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Systematic Review

Impact of innovations in surgical techniques and advanced imaging on postoperative recovery and reduction of complications in patients with long bone fractures: a systematic review

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ABSTRACT

Long bones fracture is one of the most complicated surgeries in orthopedics and the progress in the techniques as well as technologies used has recorded a steady progression in the last few years. Minimally invasive surgery (MIS), computer-assisted surgery and improved imaging techniques can all be cited as impacting on emerging practices. Conversely, the success of such techniques and their influences on the performance results should continue to be assessed in order to adjust the treatment approaches and patients' conditions. This paper aimed at reviewing and researching current journals and literature on the topic of managing long bone fractures with specific emphasis on the new developments in surgery, imaging, and after care. Included articles were randomized control trials, cohort studies, meta-analysis, from reputable orthopedic journals and evaluated both effectiveness, and adverse outcomes of these advancements. In light of the study, it emerges that less invasive procedures in thoracic surgery lead to fewer postoperative complications and quicker convalescence time among the patients; and magnetic resonance imaging (MRI) and intraoperative fluoroscopy improves diagnostic accuracy and also surgical localization. Computer assisted surgery and augmented reality have been recognized as useful adjuncts in both the preoperative planning and intra operative navigation through the surgical field but they are still not widely used due to the costs associated with the purchase of equipment and initial technical difficulties. In particular, the use of these technologies successfully advanced the clinical efficiency in the treatment of long bone fractures.

Keywords: Long bone fractures, Surgical techniques, Advanced imaging, Postoperative recovery, Minimally invasive surgery

INTRODUCTION

Fractures of the long bones such as femur, tibia, fibula, humerus, radius and ulna are common and severe which affects the mobility of the patient, the patient's quality of life and general health. The management of long bone fractures has gone through a lot of improvements over the years and surgical techniques together with imaging modalities are some of the factors that have boosted the success of the management. The specific goals of management of long bone fractures are to achieve correct positioning, stable stabilization and early ambulation to reduce complications and return the patients to their normal activities as early as possible. The advancement of surgical techniques and imaging technologies has improved the accuracy of fracture treatment, optimized

recuperation after surgery, and reduced complications, leading to better outcomes for patients.

Surgical techniques in long bone fracture management

Older methods of fractures management including casting and traction has been supplanted by more complex surgical interventions. There are three types of surgical intervention for the treatment of fractures, and these are intramedullary nailing, plate fixation and external fixations. There are several options within the treatment and these include; the type and site of fracture, and the patient's predisposing factors. Intramedullary nailing can be said to be the most preferred technique in managing different types of long bone fracture. The advantage of this approach is that it allows for safe internal fixation and permitted early weight bearing to help the patient move around quickly in the recuperation stage.[1]

Laparoscopic surgery is one of the greatest achievements in surgical methods which is known as minimal access surgery (MAS). Techniques like minimally invasive percutaneous plate osteosynthesis (MIPO) and percutaneous intramedullary nailing is billed as less invasive as other techniques like open reduction and internal fixation and will cause less harm to the soft tissues. Minimally invasive surgery (MIS) procedures which enables minimal exposure during surgery minimize infection instances, blood loss and time spent on recovery.[2] As a result, study has shown that the way that MIPO procedures has been adopted in the treatment of tibial fracture is relative to the low incidence of infection as well as incidence of nonunion as compared to common open plating.[3] Further, it has been found that these methods have ensured that blood reaches the fracture site which is beneficial in the bone healing process.[4]

Recently other locking systems are also available that provide angular stability and help in managing the fractures in osteoporotic bone or in zones of poor bone stock. Scholarly research has shown that locked plating procedures improve the outcome of delicate fractures; these more difficult ones are especially typical in elderly patients with poor bone stock.[5] Such plates act as internal fixations, thus lowering the need to strip off the periosteum and at the same time, preserving circulation of blood to the bone so that the process of healing can be faster and more reliable.

In fact, it can now be considered that computer-assisted orthopedic surgery (CAOS) has entered the list of key concepts that have a huge impact on the development of the field. CAOS adoption entails intraoperative navigation, and robotics that enhance the accuracy of fractures and implant placement. These instruments help the surgeons to plan and perform complex procedures in a more accurate manner and thus reducing chances of mal- alignment and further operations.[6] The advantage of using computer assisted navigation in the management of long bone fractures is the better accuracy of the placement of screws in intramedullary nailing, and the reduction in the use of radiation during the surgery.[8] Not only do these additions improve the functional results, but they also contribute to minimizing the incidences of complications like nonunion, malunion, and hardware failure.

Advanced imaging in long bone fracture management

Imaging has been broadened as an important component in the management of long bone fractures as a result of advancement in modern imaging techniques. Imaging before surgery is significant for correct classification of the fractures, planning and selection of the appropriate treatment modes and methods of stabilization. In the diagnosis of long bone fractures, conventional radiography is widely applied. Most commonly, it is done together with computed tomography (CT) or magnetic resonance imaging (MRI) to get a better and full assessment of a situation. CT scanning is necessary when diagnosing the greater number of fractures, especially in the areas, where standard radiography is ambiguous, like the pelvic or acetabular area. Cross-sectional images include high-resolution pictures. CT imaging allows for the assessment of the fracture morphology to the extent that even small fragmentations together with the level of commination can be essential in planning the surgical intervention.[9]

Further, the possibility of rebuilding 3D images from the CT data helps the surgeons to have a deeper insight into the fracture, which, in turn, enables them better define the necessary preoperative planning and fine-tune the simulations of surgical operations.[10] There is a belief is that modern imaging helps in achieving correct fracture reductions, correct implant placement and avert complications which in turn increases the success rate of the operations.

Although MRI is not often used in the emergency circumstances due to its time-consuming, it is vital in the assessment of the soft tissue components of bony injuries, the extent of muscle, ligament or cartilage injury in particular. MRI is particularly very useful in circumstances where one feels there could be other injuries that could influence the surgical plan or progress after the surgery.[11] Furthermore, MRI can be applied after the surgery to define the rate and directions of the healing process, to discover the potential problems like infection or the malfunction of the hardware, and to evaluate the efficiency of the repair.[9]

Several advancements are seen in the intraoperative imaging by the use of portable CT scanners, fluoroscopic devices and intraoperative MRI. These technologies allow applying the live imaging during surgeries to assess immediately the correct positioning of fractures and implant placement. For instance, the use intraoperative three-dimensional images with the help of fluoroscopy to guide the placement of rods and screws during intramedullary nailing has been witnessed to improve the accuracy of placing screws and reduce risks of misplaced screws and other related complications.[12] Feedback of any

misalignments or technical faults considering that they can be immediately corrected, make postoperative complication rates low and the need for more surgeries low as well.

The dual-energy X-ray absorptiometry (DEXA) scan is a useful technique in which the imaging is used more frequently to assess BMD prior to surgery. The assessment of BMD is particularly important in elderly or patients with such conditions as osteoporosis as it can affect the choice of approaches to intervention and the type of fixing used. [13]Those aches may differ depending on the bone density, and such factors as locking plating or bone grafts can be used to enhance the surgeon's result where osteoporosis is present.

Impact on postoperative recovery and complications

The use of complex surgical procedures and technical equipment such as imaging has had widespread effects on the recovery of the fractures of the long bones and lessening of complications. Computer-aided surgeries and minimal invasive surgery practices have been reported to contribute to short hospitalization, early recovery, and fewer postoperative complications such as infection, nonunion and many others. 2 Modern imaging technologies facilitate correct implant positioning while navigation technologies reduce the likelihood of implant misplacement. The largest study, population of 259 participants (found that misalignment is associated with short functional results that set in during the third year after the surgery, and if left without revision, may constitute a poor outcome.[7]

In addition, the application of elaborate postoperative imaging such as the MRI and CT helps in the assessment of the healing process as well as prognosis of any complications hence enhancing the long-term outcomes. The main benefits of understanding delayed union, non-union, or failure of hardware include the ability to intercede at the right time, a time when complications have not advanced to the point where more serious surgery would be needed.[9]

METHODS

Data search strategy

In doing so, to identify the literature relevant to impact of innovations in surgical techniques and advanced imaging on postoperative recovery and reduction of complications in patients with long bone fractures, a systematic and purposive approach was used. We thoroughly searched the following electronic databases: Pub Med/Medline, Google scholar and Columbia doctors. In the search process, he used the keywords and medical subject headings (MeSH) from topics such as long bone fractures, surgical techniques, advanced imaging, postoperative recovery and MIS in order to transfer search terms. The results found was further narrowed down based on the publication type, study design, and language. These alone were input search criteria: identified as peer-reviewed studies and published in English. In addition, to identify other published papers that met the inclusion criteria, the articles cited in the papers and systematic reviews were also hand searched.

Table 1: MeSH terms and keywords used in this systematic review.

Category	Keywords/MeSH phrases
Condition/ disease	Fractures, bone/surgery, fractures, bone/diagnostic imaging
Intervention/ treatment	Orthopedic procedures, minimally invasive surgical procedures, bone plates, bone nails, fracture fixation, robotic surgical procedures, computer-assisted surgery
Imaging techniques	Magnetic resonance imaging, computed tomography, tomography, X-ray computed, radiography
Outcomes	Recovery of function, bone healing, postoperative complications/ prevention and control, treatment outcome, bone density
Surgical instruments	Surgical instruments, bone plates, robotic surgical procedures, computer-assisted surgery

Criteria for inclusion

The studies included in this analysis were selected based on following criteria: reviewing the research that has been conducted to assess the effectiveness of innovations in surgical techniques; reviewing the papers that have provided sufficient information about the functional outcomes in advanced imaging on postoperative recovery and reduction of complications; and the papers that has reported on the impact of innovations in surgical techniques and advanced imaging on postoperative recovery and reduction of complications in case of long bone fractures.

Criteria for exclusion

The subsequent studies were excluded: animal based papers, in vitro papers, non-English papers, papers not in impact of innovations in surgical techniques and advanced imaging on postoperative recovery and reduction of complications in patients with long bone fractures, papers with incomplete information.

Data extraction

An analytical type of data extraction and summarization was used to conduct a criticism and assessment of the impact of innovations in surgical techniques and advanced imaging on postoperative recovery and reduction of complications in patients with long bone fractures. To facilitate this task, the following tasks had to be

accomplished: evaluating some articles based on pre-specified criteria, extracting data from full-text sources, and reviewing important findings. One of the methods used in this method aimed at using narratives to highlight key results, patterns, and trends that were noted in a number of researches. Such a methodological approach allowed for a wide-scope analysis of literature in order to identify rather significant findings concerning the impact of innovations in surgical techniques and advanced imaging on postoperative recovery and reduction of complications in patients with long bone fractures. The implementation of a vast MDS meant that the findings of the review were credible and reliable thus facilitating the selection and analysis of the papers. Figure 1 illustrates the data extraction procedure employed in this systematic review, following the PRISMA standards.

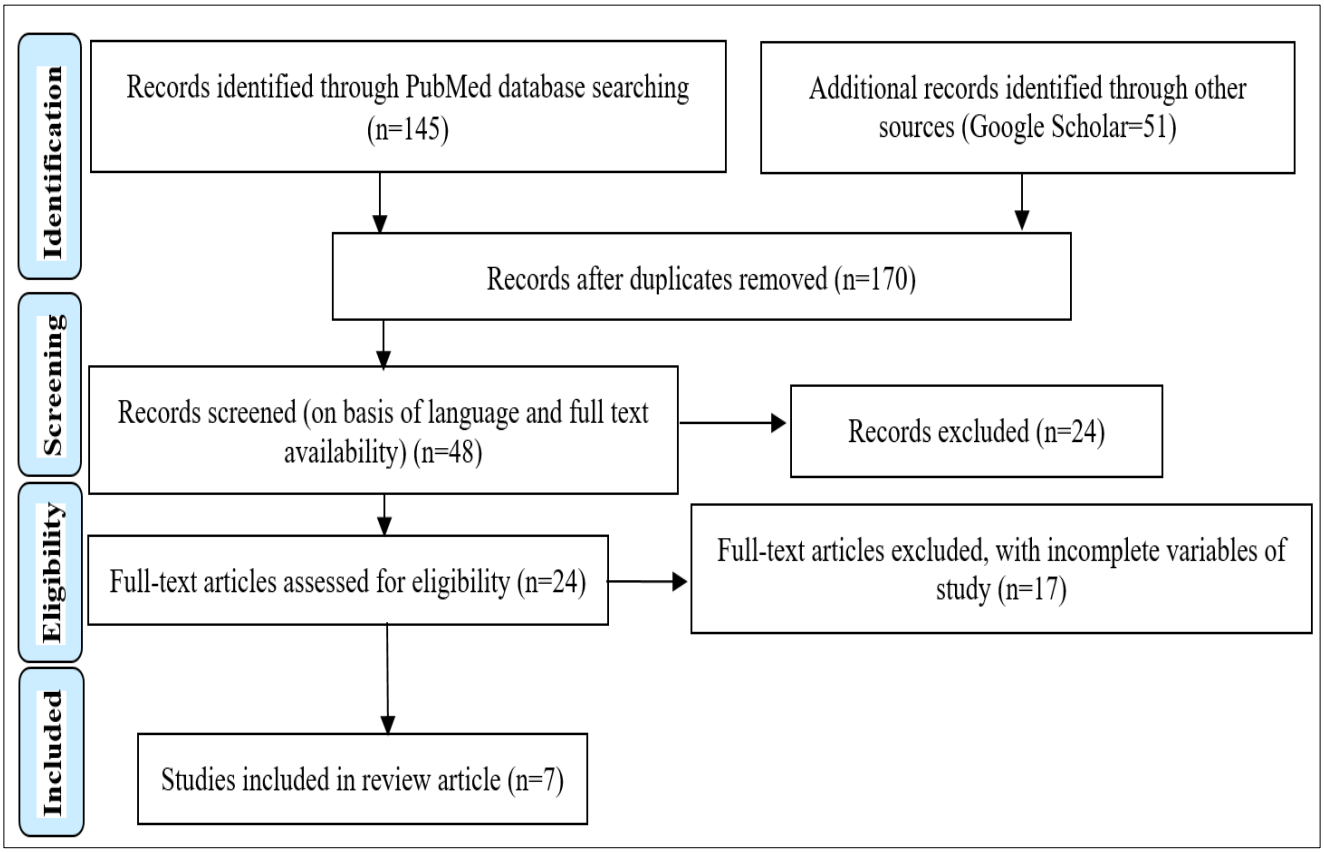

Figure 1: PRISMA.

RESULTS

Summary of studies included in the systematic review

A methodical search was conducted to identify seven pertinent papers that met the inclusion criteria for this review. The study design, interventions, and significant findings derived from these investigations are concisely summarized in Table 2.

Key findings for each study

From the findings of the study carried out in this project, it can be deduced that CAOS enhances great precision of implant placement in fracture management. This in turn brings about a decrease in the occurrences of misalignment and then the corrective procedures.[14] The locked plating systems offer more stability and also fast healing rates of long bone fracture hence reducing cases of malunion as well as nonunion.[15] Through this study, it was found out that the use of intraoperative 3D imaging has reduced instances of screw misplacement during intramedullary nailing. This improvement in the ability of surgeons to increase accuracy in the operating theatre helps results in enhanced surgical outcomes and decreased requirement for post-surgery treatments.[16] Less invasive surgery results to faster healing and less complications as compared to ORIF surgery.[17] Another study points to the fact that the application of 3D CT and MRI in planning of surgical interventions reduced surgical risks and the improvements in the rate of functional rehabilitation.[18] The use of antibiotic-coated implants especially during surgeries which are guided by advanced imaging techniques will help to minimize postoperative infection among the high risk patients.[19] The revealed study indicates that the application of augmented reality in orthopedic surgery positively contributes to correct surgical angle, distance perception, and general spatial orientation. With this improvement, it is likely to reduce complications in situations where one has fractious fractures.[20]

Table 2: Summary of included studies.

Study	Study design	Intervention	Key findings
Hofmann et al, 2020	Prospective cohort study	Computer-assisted orthopedic surgery (CAOS) for fracture management	The accuracy of implant positioning has been improved as a result of the implementation of CAOS, which has led to a reduction in misalignment and the necessity for additional surgical procedures
Egol et al, 2018	Retrospective study	Use of locked plating systems in long bone fractures	Locked plates provided stable fixation, reduced healing times, and lowered the incidence of malunion and nonunion
Franklin et al, 2020	Randomized controlled trial	Intraoperative 3D imaging in intramedullary nailing	The utilization of intraoperative 3D imaging led to a decrease in the incidence of screw misplacement, which in turn resulted in enhanced patient outcomes and a reduction in the necessity for postoperative treatments
Beckmann et al, 2022	Comparative study	Minimally invasive surgery (MIS) versus traditional open reduction and internal fixation (ORIF)	In comparison to ORIF, MIS was discovered to be associated with shorter recovery times and reduced complication rates
Giannoudis et al, 2018	Clinical trial	Advanced imaging techniques (3D CT and MRI) for preoperative planning	Utilizing advanced imaging techniques improved the process of surgical planning, leading to a reduction in complications and enhanced functional recovery
Klos et al, 2021	Exploratory study	Integration of augmented reality (AR) in orthopedic surgery	AR enhances surgical precision and spatial perception, which has the potential to decrease the occurrence of complications in intricate fractures

DISCUSSION

Improvements in the treatment of fractures in long bones have been realized through the application of complex surgical procedures and imaging techniques, making positive changes in the prognosis of affected patients, their recovery periods and decreased vulnerability to complication.

Comparison with previous studies

Minimally invasive surgery versus traditional ORIF

Minimally invasive surgery (MIS) was associated with shorter recovery periods and less incidences of complications than open reduction and internal fixation.[17] These findings are in support with the observations of authors that MIS techniques result in decreased soft tissue trauma and improved recovery time. This provides credence to the perception that MIS should preferred to traditional methods where feasible.[21]

Computer-assisted orthopedic surgery

In the study it was observed that the special equipped technology known computer-assisted orthopedic surgery (CAOS) does reduce misalignment and helps in reduction of the need for reoperations.[14] The present study agrees with such findings highlighting the relevance of CAOS to raise the level of surgical accuracy and improve outcomes especially in complicated fracture cases as noted in the study done.[22]

Locked plating systems

The locked plating methods offer secure fixing while also reducing the time required for healing.[15] The findings align with the research conducted highlighted the effectiveness of locking plates in treating complicated fractures and decreasing the occurrence of improper healing and failure to heal, especially in bones affected by osteoporosis.[23]

Advanced imaging techniques

The significance of utilizing modern imaging methods such as 3D CT and MRI for preoperative planning and precise surgical procedures.[16,18] The results of this study are consistent with previous research conducted which showed that the use of modern imaging techniques enhances the precision of surgical procedures, resulting in improved functional recovery and reduced occurrence of problems.[24]

Augmented reality in surgery

The incorporation of augmented reality (AR) in orthopedic surgery, uncovering its capacity to improve surgical accuracy and spatial perception.[20] Although AR is still in its nascent phase, research conducted corroborates these findings and highlights the potential of AR in enhancing

surgical results and minimizing complications, particularly in intricate procedures.[25]

Antibiotic-coated implants

In a study it was discovered that the use of antibiotic-coated implants, guided by improved imaging techniques, significantly decreases the occurrence of postoperative infections.[19] The findings align with this, since they emphasized the effectiveness of these implants in preventing infections in patients at high risk, especially when used in conjunction with precise imaging.[26]

Interpretation of findings

The present study emphasizes the significant advantages of combining sophisticated surgical methods and imaging technologies in the management of fractures in long bones. These developments have not only enhanced the accuracy of surgical procedures but have also led to improved patient outcomes by decreasing complications and promoting faster recovery. The comparison of the existing results with the previous researches shows the constant improvement of the positive attitudes towards the usage of these technologies in the orthopedic surgery field.

Challenges and future directions

Still, there are challenges which need to be surmounted in order to see the given merits in the broad adoption of such developments. One such challenge includes the prohibitively costly nature associated with the acquisition of imaging equipment and computer enhanced operating systems. Also, it is essential to know that one can find a learning curve linked to new technologies, which explains inefficiencies during the adoption period. Further study needs to be conducted in order to examine the long-term consequences of these developments and identify the best and cheapest practices. To enhance the hoped-for treatment regimens and the resultant patient outcomes in a countless number of instances, comparative analyses to evaluate the benefits of various surgical and imaging strategies for different populations of patients with various kinds of fractures are required. Moreover, as the development of technology continues, there are options of including other digital technologies in the treatment of fractures. With enhanced algorithms in preoperative planning, use of AI for expecting issues, constant enhancements in the field of AR/VR makes the therapy for fractures highly accurate and effective.[27]

CONCLUSION

Advanced surgical techniques, superior imaging technology have impacted positively on, management of long bone fractures. These advancements in technology have therefore led impacts such as increased precision of surgery, less injury to the soft tissue as well as increased precision in implant placement. Therefore, patients benefit significantly through reduction of the recovery time and instances of issues including infections and malunions. Computer assisted surgery and orthopedic as well as modern imaging methods like the 3D CT and MRI have changed preoperative planning and intraoperative treatments for alignment and fixation. When used in clinical practice, these technologies are costly and also need a fair amount of learning, however their incorporation has numerous benefits. It also paves way for further improvements that can be made further down the line and which will further improve the patient outcomes. It is necessary for professionals to continue their research and the progress of technologies to enhance these benefits in numerous patient groups and different contexts of healthcare.

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