INTRODUCTION

In the treatment using external fixator, current evaluation of bone healing is dependent upon radiographic examinations and clinical findings, there is the potential for recurrence of fractures and deformities after external fixation has been removed, and establishment of an assessment method and judgment criteria for bone union are tasks that we are confronted with. Therefore, we have investigated bone electrical impedance (Z values: kΩ) by using fixation pins as electrodes, and reported the increase in Z values in accordance with callus maturation. However, the reason was still uncertain how did the electrical impedance increase. This study was aimed to analyze the increase in Z values by measuring an impedance of medullary zones (Zm values), and to investigate the change in electrical properties of the callus during its maturation.

METHODS

Sixteen immatured (five-week-old) male Japanese white rabbits were used for this study. The fixation pins were insulated except of the medullary zone in order to measure the impedance only of the zone. The animals received the external fixation (Orthofix M100, Orthofix Inc., Italy) at the right tibia and were assigned to control group (Group C, n=8) and fractured tibia group (Group F, n=8). Radiographic examinations and measurement of Zm values using an alternating current stimulator (MES, Co., Ltd., Tokyo) were performed once a week after osteotomy. For the calculation of the impedance of another part of the medullary zone, the data past reported in experimental fracture model (30 rabbits) was used. The electrical circuit was approximated to be parallel circuits, consisted of medullary zone and extramedullary tissue (Zx) (Fig.1). Z values represented the between-pin total impedance (Fig.2) and Zx values in Group C and F were calculated using the formula: Zx=Zt÷Zm/2. Examination was made of the changes in Zm and Zx values in fracture healing.

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

In group F, the fracture healed at the outer callus at 2 weeks after surgery, and medullarization and corticalization subsequently progressed through 5 weeks.

Zm values in Group C significantly decreased from an average of 27.9 kΩ at 1 week to 22.5 kΩ at 8 weeks after surgery, while in Group F, Zm values increased from 1 to 2 weeks of an average 22.0 kΩ, they significantly decreased and reached a plateau at 6 weeks. Significant differences were observed between 1, 3, 5, 6, and 7 weeks (Fig.3).

Zx values in Group F continued to increase as past report of Z values (Fig.4). Zx values in Group C gradually increased from 1 to 3 weeks, and reached a plateau at that time.

DISCUSSION

Measurement of impedance using external fixator is a non-invasive method to evaluate electrophysiological changes in the callus maturation process. Yukawa and Hirashima measured impedance of the delayed union and fractured radius in in vivo clinical course, and they reported that impedance increased accompanying bone union. However, no studies to date have been conducted to evaluate the factor of impedance increase. In Group F, Zm values at initial stage after surgery were significantly lower than those of Group C (Fig.3), due to the defect of bone and the formation of hematoma after osteotomy. However, Zm values increased until 2 weeks due to the cell proliferation, and then gradually decreased accompanying medullarization until 6 weeks as past report of the changes in bone resistivity. While Zm values decreased, Zx values in Group F continued to increase as Z values increased, suggesting that the increase in Z values from 3 weeks occurred mainly as the tubular formation and narrowing conduction pathway at the remodeling stage (Fig.4). On the basis of these results, measurement of total impedance between pins (Z values) reflected intramedullary change with cell proliferation and extramedullary change with progression of remodeling. This method of measuring Z values is clinically important in that it enables evaluation of overall electrophysiological changes in bone maturation, thereby indicating it to be an assessment method of the time for removal of external fixation.

REFERENCES