dressings are changed two to three times per day, coinciding with soaking of the affected finger in a dilute solution of povidone-iodine for 5 to 10 minutes. We discontinue packing or wicking the wound at 3 to 4 days. Occlusive dressings can lead to skin maceration and should be avoided. Early motion is emphasized to prevent stiffness.

Improvement is noted in most acute cases of paronychia in 3 to 4 days with appropriate management; however, some tenderness and hypersensitivity around the surgical scars can be expected for several months. Nail deformity can occur either as a result of the infection or after minimal surgical injury to the nail matrix. Patients with an underlying medical illness may require a longer time for healing and recovery or require additional surgery. This population likewise has a higher risk of recurrent infection.

Complications are rare but do occur. Nail deformity can occur either from the infection itself or from inadvertent injury to the nail matrix from decompression. The risk of injury is minimized by gently separating the nail plate from the underlying matrix and by directing the scalpel blade away from the matrix when incising around the nail bed. Persistent infection despite appropriate treatment may be due to inadequate surgical decompression and drainage or inadequate antibiotic coverage. If the infection is not resolving at 1 week, radiographs to evaluate for osteomyelitis, cultures with antibiotic sensitivities, and repeat surgical débridement may be necessary. Robbins found that the most frequent complication of a paronychia was extension to the pulp space through a sinus at the side of the nail. This occurred in approximately 13.5% of patients treated in his series from the 1950s.[129] The occurrence of spread to the pulp space today is rare owing to improved antibiotic therapy and more aggressive surgical treatment. In children with long-standing paronychia, infection can lead to bone involvement and epiphyseal separation.

Misdiagnosis of a paronychia can occur, particularly confusion of perionychial infection with herpetic whitlow. Distinguishing herpetic whitlow from a bacterial infection is important. Incision and drainage of herpetic whitlow are contraindicated and can result in systemic viral infection and/or bacterial suprainfection.[7]

Chronic Paronychia

Clinical Presentation and Preoperative Evaluation

Chronic paronychia is characterized by chronically indurated and rounded eponychium and is a distinct clinical problem from acute paronychia. The chronic inflammation is accompanied by repeated episodes of inflammation and drainage. If left untreated, this results in thickening and grooving of the nail plate. This problem is more common in middle-aged women, with a female-to-male ratio of 4:1.[11] Frequent water immersion, particularly in detergents and alkali solutions, is a predisposing condition. Housewives, bartenders, dishwashers, nurses, swimmers, and children who suck their fingers are often affected. It also more commonly affects patients with diabetes and psoriasis.[11] Cultured organisms include gram-positive cocci, gram-negative rods, *Candida*, and mycobacterial species.[99] Preoperative evaluation includes a thorough history for contributing environmental factors, laboratory evaluation for underlying systemic diseases such as diabetes or immunosuppression, and radiographic evaluation for evidence of a foreign body, osteomyelitis, or lytic or blastic processes in the bone that could indicate a possible tumor. If the lesion is suspicious for a possible tumor, a magnetic resonance imaging (MRI) study may be helpful in distinguishing a chronic paronychia from a tumor.

Pertinent Anatomy and Pathophysiology

Chronic paronychia begins with separation between the nail plate and the dorsal soft tissue covering the nail plate, including the cuticle, eponychium, and nail fold. This leads to colonization, usually by staphylococcal organisms. Subsequent infection, by *Candida albicans* and/or colonic organisms, leads to chronic inflammation and recurrent exacerbations with episodic increased erythema and drainage. This chronic inflammation leads to fibrosis and thickening of the eponychium, with a resultant decrease in vascularity to the dorsal nail fold. The decreased vascularity reduces the resistance to minor bacterial insults, allowing for recurrent episodes of symptomatic exacerbations.[11,78]

Treatment

Conservative therapies for chronic paronychial infection have included topical corticosteroids, oral and topical antibiotics, and oral and topical antifungal agents. Although reducing exposure to moist environments and chemical irritants may be helpful, these treatments alone have been unsuccessful in a large number of cases.[11,78]

Operative Treatment. Eponychial marsupialization is the most common surgical treatment for the chronic paronychium. Under digital block anesthesia and tourniquet control, a crescent-shaped incision is made beginning 1 mm proximal to the distal edge of the eponychial nail fold and extending proximally for 3 to 5 mm. Some authors recommend removal of all thickened tissue. Others have found a 3-mm margin adequate to achieve equal results. The crescent should be symmetrically shaped and extend to the edge of the nail fold on each side (Figure 2.5). The crescent of tissue is removed down to but not including the germinal matrix. The wound is left open and allowed to drain. If nail deformity is present, removal of the nail has been reported to improve the cure rate and reduce the risk of recurrence.[11] Pabari and colleagues have described elevation of the nail fold, inverting the tissue and folding this tissue over a nonadherent gauze and anchoring the inverted skin to proximal suture with nonabsorbable suture. Anchoring sutures are removed between 2 and 7 days, and the nail fold is allowed to return to its original position[118] (Figure 2.6).

❖ AUTHORS' PREFERRED METHODS OF TREATMENT

We have found eponychial marsupialization an effective treatment for this condition. We agree with Bednar and Lane[11] that a 3-mm crescent of tissue is adequate and removal of all thickened tissue is not critical to the outcome. Special care is used to avoid injury to the germinal matrix. The removed tissue is sent for bacterial, fungal, and mycobacterial culture. The remaining tissue is sent for pathologic examination. Nail removal is performed when a nail deformity is present. Wounds are covered with Xeroform™ gauze. When the nail is removed, Xeroform gauze is placed in the nail bed and nail fold as well.

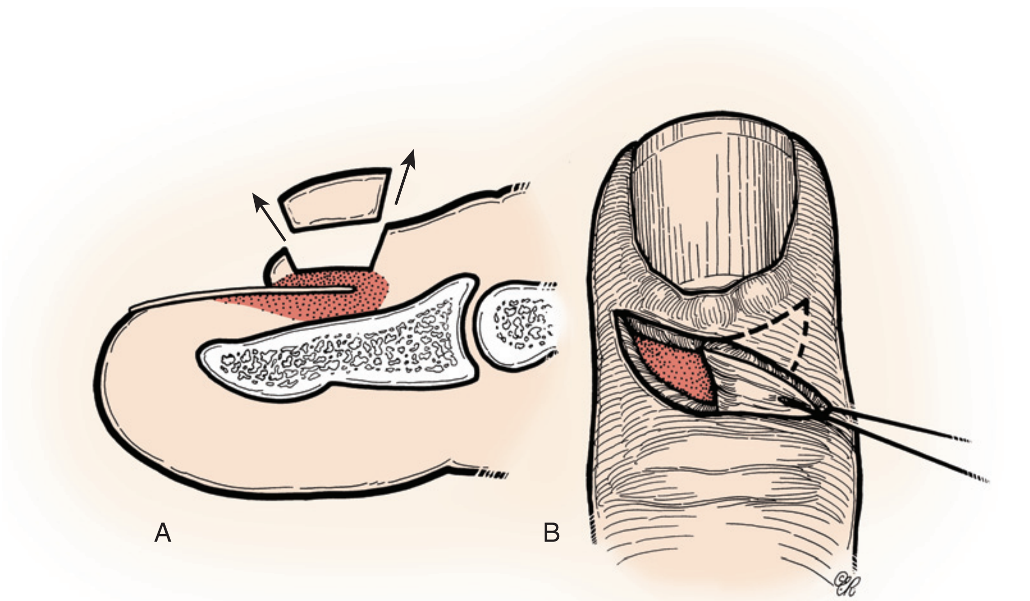


FIGURE 2.5 Eponychial marsupialization for chronic paronychia. **A**, Lateral view showing the area of wedge-shaped excision. Undisturbed matrix is stippled. **B**, Dorsal view of the crescent-shaped area of excision extending to the margins of the nail folds on each side.

FIGURE 2.6 Alternative technique of nail marsupialization for chronic paronychia, the Swiss roll technique. (Copyright courtesy of Milan Stevanovic and Frances Sharpe.)

Patients are counseled regarding exposure to moist environments. Predisposing systemic conditions, such as diabetes and psoriasis, are medically controlled. We evaluate for activities that may lead to mycobacterial exposures, such as home aquariums or terrariums, marine work, or aviary exposure.

Postoperative Management and Expectations

The postoperative dressing is removed at 48 to 72 hours by soaking in 3% hydrogen peroxide solution. The patient is instructed to soak the area three times per day in dilute povidone-iodine solution. This continues until 2 days after all drainage has stopped. Oral antibiotics are given for 2 weeks. If cultures are negative or the organism is not sensitive, the antibiotic therapy is discontinued at 3 to 5 days.

Most chronic paronychial infections resolve with marsupialization. Systemic or topical antibiotics or antifungal agents are often not required. Wound healing by secondary intention occurs over 3 to 4 weeks. Scar sensitivity is more common than in acute paronychia and may persist for several months. Nail deformity is also more common than in treatment of acute paronychia. Six to 12 months may be required for nail growth, and residual deformity cannot be assessed until that time. Recurrence rates are higher if the patient does not correct environmental factors or if systemic diseases are not medically controlled. In the event of recurrence, re-marsupialization and nail removal should be done.

Felon

The term *felon* probably has its roots from the Latin *fel*, meaning "bile" or "venom." A felon is a subcutaneous abscess of the distal pulp of a finger or thumb (Figure 2.7). However, not all abscesses of the distal phalanx are felons. Superficial infections of the most distal part of the pulp skin are known as "apical infections." Apical infections are distinct from the felon in that the palmar pad is not involved. The term *felon* should be reserved for those infections involving multiple septal compartments and causing compartment syndrome of the distal phalangeal pulp. The most commonly cultured organism from felons is *S. aureus*. Infections from gram-negative organisms have also been reported. These are uncommon and more typically seen in immunocompromised patients or diabetics.

CRITICAL POINTS *Chronic Paronychia*

Indication
- Chronic eponychial infection

Preoperative Evaluation
- Thorough workup and social history for contributing factors
- Laboratory evaluation in diabetics or immunocompromised patients
- Radiographs

Pearls
- Nail removal in conjunction with marsupialization if nail deformity is present
- Nail removal and remarsupialization even with normal nail in setting of recurrence

Technical Point
- Protect the germinal matrix during marsupialization.

Pitfalls
- Misdiagnosis with tumor or cyst
- Unrecognized systemic illness
- Failure to correct environmental factors

Postoperative Care
- Ten to fourteen days of oral antibiotics, if cultures are positive and sensitive. Different if mycobacterial organism
- Consider oral antifungal medications
- Daily soaks in dilute povidone-iodine solution
- Early finger range of motion

Clinical Presentation and Evaluation

Felons account for 15% to 20% of all hand infections.[90] A felon is characterized by severe throbbing pain, tension, and swelling of the entire distal phalangeal pulp. The pulp space is exquisitely tender, but the associated swelling does not extend proximal to the DIP flexion crease, unless the joint or tendon sheath is involved. With the progression of swelling and tension, there is compromised venous return, leading to microvascular injury and development of necrosis and abscess formation. There is often a history of penetrating injury, such as a wood splinter, glass sliver, or minor cut, preceding a felon. "Finger-stick felons" can be seen in diabetics, who repeatedly traumatize the fingertip for blood tests. Once the felon has developed, the patient may attempt a decompression with a knife or needle. The pain and swelling usually develop rapidly. The expanding abscess breaks down the septa and can extend toward the phalanx and produce osteitis or osteomyelitis, or it can extend toward the skin and cause necrosis and a sinus somewhere on the palmar surface of the digital pulp. If such spontaneous, although inadequate, decompression does not occur, it is possible that the digital vessels will thrombose and a sloughing of the tactile pulp will result. Other complications of an untreated felon include sequestration of the diaphysis of the distal phalanx, pyogenic arthritis of the DIP joint, and flexor tenosynovitis from proximal extension, although the last is quite rare.[164]

Pertinent Anatomy

Kanavel studied the anatomy of the fingertip through multiple sagittal and coronal sections of cadaveric fingers. He described the anatomy of the distal pulp as a "closed sac connective tissue

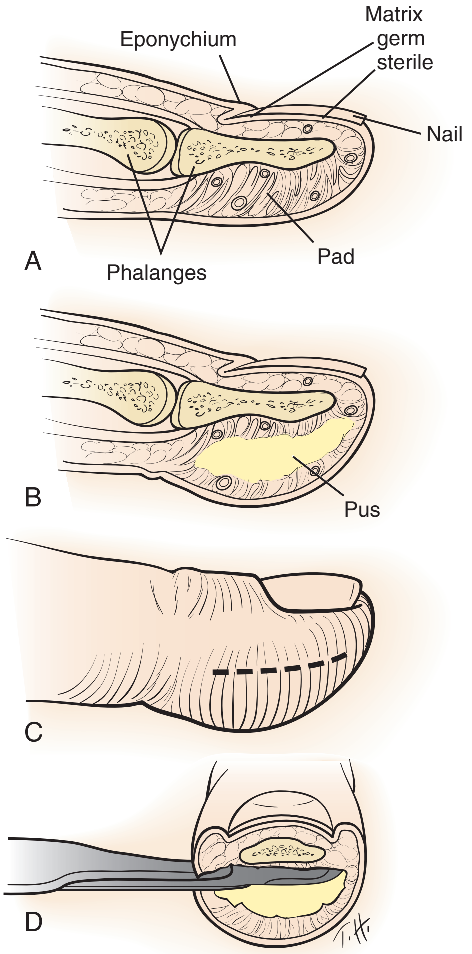


FIGURE 2.7 **A**, Cross section of the distal fingertip, showing the septated anatomy of the pad. **B**, Collection of pus within the finger pulp space. **C**, Incision for drainage of felon. **D**, The incision should include all of the involved septal compartments. (Copyright courtesy of Milan Stevanovic and Frances Sharpe.)

framework, isolated and different from the rest of the finger."[75] Multiple vertical trabeculations divide the pulp of the distal phalanx into a latticework of separate septal compartments. The trabeculae attach the periosteum of the distal phalanx to the epidermis, giving the fingertip structural support and stabilizing the pulp during pinch and grasp. The septal interstices are filled with fat globules and eccrine sweat glands, which open onto the epidermis and provide an access for surface bacteria to enter the pulp space. The digital arteries run parallel to the distal phalanx, giving off a nutrient branch to the epiphysis before entering the pulp space. The diaphysis is supplied principally from volar nutrient vessels from the terminal branches of the digital arteries. The terminal branches of the digital nerve are parallel and palmar to the digital arteries. They arborize extensively within the pulp of the distal phalanx, providing fine tactile discrimination. The highest concentration of sensory receptors in the hand is the volar aspect of the distal phalanx.

Felons may begin with penetrating wounds of the distal pulp or as bacterial contamination of the fat pad through the eccrine sweat glands. Inflammation and cellulitis lead to local vascular congestion, which is aggravated by the closed septal anatomy of the pulp. If left untreated, tissue necrosis and abscess formation follow, resulting in further microvascular impairment. The increased pressure within the pulp as a "closed sac" results in a clinical situation resembling a compartment syndrome. The ischemia of the pulp causes severe ischemic pain in the densely innervated pulp. The blood supply to the periosteum and diaphysis is compromised more than the blood supply to the skin, leading to bone necrosis and sequestration before spontaneous decompression of the felon through the skin. In children, infection or necrosis of the epiphysis is rarely seen, most likely owing to the preservation of the epiphyseal nutrient artery, which arises from the digital artery proximal to the closed space of the distal pulp and is therefore preserved.

Treatment

Treatment of the felon should be directed toward preserving the function of the finger pulp. These functions include fine tactile sensibility and a stable durable pad for pinch. In the early cellulitic phase, it may be possible to treat the felon with elevation, antibiotics, and soaks. Short-term immobilization may make the patient more comfortable. Some authors recommend surgical drainage only in the presence of abscess.[152] In our hands, surgical drainage is indicated when the pulp is very tender, tense, or fluctuant. The basic tenets of all approaches are to avoid injury to the digital nerve and vessels, use an incision that will not leave a disabling scar, provide adequate drainage, and avoid inadvertent violation of the flexor tendon sheath, causing an iatrogenic tenosynovitis.

Operative Treatment. Several surgical incisions have been described (Table 2.2; Figure 2.8); some of these are of historic interest only and are no longer recommended. Surgery may be performed under digital block anesthesia or under general anesthesia. A tourniquet is helpful for visualization. Regardless of the type of incision, surgical decompression requires thorough removal of necrotic tissue, irrigation, and wound management to allow continued drainage of the abscess cavity. To keep the wound open and draining, a gauze wick is placed in the wound. The first dressing change is done at 24 to 48 hours. Authors' opinions vary as to how long the wound is kept open with a wick drainage. Two to 5 days should be adequate for most cases, depending on the severity of infection. Soaking in dilute povidone-iodine solution as described earlier is initiated after the first dressing change and continued until wound healing by secondary intention.

❖ AUTHORS' PREFERRED METHODS OF TREATMENT

Only in the very early presentation of an acute felon should nonsurgical management be considered. The felon is more typically a very rapidly developing process, and by the time of presentation, the pulp is tensely swollen and exquisitely tender. This requires surgical decompression whether fluctuance is present or not. We prefer to perform surgery under digital block anesthetic with sedation. A forearm tourniquet is used. The extremity is exsanguinated by elevation. The surgical incision is made longitudinally. When the point of maximal tenderness is located in the middle of the pulp or when a sinus is present volarly, we use the longitudinal volar incision. When the point of tenderness is on the side of the pulp, we use the unilateral longitudinal incision. Although the incision is preferably placed on the side opposite the pinching surface, the incision should always be placed on the side of maximal tenderness. When

TABLE 2.2 **Surgical Incisions for the Treatment of Felon**

Incision	Advantages	Disadvantages	Comments and Technical Points
A: Fish-mouth incision (Figure 2.8, *A*)	None	Risks circulation leading to skin slough; unstable pulp; unsightly scar	No place in treatment
B: "J" or hockey-stick incision (Figure 2.8, *B*)	Good for extensive or severe abscess	Incision coming distally into the fingertip can cause painful scar	Adequate débridement and release of septa can be performed without crossing the fingertip (see F)
C: Through-and-through incision (Figure 2.8, *C*)	Wide access to all involved septal compartments	Additional wound; superfluous incision that can compromise circulation to the pulp	Initially described with a "J" incision on the ulnar side with a longitudinal counterincision; extension across the fingertip is *not* necessary; two dorsolateral incisions
D: Volar incision (transverse) (Figure 2.8, *D*)	Most direct access to area of abscess; easy to perform; better maintains structural integrity of palmar pad	Palmar scar; higher risk of digital nerve and vessel injury	Incision 4 to 5 mm made at site of maximal fluctuance; sharp dissection through skin and dermis only, followed by blunt dissection through the pulp; elliptical excision of sinus tract and necrotic tissue (if present)
E: Volar (longitudinal) incision (Figure 2.8, *E*)	Same as above; lower risk of digital neurovascular injury	Palmar scar	Same as above; incision should not cross DIP flexion crease
F: Unilateral longitudinal incision (Figure 2.8, *F*)			Preferred placement on the ulnar side of the index, middle, and ring fingers and on the radial side of the thumb and small fingers

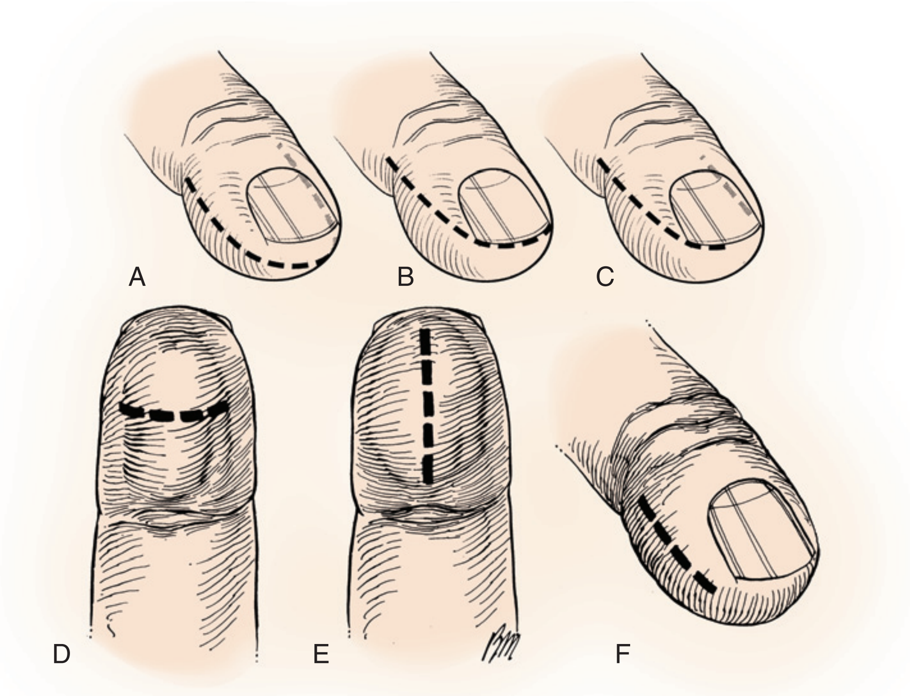


FIGURE 2.8 Incisions for drainage of felons. **A**, Fish-mouth incision. This approach is associated with significant complications and should *not* be used. **B**, Hockey-stick incision. The incision begins in the midaxial line, aims for the corner of the nail, and passes across the finger in the natural line between the skin and nail matrix (see text discussion). **C**, Abbreviated hockey-stick incision with counterincision on the opposite side. An alternative to the full hockey-stick incision is to make this incision shorter and make a second incision on the opposite side of the pulp (*faint dotted line*). **D**, Volar drainage is useful if the abscess points volarward, but this incision risks injury to the digital nerves. **E**, Alternative volar approach. There is less risk to the digital nerves, but the incision should not touch or cross the DIP joint flexion crease. **F**, Unilateral longitudinal approach. This incision is the authors' preferred method for treatment of most felons.

possible, the incision is made on the ulnar side of the second to fourth digits and on the radial side in the thumb and small finger. The incision is started dorsal to and 0.5 cm distal to the DIP joint flexion crease. It is continued distally in line with the volar margin of the distal phalanx, but it does not cross over the fingertip. The incision is deepened along a plane just volar to the palmar cortex of the phalanx until the abscess is entered. The opening in the cavity is enlarged until adequate evacuation is achieved.

All involved septa should be opened, and a wound culture is taken. The flexor tendon sheath should not be violated, unless there are signs of tendon sheath involvement, as this can cause an iatrogenic tendon sheath infection. The distal phalanx must be examined with a probe. A rough or softened surface indicates bone involvement, which requires débridement of the softened or necrotic bone. After thorough débridement and irrigation, the wound is kept open with a thin gauze wick and a sterile dressing is applied. The first dressing change is done between 12 and 24 hours.

CRITICAL POINTS *Felon*

Indication
- Tense pulp space infection with or without fluctuance

Preoperative Evaluation
- Patient history of recent injury, medical and social history
- Laboratory evaluation in diabetics or immunocompromised patients
- Radiographs to evaluate for foreign body or osteomyelitis

Pearls
- Incision made at point of maximal tenderness

Technical Points
- Avoid incisions crossing the fingertip or DIP flexion crease.
- Protect the digital nerves and vessels.
- Do not violate the flexor tendon sheath.

Pitfalls
- Misdiagnosis as herpetic whitlow
- Unrecognized osteomyelitis
- Incomplete decompression of all involved septa
- Iatrogenic septic flexor tenosynovitis
- Creation of an unstable pulp

Postoperative Care
- Intravenous antibiotic therapy for 5 to 7 days, longer if bone is involved (in hospitalized patients)
- Patients treated in an outpatient setting usually do not require intravenous antibiotics
- Gauze wick for at least 72 hours
- Soaks three times per day in dilute povidone-iodine solution
- Early finger range of motion

Postoperative Management and Expectations

The setting of the drainage procedure (office, emergency department, or operating room) and decision to hospitalize the patient depend on the severity of the infection and the reliability of the patient. In our county hospital patients, we prefer to admit the patients and give intravenous antibiotics until a favorable response to therapy is seen. Oral antibiotics can be used when the infection is controlled. Bone involvement requires longer intravenous therapy. The choice of antibiotic depends on the cultured organism and its antibiotic sensitivity. Because most felons are caused by *S. aureus*, initial antibiotic therapy should address this organism. Factors such as underlying disease, injury mechanism, or contributing occupational or social history may influence antibiotic choice. Dressings are changed two to three times per day. At the time of dressing change, the patient soaks the affected finger in a solution of dilute povidone-iodine for 5 to 10 minutes. Packing or wicking of the wound is discontinued after 3 to 5 days. Occlusive dressings are not used, because they often result in skin maceration. Early motion is emphasized to prevent stiffness.

Most felons recover in 3 to 4 weeks with appropriate management. The length of treatment and recovery depends on the severity of the infection and the presence of bone involvement. Tenderness and hypersensitivity around the surgical scars and of the entire pulp can be expected for several months after surgery. In some patients, this may be a permanent finding. Pulp deformity, most commonly pulp atrophy, occurs frequently and is permanent. Pulp instability can occur in patients where the infection has involved all of the vertical septa, regardless of the incision used. This will often resolve over time but may take 6 months to a year. In cases of osteomyelitis with large bone loss, nail deformity may occur owing to loss of underlying bone support of the nail matrix, resulting in a short finger with a short nail. Nail ablation may be necessary for painful deformities. In some cases with severe bone involvement, amputation of the distal phalanx should be considered.

Complications of treatment include recurrence of infection, usually as a result of inadequate bone débridement. In these cases, repeat surgical débridement and prolonged organism-specific antibiotic therapy will usually be sufficient. Amputation may be necessary for refractory infection. Iatrogenic septic flexor tenosynovitis has been reported. Appropriate treatment involves repeat débridement and surgical decompression and irrigation of the flexor tendon sheath, as described later.

Pyogenic Flexor Tenosynovitis

Pyogenic flexor tenosynovitis is a closed-space infection of the flexor tendon sheath of the fingers or thumb. The purulence within the flexor tendon sheath destroys the tendon gliding mechanism, rapidly creating adhesions that lead to marked limitation of tendon function and severe loss of motion. It can also destroy the blood supply, producing tendon necrosis. Early treatment is of paramount importance in limiting the morbidity associated with this diagnosis. Untreated disease and late diagnosis or presentation can lead to devastating disability in hand function. The incidence and serious sequelae of bacterial tenosynovitis are less frequent, owing to early recognition and the availability of appropriate antibiotic therapy. The most common organisms responsible for disease include *S. aureus* and β-hemolytic *Streptococcus*. *P. multocida* is frequently cultured in infections caused by animal bites. A wider host of organisms should be considered in immunocompromised patients, who have yielded positive cultures for *E. corrodens*, *Listeria monocytogenes*, and mixed gram-positive and gram-negative infections.

Clinical Presentation and Preoperative Evaluation

Most patients present with a history of penetrating trauma, typically over the volar aspect of the proximal interphalangeal (PIP) or DIP joint. A small puncture wound, often from a foreign body or animal bite, can inoculate the tendon sheath. Hematogenous septic flexor tenosynovitis is rare. When this occurs, disseminated gonococcal infections should be considered. Levy recommended that hematogenous tenosynovitis should be treated as disseminated gonorrhea until final culture results are available.[84,134]

Kanavel[74] initially described three cardinal signs of acute flexor tenosynovitis. He later added a semiflexed posture of the digit as the fourth sign.[75] All four signs need not be present, especially in the early course of the disease. Kanavel's four cardinal signs are:

1. A semiflexed position of the finger
2. Symmetric enlargement of the whole digit (fusiform swelling)
3. Excessive tenderness limited to the course of the flexor tendon sheath
4. Excruciating pain on passively extending the finger; the pain should be experienced along the flexor sheath and not localized to a particular joint or abscess.

There are different opinions as to which signs are most clinically useful. Kanavel and others believed that excessive tenderness along the tendon sheath was the most reliable and reproducible clinical sign. Neviaser believed the most reproducible clinical sign was pain with passive extension. Pang and associates noted fusiform swelling of the digit in 97% of patients. Pain on passive extension was noted in only 72% of patients.[32,75,111,119] We believe that all of these findings are useful and in combination help distinguish pyogenic flexor tenosynovitis from local abscess or pyarthrosis. Findings in the thumb and small finger may be more subtle because these fingers have a mechanism of autodecompression through the radial and ulnar bursae.

Laboratory evaluation should include a CBC. The ESR and CRP may be useful in monitoring the disease process. However, these may be elevated in noninfectious inflammatory processes, as well. Radiographs should be taken to evaluate for a retained foreign body, underlying pyarthrosis, osteomyelitis, or unrecognized trauma, such as a fracture.

There are several conditions that may mimic acute pyogenic flexor tenosynovitis. The differential diagnosis includes herpetic whitlow, felon, pyarthrosis, local abscess, and inflammatory diseases such as rheumatoid arthritis or gout or aseptic flexor tenosynovitis. Herpetic whitlow and felon, as already described, present a different clinical picture, typically with more distal findings. Herpetic whitlow is not associated with the tenseness and swelling that are found in pyogenic flexor tenosynovitis and classically presents with small skin vesicles. Pyarthrosis can more closely resemble an infection of the flexor sheath because there is commonly pain with passive joint motion and the digit is held in a flexed posture. Unlike flexor synovitis, the location of the traumatic injury is usually on the dorsal surface of the finger, the swelling is more localized around the joint, and pain with palpation is not present along the entire tendon sheath.

In cases in which the clinical presentation is not clear or there is a clinical suspicion of a nonseptic acute tenosynovitis as may be seen in gout, rheumatoid arthritis, or acute stenosing tenosynovitis, aspiration of the tendon sheath should be done. If the aspiration is negative, NSAID therapy is initiated. The patient should be closely monitored in the first 24 hours. Depending on patient reliability, this can be done on an inpatient or outpatient basis.

Pertinent Anatomy

Knowledge of the anatomy of the flexor tendon sheaths, bursae, and deep spaces of the forearm is important in understanding the presentation and possible spread of infection in the hand. The flexor tendon sheath is a double-walled structure with a visceral layer and a parietal layer. The visceral layer is closely adherent to the tendon and is essentially the epitenon. The parietal layer lies adjacent to the pulley system.[29,35] These two layers are connected proximally and distally, creating a closed system. In the fingers, the sheaths begin in the palm at the level of the metacarpal neck and end distally just proximal to the DIP joint. In the small finger, there is usually continuity between the flexor sheath and the ulnar bursa, which extends to a point just proximal to the transverse carpal ligament. In the thumb, a similar connection is seen with the radial bursa, which also extends proximal to the transverse carpal ligament.[29,35,75,136] Proximally, the radial and ulnar bursae have a potential space of communication through the Parona space, which lies between the fascia of the pronator quadratus muscle and flexor digitorum profundus (FDP) conjoined tendon sheath. This site of connection between the thumb and small fingers through the radial and ulnar bursae gives rise to the *horseshoe abscess*, in which a flexor sheath infection of the thumb or small finger tracks proximally to the wrist and then ascends along the flexor sheath on the opposite side. Although this is the most commonly described connection, many variations of flexor sheath anatomy exit. This was elegantly described by Scheldrup in 1951.[136] These potential variations and sites of interconnection should be kept in mind to direct appropriate treatment.

The flexor tendons receive their nutrient support from a direct vascular supply and diffusion from the synovial fluid. When bacteria inoculate the flexor sheath, the synovial fluid becomes the nutritional source for the bacteria. The host has limited ability to defend against the bacterial proliferation, owing to the poor vascularity within this closed system. The bacterial proliferation leads to increased volume and pressure within the tendon sheath. Schnall and colleagues demonstrated pressures exceeding 30 mm Hg in more than 50% of flexor sheath infections.[139] This high pressure likely contributes to the pathogenesis of the disease process by obstructing the arterial blood supply of the flexor tendons through the vincular system. This can quickly result in tendon necrosis and subsequent rupture. Appropriate and urgent management of flexor tendon sheath infections is imperative in preventing these unwanted complications.

Treatment

There is a narrow range of indications for nonsurgical treatment of pyogenic flexor tenosynovitis. Patients rarely present with early clinical findings, which may be managed with antibiotic therapy. Those patients who present within the first 24 hours of the onset of symptoms, have mild pain and mild swelling, and show only partial expression of one or two of Kanavel's signs may be initially treated with intravenous administration of antibiotics. A dorsal block splint is applied to place the hand at rest. The extremity is elevated. The patient is monitored with close clinical observation in an inpatient hospital setting. If the clinical symptoms are not improving in the first 12 hours, surgical treatment is indicated. Nonsurgical management should seldom be considered in the diabetic or immunocompromised patient.

Before antibiotic therapy is initiated, an aspiration of the tendon sheath is done to obtain material for culture. The aspiration is performed with a 20- to 22-gauge needle. The aspiration can be performed anywhere between the palmodigital crease and the DIP flexion crease. The aspiration should be performed away from any areas of superficial cellulitis. A small amount of saline may be necessary to lavage the sheath to obtain a specimen for culture. If frank pus is encountered on the aspiration, nonsurgical treatment should not be pursued. Patients who present with a local cellulitis along the volar surface of the finger may also have a septic flexor tendon sheath. If nonsurgical treatment is considered, aspiration should not be performed through the cellulitic subcutaneous tissue, to prevent inadvertent inoculation of the sheath.

Purulent tenosynovitis rapidly destroys the gliding mechanism within the flexor tendon sheath. Delayed or inadequate treatment increases the formation of adhesions within the sheath, permanently limiting tendon excursion and ultimately limiting the finger range of motion.

Operative Treatment. Several surgical approaches have been described for the treatment of pyogenic flexor tenosynovitis. Some of these are of historic interest only. Most describe various incisions for proximal and distal exposure of the flexor tendon sheath and various irrigation methods and solutions.

There have been two principal surgical approaches to treatment of flexor tendon sheath infections. The first is with surgical exposure of the tendon sheath through a midlateral or Brunner incision. We prefer the midlateral incision (Figure 2.9, *A*). Although this allows more direct access to the tendon sheath, it can lead to greater scarring and stiffness of the finger. In the setting of wound healing problems, this leaves the tendon or tendon sheath exposed and more typically requires return to the operating room for delayed primary wound closure.

The second approach developed because of concerns that wide exposure of the tendon sheath led to significant postoperative scarring and stiffness of the involved finger. To address this problem, a number of methods were described that were designed to limit exposure of the tendon sheath (see Figure 2.9, *B* to *D*). Variations included location of incisions, type of irrigants, and continuous methods of irrigation, but all involved limited incisions at the proximal and distal ends of the tendon sheath and proximal to distal irrigation of the sheath.

Neviaser popularized a limited midlateral incision, with opening of the tendon sheath distal to the A4 pulley. The proximal tendon sheath is exposed in the distal palm, and a catheter is placed for continuous irrigation[111] (see Figure 2.9, *D*).

In the technique of closed tendon sheath irrigation, as described by Neviaser, a zigzag incision is made in the distal area of the palm over the proximal end of the sheath. The sheath is opened at the proximal margin of the A1 pulley. A second incision is made on the ulnar midaxial side of the finger in the middle and distal segments. Access to the distal end of the sheath is obtained through a plane dorsal to the digital artery and nerve. The sheath is resected distal to the A4 pulley. A 16-gauge polyethylene catheter with a single opening at its end is inserted under the A1 pulley in the palm for a distance of 1.5 to 2 cm. The catheter is sutured to the skin, and the wound closed around it. The sheath is copiously irrigated with saline. A small drain is placed in the distal incision, making sure to be in the tendon sheath. The drain is sutured to the skin. The wound is closed around the drain. The system is flushed again to test its patency. The hand is dressed and splinted, with the catheter brought out of the dressing and connected to a 50-mL syringe. The dressing is arranged so that the drain can be seen distally. The system is tested just before the patient leaves the

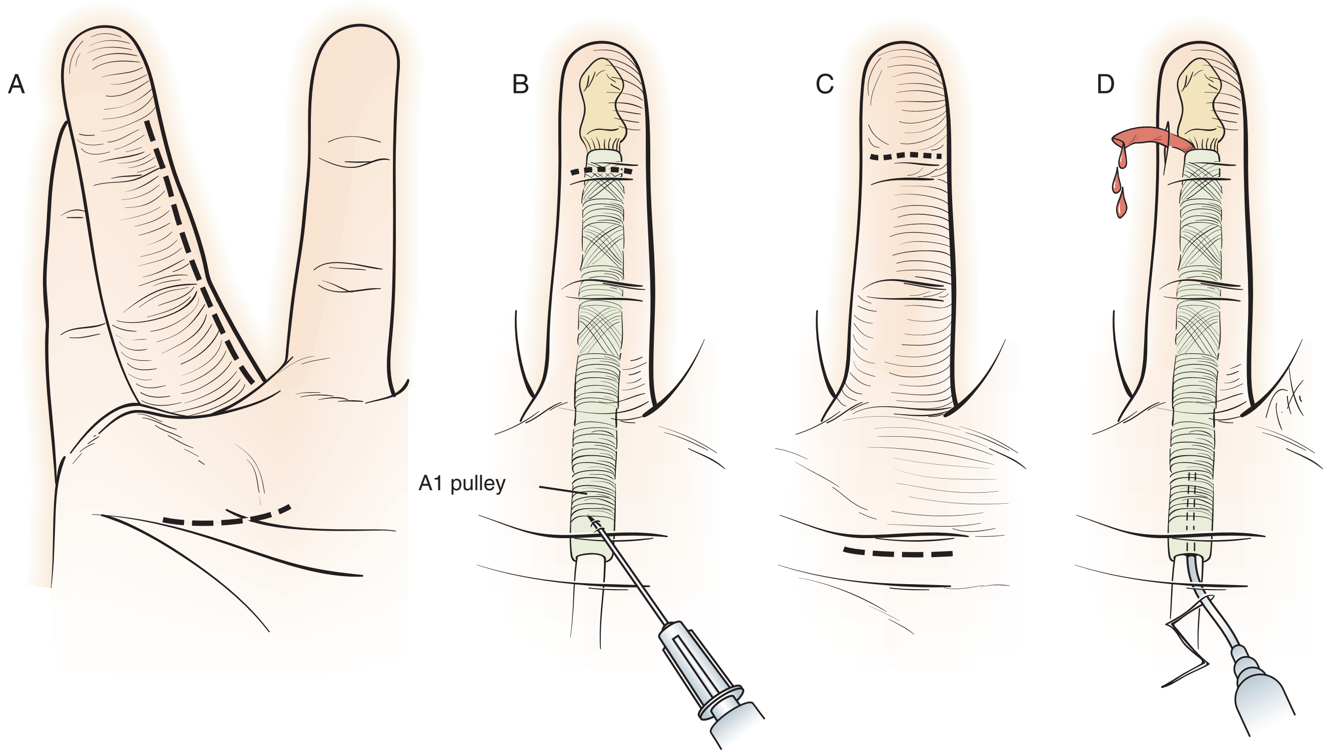


FIGURE 2.9 Incisions for drainage of tendon sheath infections. **A**, Open drainage incisions through the midaxial approach. **B**, Sheath irrigation with distal opening of the sheath and proximal syringe irrigation. **C**, Incisions for intermittent through-and-through irrigation. **D**, Closed tendon sheath irrigation technique (see Neviaser R: Closed tendon sheath irrigation for pyogenic flexor tenosynovitis. *J Hand Surg* 3A(5):462–466, 1978). (Copyright courtesy of Milan Stevanovic and Frances Sharpe.)

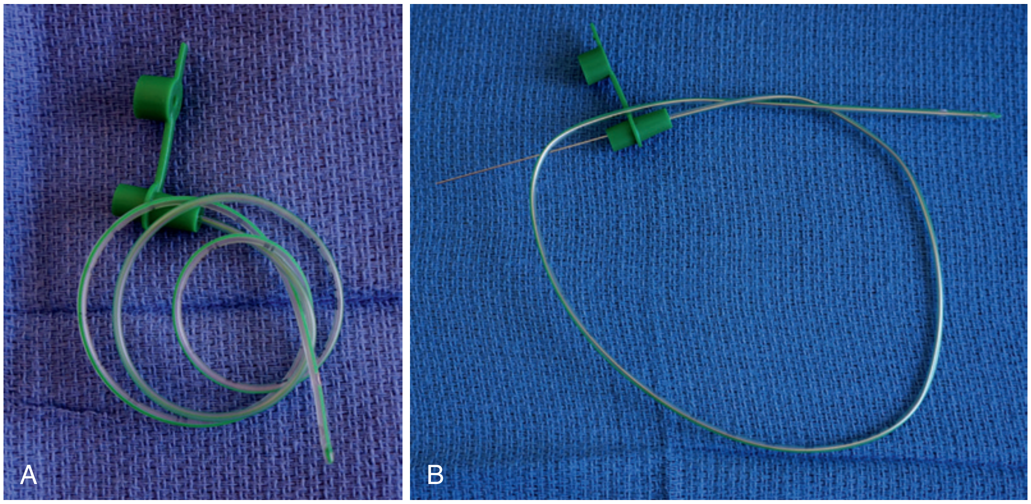


FIGURE 2.10 Cannulation of the flexor tendon sheath with a 5 Fr pediatric feeding tube can be difficult due to the flaccidity of the tube. Use of a 24-gauge wire as an obturator facilitates introduction of the feeding tube into the tendon sheath. (Technique courtesy of Dr. E. Farng.) (Copyright courtesy of Milan Stevanovic and Frances Sharpe.)

operating suite. Postoperatively, the sheath is flushed manually with 50 mL of sterile saline every 2 hours for 48 hours. At this time, the digit is inspected. If signs of infection have abated, the catheter and drain are removed. The wounds are dressed lightly to avoid impeding motion. Exercises to restore finger motion are started. If any doubt exists, the irrigation may be continued for an additional 24 hours.[111] Complete motion can be expected in a week. Several studies support the use of this technique.[32,61] Indwelling catheter placement has not been shown to be necessary and may delay active motion.[86] In our experience, we have not felt that this technique adequately decompresses the flexor tendon sheath or finger. Also, the method of continuous irrigation has often been painful to the patient, the nursing staff, and the on-call physician.

❖ AUTHORS' PREFERRED METHODS OF TREATMENT

Decompression of the septic flexor tendon sheath begins with a midlateral incision. The incisions are designed to avoid scarring on the pinching surface of the fingers. In the index, middle, and ring fingers, the incision is placed on the ulnar border, and in the thumb and small finger, it is placed on the radial side. The incision is made dorsal to Cleland's ligament (see Figure 2.9, *A*). The incision extends from the middle of the distal phalanx to just proximal to the web space. The dissection is carried out dorsal to the neurovascular bundle and down to the flexor tendon sheath. This allows decompression of the swollen finger, decreasing compartment pressure. The tendon sheath is opened distal to the A4 pulley. The sheath must be opened enough to allow the easy egress of fluid or pus, typically 4 to 6 mm. Cultures are taken from the tendon sheath effluent. A 1.5- to 2.0-cm transverse volar incision made proximal to the A1 pulley is usually sufficient to expose the proximal flexor sheath. This incision can be easily extended proximally or distally as a Brunner-type incision to allow greater exposure of the tendon sheath if it is necessary. The tendon sheath is opened proximally. If fluid for culture was not obtained distally, cultures should be taken from the proximal sheath. If hypertrophic synovitis is seen, synovial biopsy is recommended. Pathologic examination should include fungal and mycobacterial stains.

A 14- or 16-gauge intravenous catheter or preferably a No. 5 pediatric feeding tube is introduced into the tendon sheath and advanced 1.5 to 2.0 cm into the sheath (Figure 2.10). Syringe irrigation with copious amounts of antibiotic containing normal saline is done. The fluid should be seen to egress from the distal opening in the tendon sheath. The tendon sheath should be irrigated until clear fluid is seen distally. Irrigation is discontinued if there is too much fluid extravasation into the finger.

If we encounter difficulty in irrigating, the catheter is first repositioned. Mobilizing the superficialis and profundus tendons and placing the catheter dorsal to the tendons may allow easy flow of solution. Thickened tenosynovium may impede flow, and a limited proximal synovectomy or wider exposure of the tendon sheath may be necessary.

Any wounds on the volar surface of the finger should be débrided. Even small puncture wounds, particularly those caused by cat bites, should be débrided and irrigated. In cases in which there is a large volar wound and opening in the tendon sheath at a site of abscess, the irrigant may primarily be flowing out of the abscess site. In this situation, following the débridement of the volar wound, the irrigation catheter can be placed into the tendon sheath at the site of abscess and the distal tendon sheath can be further irrigated (Case Study 2.1).

Postoperative Management and Expectations

Postoperatively, the wounds are left open. A wet gauze wick is placed into the wounds to allow continued drainage. A bulky dressing is applied. The hand is elevated, and intravenous antibiotics are continued. The first dressing change should be done at 12 to 24 hours. At this time, the patient begins soaking in a dilute solution of povidone-iodine, as described earlier. Early motion is initiated. Therapist supervision may be necessary. It is important to keep this wound open to allow drainage. If left alone, the palmar wound will close almost immediately. Therefore, moist gauze wicks are used to keep the wounds open in

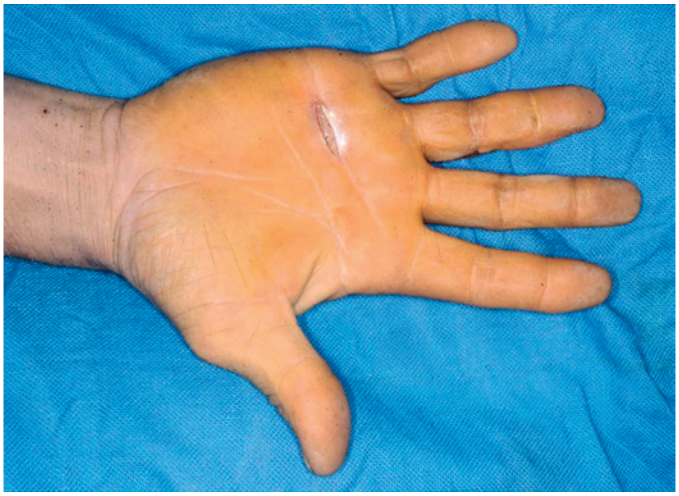
CASE STUDY 2.1 Septic Flexor Tenosynovitis

A, A 40-year-old coroner stuck himself with a contaminated sharp instrument at the distal interphalangeal flexion crease. Two days later, he developed severe swelling. Three of Kanavel's cardinal signs were present. Surgical findings included gross pus at the level of the A1 pulley (eFigure 2.1). **B**, A radial midlateral incision was used to decompress the finger and open the tendon sheath distally (eFigure 2.2). **C**, Early range of motion was initiated, and the wound was allowed to heal by secondary intention. Flexion is shown at 5 days in eFigure 2.3. Extension at 5 days is displayed in eFigure 2.4.

eFIGURE 2.1 Copyright Milan Stevanovic and Frances Sharpe.

eFIGURE 2.2 Copyright Milan Stevanovic and Frances Sharpe.

eFIGURE 2.3 Copyright Milan Stevanovic and Frances Sharpe.



eFIGURE 2.4 Copyright Milan Stevanovic and Frances Sharpe.

CRITICAL POINTS *Pyogenic Flexor Tenosynovitis*

Indication

- Septic flexor tenosynovitis

Preoperative Evaluation

- Clinical examination is the hallmark of diagnosis.
- Laboratory evaluation may include uric acid and rheumatoid factor in addition to CBC, depending on suspicion of nonpyogenic process.
- Radiographs to evaluate for foreign body or fracture, or for joint space widening suggesting joint effusion

Pearls

- Pain with palpation along the flexor tendon sheath and pain with passive extension are most useful in diagnosing early disease.
- Urgent surgical treatment, especially in a patient with diabetes or immunocompromise, reduces the morbidity associated with this infection.

Technical Points

- Perform early decompression with complete midlateral incision of the finger.
- Incise dorsal to Cleland's ligament.
- Irrigate the sheath until the effluent is clear.
- Use wick to keep the proximal and distal incisions open.

Pitfalls

- Delayed surgical treatment
- Inadequate decompression
- Injury of the digital neurovascular structures

Postoperative Care

- Intravenous antibiotics
- Pain management to allow early range of motion
- First dressing change between 8 and 12 hours
- Soaks in dilute povidone-iodine solution three times per day with range-of-motion exercises
- Repeat débridement and irrigation in 48 hours if Kanavel's signs not resolving.

the first 48 to 72 hours. Intravenous antibiotics are continued for 7 to 10 days or until clinical improvement is seen. After this, oral antibiotics are continued to complete a 4-week course of therapy.

If the clinical signs of infection are not improving in the first 24 to 36 hours, the patient is returned to the operating room for a repeat irrigation and débridement. Repeat cultures are obtained, and organism-specific intravenous therapy is continued. A low threshold for return to the operating room should be used in diabetics and immunocompromised patients.

Most patients with pyogenic tenosynovitis, if treated promptly with adequate surgical débridement, appropriate antibiotics, and therapy, will improve rapidly. Patients usually have an almost immediate sense of relief of the severe throbbing pain that was present before treatment. Wound healing of the volar incision occurs quickly as soon as the wicking is discontinued. The midlateral incision heals by secondary intention over the course of 10 to 20 days. When the swelling subsides, Steri-Strips™ can be used to bring the wound edges together, shortening the healing time. Despite healing by secondary intention, the midlateral scar is usually painless. Over time, the scar becomes soft and essentially unnoticeable. The reported range of motion after flexor tendon sheath infection varies. Ten to 20% of patients fail to recover a full range of motion. A more rigorous analysis of motion showed that only two thirds of normal motion was present at 6 weeks. This improved to 80% of normal motion at a 30-month follow-up.[15]

The more severe the initial presentation, the greater is the likelihood of complications and an adverse outcome. Maloon and associates identified three risk factors for a poor prognosis: 1) diabetes, 2) late presentation, and 3) association with a human bite.[94] Pang and colleagues identified five risk factors associated with a poor outcome, including 1) age over 43 years; 2) diabetes mellitus, peripheral vascular disease, or renal failure; 3) presence of subcutaneous purulence; 4) digital ischemia; and 5) polymicrobial infection. Patients with no purulence and no ischemia had no amputations and recovered 80% of the total active range of motion (TROM). Patients with subcutaneous purulence but no ischemia had an 8% risk of amputation. This group recovered 72% of the TROM. Patients with subcutaneous purulence and ischemic changes had an amputation rate of 59% and recovered only 49% of the TROM.[119] Any infection of the flexor tendon sheath may cause scarring and adhesions within the sheath, limiting flexor tendon excursion and gliding. Manipulation under local anesthesia in the first 2 to 4 weeks following treatment may have value in breaking up adhesions before dense scarring occurs. Tenolysis should not be considered until the infection has completely resolved and the patient has failed to improve with occupational therapy. Although we have not had to perform a tenolysis following pyogenic FTS, we would recommend at least 6 months of therapy following resolution of infection to allow for tendon recovery before additional procedures. Passive motion should exceed active motion for a tenolysis alone to improve function. Stiffness of the PIP or DIP joint is not uncommon, particularly if early motion is not initiated or if the patient is noncompliant with therapy. Soft tissue necrosis occurs rarely. Local débridement should be done as needed. When the infection is controlled, healing by secondary intention will occur. If the flexor tendon is exposed, local flap coverage should be considered, especially in patients who have good tendon gliding. Late treatment or severe infection may result in tendon necrosis. This requires excision of the necrotic tendons from the level of the A1 pulley to its distal insertion. In our experience, staged reconstruction of the tendon sheath and tendon grafting is difficult and often has suboptimal outcome. In the index and small finger with tendon necrosis, amputation may be considered, because this is more likely to improve functional outcome and shorten the healing time. Severe flexor tendon sheath infections with tendon necrosis in conjunction with pyarthrosis of any digit except the thumb may best be treated by amputation.

Radial and Ulnar Bursal and Parona Space Infections

Pertinent to the treatment of pyogenic flexor tenosynovitis are infections of the radial and ulnar bursae of the palm and the Perona space at the wrist. Infections in these spaces occur rarely in isolation but are more commonly associated with flexor tendon sheath infections of the small finger or thumb.

Pertinent Anatomy

Radial Bursa. The radial bursa is a continuation of the tendon sheath of the flexor pollicis longus (FPL) tendon. The sheath begins at the base of the distal phalanx of the thumb.

Technically, the sheath ends at the metacarpophalangeal (MP) joint. The radial bursa begins at this level and includes the length of the FPL tendon through the carpal canal. It ends 1 to 2 cm proximal to the proximal edge of the transverse carpal ligament. It is considered a separate bursal space from the FPL tendon sheath, even though in adults it was contiguous with the sheath in 95% of specimens.[136]

Ulnar Bursa. The ulnar bursa begins at the proximal end of the small finger flexor tendon sheath. The bursa widens more proximally, overlapping the mid fourth metacarpal and the proximal base of the third and fourth metacarpals. The bursa lies ulnar to the flexor tendons, which are invaginated into the bursa but not surrounded by it. The relationship of the small finger flexor tendon sheath with the ulnar bursa is less consistent than the relationship between the flexor tendon sheath of the thumb and the radial bursa. Early studies showed direct continuity in only 50% of specimens. Other studies have demonstrated a higher rate of communication, often with an hourglass-type narrowing between the small finger tendon sheath and the ulnar bursa. Communication between the radial and ulnar bursae occurs in 85% of specimens.[136]

Proximal to the transverse carpal ligament, the radial and ulnar bursae lie deep to the FDP tendons and above the fascia of the pronator quadratus muscle. Communication between the radial and ulnar bursae can occur across this space, known as the potential Parona space.[92]

Parona Space

The Parona space is the deep potential space in the distal volar forearm. It lies between the fascia of the pronator quadratus muscle and the sheath of the FDP tendons. It is in continuity with the midpalmar space. Although infections of the Parona space most commonly result from extension of infection from either the radial or ulnar bursa, the Parona space is not in direct continuity with these bursae. Rupture of these bursae due to infection leads to involvement of the Parona space. Also, radiocarpal joint infection may rupture through the volar capsule and spread into the Parona space. Isolated infection of the Parona space can occur after a penetrating injury or, rarely, as a spontaneous (hematogenously spread) deep space infection.

Clinical Presentation and Preoperative Evaluation

Because radial and ulnar bursal infections rarely occur in isolation, the clinical presentations of these infections are similar to those of pyogenic flexor tenosynovitis of the thumb and small finger. In addition to the cardinal signs of Kanavel, there may be swelling and tenderness along the thenar or hypothenar eminence. The adjacent fingers assume a flexed posture, as does the wrist. Although the uninvolved fingers may not be swollen, passive extension is painful. Kanavel believed that the most valuable sign of ulnar bursal infection was the presence of tenderness at the junction of the distal flexion crease of the wrist and the hypothenar eminence. In a similar manner, the most valuable sign for radial bursal infections was tenderness at the junction of the distal wrist flexion crease and the thenar eminence.[75]

Extensive swelling may not be evident, because the bursae rapidly become necrotic. Accumulation of pus does not occur, because the bursae rupture and decompress into the surrounding space. The infection can track into the adjacent bursa through intrabursal communication or across the potential space of Parona. An ascending infection along the opposite border digit can then occur, forming the so-called *horseshoe abscess*. Anatomic variations in the interconnection of the tendon sheaths occur in approximately 15% of patients.[136] Therefore, clinical examination of any flexor tendon sheath infection should include examination of the palm, wrist, and all of the adjacent fingers.

Isolated infections of the Parona space are rare but may present as swelling, tenderness, and, occasionally, fluctuance in the distal volar forearm. Digital flexion is often difficult and painful. Symptoms of numbness and tingling in the median nerve distribution may be present due to swelling or fluid present in the midpalmar space. Diagnostic ultrasound or MRI can be useful in demonstrating fluid within this space. More commonly, Parona space infections are associated with tendon sheath infections of the thumb and small finger. In a series of nine patients, the most common site of spread of infection was from the thumb flexor tendon sheath (seven of nine patients). Interestingly, in this group of patients, β-hemolytic *Streptococcus* was cultured from five of nine specimens.[142]

Treatment

Ulnar and radial bursal infections rarely occur in isolation but are a part of pyogenic flexor tenosynovitis, most commonly of the thumb and small finger. There is no role for nonsurgical treatment of this condition. These infections can cause rapid destruction of the bursal sheath, swelling within the carpal tunnel causing acute median nerve symptoms, and scarring and adhesions between the superficial and deep flexor tendons. Prompt surgical treatment is necessary. The septic flexor tenosynovitis must be treated in conjunction with the bursal infection. There is no general consensus regarding the surgical incision, use of drains, or open versus closed management with catheter irrigation. The following techniques have been described.

Open Treatment. Open treatment of ulnar bursal infections, as described by Boyes, included two separate incisions. The first incision is placed parallel to the proximal edge of the A1 pulley. It can be extended proximally along the radial margin of the hypothenar crease. The proximal end of the bursa in the forearm is exposed through a 3-inch incision, beginning just proximal to the wrist flexion crease. The incision parallels the volar edge of the distal ulna. The flexor carpi ulnaris and the dorsal sensory branch of the ulnar nerve are retracted volarward. By retracting these structures, the pronator quadratus muscle is exposed. The bulge of the ulnar bursa is easily visualized and opened. Cultures should be taken, and the wound is copiously irrigated from proximal to distal. Similarly, treatment of radial bursal infections is done through a distal incision placed at the level of the thumb MP joint. Boyes believed that the radial bursa could best be treated through the same proximal incision as the ulnar bursa, dissecting radially across the volar floor of the pronator quadratus to reach the radial bursa. He described a separate radial incision along the flexor carpi radialis; however, he believed this was superfluous when the ulnar incision was used. For advanced infections, Boyes advocated proximal extension of the palmar incision to include the decompression and drainage of the carpal tunnel. Drains are placed in the bursa and brought out through the skin; they are removed after 48 hours so that exercises can be started.[18]

For isolated Parona space infections, we prefer the incision described for the treatment of the ulnar bursa. Only the proximal incision is necessary. In cases in which there are associated carpal tunnel symptoms or an associated midpalmar infection, an extended carpal tunnel incision is necessary to drain both the midpalmar and Parona spaces.

❖ AUTHORS' PREFERRED METHOD OF TREATMENT

We treat bursal infections by first addressing the flexor tendon sheath infection when present. The exposure of the distal bursa is the same as that described by Boyes.[18] When a tendon sheath infection is present, the same incision used for exposure of the proximal tendon sheath is used for the distal exposure of the bursa. The proximal incision for ulnar bursal infections is a longitudinal incision beginning at the proximal wrist flexion crease. The incision is extended proximally for 5 cm, paralleling the radial margin of the flexor carpi ulnaris. The superficialis and profundus tendons are retracted radially. The flexor carpi ulnaris and ulnar neurovascular structures are retracted ulnarly. The bursa is exposed, opened, and drained. Cultures are taken. Proximal-to-distal irrigation with a 14- or 16-gauge angiocatheter or No. 5 pediatric feeding tube is performed using normal saline. The irrigation is continued until the distal effluent is clear. Radial bursal infections are treated in the same manner. Our incisions are the same as described under through-and-through treatment.

The incisions are left open. A ¼- to ½-inch Penrose drain is placed in the proximal incision site, at the pronator fascia. Distally, a moist gauze wick is used to keep the incision open.

For isolated Parona space infections, we prefer the incision described for the treatment of the ulnar bursa. Only the proximal incision is necessary. If carpal tunnel symptoms or a midpalmar infection are present, an extended carpal tunnel incision is necessary to drain both the midpalmar and Parona spaces.

Postoperative Management and Expectations

The postoperative management of bursal infections is the same as that described for flexor tendon sheath infections. We remove the Penrose drain at 24 to 48 hours.

Outcomes after bursal infections are generally not as favorable as for isolated flexor tenosynovitis. Tendon adhesions, flexion contracture of the fingers and wrist, and restricted motion are more likely to occur. Tenolysis for recalcitrant adhesions may be necessary if therapy does not adequately restore function.

Deep Space Infections

The hand has three anatomically defined potential spaces. These septated spaces lie between muscle fascial planes (Figure 2.11, *A*); they are the *thenar, midpalmar*, and *hypothenar spaces* in the hand. There are three more superficial spaces in the hand, the *dorsal subcutaneous space, dorsal subaponeurotic space*, and *interdigital web space*. Infections of these spaces are different from deep space abscesses in that they do not have well-defined anatomic borders; their presentations are similar to those of deep palmar space abscesses, however. Deep palmar space infections are increasingly rare, likely due to early recognition and surgical treatment of infections and improved antibiotic therapies.

Palmar Space Infections

Clinical Presentation and Preoperative Evaluation. Deep space infections are most commonly caused by penetrating trauma. In thenar and midpalmar space infections, infection can occur from spread from a septic tendon sheath (thumb, index, or long

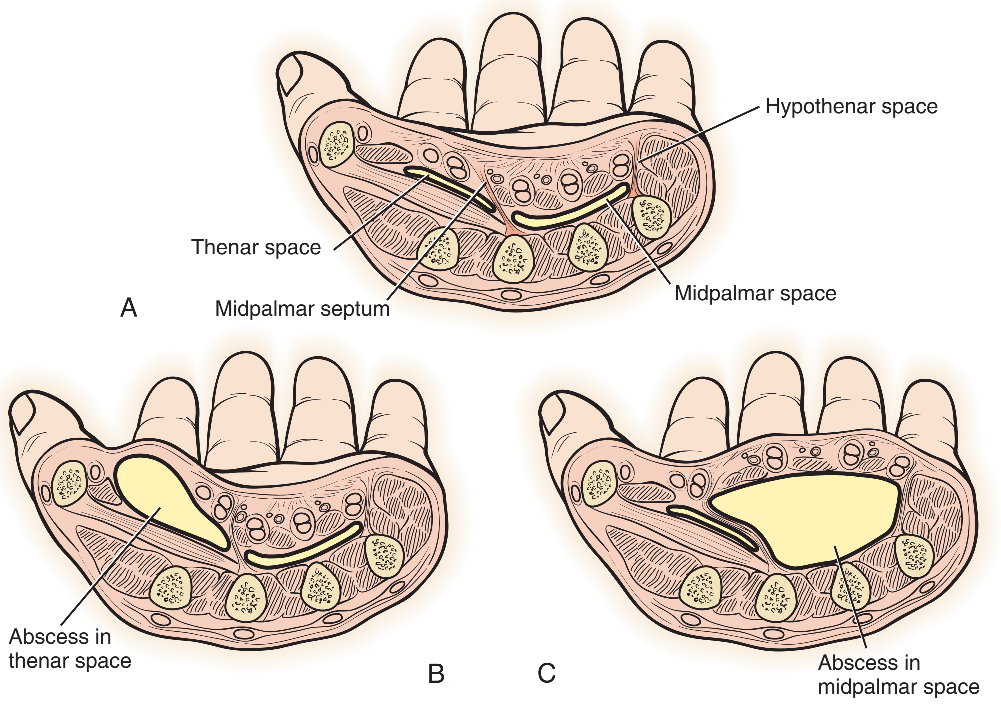


FIGURE 2.11 Deep palmar spaces. **A**, Potential spaces of the midpalm. **B**, Thenar space abscess. **C**, Midpalmar space abscess. (Copyright courtesy of Milan Stevanovic and Frances Sharpe.)

TABLE 2.3 **Characteristics of Deep Palmar Space Infections**

Space	Thenar Space (Figure 2.11, *A* and *B*)	Midpalmar Space (Figure 2.11, *A* and *C*)	Hypothenar Space (Figure 2.11, *A*)
Characteristics	Most common of deep space infections; can often track dorsally into space between first dorsal interosseous muscle and adductor pollicis muscle; can be confused with dorsal subcutaneous abscess if dorsal extension of abscess cavity	Rare infection	Extremely rare; distinctly separate anatomic space; is not in continuity with any of the flexor tendon sheaths
Boundaries	Dorsal: Fascia of adductor pollicis, second volar metacarpal, and first volar interosseous fascia Volar: Tendon sheath of index finger and radial palmar fascia Radial: Confluence of adductor pollicis fascia and palmar fascia at base of thumb proximal phalanx Ulnar: Midpalmar oblique septum	Dorsal: Fascia overlying second and third volar interosseous muscles and periosteum of third, fourth, and fifth metacarpals Volar: Flexor sheaths of long, ring, and small fingers and palmar aponeurosis Radial: Midpalmar oblique septum Ulnar: Hypothenar septum	Dorsal: Periosteum of fifth metacarpal and fascia of deep hypothenar muscles Volar: Palmar fascia and fascia of superficial hypothenar muscles Radial: Hypothenar septum Ulnar: Fascia of hypothenar muscles
Proximal and distal boundaries	Distal: Deep transverse fascia at level of MC head Proximal: Base of palm	Distal: Deep transverse fascia at level of MC head Proximal: Base of palm	Distal: Deep transverse fascia at level of MC head Proximal: Base of palm
Clinical findings	Swelling and exquisite tenderness of thenar eminence; thumb is abducted; pain with passive adduction	Dorsal swelling predominates; loss of palmar concavity (becomes convex); flexed posture of fingers (long and ring); pain with passive extension of fingers, but less than with septic flexor tenosynovitis	Localized tenderness and swelling of hypothenar eminence; no palmar swelling; no finger or flexor tendon sheath involvement

finger for thenar space and long, ring, or small finger for midpalmar space). Local spread from a subcutaneous abscess that tracks deep into the space can also be a route of infection.

Both thenar and midpalmar space infections often present with swelling involving the entire hand, particularly on the dorsal side. The tight fascia on the palmar surface of the hand limits the amount of volar swelling. The more loosely arranged connective tissue dorsally allows greater expansion of the soft tissue in this area. This dorsal swelling should be distinguished from local dorsal abscess and dorsal cellulitis. All of the deep palmar space infections will have areas of palmar swelling and exquisite tenderness localized over the involved palmar space. Hypothenar infections generally have less dorsal swelling.

Preoperative evaluation includes a careful history of the mechanism of injury and relevant comorbidities. Laboratory evaluation should include a CBC. Radiographs should be routinely obtained to evaluate for a retained foreign body, underlying osteomyelitis, or fracture. Aspiration, ultrasound, or MRI may be useful in identifying an abscess. If the clinical presentation strongly suggests a deep infection, a negative aspiration should not negate surgical exploration.

Pertinent Anatomy. The thenar and midpalmar spaces of the hand are located dorsal to the flexor tendons and volar to the metacarpals and interosseous muscle fasciae. They are divided by the midpalmar (oblique) septum, which extends from the palmar fascia to the volar diaphyseal ridge of the third metacarpal. The midpalmar space is separated from the hypothenar space by the hypothenar septum, which extends from the volar ridge of the fifth metacarpal shaft to the palmar aponeurosis (Table 2.3).

Treatment. There is no role for nonsurgical management of deep space infections. These should be treated as surgical emergencies. Intravenous antibiotics are started, preferably after obtaining a culture either from the site of a draining wound or from an aspirate of the affected palmar space. If the patient cannot be taken immediately to the operating room and cultures cannot be obtained from an aspiration, then antibiotic therapy with good staphylococcal coverage should be initiated.

Thenar Space. Incisions to drain the thenar space should provide adequate exposure of the affected areas. It is also important to make incisions that will not lead to subsequent contracture. Access to the thenar space requires that an incision be placed near neurovascular structures, specifically, the recurrent motor branch of the median nerve, the digital nerves to the thumb and radial side of the index finger, the princeps pollicis artery, and the proper digital arteries. Careful dissection is necessary to avoid injury to these structures.

Drainage of the thenar space abscess has been described through dorsal, volar, or combined volar and dorsal incisions. We avoid the dorsal transverse incision owing to the risk of web space contracture. Combined approaches should not be connected through the web space, as they can also lead to contracture and/or a painful scar.

Volar Approach (Thenar Crease). An incision is made on the palmar surface of the hand just adjacent and parallel to the thenar crease (Figure 2.12, *A*). The incision begins

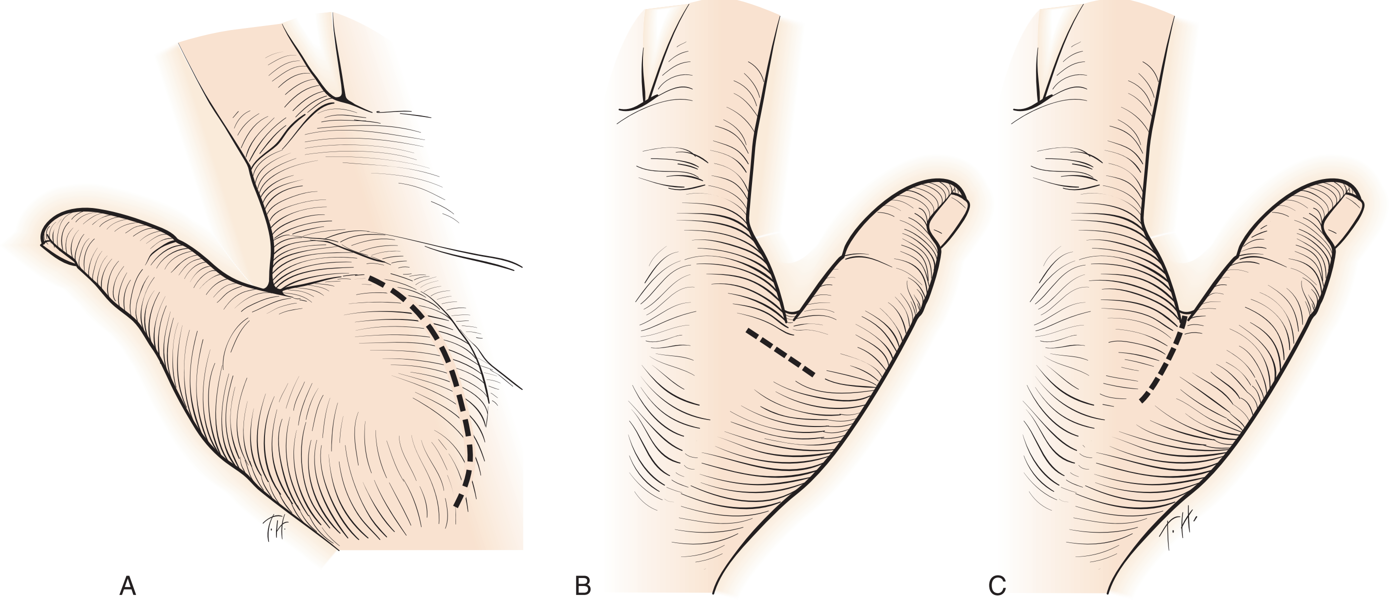


FIGURE 2.12 Incisions for drainage of the thenar space. **A**, Thenar crease approach. Motor recurrent branch of the median nerve is at risk in dissection. **B**, Dorsal transverse approach. Transverse incision is not favored as this can lead to a web space contracture. **C**, Dorsal longitudinal approach. (Copyright courtesy of Milan Stevanovic and Frances Sharpe.)

approximately 1 cm proximal to the web space and continues proximally for 3 to 4 cm. Blunt dissection through the palmar fascia is carried out toward the adductor pollicis muscle until abscess is encountered. In the proximal portion of the deep dissection, particular attention is necessary to protect the motor branch of the median nerve. After the area has been drained adequately, the dissection is extended over the distal edge of the adductor to decompress the first dorsal interosseous space.

Dorsal Longitudinal Approach. A straight or slightly curved longitudinal incision is made in the dorsum of the first web space, starting proximal to the web and extending perpendicular and proximal to the web, bisecting the interval between the first and second metacarpals (see Figure 2.12, *C*). The dissection is continued deeper into the interval between the first dorsal interosseous and the adductor pollicis, at which point pus should be encountered.

Combined Dorsal and Volar Approach. Two incisions are made: one dorsally, which is the slightly curved longitudinal approach described earlier, and one volarly, which parallels the thenar crease. Each approach is used to drain the corresponding half of the space. A separate drain is used for each incision, but through-and-through drains are not used.

Midpalmar Space. Various skin incisions have been described for decompression of the midpalmar space. These include the (1) transverse incision in the distal crease (Figure 2.13, *A*); (2) combined transverse and longitudinal approach (see Figure 2.13, *B*); and (3) curved longitudinal approach (see Figure 2.13, *C*). Whichever skin incision is used, the common digital nerves and arteries as well as superficial palmar arch are protected. The flexor tendons of the ring finger are used as a guide to the midpalmar space. The deep dissection is continued longitudinally on either side of these tendons until the abscess is opened.

Distal Palmar Approach Through the Lumbrical Canal. This approach was described by Kanavel not as a routine approach to midpalmar space infection but as treatment for a special circumstance, when a midpalmar space infection involves the lumbrical canal.[75] A longitudinal incision is made on the palmar surface of the third web space (between the middle and ring fingers). It extends from immediately proximal to the web and ends distal to the midpalmar crease. The incision should not cross the crease (see Figure 2.13, *D*). A clamp is inserted into the wound and directed proximally down the canal of the third lumbrical, dorsal to the flexor tendons, until the midpalmar space is entered and pus is encountered.

Dorsal Approach. A longitudinal incision is made between the middle and ring fingers or between the ring and small fingers. Blunt dissection is done above the periosteum on the ulnar side of the third metacarpal or along the radial or ulnar sides of the fourth metacarpal. Dissection is carried down between the metacarpal and interosseous muscles. Below the interosseous muscles lies the midpalmar space.

Hypothenar Space. The hypothenar space is decompressed through an incision in line with the ulnar border of the ring finger, starting just proximal to the midpalmar crease and continued proximally to 3 cm distal to the wrist flexion crease (Figure 2.14). The incision is deepened to the level of the hypothenar fascia. This layer is divided in the line of the incision. The abscess should be directly beneath it. After the purulence has been evacuated, a gauze dressing and/or Penrose drain is placed in the wound.

Deep Subfascial Space Infections

The deep subfascial spaces include the dorsal subcutaneous space, the dorsal subaponeurotic space, and the interdigital web space. The dorsal subcutaneous space is an extensive area of loose connective tissue without distinct boundaries, in which pus can accumulate over the entire dorsum of the hand. The dorsal subaponeurotic space lies deep to the extensor tendons, above the periosteum of the metacarpals and fascia of the dorsal interosseous muscles. The interdigital web spaces are areas of

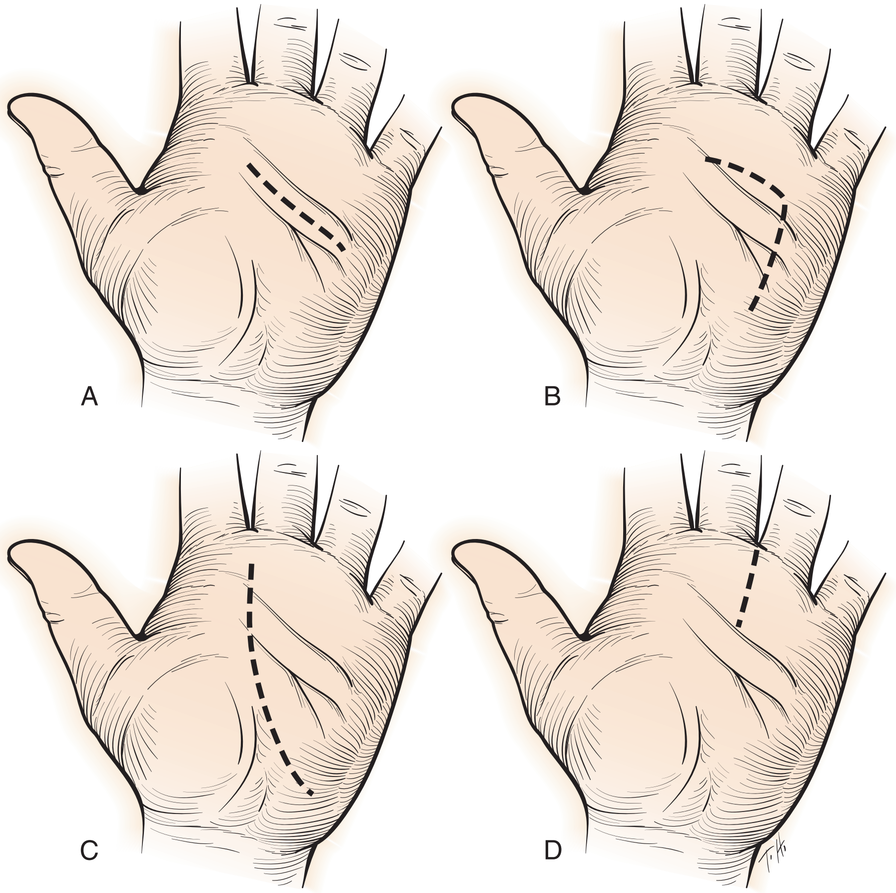


FIGURE 2.13 Incisions for drainage of the midpalmar space. **A**, Transverse incision in the distal crease. **B**, Combined transverse and longitudinal approach. **C**, Curved longitudinal approach. **D**, Distal palmar approach through the lumbrical canal. (Copyright courtesy of Milan Stevanovic and Frances Sharpe.)

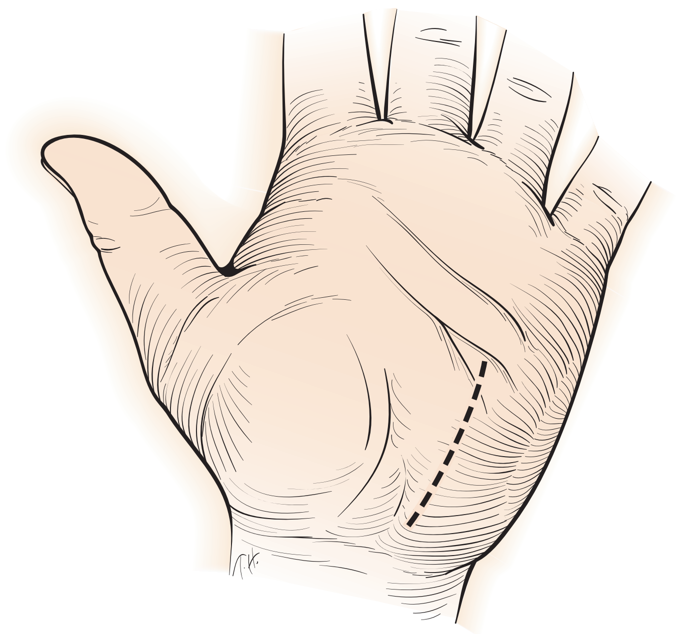


FIGURE 2.14 Approach to the hypothenar space. (Copyright courtesy of Milan Stevanovic and Frances Sharpe.)

loose connective tissue between the fingers. Infection in this area tracks both volarly and dorsally and is commonly called a *collar-button abscess*.

Clinical Presentation and Evaluation

Dorsal Subcutaneous and Dorsal Subaponeurotic Space Abscess. As with most infections of the hand, dorsal subcutaneous and dorsal subaponeurotic space infections typically result from penetrating injuries of the hand. The dorsal aspect of the hand is swollen, warm, and erythematous. The dorsal surface is tender to palpation. Fluctuance may be present. Finger extension may be difficult and is usually painful. Differentiating these infections from cellulitis or other hand infections can be difficult, because most hand infections present with dorsal swelling.

Web Space Abscess (Collar-Button Abscess). The term *collar-button abscess* refers to the hourglass shape of the abscess and the resemblance to the collar buttons used for dress shirts in the early 1900s. An infection in the web space (collar-button or collar-stud abscess) usually occurs through a fissure in the skin between the fingers, from a distal palmar callus, or from extension of an infection in the subcutaneous area of the proximal segment of a finger. The pain and swelling are localized to the web space and distal area of the palm. The adjacent fingers lie abducted from each other (Figure 2.15). The swelling may

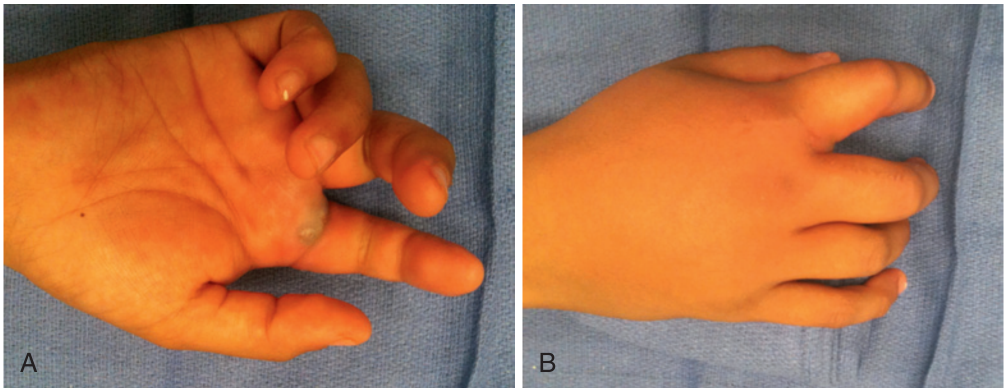


FIGURE 2.15 Clinical appearance of a patient with a collar-button abscess of the second web space, showing the abducted position of the fingers. **A**, Volar. **B**, Dorsal. (Copyright courtesy of Milan Stevanovic and Frances Sharpe.)

be more prominent on either the palmar or dorsal aspect, depending on the extent and location of the infection. Swelling is often greater on the dorsal side. However, one should not be misled into overlooking the more important volar component of this infection (Case Study 2.2).

The position of finger abduction is helpful in differentiating a collar-button abscess from a dorsal subcutaneous infection. In the dorsal subcutaneous infection, the fingers are not abducted, because there is no purulence tracking palmarly between the bases of the adjacent fingers.

Pertinent Anatomy. The dorsal subaponeurotic space is limited on its dorsal surface by the dense aponeurosis of the extensor tendons. On its volar aspect, it is limited by the periosteum of the metacarpals and the dorsal fascia of the interossei. Medially and laterally, the aponeurotic sheet merges with the deep fascia overlying the dorsal interosseous muscles, the periosteum of the first through fifth metacarpals, and the capsules of the first through fifth MP joints. Kanavel described this space as a truncated cone, with the smaller end at the wrist and the larger end toward the MP joints.

The interdigital web spaces consist of the loose areolar connective tissue between the metacarpal heads and around the deep intermetacarpal ligament. The skin of the web space is densely attached to the palmar fascia. A web space infection most commonly begins on the volar surface. The strong attachments of the palmar fascia to the skin limit the volar extension of the abscess. Therefore, the infection track is along the path of least resistance to the dorsal surface.

Treatment

Dorsal Subcutaneous and Subaponeurotic Space Abscess. Exploration of the dorsal subcutaneous and subaponeurotic spaces can be performed through one or two dorsal longitudinal incisions. The first incision is placed over the longitudinal axis of the index metacarpal. The second incision is placed between the fourth and fifth metacarpals. These incisions allow exploration of the infection to determine if this is a superficial or deep infection. The subaponeurotic space can be opened by incising along the margin of the extensor tendon. Advanced infection often involves both the dorsal subcutaneous and subaponeurotic spaces. The use of two incisions allows for good drainage of the abscess cavity, while soft tissue coverage over the extensor tendons is maintained.

Interdigital Web Space (Collar-Button Abscess). Awareness that both volar and dorsal components of infection may be present is critical for proper treatment of this abscess.

Most authors agree with both dorsal and volar incisions for treatment of these abscesses. There is agreement on the use of a dorsal longitudinal incision. The most commonly described volar incisions are the curved longitudinal and zigzag incisions. Both provide access to the volar space.

Curved Longitudinal Incision. The volar incision is begun on the radial side of the affected web space. It is continued proximally and ulnarward, stopping just distal to the midpalmar crease overlying the metacarpal of the ulnar digit involved (Figure 2.16, *A*). After the skin is divided, the subcutaneous tissue is spread with a clamp until pus is encountered. The opening in the abscess is enlarged longitudinally. Compression is applied to the dorsum of the web space by the surgeon while the volar incision is retracted. Increased drainage can be seen in the depth of the wound if there is a deep collar-button abscess.

A second incision is then made on the dorsum. It begins just proximal to the involved web space and extends proximally between the metacarpal heads for a distance of 1 to 1.5 cm or as much as is needed to decompress the abscess (see Figure 2.16, *D*). The deep tissues are divided in a plane toward the palmar abscess. When the dorsal collection is entered, the opening is enlarged in the direction of the wound. After the pus has been evacuated and the wound irrigated, gauze wicks are placed into both wounds.

One modification of this approach is a longitudinal volar incision between the metacarpals, but this provides less adequate exposure to the volar aspect of the abscess.

Volar Zigzag Approach. A zigzag incision is made on the palmar surface, starting just proximal to the web and stopping just distal to the midpalmar crease (see Figure 2.16, *B*). The flaps are reflected and the deep tissues dissected in the web while the digital arteries and nerves are retracted to either side. The superficial transverse metacarpal ligament and other fibers of the palmar fascia are divided to allow ample exposure of the volar and dorsal compartments of the dumbbell-shaped abscess. A 1.5-cm dorsal longitudinal incision is made between the bases of the proximal phalanges. Generous communication between the two incisions is established.

CASE STUDY 2.2 Collar-Button Abscess

A 35-year-old construction worker sustained a puncture wound to the left fourth web space. He presented 1 week after injury with pain, swelling, and discoloration around the web space.

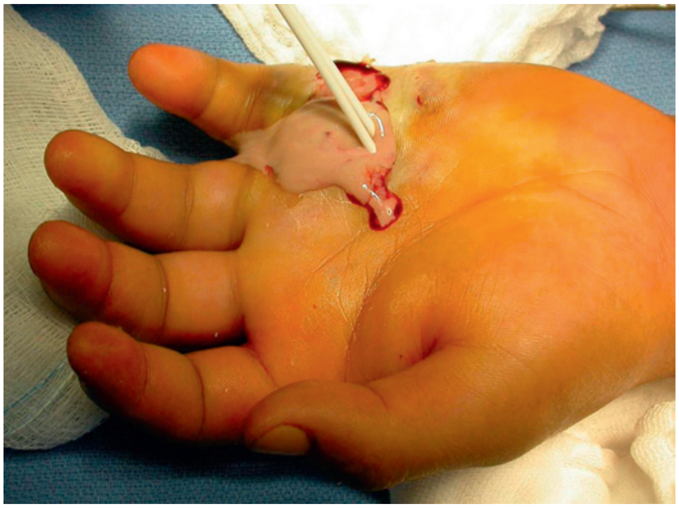
A, Initial presentation (eFigure 2.5).

B, Initial decompression (eFigure 2.6).

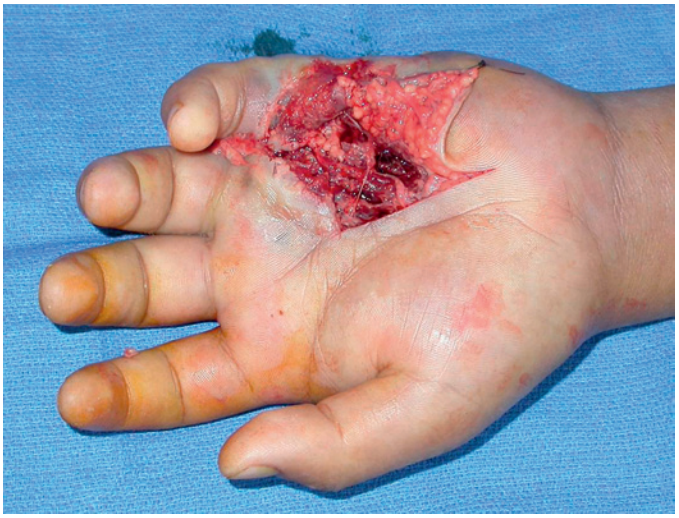
C, Proximal Brunner extension into palm to allow for adequate decompression (eFigure 2.7).

D, Dorsal longitudinal incision for débridement of dorsal component of the collar-button abscess (eFigure 2.8).

eFIGURE 2.5 Copyright Milan Stevanovic and Frances Sharpe.



eFIGURE 2.6 Copyright Milan Stevanovic and Frances Sharpe.



eFIGURE 2.7 Copyright Milan Stevanovic and Frances Sharpe.

eFIGURE 2.8 Copyright Milan Stevanovic and Frances Sharpe.

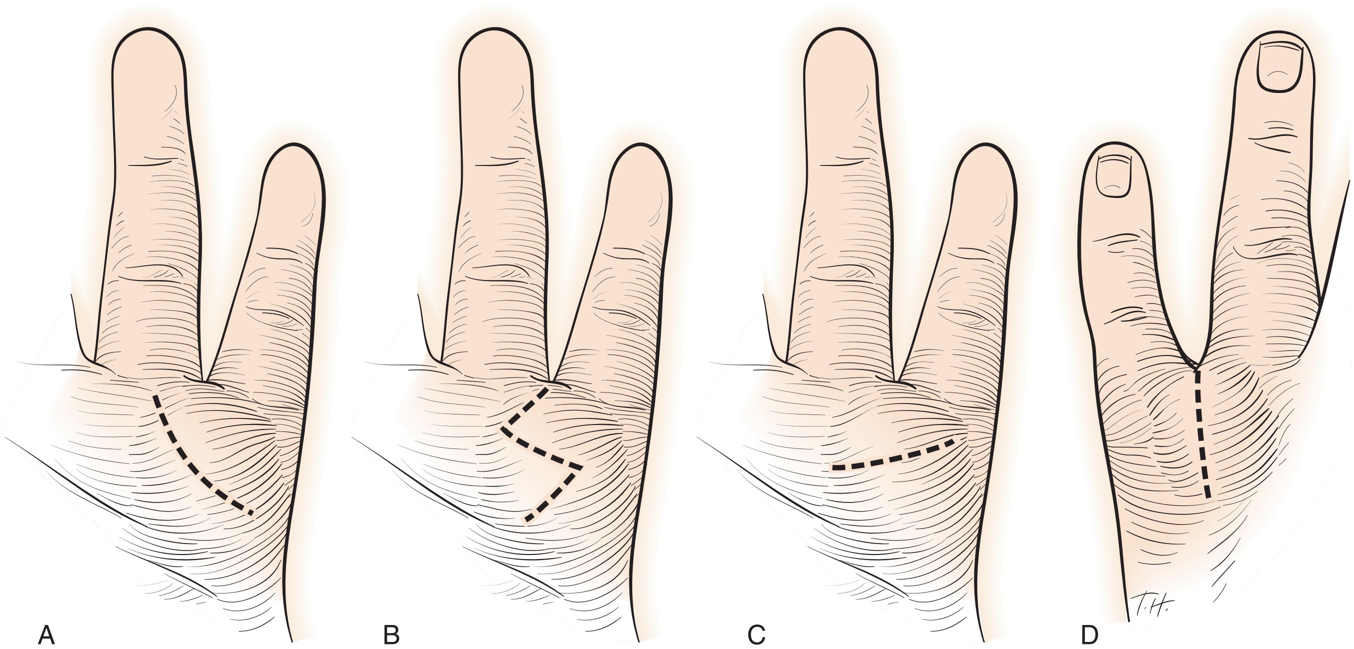


FIGURE 2.16 Incisions for web space abscesses (collar-button abscesses). **A**, Curved longitudinal incision. **B**, Volar zigzag approach. **C**, Volar transverse approach. **D**, Dorsal incision used in conjunction with any of the volar exposures. (Copyright courtesy of Milan Stevanovic and Frances Sharpe.)

Zigzag incisions provide excellent exposure for drainage of infection, but if they are left open, the flaps can retract and cause thick or tender scars. Therefore, if this incision is used, we recommend delayed primary wound closure after the infection has been controlled.

Volar Transverse Approach. Kanavel described a volar transverse incision placed parallel with the distal flexion crease of the palm over the site of maximum swelling (see Figure 2.16, *C*). He believed this was generally adequate for drainage and did not require a second incision.[75] The deep dissection is as previously described. The dorsal approach may be needed as well. One potential disadvantage of this incision is placement of the transverse limb too far distally. If this part of the incision is inadvertently carried too close to the web, a web space contracture can result.

❖ AUTHORS' PREFERRED METHOD OF TREATMENT

Thenar Space. Our preferred method of treatment for the thenar space infections is through combined dorsal and volar approaches, as described earlier. We have found that a single volar incision is not adequate to address the dorsal abscess cavity between the adductor and first dorsal interosseous muscle. Similarly, a single dorsal incision, whether it is transverse or longitudinal, can provide access to the volar abscess, but it is more difficult and we have not been satisfied with our ability to adequately decompress and irrigate the involved space. We leave the wounds open, using a moist gauze wick. We occasionally use a Penrose drain on the volar side for large areas of abscess.

Midpalmar Space. Midpalmar space infections are treated as described earlier under the curved longitudinal approach. This method provides the best exposure of the midpalmar space. It is less likely to result in a severe scar contracture, because it lies adjacent to an anatomic crease. It is an extensile incision and can be used to simultaneously access the thenar space if necessary. We leave the incisions open, using a moist gauze wick as described earlier. Healing by secondary intention occurs rapidly provided the infection is well controlled and necrotic tissue has been removed.

Interdigital Web Space Abscess (Collar-Button Abscess). We use both a dorsal and volar approach to treat these infections. Our preferred incision is the curved longitudinal incision. We find that this incision provides excellent exposure of the abscess, reduces the risk of skin edge necrosis, and provides easier access for wound management. We try to avoid crossing the web space and do not connect the volar and dorsal skin incisions. If the web space is crossed, this should be done with a longitudinal rather than a transverse incision to avoid later web space contracture.

Postoperative Management and Expectations. The same principles of management apply for all deep space infections. Postoperatively, the wounds are left open. A wet gauze sponge is placed into the wounds to allow continued drainage. A bulky dressing is applied. The hand is elevated, and intravenous antibiotics are continued. The first dressing change should be done at 12 to 24 hours. At this time, the patient begins soaking in a dilute solution of povidone-iodine, as described earlier. Early motion is initiated. Therapist supervision may be necessary. Active finger and wrist motion is necessary to reduce problems of stiffness, contracture, and tendon adhesion. Intravenous antibiotics are continued for 14 to 21 days. After this, oral antibiotics are continued to complete a 4-week course of therapy.

If the clinical signs of infection are not improving in the first 24 to 36 hours, the patient is returned to the operating room for a repeat irrigation and débridement. An MRI may be helpful in identifying areas of abscess or joint effusion that need to be surgically assessed. Repeat cultures are obtained if the previous

> **CRITICAL POINTS *Deep Space Infections***
>
> **Indication**
> - Thenar, midpalmar, and collar-button abscesses
>
> **Etiology**
> - Penetrating injury is the most common source of infection.
>
> **Preoperative Evaluation**
> - Clinical examination features may provide a diagnosis, but diffuse dorsal swelling can cause difficulty in separating cellulitis from abscess.
> - Aspiration is useful but can be misleading.
> - Radiographs are necessary to evaluate for foreign body or fracture.
> - MRI is very helpful in identifying localized abscess.
>
> **Pearls**
> - Thenar space infections present as wide abduction of the thumb and difficulty with opposition.
> - Midpalmar space infections result in loss of palmar concavity; fingers are semiflexed.
> - Collar-button abscesses are distinguished by abduction of adjacent fingers.
> - Urgent surgical treatment, especially in a patient with diabetes or immunocompromise, reduces the morbidity associated with these infections.
>
> **Technical Points**
> - We prefer two incisions for thenar space infections. Use caution for the motor recurrent branch of median nerve.
> - Single volar midpalmar incision. Use caution for superficial arch and digital nerves. Deep to the midpalmar space, pay attention to the deep palmar arch and motor branch of ulnar nerve.
> - Two incisions are required for collar-button abscess. We prefer not to incise across the web space. If crossing the web space, keep incision longitudinal.
> - Use wick to keep incisions open.
>
> **Pitfalls**
> - Delayed surgical treatment
> - Inadequate decompression
> - Injury of digital neurovascular structures
>
> **Postoperative Care**
> - Intravenous antibiotics
> - Pain management to allow early range of motion
> - First dressing change between 8 and 12 hours
> - Soaks in dilute povidone-iodine solution three times per day
> - Repeat débridement and irrigation in 48 hours if symptoms not improving

culture was negative, and organism-specific intravenous therapy is continued. Tissue biopsy with specific staining to diagnose fungal or atypical infections provides information more quickly than fungal and mycobacterial cultures. A low threshold for return to the operating room should be used in diabetics and immunocompromised patients.

Deep space infections are more likely to develop scarring and stiffness of the hand and fingers. With adequate treatment and rehabilitation, 70% to 80% of patients achieve full recovery. Most patients are able to return to their previous occupations.

Complications associated with deep space infections include stiffness and contracture. Extensor lag has been reported after dorsal subcutaneous and dorsal subaponeurotic space infections. Skin necrosis either dorsally or volarly can lead to exposed tendons or neurovascular structures. These problems may require secondary procedures for soft tissue coverage and contracture release. Tendon necrosis is less common with deep space infections but can occur, particularly on the extensor surface when there may be significant soft tissue loss. Painful scar formation along the incision is reduced by proper placement of the incisions and postoperative management with desensitization, scar massage, and early motion.

Nerve injury is uncommon but can occur during treatment. Infection causes soft tissue necrosis and can distort the local anatomy. This can lead to inadvertent placement of the surgical incision. It may be difficult to recognize a nerve or vessel within an ocean of pus and necrotic tissue.

Septic Arthritis

Septic arthritis is characterized by the presence of a purulent exudate within the closed confines of a joint. It is caused by the introduction and proliferation of pyogenic bacteria within the synovium in concentrations greater than 10^5 organisms per microliter, with subsequent production of a purulent exudate. Inoculation of the joint usually occurs from penetrating trauma. *S. aureus* and streptococcal species are the most common organisms. Gram-negative, anaerobic, and mixed infections also occur, especially in the immunocompromised host. A hematogenous origin of septic arthritis should raise suspicion of gonococcal infection. Expedient treatment is important to minimize articular destruction caused by infection.

Clinical Presentation and Patient Evaluation

Abscess within the joint cavity represents a cellular and immunogenic response within the synovium and reticuloendothelial system. Bacteria replicate within the joint cavity, producing toxins. This stimulates an immunogenic response. The responding leukocytes produce bactericidal enzymes that destroy the proteoglycan matrices and collagen of hyaline cartilage. Lymphocytes and related cells form immune complexes, which also can degrade articular surfaces. As the inflammatory response continues, there is increased pressure within the joint. This forces the joint into a position of maximum potential volume, producing pseudoparalysis. The increased volume within the joint further damages the articular cartilage through pressure necrosis. Untreated, pus under pressure may erode through the joint capsule and overlying skin. Alternatively, it may erode into the subchondral bone, resulting in osteomyelitis.

Patients generally present with a history of penetrating trauma, which may be caused by bites or by splinters, thorns, hooks, needles, or any of a variety of penetrating objects. The source of the injury is important in selecting empirical antibiotic therapy for the presumptive infecting organisms. Contiguous spread from an adjacent infection can occur. In the DIP joint, other common mechanisms of occurrence are from infection or direct inoculation of a mucous cyst or from contiguous spread from a felon, paronychia, or purulent flexor tenosynovitis. In the PIP joint, contiguous spread is most commonly related to a purulent flexor tenosynovitis. At the MP joint, infection from a clenched fist injury is frequently encountered. Hematogenous spread, although uncommon, has been reported and is more likely to occur in immunocompromised patients.

The clinical findings associated with septic arthritis are swelling, redness, warmth, and pain around the affected joint.

Active or passive motion produces exquisite pain. Fluctuance within the joint may be demonstrated by ballottement. Systemic signs such as fever, chills, tachycardia, malaise, sweats, and rash may be present but are not common. The presence of systemic symptoms suggesting hematogenous seeding should alert the physician to look for a primary source of infection.

Evaluation of the patient should address any history of penetrating trauma, insect bite, or animal bite or of previous therapeutic joint injection or aspiration, or the possibility of a retained foreign body. A history of immunocompromising conditions or inflammatory conditions that may mimic joint sepsis should be obtained. Many inflammatory conditions can present as an acutely swollen and painful joint of the wrist and hand. These include gout, pseudogout, rheumatoid arthritis, systemic lupus erythematosus, psoriatic arthritis, acute rheumatic fever, sarcoidosis, and Reiter syndrome. In the case of possible hematogenously spread infection, a careful review of systems may reveal the primary nidus of infection. Retained penetrating objects, in particular palm or cactus thorns or sea urchin spines, can create a chemical synovitis that resembles an infectious process. Distinction between infectious and noninfectious processes is difficult. In these circumstances, surgical treatment is necessary, with the difference that it is very important to remove the offending nidus of inflammation if still present. Identification of gout or pseudogout crystals on fluid analysis does not exclude the possibility of a commensurate infection. If the clinical picture supports infection, surgical treatment should be performed.

Laboratory evaluation should include the WBC count, ESR, and CRP. The WBC count is elevated in less than half of patients. The ESR and CRP are usually elevated in nonimmunocompromised patients. Blood cultures should be taken, particularly when systemic symptoms are present. Culture of potential distant primary sources, such as the urine or the urethra or oropharynx, should be considered in the setting of a hematogenously spread infection.

Aspiration of small joints may be difficult, especially when trying to avoid areas of cellulitis. Fluid yields may be low. If only a small volume of fluid is obtained, it is best sent for culture rather than cell count. Radiocarpal joint aspiration is more easily performed and may help differentiate acute infection from other inflammatory processes. Aspiration through cellulitic skin should be avoided. Radiocarpal aspiration is performed through the dorsal skin, just distal to the Lister tubercle. An 18-gauge needle is introduced and directed proximally to accommodate the normal palmar tilt of the distal radius. Aspiration of the midcarpal joint or distal radioulnar joint may be necessary if no fluid is obtained from the radiocarpal joint. If fluid is not easily obtained from either the radiocarpal or midcarpal joint, 1 to 2 mL of sterile saline can be injected into the joint and then aspirated for analysis. The aspirate should be sent for gram-stained smear, crystal analysis, and aerobic and anaerobic cultures. If adequate aspirate is available, cell count, fluid protein and glucose levels, and fungal and mycobacterial cultures should be obtained. The WBC count from the aspirate of more than 50,000/mm^3 suggests joint sepsis. A lower WBC count with a high percentage of polymorphonuclear cells (>90%) can indicate an early joint infection. A high WBC count (>90,000/mm^3), regardless of the percentage of polymorphonuclear cells, should be treated as an acute infection. A synovial fluid glucose value of 40 mg/dL or less than the fasting blood glucose level also supports a septic process.

Radiographs are useful to evaluate for a retained foreign body, osteomyelitis, or gas within the joint or soft tissues indicating clostridial or other anaerobic infections. Initially, radiographs may show joint capsular distention and periarticular soft tissue swelling. Joint space narrowing on radiographs is seen as a late sequela of septic arthritis. MRI, when necessary, is a sensitive and specific technique of identifying a joint effusion.

Treatment

Septic arthritis of the hand or wrist is treated as a surgical emergency. Articular destruction from proteolytic enzymes and toxins that degrade glycosaminoglycans begins in the first 24 hours of infection. The principle of treatment for all septic joints is prompt surgical drainage. Serial aspiration has been proposed as a form of treatment for septic joint infection. In the hand and wrist, aspiration is useful diagnostically but is therapeutically unpredictable. Leslie and colleagues reported superior results with formal arthrotomy of the shoulder joint over serial aspiration. The same principle applies to the hand, where serial aspiration of small joints is more difficult and less reliable.[83] Serial aspiration should only be considered when the patient is not medically stable for formal treatment.

Infections of the Wrist Joint (Radiocarpal, Ulnocarpal, and Midcarpal Joints)

Arthrotomy of the wrist joint may include arthrotomy of the radiocarpal and ulnocarpal joints, as well as the midcarpal and distal radioulnar joints. This can be accomplished through the standard dorsal approach to the wrist joint. This is done through a longitudinal incision centered slightly ulnar to the Lister tubercle. The retinaculum between the third and fourth extensor compartments is opened. The extensor pollicis longus tendon is identified and retracted radially. The underlying joint capsule is exposed. The capsule can be opened longitudinally or with a "T" incision. A longitudinal or T-capsular incision provides adequate exposure of the joint and can easily be left open to allow continued drainage. The ligament-sparing incision is an excellent approach to the wrist joint. In the case of sepsis, the capsular flap does not have to be completed. Transverse incisions to separately open the radiocarpal and midcarpal joints can be used, and capsular windows can be created to allow ongoing drainage. Culture of the joint fluid is obtained. The joint is copiously irrigated with gravity irrigation or bulb syringe. Pulsed lavage is not used, because this can cause additional soft tissue injury. The joint is taken through flexion and extension during the irrigation to maximize removal of purulent material. Articular surfaces are inspected for discoloration, areas of thinning, or softness. Necrotic tissue and inflammatory synovium are removed as indicated. Synovial tissue should be sent for culture and histologic studies. At the completion of irrigation, the joint capsule is left open. A gauze wick is placed down into the capsule to maintain a path for continuous drainage. Alternatively, the capsule may be closed over a drain. The skin incision is left open. One or two loosely placed sutures can be used to keep the skin edges from retracting. If the skin edges are markedly retracted, Steri-Strips can be placed to gently approximate the skin edges as the swelling decreases. A transverse skin incision can also be used to approach the joint, which results in a more cosmetic scar with less skin edge retraction. However, it is not extensile and may not provide adequate exposure in all circumstances.

Arthroscopic débridement and lavage of the infected radiocarpal joint may be a useful alternative to open débridement. Viewing and working portals are established; usually the 3-4 portal is used for viewing and for fluid ingress. The working portal may be the 6R or the 4-5 portal. An 18-gauge needle attached to intravenous tubing can be placed in the 6U portal for additional fluid egress. Arthroscopic irrigation and débridement has been shown in one study to decrease the number of surgical procedures and hospital stays in those patients with a single septic joint.[133]

Metacarpophalangeal Joint

The MP joint can be opened through a dorsal longitudinal or dorsal curvilinear incision. If a wound is present, the incision is designed to incorporate the wound and excise the wound margins. The skin flaps are elevated, and the extensor mechanism is defined. The joint capsule is exposed either through longitudinal splitting of the extensor tendon hood or through an incision in the sagittal band adjacent to the tendon. The MP joint capsule is often thin and inadvertently opened through the same incision. Once the joint is open, it is copiously irrigated with saline. Longitudinal traction opens the joint space and allows better access of the irrigant to the volar recesses of the joint. The joint should be carefully inspected for any articular surface damage or a retained foreign body, especially in the scenario of MP joint infection resulting from a clenched fist injury, described later under human bite injuries. The joint capsule and wounds are left open and covered with a moist gauze dressing.

Proximal Interphalangeal Joint

Arthrotomy of the PIP joint is performed through a midaxial incision. This incision avoids exposure of an injury to the central extensor tendon slip. The midaxial incision is placed from the distal margin of the interdigital web space and continued in the midaxial line to the level of the DIP joint. In the index finger, the incision is preferentially placed on the ulnar side of the finger. In the small finger, the incision is placed on the radial side. The central two digits can be accessed through either radial or ulnar incisions. If this approach is used for the thumb MP or interphalangeal (IP) joints, a radial incision is preferred. When the incision is correctly placed, the proper digital nerves lie protected in the volar skin flap (Figure 2.17, *A*). However, the dorsal sensory branch of the digital nerves can be jeopardized by this approach. The transverse retinacular ligament is incised, exposing the collateral ligament complex. The PIP joint is entered by excision of the accessory collateral ligament (see Figure 2.17, *B*), followed by capsulectomy. Alternatively, the joint may be exposed through subperiosteal elevation of the proximal origin of the collateral ligament. The joint is thoroughly débrided and irrigated. Inspection of the articular surfaces may be difficult through this incision, but a blunt probe or Freer elevator can be used to palpate the cartilage for areas of erosion or softening. The capsule and wounds are left open and covered with a moist gauze dressing.

Wittels and associates described a combined radial and ulnar midaxial incision for drainage. In conjunction with their functional rehabilitation, this provided very satisfactory results.[170] A dorsal arthrotomy is sometimes necessary due to the presence of a dorsal wound. In these cases, the central extensor slip and dorsal capsule are often injured or disrupted. This frequently leads to the development of a septic boutonnière deformity. When a septic PIP joint is encountered in this setting, the wound is extended proximally and distally. The arthrotomy and capsulectomy are performed adjacent to the central slip, if it is intact.

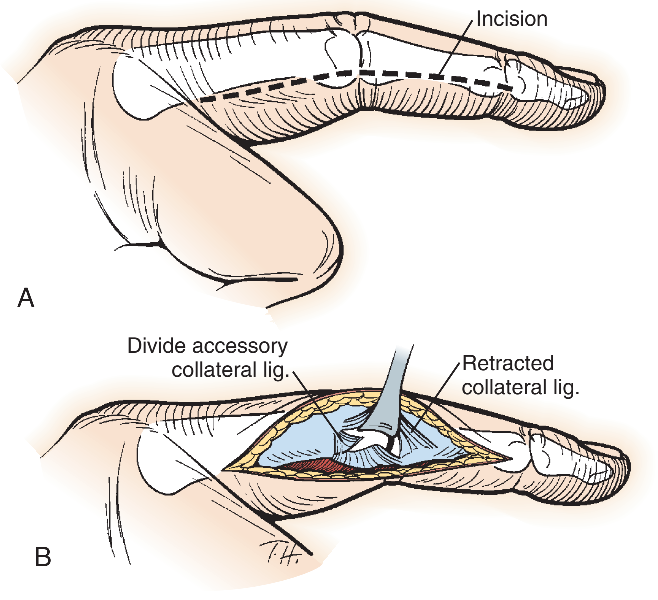


FIGURE 2.17 Lateral approach to the PIP joint. **A**, Skin incision. **B**, Arthrotomy is performed through the lateral ligamentous complex, dividing the accessory collateral ligament. (Copyright courtesy of Milan Stevanovic and Frances Sharpe.)

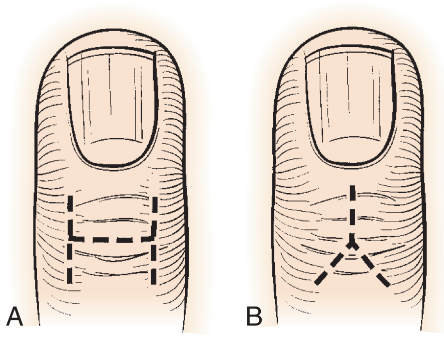


FIGURE 2.18 Dorsal approach to the DIP joint. **A**, "H" incision. **B**, Reverse "Y" or Mercedes incision. (Copyright courtesy of Milan Stevanovic and Frances Sharpe.)

Distal Interphalangeal Joint

The DIP joint is opened through a dorsal "H" incision or through a dorsal reverse "Y" or Mercedes incision (Figure 2.18). Skin flaps are elevated over the terminal extensor tendon. The terminal tendon is retracted to the side, and the capsule is opened. It is important to protect the tendon insertion because injury can result in a mallet finger deformity. Alternatively, the midaxial incision as described for PIP joint arthrotomy can be extended distally and used to expose the DIP joint. The collateral ligament is excised to gain access to the joint. This approach may be more useful when there is an associated flexor tendon sheath infection. The joint should be adequately débrided and irrigated. The wounds are left open.

Postoperative Management and Expectations

Surgical incisions are left open, with a gauze wick to maintain patency of the capsulectomy and allow for continued wound drainage. Moist gauze dressing changes two to three times per day prevent encrustation of the wound, which results in premature wound closure. Early range of motion is critical to postoperative treatment. This provides mechanical lavage of the joint and reduces the accumulation of pus within the joint. We prefer that patients soak the affected hand in a dilute solution of povidone-iodine, as described previously. Active, active-assisted, and passive range of motion is done during the soaking period.

Empirical intravenous antibiotic therapy is started immediately after obtaining a culture from either an aspirate or surgical culture. Antibiotic selection is then tailored to treat the bacterial pathogen. There is some controversy regarding the duration of antibiotic therapy necessary for septic arthritis. Previous recommendations have included duration of intravenous therapy between 3 and 4 weeks. More recent recommendations use shorter courses of intravenous therapy, with a switch to oral antibiotics after 10 to 14 days. Oral antibiotics are continued to complete a 4- to 6-week course of therapy. We agree with others that intravenous antibiotic therapy should be continued through symptom resolution, followed by oral antibiotics for 4 to 6 weeks. The duration of antibiotic therapy should be based on surgical findings, pathogen virulence, patient compliance, and clinical response to treatment. If clinical improvement is not seen within the first 24 to 48 hours, repeat surgical irrigation and débridement should be considered, and reexamination for underlying bone involvement should be performed. Amputation may be necessary if an infection cannot be eradicated or if an affected finger has a significant negative impact on overall hand function.[18,148] Every effort should be made to preserve the thumb, even if arthrodesis, shortening, or reconstruction is required (Figure 2.19).

Symptom resolution and functional outcome after septic arthritis are correlated with the duration of symptoms before the initiation of treatment.[50,124] Some degree of joint stiffness is expected. In one study, only 13 of 33 infections of the PIP joint treated with early surgical decompression achieved full restoration of motion.[170] Early mobilization reduces the degree of postoperative stiffness but cannot reverse the changes that have occurred in the articular cartilage resulting from sepsis. Joint space narrowing is generally seen after completion of treatment. Joint arthrosis and ankylosis can occur in any setting but are more prevalent in cases in which the presentation or treatment has been delayed.

Complications associated with septic arthritis in the hand and wrist include stiffness of the affected and adjacent joints. Tendon adhesions may occur in association with the swelling and inflammation caused by the infection or as a result of the surgical incision and may require secondary surgery. Osteomyelitis of the adjacent bones may complicate or prolong the course of treatment (Case Study 2.3). Additional surgical débridement, bone resection, resection arthroplasty, or amputation may be necessary. Late complications include arthrosis and arthritis.

Pediatric patients may have associated injury to the epiphysis and growth plate. Septic arthritis of infancy may be difficult to identify and may be complicated by concurrent illnesses resulting in a delay of diagnosis. This can result in partial or complete growth arrest and stiffness.[149]

Salvage of postinfectious arthritis may include arthrodesis, resection arthroplasty, or amputation. Implant arthroplasty in previously infected joints of the hand is very controversial. At the present time, most authors do not favor this treatment.

Septic Boutonnière and Mallet Deformity

Unique complications of septic arthritis occur at the PIP and DIP joints. Septic boutonnière deformity is a complication of pyogenic arthritis of the PIP joint. It occurs in those cases in which a virulent organism has caused rapid tissue destruction or where there has been late presentation or treatment. The intraarticular collection of purulence has reached a volume that can no longer be retained within the joint. The path of least resistance for escape is dorsally. The joint is well supported palmarly by the volar plate, which blends with the accessory collateral ligaments, and by the collateral ligaments on the sides. All these structures are thick and unyielding; therefore, the pus escapes dorsally through the thin dorsal capsule. There, it can destroy the extensor mechanism over the dorsum of the joint. The central slip is attenuated or eroded, allowing the lateral bands to slip volarward. This results in a classic boutonnière deformity. Management of this problem is difficult. However, the first priority is eradication of the joint infection and preservation of full passive range of motion and active flexion. Late boutonnière reconstruction can be done when the infection is resolved and the joint is supple (see Chapter 5). Late PIP joint fusion may be appropriate in cases of severe damage to the articular cartilage or when passive range of motion cannot be recovered.

Mallet finger deformity can occur after DIP joint sepsis. The mechanism of injury is similar to that which occurs in the PIP joint. The terminal extensor tendon is attenuated or destroyed. Delayed DIP joint fusion is the most appropriate treatment after infection is eradicated.

Osteomyelitis

Osteomyelitis is an infection of the bone. Traditionally, it has been believed that once the bone has been infected, it remains infected. In the hand, it may be possible to eradicate infection, because amputation can remove the involved digit or portion of the digit. Moreover, having options for later microvascular reconstruction means that adequate bone débridement can be undertaken with less risk of permanent structural and functional loss. In the hand, osteomyelitis is rare, likely owing to the hand's abundant vascular supply. It has been reported to represent between 1% and 6% of all hand infections.[102,126] It is often related to adjacent soft tissue or joint infection. The most commonly involved bone is the distal phalanx.[8,126]

Osteomyelitis can occur after penetrating trauma, crush injuries, contiguous spread from adjacent soft tissue infections, and hematogenous seeding and in the postsurgical setting. Penetrating trauma is the most common cause of osteomyelitis.[8,90,126] Patients with immunocompromise, vascular impairment, and systemic illness are more susceptible to developing osteomyelitis.

CASE STUDY 2.3 Septic Joint Progression to Osteomyelitis

A 48-year-old woman underwent irrigation and débridement of a cat bite wound over the thumb interphalangeal joint. Three weeks later, she was still having pain and her wound had not healed. Repeat radiographs demonstrated joint space narrowing. The patient was returned to the operating room, where osteomyelitic changes were noted in the condyle of the proximal phalanx and complete loss of articular cartilage was seen.

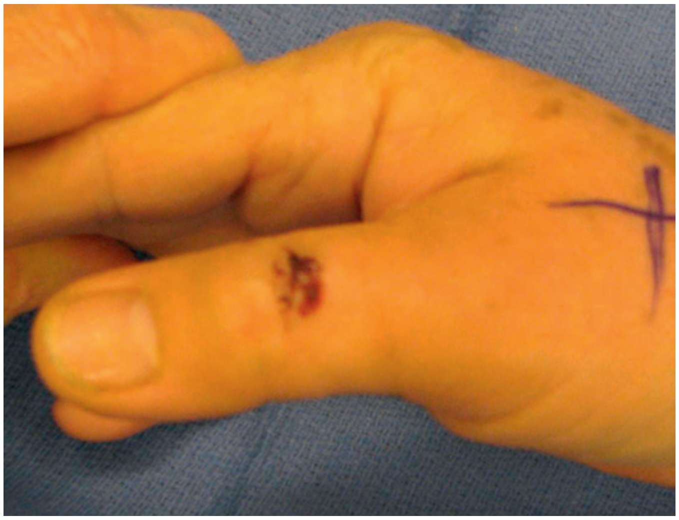
A, Initial cat bite (eFigure 2.9).

B, Initial radiographs of the thumb (eFigure 2.10).

C, Wound appearance 3 weeks after initial débridement (eFigure 2.11).

D, Radiographs at 3 weeks showing complete loss of joint space (eFigure 2.12).

E, Intraoperative findings showing loss of articular surface and erosion of the condyle of the proximal phalanx (eFigure 2.13).

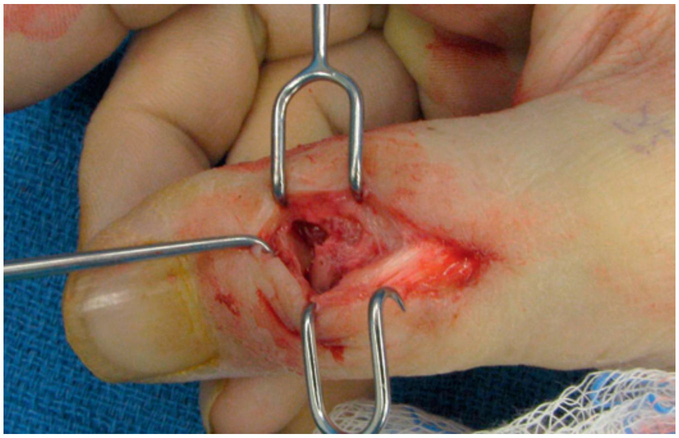


eFIGURE 2.9 Copyright Milan Stevanovic and Frances Sharpe.

eFIGURE 2.10 Copyright Milan Stevanovic and Frances Sharpe.

eFIGURE 2.11 Copyright Milan Stevanovic and Frances Sharpe.

eFIGURE 2.12 Copyright Milan Stevanovic and Frances Sharpe.



eFIGURE 2.13 Copyright Milan Stevanovic and Frances Sharpe.

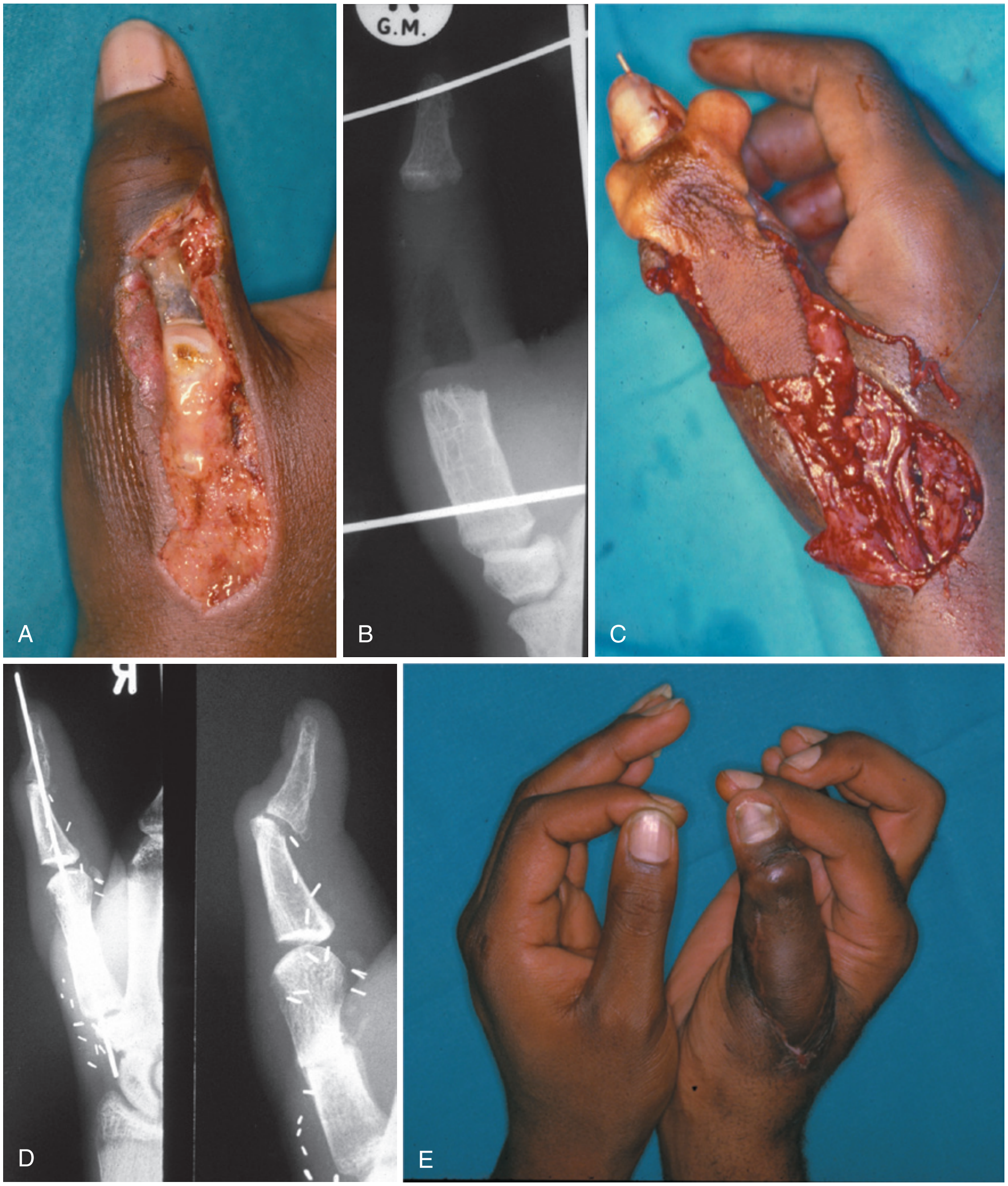


FIGURE 2.19 A 27-year-old man sustained a bite injury to his thumb during an assault. He developed a severe infection of the thumb MP joint, with subsequent spread to the metacarpal head and proximal phalanx. The volar soft tissue, flexor tendon, and neurovascular structures were intact. **A**, Open draining wound with exposed metacarpal head and necrotic proximal phalanx. **B**, Radiograph taken after resection of all necrotic bone. **C**, A free vascularized second toe transfer was used to reconstruct the bone defect, extensor pollicis longus tendon, and soft tissue defect. **D**, Radiographs immediately after surgery with Kirschner wire stabilization and at 1-year follow-up. **E**, Appearance and function of the reconstructed thumb at 1-year follow-up. There is no evidence of recurrent infection. (Copyright courtesy of Milan Stevanovic and Frances Sharpe.)

Hematogenous osteomyelitis of the hand and wrist is rare. Reilly and colleagues reported 13% of their cases were of hematogenous origin. Of those patients, half were immunocompromised.[126] Children are more susceptible to hematogenous osteomyelitis. The susceptibility to infection in the long bones in children is believed to result from the vascular arrangement around the growth plate. The long capillary loops and venous sinusoids in the metaphysis adjacent to the growth plate have a tortuous course, leading to turbulent and sluggish blood flow. These capillary loops are actually terminal branches possessing gaps that allow blood cells and bacteria to pass into the extravascular space. Once in this space, the pathogen may proliferate, causing infection. Contributing to this process is the relative acellularity of this space, decreased oxygen tension, and suboptimal phagocytic activity.[8,162] Until the age of 1 year, there is vascular continuity between the metaphysis and epiphysis via the epiphyseal plate arteries. In infants, this can lead to the spread of infection from the metaphysis into the epiphysis and