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DIAGNOSTICS, SURGICAL TREATMENT, AND REHABILITATION OF PATIENTS WITH COMPLEX FRACTURED HAND INJURIES

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Abstract

The article presents a comprehensive review of the diagnosis, surgical treatment, and rehabilitation of patients with complex hand fractures, with a particular focus on phalangeal fractures. It highlights the prevalence of such injuries, especially in low- and middle-income countries, and underscores the significant socio-economic burden they impose due to healthcare costs and loss of productivity.

The review compares various diagnostic tools, including conventional radiography, multislice computed tomography, and cone beam computed tomography, emphasizing the latter's potential for reducing radiation exposure while maintaining diagnostic accuracy. It also explores the use of automated diagnostic systems supported by deep learning techniques like convolutional neural networks, though noting their limited clinical application due to cost and accessibility.

In terms of treatment, the article discusses both conservative and surgical approaches, with a detailed examination of external fixation methods, particularly the Ilizarov method and newer dynamic distraction external fixators. The Wide-Awake Local Anesthesia No Tourniquet technique is highlighted for its effectiveness and cost-efficiency in surgical settings. Rehabilitation strategies, including mirror therapy, robotic exoskeletons, and the use of 3D printing for custom-fit splints, are also reviewed, offering insights into improving functional outcomes post-surgery.

As a result of the review, it is concluded that despite the availability of various diagnostic and treatment methods, further research is necessary to establish more effective, evidence-based protocols, particularly in resource-limited settings.

This review serves as a valuable resource for microsurgeons and healthcare providers, emphasizing the need for continued innovation and research to improve the quality of care for patients with complex hand fractures.

Keywords: *hand injuries, diagnostics, microsurgery, rehabilitation.*

Introduction

Complex fractured hand injuries, such as fractures of the phalangeal bones, represent a significant and urgent medical challenge. These fractures are the second most common fractures of the upper extremities [*Ramlatchan S et al., 2020*], with an incidence rate ranging from 10% [*Karl J et al., 2015;*

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Verver D et al., 2017] to 18% [*Gao Y et al., 2017*], depending on the study and population. The prevalence and impact of these injuries are especially critical in countries with lower socio-economic development, where healthcare systems are often under strain. Indeed, more than 50% of traumatic injuries worldwide occur in low- and middle-income countries, further exacerbating the burden on these health systems [*Bazarbaeva S et al., 2021; Landaeta F et al., 2020*].

A systematic review from the Global Burden of Diseases, Injuries, and Risk Factors Study 2017 [*Crowe C et al., 2020*] revealed that in countries with low and middle socio-demographic levels, hand injury rates have been steadily increasing, with some regions experiencing up to a 25% rise. This surge in hand injuries not only poses a medical problem but also has significant economic implications. Hand injuries represent a substantial economic burden, with high costs associated with healthcare and productivity losses. A systematic review and meta-analysis by O'Hara et al. (2020) demonstrated that 40.5% of patients with hand injuries did not return to their previous employment after 12 months, with an average work absence of over 100 days, leading to a substantial loss of earnings amounting to $14,621. These figures illustrate the broader socio-economic impact of hand injuries, which extends beyond the immediate medical costs to include significant losses in productivity and quality of life for affected individuals.

Further compounding the economic burden, the direct and indirect costs associated with these injuries are considerable. Özgen et al. (2021) conducted a retrospective analysis of 59 patients and found that the average direct cost per patient was $726.00±641.87, while the total amount of indirect costs was $2,776.93±1,619.00. Remarkably, indirect costs accounted for 79% of the total expenses [Özgen M et al., 2021]. This highlights the need for effective and efficient treatment protocols that can minimize both the physical and economic toll of hand injuries, particularly in regions where healthcare resources are already stretched thin.

Several studies have highlighted the challenges associated with the diagnosis and treatment of complex fractured hand injuries. Comparison of cone beam computed tomography and multislice computed tomography in assessing extremity fractures, finding that while cone beam computed tomography may reduce radiation exposure, its diagnostic accuracy remains under review. Similarly, automated diagnostic systems supported by deep learning techniques, such as Convolutional Neural Networks like VGG-16, GoogLeNet, and ResNet-50, have shown varying degrees of accuracy, sensitivity, and specificity in identifying fractures of the phalanx [*Dubreuil T et al., 2019; Galanopoulos I, Vynichakis G, 2019; Krastman P et al., 2020*]. However, these technologies are still evolving, and their implementation in clinical practice is limited by factors such as cost, accessibility, and the need for further validation.

Given these challenges, there is an urgent need for further research with a convincing degree of evidence to clarify the most effective strategies for diagnosing, treating, and rehabilitating patients with complex hand fractures. Such research is particularly vital for improving the quality of medical and surgical services in countries with low socio-demographic levels, where the burden of traumatic injuries is most acutely felt. By optimizing existing national algorithms and developing evidence-based protocols, healthcare systems can better address the needs of this patient population and mitigate the significant socio-economic impact of these injuries.

The purpose of this work is to review the current state of the problem of diagnosis, surgical treatment, and rehabilitation of patients with complex fractured hand injuries. This review aims to identify gaps in the existing knowledge and practice, especially in low-resource settings, and to propose recommendations for improving patient outcomes through evidence-based approaches. In doing so, it seeks to contribute to the ongoing efforts to enhance the quality and accessibility of care for patients with these challenging and debilitating injuries.

Material and methods

During the analysis of modern literature, a pool of 1,100 sources was formed, 65 of which (using keywords) were included in the final pool. Out of the 65 sources used, taken from PubMed, Scopus, Web of Science, and Google Scholar, 30 sources were published in the last 5 years from 2019 to 2023.

Results and discussion

The studies reviewed show that hand injuries are predominantly associated with occupational activities [*Stewart A et al., 2017*], particularly among manual laborers and in agriculture [*Dębski T, Noszczyk B, 2021*], with a significant portion resulting in severe skeletal damage [*Lin D et al., 2012; Shrihari V, 2016*] as per the Hand Injury Severity Score [*Campbell D, Kay S, 1996*].

Conventional radiography is a first-line imaging tool for assessing metacarpal and finger fractures.

Zhao et al. (2019) found in a study of 842 patients that ultrasound has a high diagnostic efficacy for detecting hand fractures, with a sensitivity of 91%, specificity of 96%, positive likelihood ratio of 20.66, negative likelihood ratio of 0.09, and a diagnostic odds ratio of 231.17.

An important measure is to supplement the physical diagnosis of fractures with instrumental visual diagnostic methods. In a systematic study by Krastman et al. (2020) sensitivity, specificity, accuracy, positive predictive value, and negative predictive value of the physical examination for the diagnosis of fractures of the phalangeal and metacarpal bones ranged from 26 to 55%, 13-89%, 45-76%, 41-77% and 63-75%, respectively. Visualization of fractures of the metacarpal and finger showed sensitivity, specificity, accuracy, positive predictive value, and negative predictive value in the range from 73 to 100%, 78-100%, 70-100%, 79-100%, and 70-100%, respectively.

Currently, multislice computed tomography outperforms conventional radiography in displaying intraarticular fracture lines and in accurately measuring fractures, which is crucial for preoperative planning. This superiority is due to its capability for isotropic multiplanar high-resolution reconstruction and the thinness of the imaging slices. However, the use of computed tomography raises concerns about radiation exposure. Introducing cone beam computed tomography technology could be a viable solution to reduce radiation doses.

Cone beam computed tomography has been proposed as an alternative to multislice computed tomography for imaging to assess limb injuries. Posadzy et al. (2018) in a sample of 10,000 patients showed that the diagnosis of a complex finger fracture performed using cone beam computed tomography cost 67.33 euros per patient, gave 9.08 years of life adjusted for quality-adjusted life year and received an incremental cost-effectiveness ratio equaling 29.94 euros/quality-adjusted life year and net monetary benefit equaling 9.07 euros. The use of multislice computed tomography for diagnostics cost 106.23 euros, gave 8.18 quality-adjusted life year, incremental cost-effectiveness ratio equaling 371.15 euros/quality-adjusted life year, and net monetary benefit equaling 8.09 euros at a threshold of 30,000 euros per quality-adjusted life year. The incremental net monetary benefit is 1.17 for the cone beam computed tomography strategy and 0.19 for the multislice computed tomography strategy.

Automated diagnostic systems have long supported doctors in interpreting medical images, with recent enhancements due to deep learning techniques [*Denisova D et al., 2023*]. According to Rawat W. and Wang Z. (2017), convolutional neural networks such as VGG-16, GoogLeNet, and ResNet-50 have been applied, achieving varying degrees of accuracy, sensitivity, and specificity in identifying fractures of the phalanx and normal hands. Specifically, VGG-16 achieved 84.0% accuracy, GoogLeNet 81.7%, and ResNet-50 79.4%. Treatment of hand injuries, whether conservative or surgical, depends on the type, location, and stability of the fracture.

Conservative Treatment

In Sahin et al. (2021), a study involving 39 patients evaluated through Crawford criteria showed no significant difference in Michigan Hand Outcome Questionnaire scores between surgical and conservative treatments. The surgical group results were 30.4% excellent, 13% good, 8.7% fair, and 8.7% poor. The conservative group had 25% excellent, 25% good, 37.5% fair, and 12.5% poor outcomes. Subsequent studies found no statistically significant differences in outcomes between conservative and surgical approaches for hand injuries. Khatua et al. (2020) reported no significant differences in total range of motion or Belesky scores among 60 patients. Kremer et al. (2022) found that 74% of 261 fracture patients benefited from conservative treatment, suitable for stable fractures, while 26% required surgery for unstable fractures, supported by Lögters et al. (2018). Byrne et al. (2020) observed positive outcomes with conservative treatment, including minimal pain and functional motion preservation. Held et al. (2013) demonstrated effective conservative

management of proximal phalanx fractures using dorsal plaster, maintaining inclination angles under 15° and minimal shortening. Lastly, El-Shishtawy et al. (2019) noted significant improvements in sensory outcomes, range of motion, complications, aesthetic outcomes, and patient satisfaction with conservative treatments, particularly enhanced by platelet gel for faster healing and recovery.

Surgical Treatment

The primary objective of surgical intervention for hand injuries is to restore anatomy and ensure stability, allowing for early movement. Treatment typically involves realigning the joint, securing the fracture using internal or external fixation devices, and promoting early mobilization. Effective anatomical reduction and stable fixation are crucial to prevent complications such as chronic pain, stiffness, deformity, and early-onset degenerative arthritis. Surgical options are categorized into internal and external fixation methods.

External Fixators

External fixators are of great importance in the surgical treatment of complex finger injuries. In comminuted and intraarticular fractures, an open reposition with internal fixation simply using Kirschner wires (K-wires) usually leads to the impossibility of early mobilization due to the smaller size of bone fragments or lower fixation strength caused by a local ligament. It is also not ideal when there is a risk of infection due to open wounds and when it is necessary to avoid further damage to soft tissues. Consequently, in complex fractured hand injuries, external fixation is much more optimal than internal osteosynthesis [*El-Shaer A et al., 2015; Jafari D, Ajvadi A, 2017; Hamilton L, 2018*]. Since internal fixation includes osteosynthesis using plates and screws, these methods cannot be optimal for these hand injuries.

External fixation is the use of pins and/or thin wires implanted percutaneously into the bone, connected from the outside of the body by clamps, rods, and other metal or composite devices; it is used to stabilize fractures and reconstruct complex deformities.

There are various options for external fixators.

External Fixators According to the Ilizarov Method

Shikhaleva N.G. (2018) analyzed the results of treatment of 274 patients with open fractures of the hand bones, including complete and incomplete amputations of the hand segments, for whom a mini Ilizarov apparatus was used to fix the hand bones. The most common cause of hand injuries was work on wood and metalworking machines (59.6%). When conducting a study of the function of an injured limb on the disabilities of the arm, shoulder, and hand scale during fixation of damaged bones with the mini Ilizarov apparatus, the function indicators in the group of patients with multiple fractures ranged from 17.5 to 75.7 points (on average (68.7 ± 7.2) points). The terms of fixation of bone fragments by the mini Ilizarov apparatus ranged from 37 to 109 days. The longest period of consolidation was observed in the group of patients with intraarticular fractures without a bone defect. Rehabilitation measures after removing the device averaged (22.6 ± 2.5) days. An additional stage of inpatient treatment was required in 21 patients (7.6%). The performed reconstructive surgeries allowed for achieving positive results in most clinical cases. The occurrence of complications in the postoperative period was noted in 87 (31.7%) patients.

Thus, external fixation using the Ilizarov method is effective for complex fractured hand injuries. However, it should be noted that this fixation option is still mainly used for fixing the long bones of the lower extremities.

In a study by Wang et al. (2019), 20 patients were treated with a new dynamic distraction external fixator for an average of 3 months. The results showed good joint contour on X-rays, 92% postoperative grip strength compared to the contralateral side, and satisfactory motion ranges in the proximal interphalangeal joint. Ahangar et al. (2021) and Kodama et al. (2018) further supported the effectiveness of dynamic external fixators in treating proximal interphalangeal joint fractures, with most patients achieving full or near-full range of joint movements and minimal postoperative pain. Similarly, studies by Kastenberger et al. (2020) and Abou Elatta et al. (2017) demonstrated high patient satisfaction and good functional outcomes using different external fixator designs, with most patients returning to daily activities without significant restrictions.

Innovative handmade external fixators, such as those described by Jafari D. and Ajvadi A. (2017) and Zhang et al. (2018), have shown excellent functional outcomes and patient satisfaction, pro-

viding an economical solution particularly beneficial in developing countries. Rashed et al. (2020) introduced a simple syringe fixator technique, yielding promising results in multiple complex hand fractures. These studies highlight the evolving techniques in external fixation, aiming to improve patient outcomes while minimizing complications and costs.

Speaking about the various options for external fixation in complex fractured hand injuries, an important innovative technique called Wide-Awake Local Anesthesia No Tourniquet should be noted.

Wide-Awake Local Anesthesia No Tourniquet

Introduced more than ten years ago by Lalonde D.H. (2017), the Wide-Awake Local Anesthesia No Tourniquet method has gained popularity, and the range of its surgical applications has significantly expanded. This correlates with positive results and patient satisfaction. Local anesthetics, hemostatic agents, and alkalizes are applied to the site of surgery by local injection. It is believed that the alkalizing agent (lidocaine buffered with 8.4% sodium bicarbonate NaHCO3 in a ratio of 5:1) acts beneficially to reduce the pain associated with infiltration with a local anesthetic, and additionally enhances the hemostatic effect of adrenaline.

Georgieva et al. (2022) studied the benefits of the Wide-Awake Local Anesthesia No Tourniquet method in hand surgery, highlighting its advantages in reducing hospital stays and staff requirements. Patients undergoing surgery with this method experienced significantly less pain both intraoperatively and postoperatively compared to those without it. Additionally, economic analyses by Rhee et al. (2017) and Ayhan et al. (2018) demonstrated substantial cost savings with Wide-Awake Local Anesthesia No Tourniquet. Rhee et al. found that using this method saved $393,100 in a military setting, while Ayhan et al. reported lower costs for Wide-Awake Local Anesthesia No Tourniquet compared to other anesthesia methods in hand surgeries. Tahir et al. (2020) also noted lower hospitalization costs with such method, emphasizing its cost-effectiveness. These studies collectively suggest that Wide-Awake Local Anesthesia No Tourniquet is a highly effective and economically advantageous technique for managing complex hand injuries.

Prevention of Infectious Complications with the Use of External Fixators

In the surgical treatment of phalangeal fractures using K-wires, understanding the risk of infection associated with open versus closed methods is crucial for optimizing patient rehabilitation. Research highlights that infections are more prevalent with open K-wires than those buried under the skin [*Ridley T et al., 2017*]. Despite some orthopedic surgeons lacking a clear preference for open or closed K-wires, a significant portion favors open K-wires because they generally require less frequent removal.

Further investigations into the cost-effectiveness of these methods revealed that exposed K-wires are less expensive compared to buried ones. Addressing postoperative infections, studies have shown that preventive measures, such as using betadine-soaked alcohol pads as bandages, can effectively mitigate infection risks without the need for additional interventions [*Ivanishchuk P, Kovalev A, 1993; Kovalev A, Ivanishchuk P, 1999; Kovalev A et al., 2020*]. Moreover, recent research suggests that titanium K-wires may offer a better resistance to biofilm growth compared to other materials, presenting a potentially safer option in terms of infection control. These findings contribute to the ongoing discussion on the best practices for using K-wires in hand surgery, with a focus on reducing infection risks and improving economic efficiency.

Rehabilitation Physical Exercises

Jun et al. (2021) implemented a protocol of controlled active physical exercises in the early postoperative period for patients with fractures of the proximal phalanx and metacarpal bone. This included painless active stretching in various positions for 3 to 5 weeks post-surgery. By 6 to 12 weeks, a significant improvement in the range of motion was observed, with the total angle of inclination of the affected finger exceeding 230° in some patients after 12 weeks. Follow-up X-rays showed successful bone fusion within 20 weeks.

Gutiérrez-Espinoza et al. (2017) observed that controlled home exercise programs significantly improved pain and functional outcomes in patients over 60, with notable differences in the Patient-Rated Wrist Evaluation scores at 6 weeks and 6 months.

Miller et al. (2016) compared limited synergistic rehabilitation exercises to traditional unrestricted exercises in postoperative care of proximal phalanx fractures. The study found no significant differences in improvements between the two groups in terms of active finger extension, total range of motion, strength, pain, and difficulty with hand activities up to 12 weeks post-surgery. This indicates that rehabilitation exercises, whether limited or unrestricted, yield similar outcomes after the surgical repair of phalangeal fractures.

Mirror Therapy

Mirror therapy is an effective non-drug treatment that leverages the observation of an intact limb's movements in a mirror to activate mirror neurons in the premotor cortex, enhancing hand function. Systematic reviews [*Tofani M et al., 2022*] and randomized controlled trials [*Rostami H et al., 2013; Yun D, Kim M, 2019*] indicate that mirror therapy significantly improves hand function and reduces pain in the short and long term, although it shows limited benefits for hand dexterity and range of motion.

Robotic Exoskeletons

Robotic exoskeletons are increasingly crucial in rehabilitating patients with complex finger injuries. Innovations like the virtual exoskeletal device 'Exok'ab' have shown promising results in enhancing range of motion and overall rehabilitation outcomes, offering both passive and active rehabilitation modes [*Sandoval-Gonzalez O et al., 2016*]. These devices provide an alternative to traditional physiotherapy, potentially improving the efficiency of rehabilitation processes.

3D Printing in Rehabilitation

3D printing introduces significant advancements in creating external fixators for complex finger injuries. A study involving a new, cost-effective external fixator made with 3D-printed clamps demonstrated that these devices provide comparable biomechanical stability to traditional fixators [*Arulmozhi R et al., 2018*]. The 3D clamps were modeled using SolidWorks 2017 and printed on a Markforged Onyx One 3D printer (Boston, Massachusetts) using the fused deposition modeling technique. This study included three different test configurations: axial compression, anterior-posterior bending, and medial-lateral bending. This innovation is particularly beneficial for developing countries, offering a financially accessible solution without compromising on quality and effectiveness.

Conclusion

Despite the available methods and promising approaches, many of them remain the subject of discussion and require additional research with a convincing degree of evidence. This is especially true in developing countries, where access to modern methods may be limited.

The presented review of the literature on complex fractured hand injuries not only showed current trends and approaches in medical practice but also emphasized the importance of further research and development of more effective methods of diagnosis, surgical treatment, and rehabilitation. These data have theoretical and practical significance, warning medical specialists, especially microsurgeons, against using new methods without sufficient scientific justification. Only through further research and collective efforts can we achieve an improvement in the quality of medical and surgical services provided for patients with this type of injury.

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