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Evaluation of Pedicle Screw Primary Stability Using an Instrumented Hammer

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Abstract

Spinal instrumentation has become a cornerstone in managing a wide range of spinal disorders. This technique reinstates spinal stability and alignment by securing metallic rods onto pedicle screws (PS) implanted within the vertebrae. The long-term success of the PS placement hinges on the primary stability of its fixation, referring to the biomechanical anchoring of the implant inside bone tissue. The primary stability of PS is influenced by patient specific parameters, bone preparation techniques and implant design. A poor primary stability of PS may lead to micromotion at the bone-implant interface, increasing the risk of complications contributing to implant loosening. Despite the critical importance of achieving optimal primary stability, current per-operative evaluation techniques are solely based on the surgeon's proprioception – a subjective approach prone to variability and misjudgment.

This study seeks to address this limitation by exploring the potential of impact analysis as a quantitative method to evaluate the PS primary stability. This study stems from previous works of our group demonstrating that the impulse signature of an impact performed on a bone-implant system is related to its overall rigidity. Specifically, the time-variation Δt between the two earliest peaks of the force signal recorded by an instrumented hammer decreases as a function of rigidity. An experimental design was developed to assess the sensitivity of Δt to parameters affecting PS primary stability, such as bone density, insertion depth and pilot hole diameter. Using artificial bone, low-amplitude axial impacts were performed with an instrumented hammer on a system comprising a screwdriver securely engaged with the PS inserted inside the bone sample. The values of Δt corresponding to the studied experimental configurations were extracted and analyzed. The Δt values showed a variation from 0.93±0.01 ms for a bone density of 8 PCF to 0.67±0.001 ms at 12 PCF. At the beginning of the insertion of the PS within the bone, Δt was equal to 1.41±0.08 ms, decreasing down to 0.95±0.8 ms after the 5^{th} rotation. Additionally, with pilot hole diameters ranging from 60% to 80% of the PS diameter, Δt values increased from 0.64±0.01 ms to 0.72±0.006 ms. These results demonstrated strong consistency with prior findings, reinforcing the hypothesis that impact analysis could serve as a reliable and objective tool for intraoperative assessment of implant primary stability. Notably, integrating this method into clinical practice could help surgeons improve the success rates of spinal surgeries, enhance patient outcomes and reduce the risk of complications.