Review Article

Agricultural Injuries to the Hand and Upper Extremity

Mark Aaron Yaffe, MD
F. Thomas Kaplan, MD

Abstract

Agricultural injuries involving the hand and upper extremity are common, debilitating injuries that reflect the significant occupational hazards associated with the agricultural industry. Farm injuries occur in all age groups and are associated with significant resource utilization and treatment costs. Most of these injuries are associated with machinery, including tractors, power take-off devices, grain augers, hay balers, and combine harvesters. Each piece of machinery produces specific injury patterns and a spectrum of bone and soft-tissue injuries that are frequently characterized by the loss of a digit or limb, permanent disability, loss of function, and serious complications such as infection. Management of agricultural injuries includes expedient administration of antibiotic and tetanus prophylaxis, aggressive irrigation, serial débridement, consideration of delayed wound closure, and reconstruction or replantation of amputated digits and limbs, if feasible.

From the Indiana Hand to Shoulder Center, Indianapolis, IN.

Dr. Kaplan or an immediate family member is a member of a speakers' bureau or has made paid presentations on behalf of Auxilium; serves as a paid consultant to Auxilium, Acumed, and Innovative Medical Device Solutions; has received research or institutional support from Auxilium; and serves as a board member, owner, officer, or committee member of the American Society for Surgery of the Hand. Neither Dr. Yaffe nor any immediate family member has received anything of value from or has stock or stock options held in a commercial company or institution related directly or indirectly to the subject of this article.

J Am Acad Orthop Surg 2014;22: 605-613

http://dx.doi.org/10.5435/JAAOS-22-10-605

Agricultural injuries to the hand and upper extremity are extremely common, representing from 40% to 70% of total admissions for injuries that occur on a farm.[1-4] The severity and violence with which these injuries occur reflects the occupational dangers of the agricultural industry as a whole, which had a fatality rate of 21.2 per 100,000 workers in 2012, higher than any other industry, including mining or construction.[5] The risk of fatality associated with farming is more than five times higher than the aggregate rate for all other occupations.[6]

Traumatic amputation of the fingers and high-energy open fractures of the radius and ulna are among the most common upper extremity injuries caused by entanglement in farm machinery.[7-9] Other serious injuries caused by farm equipment include lacerations, hand and limb amputations, multilevel fractures, and crush injuries to the hand and upper extremity; most of these injuries result in some degree of permanent disability.[1,3,9]

Epidemiology

Although the median age of patients who sustain serious farm injuries ranges from 39 to 44 years,[1,3] agricultural injuries commonly affect children younger than 17 years and those older than 65 years, which reflects the participation of the entire family in agricultural activities.[10] Seasonal variation in the incidence of injuries is noteworthy, with two thirds of all injuries occurring from June to November, corresponding to the most active months of crop harvest in the north central United States.[4] Farm injuries are highly gender-specific, with 90% to 97% of these injuries occurring in males.[1,10]

The root factors associated with most agricultural injuries have been studied in detail and most often include

Figure 1

Photograph of a tractor with a power take-off device (arrow).

components of inattention, complacency, rushing, or carelessness, which contribute to the decreased vigilance of the operator. Removal of safety shields and the use of machinery that does not conform to the manufacturer's or safety-sign standards is also a common contributing factor.[11-13]

The resource utilization and costs associated with management of agricultural injuries to the hand and upper extremity are significant. At one tertiary care center, >90% of admissions for farm injuries required surgical intervention, and the average hospital stay was 5 days.[1] Hand and upper extremity injuries have a significant impact on the ability to return to work. An average sick leave of 25 days and a mean period of disability of up to 135 days has been reported, and some degree of permanent impairment of hand function was common.[1,3,9,12,13] Children are particularly prone to severe hand and upper extremity injuries and machinery-related limb amputations, which require an average of seven surgical procedures and an average hospital stay of 25 days for limb-threatening injuries.[14] In 1992, the direct and indirect costs associated with management of agricultural injuries in the United States ($4.57 billion) was greater than or equal to those for management of hepatitis C and chronic obstructive pulmonary disease.[15]

Machinery Associated With Agricultural Injuries

The mechanism by which most agricultural equipment causes injury is a combination of compressive, shear, and thermal components along with contamination that results in extensive bony and soft-tissue damage.[16] The extent of the injury depends on the speed and force of the machinery, the amount of time the limb is in contact with the machine, the degree of struggle, and the method of release.[16,17] Multiple classification systems have been developed to help organize agricultural upper extremity injuries; these systems are generally based on the degree of soft-tissue loss, presence of injuries to tendons and neurovascular structures, and presence and severity of fractures and amputations.[18-22]

The machines that contribute most significantly to overall agriculture-related upper extremity trauma include tractors (10.2% to 54.3%), power take-off devices (5.4%), grain augers (6.4% to 22%), balers and thrashers (3.9%), and harvest combines (8.6% to 16%).[1,8,9] Injuries associated with these types of machinery are severe, with devastating consequences in terms of the patient's level of function and ability to return to work.

Tractors and Power Take-off Devices

Tractors are the single leading cause of occupational fatalities in agriculture, with deaths caused by rollovers being the most common.[23] In addition to acting as a primary means of transportation, tractors provide an essential power source for farm equipment (eg, hay balers, grain augers, corn pickers, blowers, manure spreaders, mowers) through the use of a cylindrical metal shaft called a power take-off (PTO) device[16,24] (Figure 1). A typical PTO spins at 500 to 1,000 rpm. Shields are provided by the manufacturer but are often inadequate, damaged, or discarded, leaving an exposed, rotating shaft.[10,24] Once a piece of clothing or glove is caught in the PTO, the person is unable to overcome the device's enormous power; it quickly pulls in the person.[16]

Common injuries sustained from tractors and PTOs include traumatic finger and upper extremity amputations, crushing and degloving injuries with complex soft-tissue defects, and serious traction injuries to the peripheral nerves and brachial plexus.[16,24] PTOs cause substantial soft-tissue damage through friction and heat, and attempts at replantation are rarely successful.[25] In a study that included 47 patients who sustained injuries caused by a PTO, 20 patients (45%) had injuries that were associated with significant permanent orthopaedic disability.[4]

Augers

Modern augers and screw conveyors are widely used to move agricultural items from one location to another and are available as independent mobile items or as part of grain handling systems such as combine harvesters, field bins, dryers, storage or silo systems, and feed mixing and distribution systems.[13] Per hour of use, augers are considered the most dangerous piece of farm equipment.[13,26] An auger is portable and composed of a long screw encased in

Figure 2

A B

Photographs of an auger (arrow) (**A**) and the characteristic upper extremity injury pattern caused by the machine: a severe mangling injury with soft-tissue loss and multiple tendon avulsions (**B**).

a cylinder; it is typically 20 to 100 ft long and is powered by a PTO device (Figure 2, A). Grain is dumped into a pile at the mouth of the auger and propelled up to the top of a storage bin.[10] The intake area should have a safety cage or shield, but the protective device may provide inadequate shielding or may be removed by the operator to prevent clogging or to increase the intake rate.[13,16]

Entanglement of the upper extremity is the primary mechanism of injury associated with augers and commonly results in fractures and amputations of the hand and upper extremity[11,13] (Figure 2, B). Because of the sheer speed with which an auger moves material horizontally or vertically (7 ft/s), a limb can be amputated and ascend 5 ft before a person has time to react.[16] Furthermore, a limb that is caught in the auger is unlikely to stall the machinery, resulting in limb amputation and multilevel, mutilating injuries as the extremity is pulled into the turning screw and entangled.[10]

Hay Balers

Hay balers tightly compress and discharge bales of hay that can weigh up to 2,500 lbs[21] (Figure 3, A). Rotary feeder forks gather the hay, and opposing compressive rollers, which operate at speeds of 50 to 150 rpm, compress the hay and facilitate its movement to the bailing chamber. The hay is further compressed, shaped, and twined with rope before discharge from the baler. Hay balers have many moving parts and material may clog the intake feeder. Severe or fatal injuries most often occur with an attempt to unclog the machine without turning the power off.[16]

The injuries are typically high energy and open and have significant crush and thermal components along with gross contamination[27] (Figure 3, B and C). The degree of tissue damage depends on the space between the moving rollers, the peripheral speed of the cylinders, the hardness of the roller surface, the temperature of the parts, and how violently the patient struggles to free the extremity.[20,28] Initially, the severity of the soft-tissue injury caused by a baler may be difficult to ascertain. Therefore, determination of a final treatment plan should be deferred until after a thorough débridement is performed in the operating room.[21]

Combine Harvesters and Corn Pickers

A combine harvester is used to harvest agricultural products by combining the reaping and threshing processes in a single piece of machinery that significantly improves the efficiency of crop harvesting. Crops are cut and harvested during the reaping process, whereas grain or seeds are mechanically separated from the hay by-product through the threshing process. Combine harvesters are commonly fitted with crop-specific head attachments.

A corn picker is a crop-specific head attachment that is used on a combine harvester to improve the efficiency and speed of corn collection. Pointed shoes or snouts guide the corn stalks into gathering chains and pull the base of the stalks into the snapping rollers (Figure 4, A). Side-by-side hardened steel rollers rotate toward each other, snapping the ears off the stalk at a rate of 12 ft/s. Ears of corn are then fed into an auger, where the "fingers" and rollers rotate to dehusk the ears. The auger feeds the ears into the throat of a combine, which shells them.[20]

On a farm, amputations and severe lacerations of the hand and fingers caused by combines and corn pickers are among the most common injuries.[3] The snapping rollers are the most dangerous part of a corn picker, and most injuries occur when the operator attempts to remove plugged

Figure 3

Photographs of a hay baler (**A**) and an example of the type of upper extremity injury (**B**) this farm machinery produces: a high-energy injury to the bone and soft tissue with associated soft-tissue loss. **C,** Lateral radiograph of the forearm demonstrating an open, high-energy comminuted both-bone forearm fracture. (Panel A courtesy of Eden Hills Farms, Rhodes, IA.)

stalks from the snapping rollers while the machine is running.[16] Given the speed with which corn stalks travel into the rollers, an operator's hand will be dragged and entangled in a corn picker within 0.15 seconds, which is twice as fast as the typical reaction time of a healthy person.[29]

Combines and corn pickers cause hand and upper extremity injuries through crushing, tearing, and thermal mechanisms. Characteristic injuries include severe friction burns, complex and grossly contaminated lacerations, crush injuries with fractures of the digits, soft-tissue tears, and primary digit amputation[12,20,29] (Figure 4, B and C). Although corn pickers are capable of causing devastating injury to the entire upper extremity, one study suggests that mutilating injuries are most commonly isolated to the fingers and hands because the breadth of the hand and the prominence of the metacarpal heads prevent further progress of the extremity into the rollers[20] (Figure 5). Management of these hand injuries often requires multiple procedures, including primary irrigation, débridement, and packing followed by application of a temporary synthetic matrix to the wound and immediate or delayed tissue and skin coverage with myocutaneous flaps and grafts. In the setting of severe injuries caused by a corn picker, replantation has limited feasibility, and relatively low rates of success have been reported.[4,10,14,20]

Exposed Chains, Belts, Rollers, and Blades

Almost every piece of machinery used on a farm has moving metal parts such as chains, belts, rollers, or exposed blades, which can easily cause injury (Figure 6, A through C). Fingers can quickly become caught in the drive mechanism or between moving gears or can be cut by a moving blade, resulting in amputations or complex open combined hand and finger injuries that involve the skin, tendon, bone, and vascular structures; these injuries often require revision amputation[19] (Figure 6, D).

Management

Between 50% to 90% of admissions for severe agricultural injuries originate as transfers from outside facilities, which reflects the rural setting where these injuries tend to occur and the expertise and resources required for definitive management of complex extremity trauma.[1] Thus, healthcare providers at referring facilities must have a baseline understanding of proper initial management of these injuries to help maximize the efficacy of definitive surgical interventions and reduce the incidence of complications.

Immediate care of an amputated finger and/or limb consists of gentle washing with a warm saline solution if available or clean water at a minimum. The amputated part should be wrapped in moist gauze and placed in a plastic bag, which is then submerged in ice water slush. Care should be taken to avoid placing the amputated part in direct contact with ice or dry ice because this can negatively affect viability secondary to frostbite and thermal necrosis. Exposed amputation sites should be dressed with moist gauze and a gentle compressive bandage, and ice packs should be applied. In cases of incomplete amputation, the affected site should be gently covered with moist gauze, the injured structures should be gently aligned and splinted in place, and no tissue should be discarded.[30] Bleeding should be controlled with compression and elevation; clamping or tying off blood

Figure 4

A B C

A, Photograph of a combine harvester with a corn picker attachment. **B,** Photograph of the forearm demonstrating a severe mangling injury of the upper extremity with near complete amputation through the distal forearm caused by a corn picker. **C,** AP radiograph of the forearm demonstrating comminuted fractures of the distal radius and ulna, with bone loss of the distal radioulnar joint, multiple carpal bones, metacarpals, and phalanges.

vessels in the emergency department should be avoided unless a clinical concern exists for possible exsanguination during transfer.

Farm machinery is heavily contaminated with organic debris, making adjunctive medical therapy critical. In the setting of open agricultural injuries, immediate administration of antibiotics and tetanus toxoid is the standard of care, with tetanus immunoglobulin administered if the patient has not received a booster in the past 5 years.[30,31] Administration of broad-spectrum, empiric antibiotics has been advocated for hand injuries with deep lacerations that involve tendons, nerves, or blood vessels; open fractures; extensive skin and soft-tissue loss; and complete traumatic amputations.[22,32]

On presentation in the emergency department, the circulation, sensibility, and tendon function of the injured limb is assessed, the wound is characterized, and a full radiographic evaluation is performed. This assessment prepares operating room personnel and allows for preoperative planning for possible surgical reconstruction.[33]

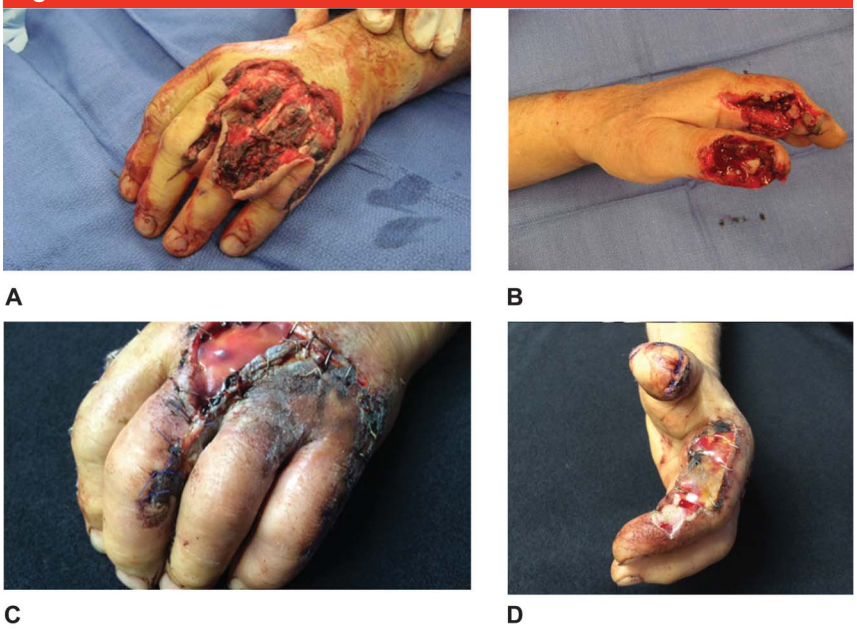
In the setting of complete amputation, the amputated part can be brought to the operating room so that it can be prepared before the patient arrives. The part is explored and, if suitable for replantation, the blood vessels and nerves are tagged, sutures can be placed in the tendons, and fixation of the bones can begin. If there is a delay preventing immediate replantation, the prepared part should be kept moist and placed within a sealed bag, which is then placed in a sterile ice bath in preparation for replantation.

Once the patient is in the operating room and anesthetized, bandages are removed and the extremity is inspected. The status of the skin and soft tissues, the posture of the fingers, the presence of deformities, and the presence or absence of active bleeding are key characteristics that help to establish the extent of devascularization.[33] The basic surgical principles of preventing infection, achieving early healing, and providing optimal function as quickly as possible should help guide the surgical plan.[16]

Aggressive surgical wound débridement is widely advocated as the most important initial step in surgical management of contaminated agricultural injuries. Wounds should be extended so that all nonviable tissues and foreign debris can be excised, leaving healthy, viable tissue and protecting vital structures such as blood vessels and nerves.[33] Conservative wound débridement performed with the belief that nonviable tissue will declare itself in a few days is discouraged and may be the cause of many infections.[33] The importance of radical surgical débridement cannot be overstated; infection is prevented by excising nonviable tissue back to bleeding margins, with the only exception being longitudinal structures with promising function (eg, intact tendons, nerves, and major blood vessels).[34]

A tourniquet may be applied to aid visualization for identification of nonviable tissues and foreign debris. In the setting of open fracture, bone ends are curetted to decrease bacterial loads, remove foreign bodies, and

Figure 5



A and **B**, Photographs of the lateral and dorsal aspects of the hand demonstrating soft-tissue loss with exposed bone and tendon. This injury was caused by a corn picker. Aggressive irrigation and débridement were performed followed by placement of a synthetic matrix wound dressing. **C** and **D**, Photographs of the lateral and dorsal aspects of the hand obtained 14 days after the application of a synthetic matrix wound dressing.

reduce the incidence of infection.[30] Intact nerves are cleansed of surface debris, and frankly divided nerves are excised to healthy-appearing fascicles. The ends of major blood vessels are excised to healthy intimae and tagged for later repair.[33]

The tourniquet is released and the wound is inspected, with further excision performed as needed until healthy bleeding tissue is uniformly apparent. Copious irrigation with normal saline is essential for reducing the incidence of infection. Irrigation performed via gravity force using sterile cysto tubing connected to 3-liter bags of saline is preferable to pulse irrigation, which can force fluid and contaminants into the soft tissues.[16] In a recent comprehensive review of irrigation techniques used for open fractures, the authors found evidence supporting the routine use of normal saline for irrigation of these fractures without the use of additives such as antibiotics or antiseptics.[35]

After irrigation, the soft tissues are reevaluated for any remaining foreign debris and nonviable tissues. This process may be repeated several times to ensure that débridement is adequate.[33] A culture may be obtained following irrigation and débridement of the wound to tailor antibiotic selection, but the efficacy of this practice has not been definitively established or universally accepted.[22,33]

Following irrigation and débridement, the surgeon must decide whether reconstruction of the hand or digits is viable or if function would be best improved with early amputation and possible reconstruction in the future.[33] The decision to replant and reconstruct an extremity or to perform a revision amputation is based on the technical possibility of successful replantation and reconstruction; the ultimate functional outcome; potential complications; impact on patient survival; and the overall functional, social, psychological, and economic morbidity of replantation.[21] Primary amputation is indicated when the surgeon believes that adequate wound excision will result in retention of little functional tissue or late amputation.[33] An early amputation prevents multiple subsequent reconstructive endeavors that may offer little hope of functional gain. For devastating injuries with poor long-term functional potential, early amputation should be viewed as an appropriate first step toward rehabilitation, rather than a surgical failure.[33]

Studies have reported limited success with revascularization and replantation performed following agricultural machinery injuries, with replantation either not feasible because of the severity of injury[4,10,19] or uniform failure of replantation attempts.[20] Results of revascularization and replantation in the pediatric population are discouraging, as well. In one study of 12 farm-related pediatric limb amputations treated at a major tertiary care center, replantation was considered for all amputations, deemed feasible and attempted in only 6 (50%) traumatic limb amputations, and was successful in only 2 cases (33% of attempted replantations), with failure attributed to vascular insufficiency and infection.[14] We note that these poor results should not discourage surgeons from attempting replantation but should be used preoperatively to educate and manage the expectations of patients and their families.

The decision to perform primary wound closure with a drain or delayed wound closure with or without graft coverage is based on the location of the wound, level of contamination, and extent of soft-tissue damage.[16]

Although emergency flap coverage is more commonly performed as a staged procedure for severe upper extremity injuries with significant soft-tissue loss, it has been performed in the acute setting with a latissimus dorsi musculocutaneous island pedicle flap[36] or free flap coverage from the medial or lateral arm, groin, latissimus, or the first web space of the foot.[34]

Recent experience with the use of negative-pressure wound therapy for extremity war injuries[37] and severe open fractures[38] suggests that this treatment modality may have a role in the initial management of high-energy, highly contaminated injuries caused by agricultural machinery. Benefits associated with negative-pressure wound therapy include reductions in the time required to attain primary closure of contaminated wounds and in the incidence of soft-tissue infection, shorter inpatient hospital stays, and fewer labor demands and improved patient comfort associated with fewer daily dressing changes.[37,38]

In highly contaminated traumatic injuries, reconstructive procedures may be delayed.[16] Wounds should be reexamined in 2 to 3 days to determine the extent of soft-tissue damage and signs and symptoms of infection, with particular attention paid to early identification of compartment syndrome, necrotizing fasciitis, and gangrene.[16] A soft, gently compressive dressing should be applied after surgery. Broad-spectrum antibiotics should be continued for at least 24 to 48 hours and should be modified based on the results of cultures obtained intraoperatively.[16]

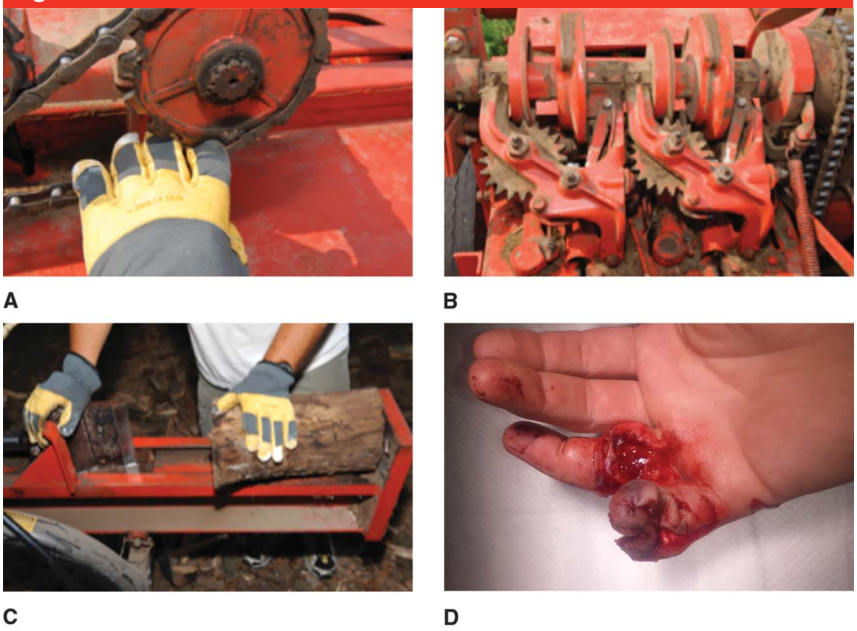
Complications

Following agricultural injuries, infection is relatively common, with deep wound infections or osteomyelitis occurring in 18% to 19% of these injuries.[7,22] Other studies have reported an infection rate approaching 100% following major limb replantation after traumatic farm injuries.[14] In a study of 214 patients with open agricultural injuries, 40 (19%) had postoperative infections and 26 of those (65%) required a return to the operating room for further débridement.[22]

In two studies of agricultural injuries, the most commonly isolated microbes following open upper extremity injuries were coagulase-negative *Staphylococci* (46%); *Enterobacter* species (42%); *Candida* species (31%); *Stenotrophomonas maltophilia* (27%); *Staphylococcus aureus* (23%); *Pseudomonas aeruginosa* (23%); and mixed flora, including *Acinetobacter*, *Klebsiella, Providencia*, *Xanthomonas maltophilia*, *Serratia,* and *Escherichia*.[4,22] Notably, Ali et al[22] found that 26 of 40 patients (65%) who developed wound infections after injury had at least one isolated microorganism that was resistant to the antimicrobial prophylaxis regimen started at the initial presentation.

Administration of broad-spectrum, empiric antibiotic therapy is recommended for high-grade, open injuries. Administration of a first-generation cephalosporin (eg, cefazolin 1 g administered intravenously every 8 hours until 24 hours after wound closure) will provide coverage against gram-positive organisms.[30,31,39,40] An aminoglycoside (eg, gentamicin administered intravenously with the dose based on weight) or levofloxacin 500 mg administered every 24 hours is added to the regimen to provide coverage against gram-negative organisms. The addition of ampicillin, penicillin, or doxycycline is recommended to address the risk of clostridial myonecrosis in the setting of agricultural injuries.[30,31,39] For the patient allergic to penicillin, a combination of vancomycin and a fluoroquinolone provides excellent

Figure 6



Photographs of a harvester demonstrating exposed chains (**A**) and gears (**B**). **C,** Photograph of a woodchopper demonstrating an exposed blade. **D,** Photograph of injuries to the hand caused by a woodcutter, including near complete amputations of the ring and little fingers and an avascular little fingertip.

coverage against gram-positive, gram-negative, and clostridial species.[39,41] Patient-specific risk factors that may further increase the risk of clostridial myonecrosis include age >50 years, diabetes mellitus, malnutrition, chronic alcoholism, peripheral vascular disease, neutropenia, high-dose corticosteroid therapy, and other risk factors commonly associated with an immunocompromised state.[42] The clinician should maintain a high degree of suspicion for clostridial myonecrosis in any patient with a contaminated agricultural injury and fever, sudden onset of excruciating pain that is not relieved by pain medications or is out of proportion to the injury, massive local edema, and evidence of soft-tissue gas on clinical examination and plain radiography.

Optimal duration of antibiotic administration has not been clearly determined, but some authors have advocated that antibiotics be continued for at least 3 days in patients with open injuries, with a longer course of antibiotics if subsequent surgical procedures (eg, wound coverage, bone grafting) are required.[31,40] Ensuring that tetanus coverage is up to date and administering tetanus toxoid plus tetanus immunoglobulin if the patient has not received a booster in the past 5 years is also considered the standard of care in the setting of agricultural injuries.

Summary

Agricultural injuries to the hand and upper extremity present a complex spectrum of trauma that reflects the major occupational hazards associated with working with heavy machinery on a farm. Injuries are typically high energy and are often associated with significant soft-tissue loss, injury to tendons and neurovascular structures, multilevel fractures, and amputations. In addition, they are typically highly contaminated with organic debris.

The surgeon tasked with treating these complex extremity injuries must often make the difficult determination whether replantation, reconstruction, or amputation is appropriate. An understanding of the specific pattern and mechanism of injury associated with each piece of agricultural machinery may help guide surgical management by providing insight into the expected level of energy, source and degree of contamination, and likelihood of success following surgical reconstruction or replantation.

References

Evidence-based Medicine: Levels of evidence are described in the table of contents. In this article, reference 38 is a level I study. References 22 and 32 are level II studies. References 1-4, 7, 9-14, 17-21, 24, 25, 27-29, 34, 36, 37, and 39 are level IV studies. References 15, 16, 30, and 40 are level V expert opinion.

References printed in **bold type** are those published within the past 5 years.

1. **Jawa RS, Young DH, Stothert JC, et al: Farm machinery injuries: The 15-year experience at an urban joint trauma center system in a rural state. *J Agromedicine* 2013;18(2):98-106.**
2. Meiers S, Baerg J: Farm accidents in children: Eleven years of experience. *J Pediatr Surg* 2001;36(5):726-729.
3. Hansen TB, Carstensen O: Hand injuries in agricultural accidents. *J Hand Surg Br* 1999;24(2):190-192.
4. Cogbill TH, Steenlage ES, Landercasper J, Strutt PJ: Death and disability from agricultural injuries in Wisconsin: A 12-year experience with 739 patients. *J Trauma* 1991;31(12):1632-1637.
5. ***US Bureau of Labor Statistics: 2012 Census of Fatal Occupational Injuries.* http://www.bls.gov/iif/oshwc/cfoi/cfch0011.pdf. Accessed July 24, 2014.**
6. Toscano G: *Dangerous jobs: Fatal workplace injuries in 1995: A collection of data and analysis*. Washington, DC, US Department of Labor, 1997. http://www.bls.gov/iif/oshcfoiarchive.htm#1995. Accessed July 24, 2014.
7. **Copuroglu C, Heybeli N, Ozcan M, Yilmaz B, Ciftdemir M, Copuroglu E: Major extremity injuries associated with farmyard accidents. *ScientificWorldJournal* 2012;2012:314038.**
8. Pickett W, Hartling L, Dimich-Ward H, et al: Surveillance of hospitalized farm injuries in Canada. *Inj Prev* 2001;7(2):123-128.
9. Hartling L, Pickett W, Guernsey JR, Alberg N, Redekop TD, Brison RJ: Injuries associated with the farm harvest in Canada. *CMAJ* 1998;158(11):1493-1496.
10. Hansen RH: Major injuries due to agricultural machinery. *Ann Plast Surg* 1986;17(1):59-64.
11. Ingram MW, Crowe TG, Wassermann J, Hagel LM, Dosman JA: Case reports of on-site investigations of auger-related farm injuries. *J Agric Saf Health* 2003;9(2):133-142.
12. Campbell DC II, Bryan RS, Cooney WP III, Ilstrup D: Mechanical cornpicker hand injuries. *J Trauma* 1979;19(9):678-681.
13. Athanasiov A, Gupta ML, Fragar LJ: An insight into the grain auger injury problem in Queensland, Australia. *J Agric Saf Health* 2006;12(1):29-42.
14. McClure SK, Shaughnessy WJ: Farm-related limb amputations in children. *J Pediatr Orthop* 2005;25(2):133-137.
15. Leigh JP, McCurdy SA, Schenker MB: Costs of occupational injuries in agriculture. *Public Health Rep* 2001;116(3):235-248.
16. Chun S: Management of farm-related injuries to the upper extremity. *Hand Clin* 1999;15(2):201-219, vii.
17. Cabbabe EB, Korock SW: Wringer washer injuries in children. *Ann Plast Surg* 1983;10(2):135-142.
18. **Işık D, Ceylan MF, Tekin H, Karadaş S, Güner S, Canbaz Y: Upper extremity injuries due to threshing machine. *Ulus Travma Acil Cerrahi Derg* 2012;18(1):55-60.**
19. Terzioglu A, Aslan G, Ates L: Injuries to children's hands caused by the engine belts of agricultural machines: Classification and treatment. *Scand J Plast Reconstr Surg Hand Surg* 2004;38(5):297-300.
20. Gorsche TS, Wood MB: Mutilating corn-picker injuries of the hand. *J Hand Surg Am* 1988;13(3):423-427.
21. Ozyürekoğlu T, Napolitano M, Kleinert JM: Hay baler injuries to the upper extremity. *J Trauma* 2007;63(1):62-69.
22. Ali MH, Hoekzema NA, Bakleh M, Shin AY, Osmon DR: The microbiology and risk of infection following open, agricultural upper extremity injuries. *J Hand Surg Am* 2008;33(1):87-93.

23. ***National Agricultural Statistics Service: 2011 Farm and Ranch Safety Survey Report*. http://usda.mannlib.cornell.edu/usda/current/FarmSafe/FarmSafe-05-30-2013.pdf. Accessed July 24, 2014.**

24. Kalenak A, Gordon SL, Miller SH, Greer RB III, Graham WP III: Power take-off injuries. *J Trauma* 1978;18(2):134-136.

25. Ozgenel GY, Akin S, Ozbek S, Kahveci R, Ozcan M: Severe hand injuries in children related to farm tractors: A report of 70 cases. *Ulus Travma Acil Cerrahi Derg* 2008;14(4):299-302.

26. Demmin D: *Save Your Fingers, Save Your Life*. Ithaca, NY, Cornell University Cooperative Extension. http://www.nasdonline.org/document/980/d000963/save-your-fingers-save-your-life.html. Accessed July 24, 2014.

27. Gainor BJ: Hay baler trauma to the upper extremity: A roller injury. *J Trauma* 1983; 23(12):1069-1071.

28. Sanguinetti MV: Reconstructive surgery of roller injuries of the hand. *J Hand Surg Am* 1977;2(2):134-140.

29. Momcilović D, Prokes B, Janjić Z: Mechanical cornpicker hand injuries. *Med Pregl* 2005;58(9-10):479-482.

30. Angoules AG, Lindner T, Vrentzos G, Papakostidis C, Giannoudis PV: Prevalence and current concepts of management of farmyard injuries. *Injury* 2007;38(suppl 5): S27-S34.

31. Zalavras CG, Marcus RE, Levin LS, Patzakis MJ: Management of open fractures and subsequent complications. *J Bone Joint Surg Am* 2007;89(4): 884-895.

32. Patzakis MJ, Harvey JP Jr, Ivler D: The role of antibiotics in the management of open fractures. *J Bone Joint Surg Am* 1974;56(3): 532-541.

33. Gupta A, Wolff TW: Management of the mangled hand and forearm. *J Am Acad Orthop Surg* 1995;3(4):226-236.

34. Lister G, Scheker L: Emergency free flaps to the upper extremity. *J Hand Surg Am* 1988; 13(1):22-28.

35. Crowley DJ, Kanakaris NK, Giannoudis PV: Irrigation of the wounds in open fractures. *J Bone Joint Surg Br* 2007;89(5):580-585.

36. Sadove RC, Vasconez HC, Arthur KR, Draud JW, Burgess RC: Immediate closure of traumatic upper arm and forearm injuries with the latissimus dorsi island myocutaneous pedicle flap. *Plast Reconstr Surg* 1991;88(1):115-120.

37. Leininger BE, Rasmussen TE, Smith DL, Jenkins DH, Coppola C: Experience with wound VAC and delayed primary closure of contaminated soft tissue injuries in Iraq. *J Trauma* 2006;61(5): 1207-1211.

38. Stannard JP, Volgas DA, Stewart R, McGwin G Jr, Alonso JE: Negative pressure wound therapy after severe open fractures: A prospective randomized study. *J Orthop Trauma* 2009;23(8):552-557.

39. Gonzalez MH, Jablon M, Weinzweig N: Open fractures of the hand. *J South Orthop Assoc* 1999;8(3):193-202.

40. Okike K, Bhattacharyya T: Trends in the management of open fractures: A critical analysis. *J Bone Joint Surg Am* 2006;88 (12):2739-2748.

41. Hoffman RD, Adams BD: The role of antibiotics in the management of elective and post-traumatic hand surgery. *Hand Clin* 1998;14(4):657-666.

42. Headley AJ: Necrotizing soft tissue infections: A primary care review. *Am Fam Physician* 2003;68(2):323-328.