# Relative Safety of Traditional Agricultural Tractor Power Take–Off (PTO) Drivelines Compared to Fluid Power – A Review

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**Abstract.** *Nearly all tractor PTO arrangements used today consist of a rotating mechanical shaft with two or more universal joints and splined couplings. Although this method of power transfer has been the standard for decades, it continues to be a hazard to farm workers. Commonly, PTO accidents involve the snagging of clothes, resulting in the victim being rapidly and violently drawn into (and around) the rotating shaft. Entanglement injuries are both common and severe in the agricultural workforce, with poor shielding maintenance as a contributing factor. If PTO loads were driven with fluid power, this entanglement hazard would be eliminated. With high–pressure injection injury being the principal hazard, the fluid power alternative appears to pose a lower risk in terms of both frequency of occurrence and severity of injury.*

***Keywords.*** *Fluid power, Hydraulic PTO, Injection injury, PTO entanglement.*

There has not been a great deal of literature published in recent years that is specific to PTO injuries. Many of the sources cited herein may be considered old; however, there is little indication that the problem has changed for decades. The machinery design and shielding methods, as well as the attitudes of equipment owners and operators, have changed little. In a recommendation for change to ISO 5674, the Health and Safety Executive notes that while PTO safety is a perennial subject, PTO accident numbers are still not falling significantly (HSE, 1999).

## Mechanical PTO Hazards

An agricultural tractor power take–off (PTO) is a means of transmitting power from the tractor engine to an implement or to attachment machinery. The driven machinery may be stationary or mobile. Nearly all tractor PTO arrangements used today consist of a rotating mechanical shaft with two or more universal joints and splined couplings (*ASAE Standards*, 2000a, 2000b). Although this method of power transfer has been the standard for decades, it continues to be a hazard to farm workers. Commonly, PTO accidents involve the snagging of clothes, resulting in the victim being rapidly and violently drawn into (and around) the rotating shaft. During the

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typical reaction time of 1 sec, a victim would be drawn 2 m (7 ft) into and around a shaft rotating at 540 rpm (the most common operating speed; Smith, 1994). At the higher 1000 rpm speed, the victim would be drawn in 3.96 m (13 ft).

Once snagged, the victim's fate is largely controlled by clothing strength. McElfresh and Bryan (1973) reported on a total of 117 PTO–related injuries suffered by 49 patients. Follow–up questionnaires, which were completed by 47 of the 49 patients, indicated that 89% of the victims had clothing entangled in the power take–off. Most of the injuries (34 of 49 patients) occurred during the fall and winter months of October to February. This time period is in contrast with that of the total of all farm injuries and deaths, as farm injury and death rates peak during the summer months (PA data; Huizinga and Murphy, 1989; Murphy and Ambe, 1996). Evidently, the heavier clothing worn during cold weather is an important factor in the severity of PTO–related injuries. McElfresh and Bryan (1973) concluded that the serious PTO accidents usually occurred when the farmer was wearing overalls, a heavy jacket, a nylon jacket, thermal underwear, or gloves or clothing that does not yield with entanglement.

PTO entanglement injuries are both common and severe. Five Pennsylvania deaths due to PTO entanglement were reported by Murphy and Kassab (2001) for the period of 1995 to 1999, a figure similar to that of 1990 to 1994. These deaths account for 5.7% of the occupational–related deaths during the period. In 1998, injury from power take–offs accounted for 5% of the estimated 317 tractor–related deaths that year (NSC, 2000). Stueland and Lee (1989) reported on 913 cases of production agriculture–related injuries treated at the emergency section of the Marshfield Clinic and St. Joseph's Hospital. About 0.5% of the injuries involved PTOs. The danger of agricultural work and agricultural machinery and the importance of tractor safety are echoed repeatedly through safety–related literature. Runyan (1993), in a bibliographic review published by the USDA, concluded that most traumatic injuries on farms involve machinery, with tractors being involved in most fatal accidents. Pratt et al. (1996) reported that the National Traumatic Occupational Fatalities surveillance system identified 8,505 machinery–related civilian worker deaths from 1980 through 1989 and notes that the data presented should be viewed as the minimum number of fatalities. Of these 8,505 deaths, tractor incidents accounted for 1,546. More specifically, PTO incidents accounted for 102 deaths. According to National Safety Council data, an estimated average of 12 deaths per year within the U.S. from 1988 through 1998 can be attributed to the tractor PTO alone (NSC, 2000).

The 1982 Farm Accident Survey Report (NSC, 1982) summarized the data obtained from 31 state surveys including 31,398 farms and ranches. Some 1,516,872 farms and ranches (60% of the nation's total) are located in the states surveyed. According to the report, an estimated 158,000 $\pm$6,000 reportable accidents occur annually in these states to farm/ranch residents, workers, and visitors. Of these, 12.1% were machinery related and classified as severe, permanent, or fatal; 5.9% were tractor related and classified severe, permanent, or fatal. Four percent of these machinery–related injuries and 6% of the tractor–related injuries involved the PTO. If the farms and ranches studied are representative of the entire U.S., about 260,000 reportable accidents may occur on farms and ranches each year. Further extrapolation suggests that over 2,200 severe or permanent PTO–related injuries may occur in the U.S. annually. Variation between studies is probably due to a combination of differences in reporting, injury classification, and region; however, all of the figures presented suggest a large number of severe injuries.

Sell et al. (1985) reported the nature of 72 investigated PTO–related accidents. Of the 72 incidents, two (2.8%) were fatal, 26.4% of the victims suffered amputation, and

31.9% suffered fractures. Other common injuries included lacerations, bruises, friction burns, back injury, avulsion of the legs, nerve damage, denuding of testes and penis, and scalped hair. In 48.6% of the reported cases, stationary equipment was involved, while 20.8% involved semi–stationary equipment (such as a forage wagon), and 20.8% involved non–stationary equipment. All of the cases included in the semi–stationary class and most in the non–stationary class occurred when the equipment was running in a stationary position. Sell et al. concluded that the following four common factors lead to most of the entanglements: (1) the equipment was in a stationary position with the PTO engaged, (2) there was a lack of shielding on all or part of the PTO (although not as common, accidents still occurred with the shielding in place), (3) a protrusion such as a spring–loaded push pin or a through bolt was present, and (4) the victim was positioned where contact with the PTO was possible.

Injuries of similar severity were reported by McElfresh and Bryan (1973). In addition to case reviews, follow–up questionnaires were obtained from 47 of the 49 patients treated. Of the 117 injuries, 82% were considered major and included 46% fractures (35% of which were open), 9.4% traumatic amputations, and 4.2% joint dislocations, as well as nerve injuries and soft tissue lesions. In 13% of the accidents the tractor was less than 5 years old, in 30% the tractor was 6 to 10 years old, in 21% it was 11 to 15 years old, in 15% it was 16 to 20 years old, and in 15% the tractor was more than 20 years old. In 6.4% of cases the tractor age was not recorded. The throttle setting was wide open, half speed, quarter speed, and idling in 17%, 21%, 21%, and 32% of cases, respectively. The throttle position was unrecorded in four instances.

In an article demonstrating the violent trauma associated with PTO entanglement, Kalenak et al. (1978) presented case reports of six agricultural tractor PTO accidents and one truck PTO accident. The six agricultural incidents resulted in two amputations, two cases involving multiple compound fractures, and two cases involving avulsion of testes and genital skin. The report emphasized the danger associated with the use of these machines and suggests that safety shields should be improved and operators educated about the importance of retaining the shields and using the machinery properly at all times.

There is a high correlation between missing or damaged shielding and PTO–related injury. Virtually all new equipment comes with protective shielding to help prevent injury, but shields are often missing or damaged on operating equipment. McElfresh and Bryan (1973) reported that the tractor master shield (the tractor–mounted shield that protects the PTO stub) was missing in 48% of the incidents and cited lack of adequate shielding as the most important factor surrounding the injuries. However, shielding was intact in 37% of the cases for the 15–year period covered by the report. The 1982 Farm Accident Survey Report (NSC, 1982) reported that PTO shielding had been removed in nearly 58% of the PTO–related accidents. Shielding was reported as damaged in 8%, and a shield had not been provided new in 25%.

The lack of shielding maintenance has been recognized repeatedly in safety literature. Murphy et al. (1998) presents baseline data from a project designed to test the effectiveness of three types of safety interventions. One facet of the study rated the condition of shielding and warning decals on PTO drivelines. The condition of tractor master shields was rated less than optimal in 49.4% of those audited. On PTO–driven machinery, 18.5% of driveline shaft shielding, 22.4% of machine master shielding, and 65.1% of driveline warning decals received less than optimal scores. In a study of 2,513 tractors on New York farms, 45.1% had no master shield, and 3.4% of those present had defects (Chamberlain et al., 1998). This study also included 2,805 pieces of trailed PTO–driven equipment; PTO shields were missing on 22%, and 13% had damaged shields. In a study of the effectiveness of inspections and insurance incentives on safety conditions, the most used tractor on each of nearly 200 Minnesota farms was inspected for safety; master shield deficiencies were found on 25.3% (Shutske and Bryant, 1994). On 36 Wisconsin dairy farms, tractor master shields were missing on 27.6% of tractors; machinery was missing 9% of driveline shields and 18.3% of input connection shields (Purschwitz et al., 1994). Not surprisingly, a statistical correlation was found between these deficiencies and the age of the tractor/equipment.

A two–year survey of hazards on New York farm tractors included 136 farms and 605 tractors, of which 47% had master shields in an unsafe condition (Hill et al., 1992). The inspection of 1,309 implements found on farms, equipment dealership lots, and used equipment auction yards in Iowa, Illinois, Wisconsin, Indiana, Michigan, Ohio, Pennsylvania, and New York from January 1985 to October 1986 showed that 40.1% of implement input driveline (IID) shielding, 37.5% of implement input connection (IIC) shielding, and 23.8% of pedestal shielding was missing (Campbell and Field, 1986). The variety of inspected equipment had 775 pieces classified as non–stationary, 176 pieces classified as semi–stationary, and 358 classified as stationary. No new or junked equipment was included. Sell and Field (1984) reported that 51.2% of the master shields had been removed, and 20% were damaged on 578 tractors. Missing shields were noted on 38.7% of the 52 machines audited in a pilot study as part of the Olmstead Agricultural Trauma Study (Gerberich et al., 1991). Based on the results of numerous studies, Kolstad et al. (1990) concluded that there is a need for alternate designs. Shielding has been used for decades, but it has not eliminated the safety hazard of PTOs.

Secondary mechanical shafts driven by the tractor PTO also present hazards and contribute to agricultural work–related injuries each year. One such example is described by a NIOSH alert that documents five cases of persons who were scalped when their hair became entangled around a rotating driveline (NIOSH, 1994). In all five incidents, the driveline was inadequately guarded, and victims were standing or walking nearby. In each case, the driveline was protected by a tunnel guard that covers the top and sides of the shaft but leaves the underside exposed. In three cases, the entire scalp was removed (one including serious facial injuries). In another case, the right side of the scalp and right ear were removed, and in the final case, a ponytail and attached skin was removed. Since 1976, OSHA regulations have required that the shafts and drivelines on all farm equipment be “guarded to protect against employee contact” regardless of the equipment age. However, OSHA regulations are not enforceable on farms that employ fewer than 11 full–time workers. The 1982 Farm Accident Survey Report included, as a point of reference, 31,398 typical farms and ranches from 31 states that had a total of 160,789 workers, for an average of 4.8 workers per unit (NSC, 1982).

## Fluid Power Alternative

The use of fluid power as an alternative to the mechanical PTO has been suggested repeatedly. Morgan (1992) suggested that a logical approach to eliminating PTO driveline accidents is to eliminate the mechanical driveline completely. He noted that in addition to eliminating entanglement injuries, hydraulic power as a replacement would offer control flexibility that would accommodate safety features such as interlocks, “dead man” controls, and equipment reversal to aid in extricating people. Bornzin (1973) also offered hydraulics as a possible solution provided we “learn to hydraulically transmit higher horsepower for PTO work and do it economically." Stepanek et al. (1993), in an article characterizing the speed and horsepower requirements of various implements and attachments as well as the hydraulic capacity of current agricultural tractors, noted that "the ramifications of using fluid drives have benefits which extend to increased equipment safety."

The use of fluid power to drive agricultural machinery has a number of potential benefits. Although electronic sensors and controls are used in wholly mechanical systems, the ease with which electronic control can be effectively applied to hydraulics is unmatched. Since the use of fluid power lends itself so well to electronic control, a number of other safety devices and control scenarios can be easily accommodated. Hydraulic locomotion can easily and quickly be reversed or stopped. This rapid control coupled with tractor stability and position sensors could be used to interrupt or warn of imminent tractor rollover. Ease of equipment reversal could also assist rescue teams in extricating people.

White et al. (2000), noting that the alteration of machinery design has a greater impact on the reduction of accidents than safety training, applied hydraulics in conjunction with an operator presence sensing system (OPSS) to a rotary mower. Their system could detect a hazardous situation and stop the blade of a rotary mower quickly enough to avoid injury. In addition, motivated by the potential to reduce product liability associated with PTO driveline injuries, Shearer et al. (1993) converted a large round baler from mechanical to fluid power drive. The potential for reducing PTO–related accidents is substantial and should be a major consideration for adoption of hydraulic drives for agricultural machinery.

## Fluid Power Hazards

Although fluid power has been suggested as a safer alternative to the traditional PTO for transmitting tractor power, it is not completely free from danger. The principle risk to an operator or mechanic working with high–pressure fluids is known as injection injury. For the purposes of this discussion, all modern fluid power systems are to be considered high–pressure systems with the potential for this type of injury. Injection injury is caused by body contact with a stream of high–pressure fluid and results in the fluid being forced into the body under pressure. Injection injury can be sustained by contacting a fine, nearly invisible stream from a leaking hose or fitting in a high–pressure hydraulic system. Although considered a serious injury, no fatalities due to injection injury were reported in the literature. Even though high–pressure hydraulic systems are common in agriculture, no agricultural safety survey reviews could be found that specifically addressed the issue of injection injury. The mining industry relies very heavily on fluid power. However, as in the agricultural literature, no mining safety summaries could be found that directly addressed injection injury. While under–reporting may be a factor, this lack of emphasis on the problem may also suggest that incidents resulting in significant injury are rare in these industries.

Substantive literature focused on injection injuries related to fluid power could not be found. The following literature review addresses the general nature of injection injury including site of injury, severity, and the effects of material type and pressure. Although not specific to fluid power, it provides insights into the potential for injury.

The three most common variants of injection injury, which dominate literature on the subject, include so–called "grease gun" and "paint gun" injuries, and diesel fuel injection injuries. Accidental penetration of tissue by oil under pressure was first documented by Rees (1937). The injury described was the result of contact with a high–pressure stream of fuel oil from a diesel engine injector nozzle. Later, Byrne (1944) reported on early injuries sustained by high–pressure grease guns. Early paint gun injuries were reported by Stark et al. (1967). Hydraulic systems are always operated in a closed system. High–pressure spray from a hydraulic system is always the result of a failure, while grease gun and paint spray gun nozzles are exposed and therefore have an inherent danger. According to Kaufman (1968a), diesel fuel injuries normally occur during the overhaul of a diesel engine or when the injector mechanism is being tested. Injectors are not exposed during normal engine operation.

From the Division of Plastic and Reconstructive Surgery, University of Michigan Medical Center, and the Department of Surgery, Grace Hospital, Ramos et al. (1970) reported an incidence of one new high–pressure injection case in every 1,400 patients. Schoo et al. (1980) analyzed 127 case reports of high–pressure injection injuries, including five cases treated at the University of Colorado Medical Center. Out of over 3,000 patients treated there for hand injuries, only five cases involved high–pressure injection. Of the 127 cases analyzed, the injected materials and frequencies were grease 31%, paint 28%, hydraulic fluid 6%, diesel fuel 5%, paint thinner 4%, and smaller incidence rates for a variety of other materials including molding plastic, paraffin or wax, cement, mud, automobile undercoating, oil, toluene, indium, creosote rustproofing, and silicone. In 9% of the cases, the material was not specified. Of 51 cases of high–pressure injection injury reported by Kaufman (1968a), 57% involved a grease gun, 14% involved diesel fuel injectors, and 18% involved a spray gun. Although hydraulic fluid was never specified, four cases involved circumstances consistent with fluid power systems. These figures indicate that injection injuries are infrequent and that accidents related to hydraulic systems are relatively few when compared to grease gun and spray gun incidents.

The site of injection injury is normally restricted to the extremities. Of the 127 cases reported by Schoo et al. (1980), the sites of injury and frequencies were the index finger 45%, the palm 23%, other fingers or thumb 33%, and the forearm 1%. Of the 51 accidents reported by Kaufman (1968a), 37% involved the index finger as the site of entry, 14% involved the palm, 37% the other fingers or thumb, 4% the eye, and 2% the forearm. The lower extremities are more often reported in literature as the site of injury when water guns used for cutting and cleaning are involved. Of 11 high–pressure water injection injuries presented collectively by Shea and Manoli (1993), Curka and Chisholm (1989), Kon and Sagi (1985), DeBeaux (1980), and Weltmer and Pack (1988), seven cases involved the foot, the hand was involved in three cases, and the abdomen in one case.

Victims of high–pressure injection injury commonly receive a puncture wound that, at first, appears rather innocuous. This can often lead to delay of treatment for what is actually a very serious injury. The course of events that follow is strongly related to the type of material injected and its strength as a tissue irritant. Injuries involving strong tissue irritants require immediate surgery to remove the foreign substance and devitalized tissue. Stark et al. (1967) reported that the time interval from injury to proper treatment is a major factor in the result. Ramos et al. (1970) concluded that the injury is not related to pressure except that the high pressure is responsible for distributing the irritant along tissue planes. Christodoulou et al. (2001) examined the functional outcome of 15 patients and determined that deterioration of hand function is a predictable outcome of high–pressure injection injury. Significant reductions in static and dynamic muscle testing parameters were noted when compared to the uninjured hand. Of the 15 patients studied, 40% lost a digit, and 27% had to change occupations. Schoo et al. (1980) reported that morbidity was dependent, to a large degree, on the type of material injected. They also found no statistically significant correlation between the pressure of injection and the occurrence of amputation. There was a 100% incidence of amputation above 48 MPa (7,000 psi), but the sample included only three cases. In their review of 127 cases, the amputation rate was 80% when paint thinner was involved, 67% for diesel fuel, 58% for paint, 23% for grease, and 14% for hydraulic fluid. Kaufman (1968a) reported an amputation rate of 72% for diesel fuel injection, 28% for grease, 62% for cases involving a spray gun (which included white spirit and mineral wax, lead tetra–oxide, lacquer, paint, and a grease/oil mixture), and 50% for all other materials, which included lubricating oil, crude oil, carbonox (soda, lime, dry clay, oil, and water), gear oil, and brake fluid.

In a case report of hydraulic oil injury to the eye, Wolter and Nelson (1991) expressed the hope that chemists will soon develop a "biodegradable" oil for hydraulic mechanisms that is "tissue friendly" and easily digestible by macrophages. Environmentally biodegradable hydraulic fluids are currently available in several forms. The new biodegradable fluids, including vegetable oils, polyol esters, diester, highly refined mineral oils, water–glycol, and alpha olefins, are reviewed by Totten et al. (1999). This article addresses general testing procedures and standards for biodegradability in water and soil, but no reference could be found that specifically addresses toxicity to subcutaneous human tissue.

The importance of the type of fluid injected is also supported by the experimental studies performed by Lin et al. (1982) on 12 Charles River rats. Rats were divided into four groups and were injected with paint ingredients (surface–coating epoxy resin, and xylene) by needle and syringe and also by high–pressure spray gun. Isotonic saline solution was injected into the third group at high pressure, while the fourth group was used to test the effects of a steroid treatment. Results indicated that paint toxicity was the major contributor to the pathological process, with similar effects regardless of whether the paint was introduced locally by needle injection or by airless injection gun. Tissue damage due to impact when isotonic saline solution was injected under high pressure was almost completely healed within one week.

Further supporting the importance of material injected, several relatively benign variants of high–pressure injection injury have been reported. Goetting et al. (1992) reported four cases of accidental injection of hexafluoroethane (Freon) used in athletic shoe manufacturing. Treatment was nonsurgical, consisting of splinting, tetanus immunization, and antibiotics. Rapid resolution of symptoms occurred in all four cases with no time loss at work. It was concluded that, in contrast to reported nonvolatile hydrocarbon injection injuries, HFE and possibly other Freons do not appear to be toxic to subcutaneous tissue. It is noted, however, that they may have potential to cause injury from direct trauma, delayed gaseous expansion, and secondary infection. In a case report of high–pressure injection of a mixture of isopropyl alcohol and Freon, Craig (1984) notes an unusually benign course, probably attributable to the nature of the substances. Exploratory surgery was performed with unremarkable findings. Recovery was quick and complete. This suggests that the Freon and isopropyl alcohol combination does not lead to the extensive tissue destruction typical of the more common types of high–pressure injection injury. Kon and Sagi (1985) described an injection injury sustained to the thumb by water delivered at a pressure of 34 MPa (5,000 psi). The patient was managed without surgery and was fully recovered within ten days. Curka and Chisholm (1989) also report nonsurgical treatment of a water jet injury to the thumb with similar success.

Although generally less severe than similar injuries sustained by grease, paint, or oil injection, not all water injection injuries can be treated without surgery; some result in permanent damage. Shea and Manoli (1993) reported on two such cases involving contact with a high–pressure stream of water that penetrated the patient's boots and entered the foot. Despite an attempt to save the involved toes, gangrene developed, and each case resulted in amputation. The case presented by DeBeaux (1980), involved a particularly powerful water jet gun used for underwater cutting and cleaning. It operates at pressures up to 100 MPa (14,500 psi) with a jet velocity of 900 km/h (559 mph). The injury is described as similar to a bullet wound, with a small entrance giving little indication of the damage to deeper tissues. It is suggested that for a variable extent along the track of the jet, the surrounding tissues will be damaged, if not killed, by the shock waves developed as the kinetic energy of the jet is dispersed. In the case presented, the victim was wearing multiple layers of heavy diver's clothing, which decreased the velocity of the jet and reduced the severity of the injury. Since the jet was fired only momentarily, the mass of the water was minimal. Following surgery, the patient recovered fully without complication. Weltmer and Pack (1988) presented a total of six high–pressure water injection injuries. Local irrigation and debridement, together with antibiotics resulted in complete recovery. Weltmer and Pack noted that their findings differ substantially from those of usual high–pressure injection injuries involving more caustic agents, but they caution that prognosis for the full return of function is guarded, even after proper surgical treatment.

Kaufman (1968b) reported the results of experimentally produced high–pressure injection injuries of the hand. In order to better understand the immediate physical damage inflicted by high–pressure injection and distribution of the injected material, simulated injuries were inflicted on selected sites on a cadaverous human hand. A stained mixture of white spirit and wax was injected at an effective nozzle pressure of 5.17 MPa(750 psi). It was demonstrated that penetration of the skin occurs easily, and immediate contact between the gun and skin is not necessary. The jet penetrates the tissue in its line of fire with little lateral spread until striking a resistant structure (fibrous part of the flexor sheath, the tendons, or the bone), which deflects the material sideways. Regardless of the site of injection, the following characteristics were always present: (1) a typical puncture wound exuding wax, (2) local distension of the part injected, (3) spread along a superficial plane beneath the skin, and (4) spread along a deeper plane, the level of which is dependent on the tissues within the line of fire. It was concluded that dispersion of the injected material was dependent on several factors, of which ejection pressure of the gun and the injection site seemed to be most important.

Written safety precautions and procedures for working with high–pressure hydraulics are readily available to agricultural workers since most modern tractors incorporate limited high–pressure hydraulics for operation of various accessories. Sample cautions and safety rules for using and repairing high–pressure hydraulic systems are (Deere and Company, 1987):

CAUTION: Escaping fluid under pressure can penetrate the skin causing serious injury. Relieve pressure before disconnecting hydraulic or other lines. Tighten all connections before applying pressure. Keep hands and body away from pinholes and nozzles which eject fluids under high pressure. Use a piece of cardboard or paper to search for leaks. Do not use your hand.

If ANY fluid is injected into the skin, it must be surgically removed within a few hours by a doctor familiar with this type of injury or gangrene may result.

## Summary

Injuries from mechanical PTO drivelines are relatively frequent and appear to be on the order of 2,000 injuries annually in the U.S. Major causative factors are stationary operation, lack of adequate shielding, protrusions on the driveline, and victims in close proximity. When PTO accidents occur, they are severe; many cause death (3%), amputation (26%), and fractures (32%).

Injuries from high–pressure injection with fluid power drives are infrequent in number; so infrequent that they are not identified as a specific injury category in the literature. Hydraulic fluid injection injuries, if neglected, can become serious and result in amputation of digits or limbs, but with proper medical treatment should have little long–term effect. Within the range of typical mobile hydraulic system pressures (41 MPa, 6,000 psi), the injection site (often digits, sometimes limbs, occasionally eyes) and substance have more to do with subsequent damage than the pressure. New biologically based fluids hold potential to make fluid drives even safer and more environmentally friendly. Combined with functional advantages of fluid drives, particularly when electronic control is implemented, safety considerations are compelling enough to warrant further research and development to replace mechanical drivelines with fluid power drive systems.

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