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Pathological and hemodynamic study in a new model of femoral head necrosis following traumatic dislocation

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Abstract The blood of the femoral head is thought to be supplied by vessels originating from the medial and lateral circumflex femoral arteries and via the marrow cavity of the neck. Therefore, it is difficult to induce osteonecrosis of the femoral head when the marrow cavity of the neck is preserved. In the present study, we established a new model of femoral head necrosis by dislocating the hip joint and ligating the medial and lateral circumflex femoral arteries and veins. Measurement of femoral head blood flow revealed that a marked decrease to 14.7% of the control value was achieved by both hip dislocation and ligation of blood vessels. Pathologic examination showed no necrosis with either dislocation or ligation alone, whereas at 2 and 4 weeks 80% of the animals subjected to both procedures showed widespread necrosis. These pathologic findings considered in the light of results of the blood flow measurements suggest that a decrease in femoral head blood flow below 20% of the control value is needed to cause osteonecrosis. In addition, magnetic resonance images (MRI) of the model were evaluated in the combined dislocation and ligation group at 4 weeks (n = 5). Changes on MRI were seen in 3 of 5 dogs. The necrotic changes of the femoral head are thought to be detectable on MRI within 4 weeks after ischemia without enhancement.

Introduction

The etiology of femoral head necrosis following traumatic hip dislocation remains obscure, due in large part to the fact that no suitable models of femoral head necrosis following dislocation have been established for the study of its pathophysiology. Some necrosis models following femoral neck fracture in which the blood vessels of the femoral neck marrow and those external to the bone were disrupted have been tried in a variety of experiments [1, 2, 4, 6]. The few hemodynamic studies using these models were qualitative in nature [12, 16]. Here we present a quantitative hemodynamic study using the electrochemically generated hydrogen clearance method and a pathological study with a new model of femoral head necrosis following traumatic dislocation.

In addition, in order to increase its relevance to the human condition, we tried to detect the magnetic resonance imaging (MRI) changes in the ischemic femoral head with the marrow cavity of the neck preserved.

Materials and methods

Mongrel adult dogs each weighing 8–12 kg were used. To investigate to what extent vascular injury to the femoral head of varying degrees of severity influences osteocyte viability, the dogs were divided into three groups which were subjected to hip dislocation alone, ligation of blood vessels alone, or both hip dislocation and ligation of blood vessels, respectively. At 2 and 4 weeks after treatment, 5 animals in the hip dislocation alone and ligation group were killed and pathological studies performed. In addition, MR images of the model were evaluated in the combined dislocation and ligation group (n = 5).

Femoral head blood flow was measured in 10 dogs to evaluate quantitatively to what extent the dislocation and blood vessel ligation influence femoral head blood flow volume.

Methods

After the induction of anesthesia by intramuscular (i.m.) injection of ketamine hydrochloride (25 mg/kg), sodium pentobarbital (5 mg/kg h) was administered intraperitoneally (i.p.) with blood pressure monitoring to maintain general anesthesia. A skin incision was made above the major trochanter at the lateral side of the hip, the gluteal muscle group detached from the major trochanter, and the joint capsule exposed. An approximately 1-cm-long incision was then made on the capsule, the round ligament severed, and a cervical vertebra spreader used to create and maintain the dislocation. The hip was dislocated posteriorly, and the extent of the dislocation kept consistently at a distance of one and a half femoral heads from the original position. Also, based on the experiments of Kawakita, previously performed in our department, which demon-
Fig. 1 Schema of the circuit for measurement of blood flow. In circuit I, a direct current of 8 A is allowed to pass from the generator until a certain amount of hydrogen gas is produced around the measuring electrode. In circuit II, a polarographic apparatus and a recorder are used to measure the clearance of the hydrogen gas.

Measuring probe (Pt-Black)

Reference electrode (Ag/Ag Cl)

DC. generator

Reference electrode (Ag/Ag Cl)

Polarographic meter

Fig. 2 Photomicrograph of the combined dislocation and ligation group at 4 weeks. Massive empty lacunae and appositional bone formation are seen (hematoxylin and eosin, × 100)

Fig. 3 Photomicrograph of the combined dislocation and ligation group at 4 weeks, demonstrating empty lacunae and appositional bone formation (hematoxylin and eosin, × 100)

Results

Pathological study

In the dislocation only group, some cases showed congestive changes and a decrease in the number of marrow cells, but almost no empty lacunae were seen at either 2 or 4 weeks, with no necrosis found in any of the 10 animals.

In the ligation only group as well, no empty lacunae were found at either 2 or 4 weeks, and no case showed findings of necrosis. Examination of marrow tissues showed a decrease in the number of marrow cells, although as a whole these changes were also slight.

In the combined dislocation and ligation group, osteonecrosis was seen at 2 weeks in 8 of 10 (80%) and at 4 weeks in 8 of 10 (80%) dogs (Fig. 2). Also, in the majority of cases, appositional bone formation, which is thought to be a manifestation of the repair process of the necrosis, was seen (Fig. 3). In some cases, fibrous tissue was found, on the joint side of which no appositional bone formation was seen in contrast to vigorous appositional bone formation on the neck side. With regard to the distribution of the necrotic area, a picture similar to that seen in human femoral head necrosis was found, with the necrosis more extensive on the joint side than on the neck side, and conversely more evident manifestations of repair on the neck side. Although the extent of necrosis showed considerable individual variation, in most cases it was found over a wide area centering on the weight-bearing region. Summarizing the above findings, no osteonecrosis was found in either the dislocation only or the ligation only groups, whereas it was al-

\[ F = 69.3 \times (1/T_c - 1/T_d) \text{ (ml \cdot min}^{-1} \cdot 100 \text{ ml}^{-1}) \]

where \( T_c \) is the half-time of decay estimated from the hydrogen washout curve in the presence of blood flow, and \( T_d \) is the half-time of decay similarly obtained when blood flow is absent (immediately after death; Fig. 1).

MR images of excised femoral heads were examined within 2 h after excision. MRI was performed using a Sigma (General Electric, Milwaukee) 1.5-Tesla superconducting magnet. T1-weighted images were obtained with a short TR (500 ms) and short TE (20 ms), and T2-weighted images with a long TR (2500 ms) and a long TE (60 ms); slice thickness was 3 mm. The coronal plane was used in all examinations.