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Dynamic range improving is reached due to addition of 4 subpixels around the main pixel.

Conclusions

Given information demonstrates a wide spectre of use of hexagonal raster for image creating. It is believed, that screens, that are made on a hexagonal pixel basis, will be used in VR visualisation systems.

9.3 Intelligent implants in orthopedic surgery

Introduction

Intelligent implants can provide personalized medicine, optimize the care of individual patients, and improve results while reducing costs [205]. As diagnostic tools, smart implants can provide information that characterizes the environment inside the body that cannot be obtained in any other way. This information can provide objective quantitative data for adapting treatment, initiate changes in care, and detect adverse events at an early stage of treatment. Intelligent implants can also provide continuous monitoring of critical parameters for real-time processing. The integration of implants into daily clinical practice has the potential for large cost savings in the healthcare system by minimizing costly complications, shortening recovery time, and reducing lost working days after surgery and procedures. Implant-based intelligent research has also made an important contribution to understanding pathophysiology, healing, implant interfaces, and biomechanics. They also provide important knowledge for the development of next-generation implants and surgical techniques. Although the technology behind smart implants, including sounding, energy transfer, energy storage, and wireless, has advanced significantly in recent years, there are still significant technical challenges that must be overcome before implants become part of healthcare. In all applications, the intelligent implant - e is the vehicle that carries the diagnostic technology in the body. Due to the relatively large physical dimensions of many orthopedic implants, the bulk provides the possibility of symbiosis between the implant and sensor technology. Physically large implants have the means to incorporate sensors, electronics, and telemetry into the implant itself or on its surface. Due to the possibility of integrating sounding technology in recent years, there have been many innovations and developments in the field of the use of intelligent orthopedic implants. Orthopedic implants are of sufficient size and volume to accommodate sensors, electronics, and antennas. This facilitates their modification into intelligent implants. Once placed in the body, radio frequency communication facilitates the collection of data from the implant.

Intelligent Implant Technology

Sensing based on strain gauges is the basis of intelligent implants. Strain gauges are thin sheets of foil deposited on the base. The sensor adheres directly to the implant surface. As the implant deforms, the strain gauge also deforms, and with this deformation, the resistance of the sensor changes, which is proportional to the voltage experienced by the implant. The generated signal is proportional to the voltage. Protecting strain gauges and their circuits from exposure to body fluids is a challenge. The strategy to resolve e of the problem is the modification of the implant so that strain gauges can be installed inside the implant. For many applications, the implant has cavities or recesses in which strain gauges can be installed and electronics placed. After placing the sensors and electronics in the cavity, the lid is sealed with a laser in order to seal the cavity. Strain gauges inside the implant have lead wires or antennas for data transmission.

Early implants used lead wires that connected directly from the instrument implant to an external data logger. The obvious limitations of the lead wires have big drawbacks, this is the possibility of infection, limited patient mobility, etc. Although such technologies are not good for clinical applications, they, however, provide an inexpensive and high-performance technology for preclinical studies. To go beyond the limitations of wired systems, the second generation of implants use telemetry transmitters that are powered by batteries. Battery-powered systems provide direct power to implantable electronics and do not have the disadvantages of wired technology. Battery-powered systems are only limited by their large size (to accommodate the main part of the battery) and the end-of-life of the battery itself. Due to the limited battery life, smart implants are also poorly functional, with the exception of preclinical studies.

How such technologies have evolved over several decades can be seen on hip prostheses, from wired electronics to wireless systems. Inductively powered, intelligent, intelligent implant systems have been developed. These systems are based on the transfer of electromagnetic energy between a source outside the patient and a receiver integrated into the implant. Electromagnetic energy is transmitted by inductive coupling through radiofrequency fields. Implanted systems do not have batteries, but usually contain energy storage elements that feed the circuit after inductive energy transfer. Since the earliest inductive intelligent implant systems were developed back in the 1960s and 1970s, these systems were generally complex and cumbersome, mainly due to the size of the electrical components available at that time. Several printed circuit boards were needed to interface the sensors with signal conditioning and data electronics. Because of their complexity, these systems had low reliability and a high failure rate. With the development of electronic technology, telemetry systems have become more compact and reliable, which has allowed intelligent implant technology to become more viable for clinical applications over the past two decades. Typical intelligent implants include strain gauges, a power coil for inductive coupling, an antenna for transmitting data, signal conditioning circuits, and a telemetry system. External readers generate a radio frequency signal that is transmitted through an external antenna to the implantable system. Individual implants are pre-calibrated by applying a known parameter (e.g., force or pressure) to the implant. To calibrate the implant, appropriate strain signals are used. The calibration data of each implant is used to convert the transmitted strain into a signal representing the measured value. Orthopedic implants are mainly used to measure physical parameters, including pressure, strength, tension, displacement, and temperature. The measurement of physical parameters is achieved through the integration of applied technology with the implant. Intelligent prosthetic implants have been used for knee arthroplasty, hip arthroplasty, vertebroplasty of the spine, and other applications.

Knee arthroplasty

Osteoarthritis of the knee joint is one of the most common pathologies of the musculoskeletal system worldwide. For patients who are not helped by conservative therapy, knee arthroplasty is a good standard of treatment [206]. By 2030, demand for primary knee replacement endoprosthesis is projected to grow to four million procedures in the United States. During arthroplasty and the knee, the distal femur and proximal tibia, and often the patella, are resected. The distal femur and the proximal tibia are replaced by metal components, and an insert of extra high molecular weight polyethylene is attached to the tibial component, on which the femoral component is articulated. The extra high molecular weight polyethylene insert adheres to the posterior patella to articulate the patellofemoral joint.

Although knee arthroplasty is a common procedure with a low complication rate, postoperative joint biomechanics can affect a range of motion, implant survival, and long-term results. These factors largely depend on the surgical technique and implant design. Feedback indicating the strength, pressure, displacement or stress on the implant intraoperatively and postoperatively can be used to optimize the implant design, choice of implant and surgical technique, all of which affect the patient's results. Thus, smart knee implants play an important role in understanding the biomechanics of the knee joint. Knee forces are very dynamic and depend on body weight, external loads, muscle activity, and kinematics of the joints. The magnitude of these forces dictates the rate of wear of the implants and the survival of the components of the implants. Evaluation of strength through the tibial and patella-femoral joints remains a problem due to complex and excessive muscle contributions. Intelligent implants have been used to measure the strength of the tibiofemoral joint for patients undergoing knee arthroplasty.

First-generation implants integrated strain gauge strain gauges into the tibial tray. The barrel of these components was hollowed out to accommodate signal conditioners, microprocessors, and telemetry. The second-generation design was capable of measuring multiaxial forces using six or twelve strain gauges attached to the distal tibial trunk.

According to the implants of the knee joint, the peak strength when walking after arthroplasty is two and a half times the body weight and concentrated in the middle of the tibial tray. Walking on a treadmill reduces the strength of the knee relative to the hard floor while increasing walking speed increases strength. Jogging leads to a fourfold increase in strength. Strength in the knee is 20% higher when walking in shoes than without shoes. During climbing stairs, the forces increase threefold from 30 ° to 50 ° of knee bending. Strength through the knee can exceed fivefold values when the muscles work during a loss of balance. During all activities, shear forces are small compared with axial loads.

Although significant research has been done using intelligent implants to better characterize the tibiofemoral forces in the knee, few studies have been done on the patellofemoral joint. The patellofemoral joint is physically small, and thus there is little space for the placement of sensors, signal conditioning electronics, and telemetry inside the patella implant. This has made the development of smart knee implants difficult with traditional technologies (such as strain gauges). Only recently, a smart patella implant was developed to measure the strength of the patellofemoral joint. Three passive resonant force transducers were integrated with a pre-inserted extra-high molecular weight patella polyethylene without modifying the implant in a configuration where all forces transmitted through the patellofemoral joint were also transmitted through the transducers. Although this technology has not yet been used, the simple integration of sensors with the implant makes this technology promising.

To date, all applications for permanent implants of the smart knee joint have been focused on research, and not on clinical practice. The data led to improvements in implant design, surgical technique, and postoperative care and rehabilitation strategies. Future applications for permanent smart knee implants include control forces during activity to avoid implant failure. Although collecting data from permanent implants remains a challenge, there is significant clinical value for intraoperative force measurements using test implants during knee arthroplasty. Alignment and calibration of components intraoperatively are crucial to achieving balance and the corresponding mechanical axis of the knee. Collateral tendon relaxation was commonly used to regulate tension between the medial and lateral sections. Implants, which provide strength measurement in two departments, were used intraoperatively to control ligament balance. For intraoperative measurements, preliminary or trial components of the first generation were equipped with four piezoelectric elements for measuring forces in the anterolateral, posterolateral, anteromedial, and posterolateral knee quadrants. This technology has evolved into a family of intelligent tibial test components controlled by an ortho sensor. The system consists of an array of sensors and a microprocessor, which wirelessly transmits real-time data to a portable graphic display unit, showing the forces and contact points in the component intraoperatively.

Hip Arthroplasty

As in the knee, osteoarthritis is common in the thigh. For patients who are not helped by conservative care, general hip replacement is an alternative standard of treatment [206]. By 2030, demand for primary general hip arthroplasty is estimated to grow to half a million. In for hip arthroplasty, the proximal femur is resected, and the acetabulum comes out. The proximal femur is replaced with a metal rod and a metal or ceramic ball. A metal cup is placed in the acetabulum using ultra-high molecular weight polyethylene or a ceramic insert on which the femoral component is articulated. As for the tribes called on the first joint, biomechanics plays a crucial role in the survival of implants and patient satisfaction after arthroplasty. Intelligent implants have played a significant role in understanding the biomechanics of arthroplasty and optimizing results.

The first intellectual implant was created back in the sixties. In this landmark study, a custom three-part femoral component with strain gauges in the neck was designed and manufactured. The prosthesis was wired, and wires ran through the skin from the implant to an external data logger. Only almost a decade later, the next-generation wireless prosthesis was developed and clinically used. These systems included up to fourteen strain gauge sensors, signal conditioning circuits, and battery-operated and telemetry systems. Sensors and up to five printed circuit boards, which made up the telemetry and signal generation electronics, were placed in a hollow ball and a hollow neck of the femoral component. The longevity of these implants was limited, and initial data was collected over the course of a month. Similar implants were used to measure contact pressure in the thigh for three years after surgery. Later implants measure loads and bending moments in all six directions with an error of less than one percent. Some systems are equipped with two telemetry devices and sensors for measuring force and temperature throughout the femoral component. Modern implants measure strength and temperature with the help of electronics contained in a titanium rod (without an antenna outside the prosthesis). The data from the hip joint implant indicate that the forces reach four times the excess weight for one standing leg, three - when walking. The data also show that while walking, the temperature in the thigh can exceed 43 ° C in joints with a ceramic ball and a cup of ultra-high molecular weight polyethylene. In addition to measuring strength, pressure, and temperature, hip implants have also been developed to detect weakening prostheses, which is one of the most common complications. The implants were equipped with vibration-sensitive blocking amplifiers and telemetry. When the femur vibrated during the simulation, the systems were able to detect attenuation. Like the knee, the motivation for using such an implant today is research applications and not the practice of caring for patients.

Vertebroplasty of the spine

Pain in the lower back and neck are the main causes of disability worldwide. After unsuccessful conservative treatment, many patients prefer to undergo spinal fusion surgery [207]. In the United States, more than half a million spinal fusions occur annually. The goal of spinal fusion is the production of arthrodesis between two (or more) adjacent vertebrae in order to facilitate bone bridges between the vertebrae. In the cervical spine, this is usually achieved by placing a cell implant in the intervertebral disc space and then attaching the anterior cervical plate to adjacent vertebral bodies. In the lumbar spine, there are several surgical options, among which the most common are posterior decompression and fusion. A laminectomy is performed to decompress the spine, the cell is placed in the space of the intervertebral disc, and the screws and leg rods are used to stabilize the spine. The success or failure of spinal fusion is highly dependent on both biology and biomechanics. However, biomechanics of the spine are poorly understood. The load is extremely difficult due to the repeatedly excessive internal and external muscles acting on the spine. After surgery, the implants are subjected to axial forces, as well as bending moments during bending, extension, lateral bending, and torsion. Understanding these forces is crucial for choosing the appropriate intervention, developing effective implants, and prescribing optimal postoperative rehabilitation.

Intelligent implants have been used as research tools to understand the biomechanics of the spine from the sixties of the last century when they instrumented rods with ten strain gauges and implanted them in patients undergoing fusion for scoliosis. Tool rods were temporarily placed in the spine and used to collect strength data until they were replaced with traditional rods in the following procedure. The rods had lead wires that ran through the skin and connected directly to the data logger. Later, a technology was developed to have the function of the rods as a variable inductance of the transducers, in which the inductance varies with the use of force. In a modified version of the first generation rods, the sensor was connected to a telemetry system. To overcome some of the limitations of these first-generation rods, next-generation systems were included by installing strain gauges on hooks that attached the rod to the spine. Strain gauges were attached to wires that ran through the skin. The systems were used intraoperatively to measure forces during spinal distraction in the correction of scoliosis. As rods are less used, next-generation intelligent spinal implants have been developed using similar strategies, such as common knee and hip components; hollow spaces were created in large fixtures to accommodate strain gauge sensors, signal conditioning electronics, and telemetry systems. The only fixators of the spine, physically large enough, were rods placed on the back spine in a configuration where they were loaded in parallel (i.e., sharing the load) with the spine. The implants were adapted to measure forces and bending moments in all directions. As research tools, the forces measured by the back rods provided a valuable insight into the biomechanical environment in which the rods are exposed, but since the rods share the load with the spine, the forces in the spine itself cannot be determined in this way. Unlike the posterior rod systems, implants and implants of corpectomy(replacement of vertebral bodies) are loaded sequentially with the spine and, thus, are exposed to the same forces that the spine is exposed to. As hip and knee implants, vertebral implants are large enough to accommodate strain gauges, signal generation electronics, and telemetry inside. However, implants are much smaller than intelligent hip, knee, and posterior spinal implants, and therefore different strategies are used for these systems. Strain gauges were used for the cells to transmit force, but because of their small physical size, these systems either required wires or the implants were connected to telemetry systems that were placed outside the spine in a subcutaneous bag.

Applications for fracture fixation

In the surgical fixation of long bone fractures, the implant attaches to the bone both proximal and distal to the fracture in order to act as a support. Implants stabilize bone fragments to facilitate healing. Fracture fixation options are plates, intramedullary rods, and external fixators. When the bone is loaded (for example, the tibia is loaded when weight is transferred to the lower limb), the loads are transmitted through the bone and fixative. In the acute postoperative period, the fracture is not able to withstand any load, and thus, if the patient carries weight on the limbs, the forces are transmitted exclusively through the retainer, not the bone. As bone marrow is formed, the bone is able to carry some load, and thus the fixer experiences less force. Thus, monitoring the loads on an intelligent fracture fixation device while carrying a load can be used as an indicator of fracture healing. When treating a fracture with open reduction and internal fixation, the forces applied through the bone are transmitted through the plate (Fig. 73). Forces measured with intelligent fracture fixation devices can be used to provide objective data to guide rehabilitation strategies at different stages of treatment. For example, to determine when the patient can get up, or when the patient is healed enough to return to work or daily life activities.

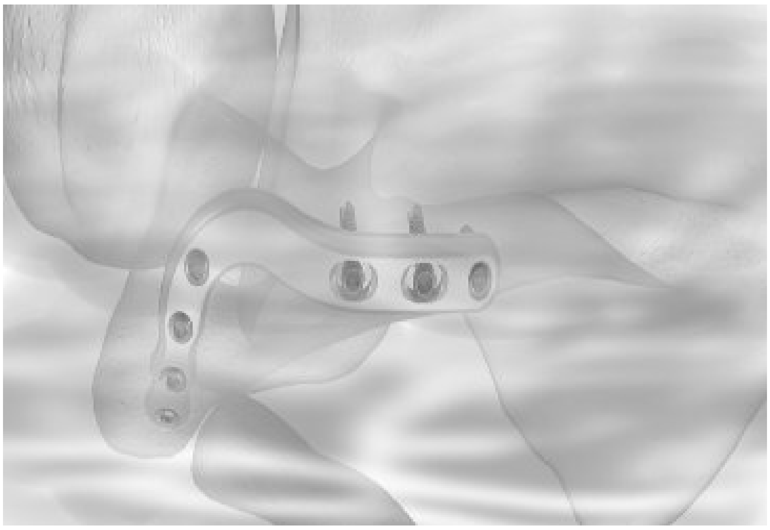

Fig. 73. In the treatment of a fracture with open reduction and internal fixation, the forces applied through the bone are transmitted through the plate.

Problems and new technologies

Despite decades of research, with very few exceptions, smart implants have not yet become part of everyday clinical practice. This is primarily because there are a number of limitations and problems that still have to be overcome in the technology of manufacturing intelligent implants. For systems with complex electronics, technical problems include power consumption, communication range, data transfer rate, size, reliability, and cost. To solve the problems of energy consumption, ultra-low power schemes were studied in combination with energy collection strategies. Using these strategies, the implant generates energy from sources such as vibration, rotation, and deformation during the time , for example, walking. Although energy harvesting strategies are promising, the amount of energy is not enough to power the electronics. To reduce the size of sensors and signal generation circuits for the use of intelligent implants, the technology of microelectromechanical systems (MEMS) is used. Components at the micro-level have proven themselves in the manufacture of

MEMS. This makes them attractive for custom electronic and touch applications. MEMS sensors can be fabricated from biocompatible materials and materials used in the prosthetic implant that x, including polyethylene, titanium, and perylene. Smaller sensors require less energy but usually operate at higher frequencies (from hundreds of megahertz to gigahertz). One additional problem for higher frequencies is that, at higher frequencies, more energy is absorbed by the tissues, which can cause heat and attenuation of the signal between the external electronics and the implanted sensor. Although many MEMS-based sensors have been developed for use in orthopedic intelligent implants, testing has been limited to bench work and preclinical models. Perhaps the most significant barrier to integration into clinical practice was the need to modify the host implant to accommodate sensors and electronics. Creating hollow resonators, complex electronics, and strain gauges is a technically challenging and expensive task. Sensors for next-generation intelligent implants will be small, simple, reliable, and inexpensive and require little to no modification to existing implant designs. Recently, piezoresistive polymers have been used for smart prosthetic implants. The electrical properties (resistance) inherent in these composite polymers change when loads are applied to them. Thus, a piezoresistive polymer with a low wear rate and good biocompatibility can be used as a force-sensitive smart implant in applications where ultra-high molecular weight polyethylene is used today, including arthroplasty of the knee, hip, and shoulder. In a similar way, force sensors and their signal conditioning circuits integrated into a polyethylene insert were developed.

Passive resonators are an alternative to traditional sensor systems because passive resonator sensors do not require electronics. Passive resonant sensors are usually small, simple, and consist of several components [208]. They do not require a signal generation or telemetry, because when they are exposed to an RF field (through an antenna), they resonate. The frequency at which they resonate indicates the state of the sensor. The main (resting, not stimulated) frequency of the sensor is proportional to the electrical characteristics of the sensor (capacitance and inductance). With proper design, when a sensor undergoes a change in a parameter of interest (for example, force, pressure, or voltage), the parameter causes aphysical change in the capacitance or inductance (or both) of the sensor, which shifts the resonant frequency of the sensor. The resonant frequency of the sensor can be detected using an external antenna.

Recently, a family of passive sensors based on resonators has been described, which are wireless, without battery, telemetry, and do not require electrical connections [208]. Small, simple, inexpensive sensors can be installed in various implants in order to measure parameters, including strength, pressure, temperature, and more. Due to their small size and simplicity, these sensors can be integrated into standard implants with minor modifications or without an implant at all. While this technology was tested only in artificial conditions, it shows great potential for future applications of intelligent implants.

Conclusion

The clinical utility of intelligent implants has been convincingly demonstrated, and the potential of such technology can affect personalized medicine. However, to date, the use of smart implants in everyday clinical practice has problems. However, with the rapidly evolving technology, the widespread introduction of intel l ektualnyh implants really. New sensory technology that minimizes modifications to existing implants is key to introducing smart implants into everyday clinical practice.