Introduction: Although external fixation is widely used for fractures and limb lengthening, evaluation of the time for removing the external fixator is dependent upon radiographic examinations and clinical findings, and a useful method has yet to be established clinically. Measurement of impedance is currently used in applications such as measuring body fat percentages and muscle volume of the extremities1), has proliferated considerably due to the advantage of enabling measurements to be performed easily and non-invasively. This study aimed to measure the increases in bone electrical impedance (Z values: Ω) by using external fixation pins as electrodes, and examine the relationship with mechanical strength of the callus.

Materials and Methods: Fifty-four immatured (five-week-old) male Japanese white rabbits received the external fixation (Orthofix M100, Orthofix Inc., Italy) at the right tibia and were assigned to control group (group C; n=5), fractured tibia group (group F; n=25), and 10mm callus distraction group (group D; n=24). Radiographic examinations and measurement of Z values using an alternating current stimulator (MES, Co., Ltd., Tokyo) were performed once a week after osteotomy or completion of distraction. In weeks 2, 3, 4, 5, 6 (n=5, for each group F) and 2, 4, 6, 8 (n=6, for each group D), the tibias were excised followed by measuring callus sectional area (CS-A: mm2) as a conductive pathway, and maximum bending stress (Bmax: N/mm2) at the fracture site and mid-callus respectively, using a 3-point bending tester (Instron 5500R, USA, load cell: 500 N, rupturing speed: 1 mm/min) as biomechanical testing. Examinations were made on temporal changes in Z values of group C, D and F, CS-A and Bmax of group F and D during maturation of callus.

Statistical analysis was performed by using Mann-Whitney's U test. P values less than 5% were regarded as statistically significant (p<0.05).

Results: Osteolytic and periosteum reactions were present around the pin-bone interfaces starting 2 weeks after surgery and completion of distraction. In group F, the fracture healed at the outer callus at 2 weeks after surgery, and medullarization and corticalization subsequently progressed through 5 weeks. In group D, tubular formation by new cortical bone was observed in week 4 after distraction, and thickening of cortical bone and progression of the remodeling process were observed through 6 weeks.

Although Z values in group F increased over time reaching a peak at 5 weeks, Z values in group C remained essentially constant at 3 weeks, and there was a significant difference at 4, 5, and 6 weeks (IMAGE 1). In group D, although the rate of change based on Z values at completion of distraction demonstrated a slight decreasing trend through 2 weeks after distraction, it increased significantly from 2 to 6 weeks, and remained nearly constant at that time (IMAGE 1). The values of CS-A significantly decreased through 5 weeks in group F and 6 weeks in group D (IMAGE 2), while Bmax increased through 5 and 6 weeks respectively, and remained constant at that time (IMAGE 3).

Discussion: Measurement of impedance using external fixator is a non-invasive method to evaluate electrochemical changes in the callus maturation process. Yukaw2) and Hirashima3) measured Z values of the delayed union and fractured radius in their clinical course, and they reported that Z values increased accompanying bone union. In this study as well, in contrast to Z values having reached a plateau starting at 2 weeks after surgery in group C, in group F and D, Z values increased significantly and reached a plateau at 5 and 6 weeks respectively. Therefore, Z values were under influence of not only the pin-bone contact resistance but also the state of callus maturation. According to the electrical properties of the substance, overall electrical resistance was considered to have increased due to narrowing of conductive pathway accompanying remodeling, and Bmax reached a plateau at 5 weeks in group F and 6 weeks in group D, this was believed to be the optimal time for removal of external fixation. On the basis of these results, temporal increases in Z values are considered to reflect the callus maturation process, and measurement of Z values over time makes it possible to determine the optimal time for removal of external fixation.


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