Optimization of fracture healing by improved stabilization

Millions of fractures occur every year worldwide. Most of them heal uneventfully but 5-10 % show delayed healing or non-union. This leads to a great burden for the patients and high economic load for the healthcare system. Knowledge of the best technique for the operative treatment of fractures with implants such as external fixators, plates and intramedullary nails, (Fig. 1) is particularly important to avoid the aforementioned complications.

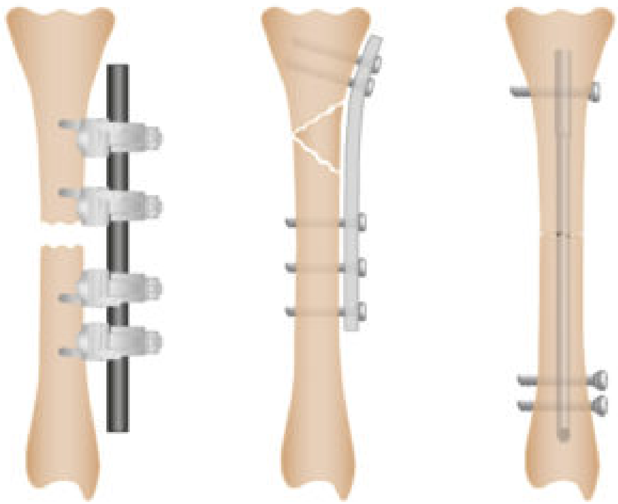

Fig. 1. Most important techniques of internal fixation of fractures. Left: external fixator, middle: plate, right: intramedullary nail.

Beside the injury severity of the broken extremity, the stability of the fracture fixation is a major factor for the success of the fracture treatment. The stability of the fracture fixation and the loading of the fracture zone by weight bearing and muscle activity of the patient determine the interfragmentary movement in the bone healing zone. This interfragmentary movement leads to an interfragmentary tissue strain that guides the cell differentiation and activity responsible for the tissue differentiation from haematoma to bony bridging and final healing of the fracture.

A tissue transformation hypothesis which takes into consideration the results of animal experimental studies, cell-biomechanical investigations, and numerical methods was developed. Based on this hypothesis, further rules describe the cell and tissue differentiation as a function of the local tissue strain. This allows the prediction of bone healing by intramembranous and endochondral bone formation as a function of the local tissue strain in the fracture healing zone.

Unfortunately, direct determination of the local mechanical environment in the bone healing area based on clinical parameters is not possible. The most practical quantitative parameter to describe the stability of a fracture fixation is the stiffness. This can be determined for several types of fixation through in vitro biomechanical methods and in some in vivo clinical studies. Using the stiffness of the fracture fixation and the physiological loading of the broken bone, the initial local tissue strain can be estimated.

With the estimated tissue strain and the rules of the hypothesis, the tissue differentiation can be predicted. With a numerical fracture healing model, the tissue transformation can be simulated in a stepwise manner until the bone has healed completely.

Using numerical fracture healing models based on the tissue differentiation rules found in basic research, it is now possible to calculate optimal stiffness parameters for various fixation techniques. However, such numerical simulations are highly complex and time consuming methods and not suitable to analyze individual clinical patients. To overcome the difficulties, the bone healing simulation was performed for 96 different combinations of shear stiffness and axial stiffness. The resulting bone healing outcomes were mapped as a function of combined axial and shear stiffness. From this map, the stiffness combinations that are optimal for bone healing can be detected. This allows the selection of fracture fixation stability which can guide high-quality bone healing.

By comparing the stiffness of various fixation techniques used in clinical applications with the stiffness map, it becomes evident that the most frequently used methods (unreamed nail and external fixator) have shear and/or rotational stiffness characteristics that are too low to achieve optimal healing. Furthermore, the high axial stiffness of plates can delay the bone healing process by suppressing the stimuli for bone formation. The stiffness of unreamed nails can be improved by the surgeon using nails with diameters as large as possible and angle stable interlocking screws. The stiffness of external fixators for bones with thin soft tissue coverage can be increased significantly by placing the fixator as close as possible to the bone and using screws with sufficient diameter. Technical solutions to reduce the very high axial stiffness of plates are currently under development.

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