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Bone Immobilization devices and consolidation mechanisms: Impact on healing time

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Abstract

The human skeleton is formed by living tissues that react to loads and ensures the support of the remaining tissues of human body like muscles, ligaments, tendons, etc. However, its integrity can be compromised due to fractures or injuries of the bone tissue that require orthopedic surgery and immobilization methods, such as external fixators, intramedullary nail or osteosynthesis plates.
One of the most important characteristics of living tissue is its capacity of self-regeneration. It is a complex process that implies several mechanisms during the consolidation time. Therefore, the knowledge of the involved mechanisms and their interdependence on external factors, will allow accelerating the regeneration process and contributing to the success of the rehabilitation process.
Several techniques have been developed to characterizing characterize the mechanical loads acting in fractured bone to better understand the fracture consolidation and obtain useful information for the orthopedic doctors. This information is relevant to enable each patient follow-up and optimize the clinic procedures. As such, it is important to understand what happens during fracture consolidation to predict the necessary structural immobilization time and mechanical stimulus which shorten the healing process.

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The purpose of this work is twofold: primarily, to study the consolidation process using different immobilization systems, and secondarily, to explore the necessary time for bone consolidation by recording the relevant mechanical parameters time story.

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Keywords: Bone fracture, Consolidation Process, Immobilization system, Internal/external fixation; time healing

1. Introduction

The living tissues of human body have different properties and function, but they all react to loads and ensure the support of the remaining tissues of human body, such as muscle, ligaments or tendons [1]. However, bones are an important component of the skeleton system providing protection and structure, and supporting mobility. Nevertheless, its mechanical integrity can be compromised to traumatic fractures or injuries of the bone tissue which requires operative treatments and immobilization.

There are many fixation devices available for fracture immobilization that can be classified according to its use as external and internal fixators. It is expected that the fixation device provides sufficient mechanical stability during the initial phase and some load transfer during healing. The fixation stability is an important factor on healing outcome and the degree of stability is determined by the stiffness of the fixator. However, there several aspects about the fracture and immobilization systems that are still unknown, namely on the influence of the mechanical stimulus on bone cells proliferation and differentiation.

The main objective of this review is to compile information on the different types of immobilization systems, the features of the consolidation process each one fosters, so that observed healing times can be studied as a result of fixators types and applied load patterns as previously stated.

2. Methods

To provide a comprehensive overview on fracture consolidation and their process, a thorough literature review was carried out in the present work on bone fracture, consolidation, fracture immobilization and internal/external fixation. The next search stage was centered on a few of these, considered more relevant for the matter and focused on specific aspects of the work, namely those reported in this work. But, primarily and to underlay the base knowledge to better understand the influence of the fixators types and their loading characteristics, one has to understand the bone consolidation mechanisms and all its phases, as much as possible.

The most common causes of fracture are trauma, osteoporosis and excessive load, but there are several of other factors that can promote bone fracture. There are different approaches to perform the bone fracture immobilization which include: external fixation; internal fixation; intramedullary nailing, and; plate fixation. Such methods are not all appropriate for every type of fracture, for instance, diagonal femur fractures should be treated with intramedullary nailing.

The treatment method is normally selected according to the following principles: restoration of alignment, rotation and length; preservation of the blood supply to aid union and prevent infection; and finally, the rehabilitation of the extremity and the patient [2]. Accordingly, the methods for fracture immobilization mean time for healing are different, as represented in Table 1. However, the fixation method is not the unique aspect that influences healing time.

Table 1 Average time of consolidation according different systems

Authors	Systems Type	Fracture Type	Average time of consolidation (weeks)
Allonso JE et al [3]	External fixator	20 Open	16
Anand A. Parekh et al. [4]	External Fixation	17 Closed 35 Open	20.5
M. Zlowodzki et al.[5]	External Fixation	13 Closed 30 Open	25 31
Guaracy Carvalho Filho et al.[6]	External Fixation	23 Closed 3 Open	12
Hakan Cift et al[7]	Intramedullary nailing	34 Closed 9 Open	18.7
R. Pascarella et al.[8]	locking plate	67 Closed 23 Open	16.3

3. Discussion

The differences in the described treatment approaches are important to understand the healing or consolidation mechanisms, stress distribution and the main aspects of each approach.

3.1. Immobilization System

The external fixation has traditionally been used under clinical indications such as open fractures, concomitant soft tissue injuries, and unstable or polytrauma patients [9]. This system use pins and/or wires secured to external scaffolding to provide support to a limb and stabilize the trauma or limb reconstruction [9]. This is an effective treatment option mainly for the treatment of the femoral shaft fracture in children because it is easy to carry out and it conduces to the shortest hospital stay. However, the common complication of external fixation is the pin-track irritation/infection [10].

On the other hand, the indications for intramedullary nailing are essentially found on extra-articular fractures with the main advantages related to both conservation of hematoma and the fact that extra-articular implants are relatively easy to remove [11].

In relation to osteosynthesis plates, there are three main approaches: blade plate, dynamic compression plate and locking compression plate. The first, is indicated for extra-articular fractures, sagittal unicondylar fractures or supracondylar and intercondylar fractures. These systems are monoblock, pre-shaped implants that are adapted to the anatomy of the fractured bone [11].

Therefore, compression plates fixation should be avoided for treatment of comminuted fractures and external fixation is not indicated for definitive treatment [12] [11]. On the other hand, the external fixation, when compared with internal plates and intramedullary nails, promotes less disruption of the tissue, good osseous blood supply and periosteum [9].

3.2. Consolidation mechanism

One of the most notable features of living tissue is its ability to self-regenerate. It is a complex process involving cellular differentiation which is strongly stimulated by mechanical loading [13]. Knowledge of the mechanisms involved and their interdependencies with external factors supports the understanding of the accelerated regeneration processes and the success of rehabilitation [14]. This will result in more efficient treatment and lower costs for the health system.

The fractured bone is immobilized using a specific method for repair and restore the main function of the bone. In this process, the bone goes through four main phases: inflammation, soft callus formation, hard callus formation and bone remodeling. The fracture healing can be influenced by certain factors that can be divided in two categories: systemic factors such as age, pathologies or external factors, and local factors such as the degree of fracture, type of bone, blood supply, degree of vascularity and mechanical factors [15] [16] [17].

With the recovery of the fracture, the tissue of the bone callus starts to have some capacity for load transmission, which stimulates bone formation to activate lining cells [18]. Although many efforts have been made to study the influence of the fixation stability in relation the healing time, the optimal stability is still not known [19]. Factors such as type of the fracture, the healing mechanics and the mechanical factors influence the healing process and the choice of the fixation devices. However, neither the fractured nor the consolidated bone stiffness is completely uniform or linear [16]. Therefore, a reasonable approximation for the generation of a good mechanical performance of the healed fracture would be to maximize the rigidity of the fractured region in order to reduce deformation in the initial phase of the healing process and promote the creation of cartilage and bone.

The fixation system allows an optimal vascularization of the fractured zone. During the intermediate phase of the recovery period, the fixation should allow a progressive transfer of charge through the fracture. Finally, in the last phase of the recovery, the effect of the load transferred by the fixation system should be maximized to reduce the movement in the fractured region [16].

As such, it is important to choose a fastening method which provides a good initial stability of the fracture, and allows some transfer of charge during the consolidation process. In this way, the healing time could be greatly reduced by modification of the fixator design [20].

3.3. Monitoring and modelling – prediction validation through experiment

The characterization of the mechanical properties of bone tissue is currently one of the priorities of the medical professionals dedicated to human rehabilitation [21]. Prediction through numerical modelling is evolving at a fast pace with complex multi-body models that support the requirements of the clinic. The confidence on complex numerical models is supported by experiment on animal and/or cadaveric tissue to determine tissue proprieties [22]. Several researchers in INEGI are involved in this type of research. Joana Machado et al., [23], characterized swine knee articular cartilages by undergoing mechanical compression tests, and created a numerical model which simulates knee behavior and predicts risk situations. Along the same line of mechanical characterization of living tissue, Joana Silva et al., [24], characterized mechanically knee ligaments, by experimental tests and development of a finite element method (FEM). A new clamp for the bone - ligament - bone complex was developed, in order to be used in uniaxial tensile testing. Also, in FEM analysis, four constitutive models, two isotropic and two anisotropic, were studied to define the behavior of the ligaments.

Biomechanics of bones is an important issue around the globe, for orthopedic clinicians, mechanical and biomedical engineers, physicists, athletes. This fact is due to its complexity [25] and social impact of the recovery of these injuries [26], during reconstruction surgery, in search for total healing and stability.

Currently, the evolution of bone consolidation is mostly monitored with radiographic imaging, without means to precise quantifying metrics. It is therefore still not possible to predict or measure complete bone consolidation. Some authors are actively involved in this subject to increase healing time precision. P. Beillas [27] describes a method for studying the in vivo knee soft tissue behavior, by combining finite element simulation models obtained from CT or MRI images of a patient, with three-dimensional kinematic analysis for that same patient, to study the tibiofemoral joint.

The creation of mathematical models to simulate these processes is an important asset for studying the tissue rehabilitation processes [28]. The determination of the best solution for the immobilization method to use is a complement, which, together with the imaging evolution as well as gait analysis assessment, would promote more consistent and crucial information to find solutions for both treatment development and future rehabilitation [29].

However, the variability of the mechanical properties of the tissues and their interdependencies of the individual characteristics increases models complexity and requires a multidisciplinary approach. The high performance achieved by today's computers and the sophistication of existing numerical methods has enabled the convergence of the numerical models to mimic the response of living systems [30].

Since human body monitoring is becoming almost a daily routine for certain activities, namely during jogging or other type of sports, with the well-known benefit it can carry for the person [31] [32], it should not be surprising that in orthopedics, doctors dream of a system, which could continuously monitor the healing process objectively, instead of relying on the information of the patient [33]. Obviously, these image systems are the greatest help for the clinician, but there are still a lot of missing answers for complete understanding of the bone healing process [34].

4. Conclusions

In conclusion, the results of this work showed that the choice of the fixation method is an important step for consolidation bone success for repaired and turn back the main function of the bone. It is expected that the fixation device provide a sufficient stability during the initial phase and some load transfer during healing.

The fixation stability is an important factor on healing outcome and the degree of stability is determined by the stiffness of the fixator.

From this work, it is clear that the tissue healing process is not fully understood and that a great contribution could arise from experimental real-time monitoring of the process. Information gathered by such systems could help medical and scientific communities to understand better fracture consolidation involved mechanisms. The major advantage of this contribution will indeed be the chance of providing a better care to patients, namely by reducing their rehabilitation time.

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