Hand Injury from Powered Wood Splitters

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Abstract

The purpose of this study on hand injury from powered wood splitters was to describe injury epidemiology and anatomy, to rate injury severity, to evaluate the outcome after injury and to describe factors of possible importance for the occurrence of injury.

By searching a computerized patient registry, 131 patients injured by wood splitters from 1995 to 2001 were identified. Information was obtained from hospital records and radiographs, a written questionnaire and a structured telephone interview. Injury severity was rated according to the Hand Injury Severity Scoring System (HISS system) and the Injury Severity Score (ISS). Outcome was evaluated with the Disabilities of the Arm, Shoulder and Hand outcome questionnaire (DASH) and, in 26 of the most severely injured patients, with the Sollerman test.

Forty-six percent of the injuries occurred during April or May. Wedge splitters caused 82% of all injuries and most often injured the index finger, while screw splitters caused 18% of all injuries and most often injured the metacarpus. Screw splitters caused palmar perforation and thumb avulsion. Sixty-three percent of all patients had an amputation or devascularising injury. The reliability of HISS rating was good. The mean Hand Injury Severity Score (HISS) was 63 which is equivalent to a severe hand injury. The mean ISS was 3.7. Nineteen percent of patients had minor, 31% had moderate, 23% had severe and 27% had major injury according to the HISS system. Children had more severe injuries than adults. There was no significant difference regarding HISS or DASH scores between wedge and screw splitter injuries. The mean DASH score was 15, indicating moderate residual sequelae, but patients without sequelae and patients with grave sequelae were found in all HISS severity grades. There was a weak but significant correlation between the HISS and DASH scores. The mean Sollerman score in the injured hand was 66, indicating significantly impaired hand function. Twenty-nine percent of splitters were home-made. Very few machines had the safety measures required by European Standards. Children were present during splitting in at least 15% of cases. Not being alone at the machine was one cause of wedge splitter injury. Glove use was one cause of screw splitter injury.

Hand injury from powered wood splitters is a significant problem. Many of the injuries are severe, and cause long term sequels and impairment of hand function. Prevention is essential and should focus on unsafe machines and dangerous patterns of use.

Keywords: Wood splitter, Wedge splitter, Screw splitter, Consumer product related injury, Agricultural injury, Occupational injury, Hand injury, Child injury, Injury prevention, Vedklyv, Kilklyv, Hydraulklyv, Skruvklyv, Arbetsskada, Handskada, Skada barn, Skadeprevention

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To those involved in the care of patients with injury from powered wood splitters or in the prevention of such injury.
List of Papers

This thesis is based on the following papers, which are referred to in the text by their Roman numerals.


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Abbreviations

ADL     Activities of Daily Living
AIS     Abbreviated Injury Scale
AMA     American Medical Association
ANOVA   Analysis of variance
CMC     Carpometacarpal
DASH    Disabilities of the Arm, Shoulder and Hand Outcome Measure
HISS    Hand Injury Severity Score
HISS system Hand Injury Severity Scoring System
ICC     Intraclass Correlation Coefficient
ICD     International Classification of Diseases
ISMN categories The tissue categories in which points may be scored in the HISS system: Integument, Skeletal, Motor and Neural
ISS     Injury Severity Score
MCP     Metacarpophalangeal
SRCC    Spearman Rank Correlation Coefficient
Introduction

Injury – a global health challenge

Injury is a major cause of morbidity and mortality throughout the world. In 2004 an estimated 5.8 million people died from injuries and injury accounted for 9.8 % of deaths worldwide.[38] Although these are staggering figures they tell only part of the story about the health impact of injury. For every fatal injury there are thousands that are not fatal, many of which result in permanent disability.

Furthermore, injury mortality is highest among older children and young adults. Some other important causes of death such as cancer and cardiovascular disease primarily affect older people. As a result, in many high income countries injury is the leading cause of premature deaths, defined as deaths prior to the age of 70.[10] In addition, when injury results in permanent disability, children and young people are more likely than the elderly to be affected for a long period of time.

The global burden of disease from all causes has been projected to decrease significantly between 2004 and 2030. However, the part of the global burden of disease caused by injury, which was 12.3 % in 2004, has been projected to increase. Between 2004 and 2030 the global number of deaths from injury has been projected to increase by 28 %. A major contributing factor in this regard is an increase in the number of road traffic accidents. Such accidents are projected to increase from the ninth leading cause of death globally in 2004 to the fifth in 2030.[37]

Injury is often divided into two basic groups, Intentional injury and Non-intentional injury. As might be expected, injury from all forms of violence, such as wife-battering and warfare is obviously considered intentional injury, as is suicide. Most other injuries such as those that are caused by “accidents” belong to the non-intentional group of injuries. The very word “accident”, however, is avoided by some injury prevention researchers due to the previous tendency in society to view accidents as unpredictable and unavoidable, although this was often not the case.[29]

For prevention purposes injury is often classified according to its aetiology or mechanism of injury. We talk about road traffic injuries, falls, burn injury, consumer product-related injury, drowning, poisoning, interpersonal violence, etc. Alongside this kind of classification, injuries are commonly grouped according to the place where the injury occurred or the
activity that was going on there. For example, we often find reports about occupational injury, industrial injury, agricultural injury, sports injury, etc. Finally, injuries can also be classified on the basis of patient characteristics. One example of this is childhood injury.

These different ways of subdividing injuries are helpful in injury research and prevention, but since the categories overlap an injury can often be classified in several different categories. Just consider the 10-year-old who sustains an injury while helping her father split wood from the forest on the family farm with a factory-made wood splitter. She not only has a non-intentional injury and a childhood injury, she also has an agricultural injury and a consumer product-related injury.

The common causes of injury vary enormously among different countries and regions of the world. Differences in income levels, livelihoods, attitudes concerning safety, traditions, climate and many other factors contribute to corresponding differences regarding the spectrum of causes of injury. Therefore country and region specific injury data are important for prevention and health care planning.[8]

Hand injury – an introduction

The hand is of obvious importance to us because we need it to grip objects and perform different tasks during work and leisure time. What may not be quite as obvious is that the hand is also a sensory organ. When we put our hand in our pocket we can usually distinguish a coin from a paper-clip – the hand “sees” the object. (Figure 1) The fine sensibility required for this ability is very important for hand function in everyday life.[44] The hand is also of great cosmetic importance. Like the face, it is often visible, and it is seen in socially important situations like hand-shaking. It is not unusual for patients with prominent scarring or deformity after hand injury to hide the hand because they are ashamed of it.
When we perform activities of daily living, we use different hand grips. Sollerman divided these grips into eight main types.[50] For example, “Lateral Pinch”, with the thumb against the side of the index finger, is used to turn a key in a lock, and “Diagonal Volar Grip” is used to hold a knife or fork while eating. The thumb is involved in all eight hand grips, and most of them would be impossible without the thumb. Thus, it is not surprising that the thumb is regarded as a very important part of the hand. Indeed, it is of such importance for hand function that the invalidity recognized by insurance companies for complete loss of the thumb is 50% of that recognized for amputation of the entire hand.[55]

Another important aspect regarding hand function is the difference in dexterity which is often found between the dominant and the non-dominant hand. We usually pay little attention to this difference, but it can become painfully apparent to the patient who is unable to use the dominant hand after injury. Normally simple tasks like, writing one’s own name with a pen may suddenly be almost impossible. Therefore whether a hand injury is located in the dominant or the non-dominant hand can be of great importance regarding the outcome of the injury.

Although relatively small, the hand comprises a multitude of well defined anatomical structures including bones, ligaments, tendons, muscles, nerves, vessels, skin and nails. Injuries to these structures can be of different aetiology, different types and grades, and come in different combinations. Consequently there is a very large spectrum of possible types of hand injury. Since the skeleton is the firm fundament of the hand, fractures may lead to deformity of the hand or wrist. If immobilized in the correct position they usually heal with no deformity. However the scaphoid bone is an exception.
Because of the anatomy of its blood supply, the fractured scaphoid often does not heal. In such cases a fibrous connection often forms at the fracture site, but movement between the ends of the fractured bone is still possible. If treatment does not result in healing in anatomic position, the natural course is usually wrist joint destruction, which may take years or decades to develop.[63] Intraarticular fractures are fractures that enter a joint. Many of these fractures carry a risk of subsequent destruction of joint surfaces, particularly if the fractures do not heal in anatomical position.[33] Open fractures are fractures that have a communication to the outside world, usually through a wound. The communication makes it possible for bacteria to invade the fracture site. This may lead to chronic infection of the fracture site and significant difficulties regarding fracture immobilisation in the correct position and healing.[23]

Tendons usually connect a muscle to bone, thereby making it possible for muscle contraction to result in joint movement. In the hand, extensor tendons enable us to open the hand and bend back the wrist. Flexor tendons are important in making a fist and flexing the wrist. In the distal part of the palm and proximal two thirds of the fingers, flexor tendons run in tendon sheaths. Tendon injury in the hand usually entails a risk of losing the ability to move a part of the hand, or at least of losing some of the strength in moving that part. For example, when both flexor tendons of a finger are cut, the patient loses the ability to actively flex the two most distal joints of that finger. Abscised tendons can often be repaired, but it is generally more difficult to obtain good results in flexor tendon injury than in extensor tendon injury. Flexor tendon injuries in the area of the tendon sheath are particularly difficult to treat successfully. Indeed, in the relatively recent past successful repair of an injured flexor tendon was considered a rarity.[14] The difficult area of the tendon sheath was called “no mans land”, and primary repair of a flexor tendon abscessed in this area was avoided because of the expected poor results.[43] With more modern treatment regimens results have improved considerably, but flexor tendon injury in the area of the tendon sheath can still constitute a challenge for health care providers.

The nerves of the hand have two major tasks. First, they transmit impulses to its muscles, thereby making movements and positioning of the hand possible. Second, they transmit impulses from the hand to the central nervous system, giving us the benefit of sensation, for example “seeing” the coin in our pocket, telling us just how hard we are gripping the object we are holding, or warning us that the hand is being injured. Digital nerves, the nerves of the fingers, carry the sensory nerve impulses from the skin of the fingers but are of no importance for the ability to move the fingers. Thus, digital nerve injuries result in loss of sensation distal to the injury, but not in paralysis. The median or ulnar nerves are important both for sensation and for movement in the hand. Thus, injury to these nerves or their branches in the hand may result in loss of sensation, or paralysis of hand muscles, or
both. Injuries to the main trunks of the median and ulnar nerves often leave considerable residual impairment and are considered serious hand injuries.[35] Injury to any sensory nerve, even a small digital nerve, also entails a risk for the occurrence of neuropathic pain. This kind of pain often occurs with injury to the superficial branch of the radial nerve. It is often difficult to treat with normal pain medication and may cause great problems for the patient. The chance for good recovery after nerve injury can be considerably improved with surgical repair of the injured nerve, but the surgeon can only try to provide the best possible conditions for healing. The rest depends on the patient’s biological healing ability, which is often excellent in young children but less favourable in the elderly.

Vessel injury may cause bleeding. This, however, is seldom life threatening in the hand, where it can be controlled with a compression dressing and elevation of the hand. Instead, the main problem with vessel injuries in the hand is when the injury deprives a finger, or indeed the entire hand, of its blood supply. The affected hand part is then called devascularised, and if the blood supply is not restored it will not survive. If the vessels have been cut, the operation required to restore blood flow is called revascularisation. This is often a fairly time consuming type of operation requiring special training and equipment not available in all hospitals.

In a traumatic amputation, many of the problems involving the specific injuries mentioned above are added together in a single case. Amputation of a single finger, for example, usually includes complete abscission of the extensor tendon, digital nerves, arteries and veins, one or two flexor tendons, plus an open fracture, which may be intraarticular. An operation aiming at reattachment of an amputated part may be possible and is called replantation. This is usually considered when the injury is suitable for this operation and the patient is reasonably healthy. It can be a very time consuming operation and a good result can by no means be guaranteed. Due to the long period of time on the operating table it can also be dangerous, particularly for very old patients and for patients who are vulnerable due to pre-existing disease. These patients are seldom selected for replantation. If the decision is made not to attempt replantation, the remaining part of the hand is adjusted so that the wound can be closed in the best possible way.

A very small proportion of all hand injuries lead to a fatal outcome. Instead the main problem with hand injuries is the morbidity they cause. The patients’ ADL abilities are commonly impaired and both working capability and leisure time activities are affected. Together, the direct health care costs, the costs for sick leave compensation, and the indirect costs of lost production from hand injuries can be substantial. On the group level the costs of hand injury have been shown to correlate to the initial injury severity.[48]
Injury prevention

Modern surgical care can in many cases cure those who are injured, and at least improve the outcome in many others. Even so, many people are killed every day because of injuries, and many more are left with permanent disability. From the patient perspective it is obviously better if the trauma can be prevented. Even when considering costs and other obstacles to preventive efforts, prevention is often the most sensible option for reducing the negative effects of trauma.

Many professionals are more or less directly involved in injury prevention: work environment inspectors, engineers, psychologists, architects, social workers, industrial designers, injury prevention researchers, city planners and many others. The field of injury prevention is truly multidisciplinary. But is injury prevention really something for medical personnel to be involved in? If the question were posed as to whether medical personnel have an important role in efforts to reduce smoking in order to avoid cancer, the answer would be quite obvious. And just as cancer due to smoking concerns health care providers, this is also the case regarding injury due to its different causes.

Health care providers are in a unique position to identify injury hazards. Types of injury which are uncommon may be “invisible” to most people in society, but are seen fairly frequently in a hospital or a specialised hospital department.[11] Thus, one could say that the personnel at such a department are positioned at the top of a “watchtower” where they have an overview of the injuries in the region that few people can match. Since they meet the patients in person and have access to the patients’ case documentation, they are also in a good position to record information about the causes, types and severity of injuries. Furthermore, they may be able to identify individuals at particular risk of injury, such as substance abusers, epileptics and patients with social problems, dementia or mental disease. All this information is often valuable for injury prevention purposes.

Many health care professionals have the confidence of patients and families and are respected persons in their community. This makes it easier for them to reach patients and their families with information and to get the attention of decision makers when advocating injury prevention measures. Decisions to undertake injury prevention measures are more likely to be made if there is research which supports the decisions. Health care providers can conduct injury prevention research and thereby help eliminate or diminish injury risks.[11]

Campaigns to educate people about injury risks and make them behave in a safe way can sometimes be effective in reducing the rate of injury. However, relying exclusively on education to reduce injuries is often ineffective. It is hard to reach all those involved with an injury prevention message, and many times even those who receive and understand the message will not
change their behaviour. Another option is the use of injury counter measures that offer automatic protection. Such measures protect people without their having to perform some action or behave in a specific way, and are often more effective than education. Therefore injury prevention measures that provide automatic protection are the “strategies of choice” for injury control.[11]

An example of the role that health care providers can play in injury prevention, and an example of automatic protection, is near at hand in the history of Swedish hand surgery. A plastic surgeon in Umeå noted that many flexor tendon injuries were caused by a type of knife that was common in Sweden and that traditionally had a spindle shaped handle and lacked a tang. The injuries occurred when the user stabbed with the knife to make it stick in a tree stump or the like, and had the sharp side of the blade turned distally. (Figure 2) In that situation the fingers slipped from the handle, down over the sharp side of the blade and the user sustained incised wounds with flexor tendon injuries in one or more fingers.[22]

![Figure 2. Holding the Mora-knife with the sharp side of the blade turned distally.](image)

Photography: Aron Lindqvist

Hand surgeons in Uppsala conducted further clinical research on the problem. It was found that 20% of those injured were males, most of them children or young adults. None of them had a profession that is commonly associated with the use of knives. The surgeons tried to raise public awareness about the problem by means of publications in both scientific and other journals. An information brochure was proposed describing safe use,
that was to accompany every knife that was sold. However, considering the
group of patients typically affected by these injuries the possibility of
changing behaviour through information was considered small. The surgeons
also cooperated with The Swedish Consumer Agency which negotiated with
the manufacturers who agreed to mainly market the knife with a tang to the
general public. The traditional version without a tang would still be available
in hardware stores geared to professional craftsmen. (Figure 3) [19] The tang
is a good example of automatic protection.

![Figure 3](image)

**Figure 3.** Mora-knives without and with a tang. Photography: Aron Lindqvist

In everyday life we often say that an injury has “a cause”, and by this we
often mean merely the object or mechanism involved when the injury
occurred. “He injured his hand on a wood splitter”. But if we really want to
understand why the injury occurred, this is often insufficient. In many cases
events or circumstances form a “causal chain” which leads to injury.[11] The
events or circumstances may also interact in different ways. Thus, if we
think further, we realise that “the cause” of an injury is often multifactorial
and complex.

Consider the user of a wedge splitter with a single control lever. His
jacket has long sleeves, he works although it is raining a bit and he allows a
collection of split wood to gather around the machine. Suddenly he slips on a
piece of wet wood and falls onto the splitter. At the same time one of his
long sleeves catches the lever, sets the pressure plate of the splitter in motion
and his hand is injured. What was the cause of this injury? Was it the rain
that made the wood slippery? Was it the carelessness of the operator who
had long sleeves and did not remove all split wood immediately? Or was it
the lack of two-hand controls on the machine? In this case, and many others,
there was clearly not a single cause. It may be more useful to think of a
number of factors all of which contributed to the occurrence of the injury.
Wood splitters

Firewood is mankind’s oldest energy source and is still used extensively around the world.[3] In Sweden 21.6% of the energy used to heat detached houses and 1.5% of the country’s total energy consumption come from firewood.[46, 52] Given the steadily rising prices of other energy sources, the use of firewood is not likely to decrease in the future. In Finland it was found that 15000 households planned to start using firewood and 200000 planned to increase their consumption.[57] Furthermore, there are motives other than those that are economic for the production of firewood. Old firewood producers attach great importance to this work in terms of recreation and work satisfaction.[16] Also, in light of the debate about environmental issues, the use of firewood for heating might be seen as an attractive option compared to continued use of fossil fuels or nuclear power.

Firewood production is mainly a small scale activity. Many non-industrial private forest owners produce firewood for heating their own homes. Since the work is mostly done on a self-employed basis or during leisure time, there is usually no employer-employee relationship and no government regulation of the work. Accidents that occur during firewood production are seldom considered as occupational by the injured, and are underreported in official Swedish statistics.[24, 25, 31] The work is characterised by highly repetitive operations, often with potentially dangerous equipment. In a Swedish study of firewood producing households the mean age of those doing the work was 49.0 years and 70.8% were males. The mean annual work time per producing person was 54.6 hours and males spent on average more than twice as much time on firewood processing work compared to females.[31]

When full grown tree trunks are used for firewood, they are first cut, i.e. divided perpendicular to the fibres. The shorter pieces thus obtained are then split, i.e. divided parallel to the fibres. There are several possible means for splitting. One is the axe, which has been used for both cutting and splitting for thousands of years, and which is still used today. A sledgehammer and wedges is another ancient splitting method still in use. It can be particularly useful when an unusually tough piece of wood cannot be split by an axe, or has stuck on the wedge or screw of a powered wood splitter. Another manual method is the hand powered clas wood splitter, which was previously sold at the Swedish retail chain Clas Ohlson. (Figure 4) In this wood splitter the working principle is to use the momentum of a weight gliding on a metal rod to successively drive a wedge through the wood, thereby splitting it.
During the structured interviews conducted with the patients who are the focus of this thesis, several of the patients spontaneously mentioned a type of powered wood splitter that reportedly was used more frequently in Sweden several decades ago. It basically consisted of a giant wooden wheel on which an axe head was attached. A power source was connected to the wheel to make it revolve. It was often encased in a wooden box with a hole through which the axe could be seen passing at regular intervals. The operator would grab the wood firmly by one end and position the other end into the hole, whereupon the axe would come down with great speed and power and split the wood. Several patients perceived that this older type of machine was more dangerous than screw splitters and wedge splitters. A fairly similar model is shown in Figure 5.
At present two main types of powered wood splitters are used in Sweden, wedge splitters and screw splitters. Wedge splitters have a piston with a plate at the end which pushes the log towards a stationary wedge, or a moving wedge which pushes the log against a stationary plate. As the distance between the plate and the wedge decreases the wedge is driven into the wood and it is split. Most wedge splitters have a single wedge or knife. Some models, however, have a wedge that simultaneously splits the log in more than two pieces, or that can be fitted with such a wedge. It is often called a 4-way wedge or a 6-way wedge depending on the number of pieces into which it splits the log. (Figure 6) Most wedge splitters work horizontally, i.e. with the log lying on a table or in a trough. (Figure 7) Some wedge splitters, however, work vertically, i.e. with the log standing on a table or plate, and these splitters often have a moving wedge. (Figure 8) The force moving the piston is usually generated by hydraulics and often amounts to several tons.

Figure 5. Powered wood splitter with giant wooden wheel. User points at blunt end of axe head. Courtesy of Hannu Koskela, Örebro University Hospital.
Figure 6. A 6-way wedge which can split a log into 6 pieces. a) The wedge is seen in the foreground and the push-plate in the upper left corner. b) A log being split. By kind permission from BALA.

Figure 7. Horizontally working wedge splitter with stationary wedge. Photography: Aron Lindqvist
Figure 8. Vertically working wedge splitter with moving wedge. Photography: Aron Lindqvist

Figure 9. Screw splitter with spring-loaded protective device folded down. Photography: Aron Lindqvist

Screw splitters have a threaded mandrel which is connected to the power source by a steel axis. (Figure 9) The user pushes the log towards the tip of the rotating mandrel which is screwed into the log until it splits. There is often a table under the mandrel on which the log can be placed before it is pushed towards the mandrel.

Dual purpose cutters and splitters have devices to both cut and subsequently split the log. Machines with these two functions may also be
called firewood processors.[31] The device for cutting is usually a powered circular saw but may also be a chainsaw that is integrated into the machine. The splitting device may be a wedge splitter or screw splitter. Some dual purpose cutters and splitters have a powered circular saw and a screw splitter mandrel on the same steel axis. Many dual purpose cutters and splitters are constructed in such a way that when a segment of the log has been cut off, it drops directly into a trough ready for wedge splitting. There is a trigger in the trough of some of these machines. When the log drops into the trough it depresses the trigger which automatically starts pressure plate movement.

A recent Swedish study shows that 12095 wood splitters, including firewood processors, were sold in Sweden in 2002. This means that new sales of wood splitters were eight times as high in 2002 as in 1986.[32] Since three companies chose not to contribute information to the study, the actual number sold was probably even greater.

Control design and function are important for wood splitter safety. If the controls permit the machine to be switched on or to start operating when this is not the intention of the operator, injury may occur. Controls with “hold-to-run” function require the active participation of the operator to make the machine work. This type of control function is meant to ensure that the operator is present at the controls when the machine is working, and thus has the possibility to oversee the work and stop the process if danger should arise. Two-hand controls of the “hold-to-run” type compel the operator to have both hands on the controls, and thus be in a safe position, to make the machine run. Two-hand controls of the hold-to-run type should require reinitiation of the output signal, i.e. both controls should have to be released before a new cleaving cycle can be started. If not, the operator may manipulate controls to enable operation of the machine with only one hand, which allows faster work at the expense of safety. (Personal communication: Ulf Andersson, Swedish Work Environment Authority 2001) On wedge splitters, pedal control as well as dual controls are unsafe, and controls which do not work in the same direction as the moving part may cause confusion and danger.[47]

Since Sweden is a member of the European Union, the design of wood splitters sold in Sweden is regulated by European Standards.[1, 2] European Standards for wood splitters stipulate that every splitter must have a warning notice, a support for the log, and an instruction handbook specifying safe working practices. The warning notice should always include “Danger! Keep clear of moving parts” and “To be operated by one person only”. The support for the log should allow it to be split without being held in position by hands or feet. In screw splitters log support may be a feeding device with a handle and in wedge splitters there may be a V-shaped trough that keeps the log from rolling sideways more efficiently than a flat surface would. (Figure 10) European Standards also require that all electrically powered...
splitters have a starting and stopping device within reach from the operating position.

![Image](image1.jpg)

**Figure 10.** Screw splitter with feeding device. Photography: Aron Lindqvist

The European Standards for wedge splitters require guarding of the splitting zone in one of two possible ways. Either the splitter should have an “interlocking guard with guard locking”, a protective shield over the splitting zone which is impossible to open while the piston is advancing, or two-hand controls of the “hold-to-run” type. The European Standards also specify how machines with a moving wedge must be designed to protect the operator from entrapment between a log jammed on the wedge and other machine parts during return movement of the wedge. The European Standards for screw splitters require guards to protect the operator from touching the screw, and devices to prevent log rotation, so called “windmilling”, and to remove partially split logs from the screw.

![Image](image2.jpg)

**Figure 11.** Home-made wedge splitter with stationary wedge. Courtesy of R. Skog.
Some reports mention home-made wood splitters. [25, 27, 56] (Figure 11) The design of home-made splitters is not controlled by the authorities. According to Hellstrand (1989) protective devices on home-made screw splitters seemed inferior to those on factory-made screw splitters.

Hand injury from wood splitters

Injuries have probably occurred during the splitting of wood as long as humans have been engaged in this activity. Axes can cause injury to different body parts, including hands.[45] In a study of accidents in family forestry’s firewood production in northern Sweden, axes were associated with a higher accident rate than all other types of equipment except wedge splitters, which had the highest accident rate.[31] Injuries can also occur during the splitting of wood with a sledgehammer and wedges. The clas manual wood splitter was marketed as “the new efficient family axe which suits everyone in the family” and “is safe for anyone to use”. (Figure 12).

![Figure 12. First page of leaflet supplied with the clas manual wood splitter.](image)

During the search for patients injured by powered wood splitters in the initial phase of this project, however, an injury caused by the clas was found. This demonstrates that the clas, like other types of equipment for wood splitting, is not completely safe.

Apart from the studies on which this thesis is based, we found only 11 reports in the literature mentioning patients with hand injuries from powered wood splitters.[6, 24, 25, 27, 28, 31, 34, 36, 39, 47, 56] Many of these reports are based on fairly small patient materials. One is a letter to the editor and two are case reports.[36, 39, 56] In two studies the wood splitter injuries are just a part of a larger material and are not the focus of investigation.[6, 34] Most of the reports concern wedge splitter injuries, and only one
describes screw splitter injuries exclusively.[24] One report is a thorough study of potential injury hazards in powered wood splitters from an engineering perspective, based on investigation of 28 wood splitters. It also contains a short section about 12 cases of injury.[47]

The epidemiology of injury from powered wood splitters is not well known. There are reports about such injury originating in the US, Britain, Sweden, Denmark and Turkey. In the US the number of injuries associated with wood splitters in 2008 has been estimated at 6882. [58] The corresponding figure for Sweden the same year is 1400 injuries. (Personal communication: Anders Tennlind, Swedish Board of Health and Welfare 7 January 2010)

One might expect wood splitter injuries to occur only in adults, but children injured by wood splitters are mentioned in several studies.[25, 27, 28, 36] The majority of the injured are men. In studies that report wood splitter injuries in women, the percentage of injuries affecting women ranges between 5.8 and 22%. [24, 25, 27, 28, 31, 56] In several studies the location and type of injury and the operative treatment are described. Wedge splitters often cause traumatic amputations of digits and sometimes of the entire hand. [25, 27, 28, 31, 34, 39, 56] They may also cause crush injuries. In a material of 23 wedge splitter injuries, Jaxheimer et al. noted a preponderance of “injury to the central digits”, i.e. equal involvement of the first, third and fourth fingers with sparing of the second and fifth fingers. They felt that this pattern of injury reflected the patient’s power grip of the log at the moment of injury. [27] Hellstrand noted that the tip of a screw splitter mandrel can enter the palm and go either in a proximal direction or directly through the palm to the dorsum of the hand. He called this a “perforation”. He also noted avulsion type amputations of three thumbs, one index finger and one middle finger. [24] (Figure 13)
Figure 13. Avulsion type amputation caused by a screw splitter. Note that the level of digital nerve injury is proximal to the level of skin and skeletal injury. The patient is not from the patient material described in this thesis. Photography: Aron Lindqvist

Circumstances involved in wood splitter injury

Information on the correct way to handle a wood splitter can obviously be of importance in reducing the risk of injury. This information could be obtained, at least in part, by a user’s manual, warning signs/notices on machines, and verbal instructions. Holm reported that of 52 patients injured by wood splitters, 23% had received verbal instructions, none had received written instructions and two thirds had not received any instructions at all.[25] Jaxheimer found that nearly one fourth of the injuries occurred during the first or second experience with the machine.[27] This supports the view that it would be desirable for wood splitter users to be informed about safe practises for use before using the machine.

Many of the injuries associated with powered wood splitters obviously occur with splitters owned by the injured person or the household where he or she lives. Jaxheimer et al. found that 43% of injuries (10 of 23 patients) were caused by a personally owned splitter. In many places, however, wood splitters are also available for rental.[28, 39, 56] For those who have the opportunity to split all the firewood they need in one or a few intense workdays per year, the rental opportunity might seem a more sensible and economic option than buying a splitter. Borrowing the machine from a friend, relative or neighbour could be even more economically beneficial. In the comparatively large material of wedge splitter injuries collected by Holm, 47% of the patients were injured by a borrowed splitter, 15% by a rented splitter and 34% by a splitter owned by the patient or his/her household.[25]
Sometimes both wedge and screw splitters can fail to split the wood, which then in most cases remains stuck on the wedge or screw. This is more common when the wood is stringy and rich in knots. With wedge splitters it is also more common if the maximum pressure generated by the splitter is relatively low, if a 4-way wedge is used, or if the pressure plate stops too far from the wedge. When the wood has stuck on the wedge or screw, the operator usually wants to remove it to be able to continue splitting. In some screw splitters this can be accomplished with a reversing gear that makes the screw rotate backwards. However, this method of removing the wood does not always succeed because the safety disconnection breaker may stop the engine when the reversed movement strikes resistance. Another way to remove wood from the wedge or screw is by using a sledgehammer and wedges to complete the splitting. If removal includes use of hands or other body parts in the area of splitting there is a possibility that injury will result.[47] An example of this was noted by Jaxheimer et al. When the pressure plate of wedge splitters did not traverse the entire distance to the wedge, the log was not completely split. The patients then reversed the piston to insert an additional block of wood between the piston and the incompletely split log. In a material of 23 patients with wedge splitter injury, five patients injured their hand between the two blocks of wood during this manoeuvre.[27]

As previously mentioned, European standards require all wood splitters to have a warning sign saying that the machine should be used by a single operator. Nevertheless it is clear that wedge splitter users often work in pairs, one placing wood in the trough and another handling the control. Due to a misjudgement in timing the control may be activated before the person who places the wood is aware of it and an injury may occur. Sometimes even more than one person, apart from the operator, work at the machine. For instance they may help in placing the wood in the trough, stacking and transport. Holm found that only 42% of the injured had been working alone at the machine. In another 42% of cases there had been two persons, in 14 percent three persons and in two percent (one case) there had been four persons at the machine at the moment of injury.[25] Splitting productivity has more to gain by multiple workers working in unison than have cutting and many other activities in firewood production, which may explain why two or more persons often work together at the splitter.[31]

If gloves are used during work with a screw splitter they can get caught in the rotating mandrel. In his series of 15 screw splitter injuries Hellstrand noted that 13 patients wore gloves at the moment of injury and almost all injuries occurred when the glove was caught in the mandrel. He specifically mentioned the uncovered tip of the mandrel as the point of danger. At the very end of the tip of many screw splitter mandrels there is a small barb to make it easier for the mandrel to “catch” the wood. It is possible that a glove can also get caught more easily because of this barb. Owen and Hunter
(1993) discouraged glove use during work with screw splitters. Gloves can also get caught during work with wedge splitters and an injury can occur.[25]

Measurement of severity and outcome

Both the number and the causes of injuries, as well as their severity, are of importance for priority setting in prevention and health care planning. Mortality, and the rate of hospital admission, can be used as measurements of injury severity.[9] These measures may be somewhat blunt for this purpose, but have the advantage of often being available for large patient groups. However, the rate of hospital admission is of very limited value in countries where many people have no access to health care.

Injury Severity Score

For more accurate measurement of injury severity, several rating instruments are available. The classical instrument is the ISS (Injury Severity Score), which was designed to rate overall injury severity in patients with multiple injuries to different body regions.[7] It is based on the AIS (Abbreviated Injury Scale), which gives every possible injury a numerical code.[4] The last digit of such a code is the AIS score which ranges from one to six and increases with injury severity. The ISS is the square of the highest AIS score in each of the three most severely injured ISS body regions which are, Head or neck, Face, Chest, Abdominal or pelvic contents, Extremities or pelvic girdle and External. The ISS ranges from 1 to 75, with higher figures signifying more severe injury. An ISS of 75 obviously can be the result of injuries with an AIS score of 5 in three ISS body regions, but it can also be the result of a single injury with an AIS score of six, which automatically gives an ISS of 75.

The ISS has shown good correlation with mortality in patients with multiple trauma but it was not constructed specifically to rate the severity of hand injury. Consequently it is not ideal for this purpose. For example, a skin contusion or a sprained finger yields the same ISS as a finger fracture or a flexor tendon injury. Ten flexor tendon injuries result in the same ISS as one flexor tendon injury.

Hand injury severity scoring system

In contrast to the ISS, the Hand Injury Severity Scoring System (HISS system) was designed specifically to rate hand injury severity.[15] When our study was begun there were very few published studies in which the HISS system had been used. The HISS system divides the hand distal to the carpus
into four categories, Integument, Skeletal, Motor and Neural. These are called ISMN categories. Skin and nail injuries belong in Integument, fractures, dislocations and ligament injuries in Skeletal, injuries to tendons and intrinsics in Motor, and nerve injuries in Neural. (Figure 14) An injury receives points for the damaged structures in each category. Points scored for injuries on a ray (a digit including its metacarpal components) are Weighted values. That means they are multiplied by a weighting factor to adjust for the relative importance of the injured ray. This factor is 2 if the injury is located on the index finger or small finger rays, 3 if it is located on the middle finger or ring finger rays, and 6 if it is located on the thumb ray. There are also Absolute values which apply to injuries that are hard to assign to a particular ray. These injuries are skin loss on the palm or the dorsum of the hand and injuries to the recurrent branch of the median nerve or the deep branch of the ulnar nerve. The Absolute values require no further modification. (Figure 14)
### INTEGUMENT

<table>
<thead>
<tr>
<th>Skin loss</th>
<th>Absolute values (hand):</th>
<th>Dorsum</th>
<th>≥ 1 cm²</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>&gt; 1 cm²</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 5 cm²</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Palm</td>
<td>Dorsum × 2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Weighted values (digit):**

- Dorsum < 1 cm²: 2
- Dorsum ≥ 1 cm²: 3
- Pulp < 25%: 3
- Pulp ≥ 25%: 5

### Skin laceration

- < 1 cm: 1
- > 1 cm: 2

*(If extends across more than one ray, include in *both* rays score)*

#### Nail damage

- 1

### SKELETAL

<table>
<thead>
<tr>
<th>Fractures</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple shaft</td>
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</tr>
<tr>
<td>Comminuted shaft</td>
<td>2</td>
</tr>
<tr>
<td>Intraarticular DIPJ</td>
<td>3</td>
</tr>
<tr>
<td>Intraarticular PIPJ/IPJ of thumb</td>
<td>5</td>
</tr>
<tr>
<td>Intraarticular MCPJ</td>
<td>4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dislocations</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Open</td>
<td></td>
</tr>
<tr>
<td>Closed</td>
<td>2</td>
</tr>
</tbody>
</table>

#### Ligament injury

- Sprain: 2
- Rupture: 3

### MOTOR

<table>
<thead>
<tr>
<th>Extensor tendon</th>
<th>1</th>
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</thead>
<tbody>
<tr>
<td>Proximal to PIPJ</td>
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</tr>
<tr>
<td>Distal to PIPJ</td>
<td>3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Flexor profundus</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Zone 1</td>
<td></td>
</tr>
<tr>
<td>Zone 2</td>
<td>6</td>
</tr>
<tr>
<td>Zone 3</td>
<td>5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Flexor superficialis</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intrinsic</td>
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</tbody>
</table>

### NEURAL

<table>
<thead>
<tr>
<th>Absolute values</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recurrent branch median nerve</td>
<td></td>
</tr>
<tr>
<td>Deep branch ulnar nerve</td>
<td>30</td>
</tr>
</tbody>
</table>

**Weighted values**

- Digital nerve × 1: 3
- Digital nerve × 2: 4

---

**Figure 14.** Figure from the original article about the HISS-system showing the number of points to be scored for injuries to different structures. By kind permission from SAGE.

To calculate the Hand Injury Severity Score (HISS) the Weighted values for each ray multiplied by the appropriate weighting factor are added to the
Absolute values. This is facilitated by use of the hand injury severity scoring chart. (Figure 15)

<table>
<thead>
<tr>
<th>INTEGUMENT</th>
<th>SKELETON</th>
<th>MOTOR</th>
<th>NEUROLOGICAL</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>THUMB</td>
<td></td>
<td></td>
<td></td>
<td>x 6 =</td>
</tr>
<tr>
<td>INDEX</td>
<td></td>
<td></td>
<td></td>
<td>x 2 =</td>
</tr>
<tr>
<td>LONG</td>
<td></td>
<td></td>
<td></td>
<td>x 3 =</td>
</tr>
<tr>
<td>RING</td>
<td></td>
<td></td>
<td></td>
<td>x 3 =</td>
</tr>
<tr>
<td>LITTLE</td>
<td></td>
<td></td>
<td></td>
<td>x 2 =</td>
</tr>
</tbody>
</table>

Figure 15. Figure from the original article about the HISS-system showing the hand injury severity scoring chart.

The HISS ranges from 0 and upwards, a higher score signifying a more serious injury. No maximal HISS is mentioned in the original article or, as far as we know, elsewhere in the literature. Each injury can also be placed in the appropriate severity grade according to its HISS. Injuries with a HISS below 21 are graded as minor, those from 21 to 50 as moderate, those from 51 to 100 as severe and injuries with a HISS of 101 or more as major.[15]

There is a correlation between the HISS and the amount of time off work after hand injuries.[42, 59] The HISS is also correlated to the outcome of hand injury as measured with the Purdue pegboard.[30] Mink van der Molen et al. found that HISS was correlated to the degree of impairment resulting from hand injury assessed according to the American Medical Association (AMA) guidelines.[20, 41]

An obvious limitation of the HISS system is that injuries proximal to the CMC joints are not included. This excludes many of the more severe hand injuries which often have a proximal component.[42] Also, while injury to many other structures like nerves and tendons receives points that contribute to the HISS, vascular injury is not included in the system and receives no points. Considering that vascular injury may cause loss of digits, or indeed the entire hand, this seems illogical. One could argue that once vessel injuries have been microsurgically repaired they will not greatly affect the outcome of a hand injury. However, microsurgical facilities are beyond the
reach of the majority of the population in the world. Furthermore, even when microsurgery is available, it should not be used, and is not used, for all cases of devascularising hand injury. Nor does microsurgical vessel repair always succeed. Therefore the suspicion remains that the absence of vascular injury in the HISS system is a weakness of this system. In addition, burn injuries of different degrees and high pressure injection injuries are also absent in the HISS system. It has been proposed that in a revised score burn injury should be defined as skin loss.[42]

DASH outcome measure

The Disabilities of the Arm, Shoulder and Hand outcome measure (DASH) is a self-report questionnaire designed to measure physical function and symptoms in patients with upper limb disorders.[26] It consists of one disability/symptom module of 30 questions, the sports/music optional module and the work optional module. The optional modules consist of 4 questions each, and are designed to identify the specific difficulties that professional athletes/performing artists or other groups of workers might experience. Each completed module yields a score ranging from 0 to 100, a higher score indicating greater disability. DASH has been shown to be reliable and valid in a patient population with various upper extremity disorders.[40] Similarly, the Swedish version of DASH has been shown to have good reliability and validity in a material of patients with mixed upper extremity disorders.[5]

Wong et al. evaluated 146 hand trauma patients admitted to hospital and found a mean initial DASH disability/symptom score (DASH score) of 45 which decreased to 14 in the last week before discharge from rehabilitation.[62] In 78 patients with multiple phalangeal fractures, Van Oosterom et al reported a mean DASH score of 11 at a mean time of 7.5 years after injury.[61]

Other authors have investigated the relation between the HISS and the DASH score. Mink van der Molen et al evaluated 110 hand trauma patients admitted to hospital for surgery and found no correlation between the HISS and the DASH score. Five to six months after injury the mean DASH score was 14.[41] Similarly, Chan et al found no correlation between the HISS and the DASH score in 57 patients admitted to hospital because of acute hand injuries requiring surgery.[17] Saxena et al, however, evaluated 22 hand injury patients from a sample of 70 and found an association between the HISS and the DASH score.[49] Rosberg et al, who evaluated 140 patients with hand and forearm trauma, also found a correlation between the HISS and the DASH score.[48]
Sollerman test

The Sollerman hand function test (Sollerman test) is a standardised hand function test which consists of 20 activities of daily living and is based on seven of the eight most common hand grips. (Figure 16)

![Figure 16. Patient who lost fingers II and III on the left hand due to injury from a wood splitter. Picture shows patient being evaluated with the Sollerman hand function test.](image)

According to test performance each hand is given a score ranging from 0 to 80 points, a higher figure signifying better hand function. However, three of the 20 activities of daily living included in the test require the use of both hands. Therefore the Sollerman score of one hand may to a certain degree be influenced by the performance of the other hand. The Sollerman test has been used to evaluate hand function in tetraplegia, gout, and after hand trauma.[12, 18, 51] It has a good intra- and inter rater reliability when used in patients with chronic stroke.[13]
Aims

- To describe the epidemiology of hand injury from powered wood splitters.
- To describe the location and tissue damage of hand injury from powered wood splitters including typical patterns of injury.
- To rate the severity of hand injury caused by powered wood splitters and investigate possible relations between injury severity and machine type.
- To describe hand injury from powered wood splitters with special consideration to children.
- To evaluate the outcome after injury from powered wood splitters, to relate the outcome to the initial injury severity, and to measure the objective functional loss in severely injured patients.
- To describe some aspects of wood splitter construction and design considered to be of importance for the safety of the users.
- To describe some patterns of wood splitter use and injury events with the objective of facilitating prevention of hand injury from powered wood splitters.
Patients and methods

Patient search

Uppsala University Hospital is a referral hospital serving a population of around one and a half million. To find all cases of upper extremity injury from powered wood splitters seen at the Department of Hand Surgery at this hospital during the period 1 January 1995 – 31 December 2001, a search was performed in a computerized patient registration system based on the ICD 9 and 10.[53, 54] As a first step, codes reflecting external causes (ICD-9 codes E918, E919, E920, E928 and ICD-10 codes W23, W29, W30, W31 and W 49) were combined with injury codes for all possible injuries to the hand and arm, including applicable codes regarding injuries involving multiple body regions and injuries to unspecified body parts. Patients registered as pseudarthrosis (733W and M84.1) were included in the search without a code for an external cause. This first search yielded 1924 patients whose records were screened. All who had been injured by a saw, axe, wood splitter or unspecified machine or during work with firewood were contacted by mail or telephone and asked about the cause of their injury. In 124 cases, injury caused by a powered wood splitter was verified and these patients were included in the patient material. In addition, colleagues recalled five patients whom we had not found in the initial search. These had been classified by codes T87.3, T92 and Y86 which previously had not been included in the search. A complementary search was therefore done using these and similar codes (subgroups of T75, T79, T87, T92, T94, T98 and Y86), which added the last two patients for a total of 131 patients. Outpatients had not been entered in the patient registration system that was used until 9 February 1999 and only two outpatients injured by wood splitters before this date were found and included in the present study.

Inclusion

All patients seen at the Department of Hand Surgery at Uppsala University Hospital with an upper extremity injury caused by a powered wood splitter during the period of study were included in studies I and II. Four patients were injured by the saws of dual purpose cutter and splitters. One of them was included because his hand had been pushed onto the rotating circular
saw by a piece of wood which in turn was pushed by the returning pressure plate. The remaining three were excluded along with all other patients injured by saws. The previously mentioned patient who had been injured by the clas wood splitter was excluded, as were all patients injured by axes.

Injury anatomy and severity

Injury data were collected from patient records and radiographs. The records sometimes contained contradictory pieces of information about injury anatomy and were studied very carefully to determine what structures were actually injured. Written answers to radiographic examinations were compared with the actual pictures whenever these were possible to obtain. All injuries were rated according to the ISS. One hundred and nineteen injuries were rated according to the HISS system, but 12 injuries were located too proximally to receive a HISS. Since these patients constituted nine percent of the material it would have been unsatisfactory to leave them out of HISS severity rating altogether. Therefore, the severity of each of the 12 proximally located injuries was estimated. According to these estimations, each injury was subsequently placed in the appropriate HISS grade. HISS grading without having a HISS has previously been done by other authors.[48]

In a number of cases it was felt that the original article in which the HISS-system was first described did not define clearly enough how to use the system. Instead of just scoring arbitrarily in these situations, we wanted to score the same way each time a particular type of injury occurred. Therefore a number of complementary principles were defined and used. None of these principles included a change in the original system, they simply clarified how to rate the injuries when the original article about the HISS system gave no information. An example of this is the scoring of points for digital nerve injury.

According to the original article about the HISS system one digital nerve injury gives three points, and “Digital nerve x 2” gives four points. Exactly what is “Digital nerve x 2”? Is it two injured digital nerves in the same finger? Or two injured digital nerves in different fingers? Or one digital nerve injured at two levels? Or one injured common digital nerve? Since the number of patients with two or more digital nerve injuries was quite high, these questions constantly arose and we felt we needed a clear rule to follow.

If two injured digital nerves, each in a different finger together are given four points, it will be difficult to say what weighting factor to multiply the points by if the fingers or rays that these nerves supply have different weighting factors. That indicates that “Digital nerve x 2” should not be interpreted as two injured digital nerves in different fingers. The same difficulty arises if “Digital nerve x 2” is interpreted as an injured common
digital nerve. One digital nerve injured at two levels would be a possible interpretation. However, recovery after a single transsection of a digital nerve is often not very good, and it is questionable whether transsection at two levels really results in an outcome that is much worse. Further, transsection at two levels was very uncommon in our patient material. We decided that two injured digital nerves in the same finger, but not in different fingers, was “Digital nerve x 2” and should receive four points. Injury to a common digital nerve was scored as injuries to the two digital nerves it divides into, and a digital nerve injured at two levels was scored as if it was injured at only one level.

When HISS rating was complete, a study of its reliability was performed in the following way. From the 119 injuries with a HISS, a sample of 60 patients was extracted by proportional stratified selection. The sample size was determined according to the desired confidence interval for ICC values. The sample patients were HISS rated again according to the same principles as before by the physician who had done the initial rating, and by two other physicians. The contribution of each ISMN category to each HISS of the patients in the sample was also calculated. Intra- and inter-rater reliability concerning the HISS and the sub-scores derived from each ISMN category were determined as ICC-values.

Information from patients

One to nine years after the injury further information about machine safety, patterns of use and injury events was gathered from the patients or their relatives by written questionnaire and structured telephone interview. Four patients were dead, two were demented and four chose not to participate. The participation rate was 92 %. The questionnaire and structured telephone interview contained both questions with clearly defined answer alternatives, and open-ended questions. The defined questions may give reliable information about proportions but the open-ended questions only provide a baseline for the occurrence of a particular factor in the material.

The patients were also evaluated with the Swedish version of DASH.[5, 26] This evaluation was done one to nine years post injury and was called “DASH 1”. A total of 24 patients were excluded from DASH 1, giving a participation rate of 82 %. Reasons for exclusion were as follows: four patients were dead, three were demented, 10 had an additional upper extremity injury, two had a disease affecting the hand and five chose not to participate. Seven to 14 years post injury, 26 of the 31 patients in HISS grade Major completed a second evaluation with DASH, which was called “DASH 2”, and the Sollerman test. Five patients in HISS grade Major were excluded from DASH 2 and the Sollerman test only. Reasons for exclusion
were death, other upper extremity injury or patient’s choice. The time between DASH 1 and DASH 2 ranged between five and eight years.

Statistics

Statistical methods used include Fisher’s Exact test, the Kruskal-Wallis test, the Mann Whitney test, Wilcoxon’s signed rank test and ANOVA. The Spearman Rank Correlation Coefficient (SRCC) was used to measure the degrees of association. The Intraclass Correlation Coefficient (ICC) was used to measure the inter- and intra-rater reliability of HISS rating. Probabilities of less than 0.05 were considered significant.
Results and discussion

Epidemiology

In this study we describe hand injuries from powered wood splitters in 131 patients. Seventy-three percent of the patients were men. Wedge splitters caused 82% and screw splitters 18% of all injuries. (I) The proportions of injuries caused by wedge splitters and screw splitters found in our study differ from those in other Swedish studies. In a material of patients injured from 1982 to 1986 Hellstrand found only screw splitter injuries, no wedge splitter injuries.[24] That study was performed at Örebro University Hospital. Lindroos et al. collected a material of patients injured between 1996 and 2001 in the Umeå region in northern Sweden. They found 43 patients injured by wedge splitters, 11 injured by firewood processors and only 2 injured by screw splitters.[31] A possible explanation for the differences regarding splitter type between the study of Hellstrand and our study might be that our patients were injured several years later. During the time that passed between the two studies there may have been a general change from screw to wedge splitters among users. The proportions of patients injured by wedge and screw splitters also differ between the study of Lindroos et al. and our material. The reasons for this difference are unclear, but since the studies were conducted during almost the same time period, a general change over time from screw to wedge splitters is not a likely explanation.

In the beginning of this project it was expected that some machine brands or models would have particular safety problems, resulting in particular injury anatomy and requiring particular preventive measures. It soon became clear, however, that in many cases it was not possible to obtain the brand or model name. Also, the injuries were caused by a large number of different brands or models of splitters. This is in accordance with the results of Lindroos et al., who studied investments in equipment made by Swedish non-industrial private forest owners and found that the type of forestry equipment available in the greatest range of models was wood splitters.[32] Among the 56 patients in the present material who could identify the brand or model of the splitter that caused their injury, 21 brands or models of wedge splitters and five brands or models of screw splitters were found. (Table 1) No single model could be associated with more than four injuries, which may have contributed to the difficulties in identifying model-specific
patterns of injury anatomy. Further, it is not possible to calculate a relative risk without information concerning proportion of users of the different brands and regarding the frequency of use.

In some previous studies concerns are expressed over an increasing rate of injury from wood splitters. The mere number of injuries found in the present material would seem to confirm that the concerns were justified. From the time when powered wood splitters were first introduced in Sweden until the period under study there must obviously have been an increase in the number of machines as well as the number of injuries associated with them. In the present material, however, there was no statistically significant increase or decrease over time in the incidence of injuries resulting in hospitalization. (I)

There was a preponderance of injuries during spring and summer with a peak during April and May. Forty-six percent of all injuries occurred during April or May and only 14 % from September to February. (I) One factor that may provide part of the explanation for the spring time peak in injuries is the advantage of letting the split wood dry before use, which is most easily done during summer. It might be of benefit to let information about the monthly incidence of these injuries guide the timing of any efforts to raise public awareness about the problem.

Injury anatomy

The hand part most commonly injured by wedge splitters was the index finger, closely followed by the middle finger. The finger least frequently injured by wedge splitters was the small finger. Thus, we were able to confirm the sparing of the fifth finger in wedge splitter injuries found by Jaxheimer et al., but our findings clearly contradict the reported sparing of the index finger.[27] Screw splitters most commonly caused injury to the metacarpus. (I)

Among those injured by wedge splitters, 47 % had devascularising injury which most often affected the index finger. Twenty-nine percent of those injured by screw splitters (seven patients) had devascularising injury which most often affected the thumb. The devascularising thumb injuries caused by screw splitters were avulsion injuries with a very similar anatomy. They were all located at the level of the proximal phalanx, and torn out digital nerves as well as tendons that had been ripped from their antebrachial muscle origins were still attached to the completely amputated distal thumb part.

Ten out of 24 patients with screw splitter injuries had palmar perforation injuries. (I) The findings in the present material of palmar perforation injuries and the type of avulsion amputations mentioned above confirm the previous findings of Hellstrand.[24] In both the present material and that of
Hellstrand, most of the traumatic amputations caused by screw splitters were thumb amputations. The level of amputation was also similar, if not identical. The thumbs in Hellstrand’s study were amputated at the MCP-joint level while the thumbs in the present material with traumatic amputation caused by screw splitters were amputated at the level of the proximal phalanx.

Children

It is clear from previous reports that hand injury from powered wood splitters does occur in children. The present material not only confirms that such incidents happen, it shows that they are a regular part of the panorama of injury from powered wood splitters. Eleven percent of the injuries affected patients below the age of fifteen years, and children were present during work with the wood splitter in at least 15% of cases. Sometimes children were even allowed to handle the controls.

Injuries in children were more severe than those in older patients, regardless of whether injury severity was measured as mean HISS or as distribution in HISS grades. (II) This difference between children and adults was statistically significant. The mean DASH score was lower for children than for adults, but there was no significant difference between children and adults regarding the mean DASH score. Thus, compared to adults, children had more severe injuries, but not a worse outcome. One possible explanation for the discrepancy between injury severity and outcome in children could be their superior healing ability. Also, it is unclear if the same levels of significance would be found if a larger patient material were obtained and analysed. Nevertheless the present findings indicate that hand injury from powered wood splitters in children should be taken at least as seriously as in adults. One should remember that any residual impairment is likely to affect a child for a much longer time than the same impairment in a 70-year old patient. Thus it is clear that when children are present during work with wood splitters it is possible that they will get seriously injured. This should be reason enough to keep children away from wood splitters.

In addition to this, the present material shows that children may contribute to hand injury from powered wood splitters in adults. For example, one of the three injuries caused by wedge splitters with two-hand controls was caused by a child who came up from behind the operator and activated the machine without his knowledge. (IV) This gives further support to the view that keeping children at a safe distance from powered wood splitters during work is one of the important strategies for prevention of injuries caused by these machines.
Severity

The mean ISS was 3.7 (range 1 – 13) indicating that hand injury from powered wood splitters is of minor severity according to the ISS. This is not surprising. The ISS compares hand injuries to injuries in other ISS body regions. Unlike the head, chest and abdomen, the hand contains no vital organs and consequently even extensive hand injuries can never become as severe as extensive injuries to these other regions. Baker et al. found no deaths among patients less than 50 years of age with an ISS below 10.[7] Thus, injuries with an ISS in the same range that was found in our material would seldom be fatal. Hand injuries of this severity can, however, result in considerable residual impairment.

The mean HISS was 63, (range 0 – 208) indicating that the average injury in the present material was severe according to the HISS system. (II) We should remember, however, that some outpatients may have been seen at the Department of Hand Surgery between 1 January 1995 and 8 February 1999 and may still be missing in the present material. If so, it is probable that they had less severe injuries and would have contributed to a lower mean HISS if they had been found. However, the 12 injuries with HISS severity grade placement based on estimations of injury severity turned out to be over-represented in HISS grade Major, indicating that they were much more severe than the other injuries. Thus, it is probable that if each of the proximally located injuries could have received a HISS they would have contributed to a higher mean HISS. Therefore we assume that the mean HISS of 63 gives an accurate picture of the severity of injury from powered wood splitters seen at the Department of Hand Surgery.

Nineteen percent of the patients had minor, 31 % had moderate, 23 % had severe and 27 % had major injury according to the HISS system. (II) Thus, half of the patients had severe or major hand injuries. This does not mean that there are generally the same proportions of such severe hand injuries from powered wood splitters in our catchment area. The present material includes local patients along with patients referred for specialized care. The referred patients are likely to have more severe injuries and may differ from the local patients in other ways as well.[60] Many of the less severe injuries in our catchment area were probably handled at smaller hospitals, by general practitioners, and even by the patients themselves. Therefore we assume that the full spectrum of hand injuries from powered wood splitters in our catchment area during the period of study was of a much lower severity, and the number of injuries much higher, than in the present material.

As previously mentioned, the injuries with HISS severity grade placement based on estimations of injury severity were over-represented in HISS grade Major. It was not clear if this over-representation was due to an exaggeration of the severity of these injuries, possibly caused by the unorthodox way of grading them. The mean ISS of those with estimated HISS grades was 7.6,
which is significantly higher than the mean ISS of 3.3 for all other injuries. This provides some support for the correctness of the estimations, provided that the HISS and ISS are reasonably well correlated. In all patients who had both a HISS and an ISS, the correlation between these two scores was tested and a SRCC of 0.61 was found. (II) In our opinion this indicates that the HISS grading based on estimation of injury severity in the present patient material was reasonable. We therefore consider it correct, in studies based on this material, to use the distribution of injuries in HISS grades as one way of assessing the severity of groups of injuries although they include injuries with estimated HISS grades.

A large proportion of the patients (44 %) had devascularising vessel injury, which is associated with a risk for loss of a part of the hand. Since vessel injury is not included in the HISS system, the vessel injuries did not contribute to the HISS of these patients. Sixteen out of 57 patients with devascularising injury were found in HISS grade I or II. Some of these may have received a lower HISS than their injury "deserved". It is therefore possible that when the HISS system is used for rating the severity of hand injury from wood splitters, the absence of devascularising vessel injury in the system is a disadvantage. The HISS system did, however, identify the group of devascularising injuries as more severe than other injuries. This could support the view that despite the absence of vascular injury in the HISS system, it serves its purpose when used for rating on the group level.

Only one patient in the present material had a burn. Therefore the lack of instructions on scoring of burn injury in the HISS system seems to be of practically no importance for the rating of wood splitter injury according to this system. The burn was full thickness and was scored in the HISS system as skin loss as suggested by Mink van der Molen et al.[42]

The analysis of the rating according to the HISS system showed good or very good inter- and intra-rater reliability concerning the HISS (ICC 0.861 - 0.954). (II) This supports the view that the HISS system is of use for rating the severity of the kind of hand injury found in our material. The analysis of the contributions of each ISMN category to each HISS also revealed good or very good inter- and intra-rater reliability for the categories Skeletal, Motor and Neural. The inter-rater reliability concerning the Integument category, however, was poor (ICC 0.435 – 0.539). In this context it is of interest that Saxena et al. found a significant correlation between the ISMN scores for the categories Skeletal and Motor and the subsequent outcome as measured with DASH, but no correlation between the ISMN scores for the Integument category and outcome. One possible interpretation of the poor inter-rater reliability concerning the Integument category found in our study is that there is room for improvement in the HISS system concerning the scoring of injury within the Integument category. However, another possible explanation is that the injuries in the Integument category may have been less well documented in the records than the injuries in the other categories,
which may have contributed to poor inter-rater reliability. Therefore the present results concerning the reliability of the rating of injuries in the Integument category must be interpreted with caution.

If one of the two main splitter types had caused all serious hand injuries, it might have been possible to prevent serious hand injuries by abandoning that type and using the other one instead. In the present material, however, there was no difference regarding severity between wedge and screw splitter injuries. Therefore the findings in the present material do not indicate that this preventive strategy is practicable.

DASH

In our study of the outcome of hand injury from powered wood splitters we found a mean DASH score of 15. (III) This is similar to the mean DASH score reported by Mink van der Molen et al 2003, and slightly higher than that found by van Oosterom et al. 2007. The DASH scores in our study show that many patients with injury from wood splitters have sequelae even a long time after the injury. On average these sequelae are of moderate degree. However, patients with no or minimal sequelae, and patients with very marked residual symptoms or disability, were found in all severity grades.

As previously mentioned, Mink van der Molen et al. and Chan et al. found no correlation between the HISS and the DASH score, while Saxena et al. and Rosberg et al. did find such a correlation.[17, 41, 48, 49] In our material we found a correlation between the DASH score and the HISS (SRCC 0.336, p<0.001, n = 96) and also between the DASH score and HISS grade (SRCC 0.301, p = 0.002, n = 107). Although these correlations were weak, they indicate that the more severe the initial wood splitter injury, the worse the outcome. On a more general level they also provide some support for the findings of Saxena et al. and Rosberg et al. indicating that there is a correlation between higher HISS and higher DASH score.

There was also a weak correlation between the DASH score and patient age at injury. One possible reason for this could be that children and young people have a greater potential for healing and are less prone to residual joint stiffness after trauma, whereas the elderly are less fortunate in this respect.

No difference was found between the DASH scores of those injured by wedge splitters and those injured by screw splitters. Considering that wedge- and screw splitter injuries had similar injury severity this is not surprising. The findings indicate that it would probably not be possible to improve the mean outcome of wood splitter injuries by using only one of the two main splitter types and abandoning the use of the other.

The 26 patients in HISS grade Major who participated in DASH 2 and the Sollerman test had a mean DASH 1 score of 21 (range 0 – 58) and a mean DASH 2 score of 14 (range 0 – 50). The mean change in DASH score
(DASH 1 minus DASH 2) in this group of patients was -7.5 (range -27 – 21). This is a statistically significant decrease in the DASH score which implies that even years after the injury the most severely injured patients are still improving after, or adapting to, the injury.

Sollerman test

Ekerot et al reported a Sollerman score of 77 in a group of eight patients with replanted or revascularised thumbs, and a score of 73 in their eight matched controls who had lost their thumb.[21] Among the patients in HISS grade Major, we found a mean Sollerman score of 78 in the uninjured hand and a score of 66 in the injured hand. Thus, the mean Sollerman score of the patients in HISS grade Major found in our study suggests that these patients had a greater average impairment of function in the injured hand than the patients who had lost their thumb. However, the extent to which this difference in Sollerman scores between the two groups could be due to differences between raters is unclear. In our study there was a statistically significant difference regarding the Sollerman score between the injured and the uninjured hand (p<0.001). (III) The Sollerman test results in our study show that the most serious injuries from powered wood splitters result in significantly impaired function in the injured hand.

Occupational and leisure time injuries

Only seven percent of the injuries occurred at work, while 85 % occurred during the patient’s leisure time. (IV) This corresponds well with results from other studies. Hellstrand found only one occupational injury in a material of 15 screw splitter injuries.[24] Among 52 wedge splitter injuries, Holm noted 10 occupational injuries.[25] Our findings are also in accordance with the view of Lindroos that firewood production is often conducted on a leisure-time basis and without any employer-employee relationship.[31] It may have been difficult for some patients, such as self-employed farmers splitting wood from their own forests, to say whether the injury occurred during work or leisure time. Nevertheless, the figures are convincing enough to conclude that most of the injuries occur during leisure time. One might hypothesise that consequently preventive measures which are directed towards employers would consequently not be as effective against wood splitter injuries as they are regarding machine injuries in factories, for example.
Information given to wood splitter users

Adequate information given to operators about how to use a machine safely is one of the common strategies for preventing injury from machines. In this material only 40% of the patients reported that the splitter had a warning notice, or a users manual, or both. Furthermore only 30% stated that they had read the available notice or manual, totally or in part. The most common source of information was verbal instructions of some kind about how to use the wood splitter. Seventy-one percent of the patients had received such instructions, but there is no information whatsoever about the thoroughness or relevance of these instructions in relation to injury prevention. Thus, the exact proportion of patients who had received adequate information about safe working practices before they were injured is not known. One fourth of the injuries occurred within the first 10 hours of using the machine, which supports the view that it is desirable for users to receive information about safe working practices before commencing any work with the machine.

Ownership

The owner of the splitter was the patient’s household in 44% of cases and the patient’s employer in only three cases. In 33% of cases the splitter was borrowed and in five percent it was rented. (IV) Thus, the proportion of borrowed and rented splitters was relatively high, but not as high as in the study by Holm who found that 62% of the splitters were borrowed or rented.[25] Users of borrowed or rented wood splitters have to return the machine to the owner, sometimes at a certain time or date. If the machine is rented there may even be an additional cost if it is not returned on time. One might hypothesise that users of borrowed or rented wood splitters work faster, or work a longer time without rest, than users of personally owned machines in order to finish the planned splitting on time. One might also hypothesise that information supplied with the splitter when it is purchased is not always available with the splitter when it is borrowed or rented. Testing these hypotheses, however, is beyond the scope of this thesis.

Controls

In 73% of the wedge splitters the type of control device was a lever. In 53% of these machines the piston moved in the same direction as the lever, while in 37% it moved perpendicular to, or opposite to, the direction of lever movement. The most common type of control function in wedge splitters was return-on-release, which was found in 36% of these machines. Twenty-nine percent had a hold-to-run function and in 17% the piston continued
through a whole cleaving cycle once its movement had been initiated. The proportion of splitters with two-hand-controls was very low, and only two injuries had been caused by splitters with intact controls of this type. Whether the proportion was low because splitters with two-hand-controls were unusual during the period of study, or because they were safer than other splitters, is not clear.

**Home-made wood splitters**

Although most injuries were caused by factory-made wood splitters, 29% of the injuries were caused by home-made machines. (IV) This could be seen as a surprisingly high figure considering the high level of industrialisation, the generally high income level, and the comparatively low prices of factory-made wood splitters in Sweden. At least the simpler models should be affordable to almost anyone. A significant number of people apparently still find it worthwhile to produce home-made splitters, and this production is not under the control of the authorities. In our material, home-made splitters were inferior to factory-made splitters regarding warning signs, user’s manuals and protective covers. On the other hand, home-made wedge splitters had controls with hold-to-run function more often than factory-made wedge splitters. It is unclear whether the differences between factory-made and home-made wood splitters translate into differences regarding injury risks.

**Unsplit wood**

Most splitters had no device for removal of wood from the wedge or screw and only seven patients reported that the machine had a removal device. Responding to open-ended questions, six patients reported being injured while trying to remove wood that had stuck on the wedge, and six other patients reported being injured in a situation immediately after the machine had failed to split the wood. It has previously been reported that injury may occur in situations that arise when the machine has failed to split the wood, and this is confirmed by the observations in the present study.

**Number of persons present at the wood splitter during work**

Fifty-two percent of those injured by wedge splitters and 21% (five patients) of those injured by screw splitters were not alone at the machine when the
accident occurred. All in all 22 % (29 patients) reported that not being alone at the machine contributed to the accident. (IV) Only one of these patients had been injured by a screw splitter. Answering open-ended questions, 14 of these patients, all injured by wedge splitters, claimed that a communication failure between the person who handled the control device and the patient was one cause of the injury, and five reported having been distracted.

This supports the observations and opinions of previous authors who have reported that not being alone during work with a wedge splitter can contribute to causing an injury.[25, 27, 28, 31, 39, 47, 56] We believe it can be of benefit for wedge splitter users to be aware of the potential dangers of not being alone at the machine during work, particularly the dangers of communication failure and distraction.

Screw splitter safety and gloves

Of 24 patients injured by screw splitters, 20 (83%) were included in the study. Nineteen of them reported that in order to use the splitter that injured their hand it was necessary to hold the wood by hand. Nineteen of them also reported that the machine lacked an emergency stop device and nine of these patients found the usual on-off switch easy to reach from the working position while eight did not. Unlike most wedge splitters, the screw splitters had no other control device that was normally used when operating the machine and that could be used to stop it. It seems very likely that the screw splitters would have been safer if they had been equipped with a device to hold the wood in place without the use of hands or feet. Also, it is not improbable that an emergency stop device could have improved safety in these machines, at least in those with an on-off switch that was not easy to reach.

All 20 participating patients injured by screw splitters reported that they wore gloves at the moment of injury, and that the screw caught the glove and then injured the hand. (IV) All but one of them stated that the use of gloves was one cause of the accident. This indicates that wearing gloves during work with screw splitters is dangerous. However, European Standards require that all screw splitters have a feeding device so that the user does not have to hold the log during splitting. Only one injury in this material was caused by a screw splitter with a feeding device, and how often gloves cause injury in users of machines equipped with a feeding device is uncertain. Furthermore, screw splitter users not wearing gloves would be at greater risk for minor injuries from the handling of wood. Therefore a warning against glove use during work with screw splitters that do not comply with existing standards is considered appropriate, and it is recommended that splitters that do not comply with standards should be exchanged for splitters that do.
Limitations regarding answers to questionnaires and telephone interviews

Almost all the information in this study about the wood splitters that were involved in the accidents, the patterns of wood splitter use, and the injury events comes from the written questionnaires and the structured telephone interviews. These were answered by the patients several years after the injury. Although it is our impression that many patients vividly remembered injury events, the possibility that memories have changed over time must be considered. Patients may also have been reluctant to report some circumstances, i.e. being under the influence of alcohol or having manipulated the splitter. Furthermore, patients may have been unaware of certain facts at the moment of injury. For example, patients injured by an unfamiliar splitter may not have been acquainted with details regarding machine construction or function. Such information could probably have been obtained with greater accuracy and detail if each accident site had been visited soon after the injury.

Overall machine safety and injury prevention

The overall impression is that there was a huge gap between the reported level of machine safety and the requirements in existing standards. Extremely few splitters in this study met these requirements. Only two wedge splitters had functioning two-hand controls of hold-to-run type. The vast majority of wedge splitters could be operated with one hand while the other was held in the cleaving zone. Moreover, at least 29% of wedge splitter users were in the habit of holding their hand on the wood during splitting. Only one screw splitter could be used without holding the wood. No splitter had an intact interlocking device that made it impossible to reach the cleaving zone while the machine was working.

Integrating safety in the design of machines and environments to achieve automatic protection is often a more successful approach in injury prevention than attempting to change behaviour with information.[11] Exchange of unsafe wood splitters for splitters that comply with existing standards would be an important step in this direction, and could probably contribute substantially to reducing the rate of hand injury from powered wood splitters. In fact, it is probable that a change of this kind is going on all the time as old splitters are discarded for various reasons and replaced by new factory-made splitters. This is a hopeful thought, but unfortunately other factors indicate that the ongoing exchange of machines will not radically reduce the incidence of wood splitter injuries in the near future.

Many people will keep their old splitter as long as it works, and it may work for decades. Thus machines that do not comply with standards will be
used long after their production and sale becomes illegal. Also, many splitters are home-made, and how large the proportion of home-made splitters that comply with standards will be in the future is very uncertain. Furthermore, even splitters that comply perfectly with standards can cause injury if not used as intended. The most important example of this is probably wedge splitters with two-hand controls. These splitters are comparatively safe when used by a single operator, as intended, but may be very unsafe if one person puts the wood in the machine and another handles the controls. They may obviously also become unsafe if the controls are manipulated to allow splitting with only one hand at the controls. Children will continue to be playful and unpredictable. As long as they are allowed to be present near the wood splitter during work a risk for injury will remain.

Improved machine safety probably can contribute substantially to reducing the rate of hand injury from powered wood splitters, but it is also essential to change patterns of machine use.
Conclusions

- The incidence of hand injury from powered wood splitters peaks during April and May and most injuries are caused by wedge splitters.

- Wedge splitters most frequently injure the index finger and screw splitters most frequently injure the metacarpus. Screw splitters cause palmar perforation injury and both splitter types cause amputations.

- Many of the hand injuries caused by powered wood splitters are severe, and the severity does not differ significantly between injuries caused by wedge splitters and those caused by screw splitters.

- Children are a regular part of the panorama of injury from powered wood splitters. Their injuries are more severe than those in adults.

- Many injuries from powered wood splitters result in residual symptoms or disability. The more severe the injury, the worse the outcome. The most severe injuries significantly impair function in the injured hand.

- Home-made splitters injured 29% of patients and often lacked a user’s manual and a warning text. Very few of both factory-made and home-made wood splitters complied with European Standards.

- Most patients were injured during their leisure time. Not being alone at the machine contributes to wedge splitter injury and glove use commonly contributes to screw splitter injury.
Avsikten med denna studie av handskador orsakade av motordrivna vedklyvar var att beskriva skadornas epidemiologi och anatomi, att gradera deras allvarlighet, att undersöka om de orsakar resttillstånd och att beskriva faktorer som bidrar till att skadorna uppkommer.


Medelvärdet för DASH-poängen var 15 och det fanns ett samband mellan skadornas allvarlighet och graden av resttillstånd. Det innebär att patienterna i medeltal fick resttillstånd av måttlig grad och att resttillståndet i regel var av värre grad ju allvarligare den ursprungliga skadan var. Bland såväl lindriga som måttliga, allvarliga och mycket allvarliga skador fanns dock både patienter utan resttillstånd och patienter med mycket svåra resttillstånd.


Medelvärdet för poängen i Sollermantestet var 78 i den oskadade handen och 66 i den skadade. Patienterna med de mest allvarliga skadorna hade alltså en tydligt nedsatt handfunktion.


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