

Morphological change during postnatal development of the Patella Femoral Joint associated with mechanical force

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INTRODUCTION: Patellar dislocation is a pathology characterized by the displacement of the patella from the femoral condyle and accounts for 2-3% of all knee disorders. [1] Major factors comprise age, gender, family history, a history of dislocation, and lower limb anatomical structures. [2] It has been reported that 96% of patients with a history of dislocation have Trochlear Dysplasia, a condition affecting the Patella Femoral joint (PF joint) surface. [3] In fundamental research employing experimental animals, it has been reported that intentionally reducing the contact area of the PF joint resulted in decreased pressure on the femoral condyle by the patella depending on the quadriceps contraction, leading to Trochlear Dysplasia. [4-8] Thus, the reduction in mechanical stress on the PF joint is clearly established as one of the key factors leading to patellar dislocation. However, the mechanism through which mechanical stress is applied to the PF joint during development and the formation of the Trochlear Groove remains unclear. It has been reported that mice undergo rapid changes in posture and improved walking ability in the first 2 weeks of postnatal development. [9-10] We hypothesized that mechanical stress on the PF joint changes during this early postnatal period, which is a critical point in joint morphology formation. Therefore, this study aims to investigate the changes in the patellofemoral joint formation during the early postnatal development of mice.

METHODS: C57BL/6 mice were sacrificed at postnatal days (P) 0 to 14, 21, and 28, and knee joints were collected (n=3/each time point). Samples were fixed in 4% paraformaldehyde/phosphate-buffered saline for 24 hours and decalcified in 10% ethylenediaminetetraacetic acid for 14 days, then dehydrated in 70% and 100% ethanol, cleared in xylene, and embedded in paraffin. After these procedures, 5 μ m sections were cut in the sagittal and surface perpendicular to the PF joint plane using a microtome. To observe the structural changes of knee joints, sagittal and perpendicular to the PF joint sections were cut and stained with Safranin-O/fast green, and histological images were taken using a BZ-X700 microscope (Keyence). Additionally, μ CT imaging was conducted on lower limb tissues at P2,6,10, and 14 (n=1). Macroscopic analysis of the bone structure of the PF joint was conducted at P2,6,10, and 14 using μ CT. This study was approved by the Ethics Committee of Saitama Prefectural University and was performed in strict conformance with the on-campus animal experiment guidelines (approval number: 2019-10).

RESULTS SECTION: Ossification within the central portion of the femoral condyle was observed in tissue images at P7 and 8 (Fig.1). Additionally, μ CT imaging confirmed ossification within the same region at P10. In contrast, the patella was not observed at all times in μ CT imaging (Fig.2). However, tissue images at P13 and 14 indicated the initiation of partial patellar ossification within the central portion (Fig.1). Macroscopic observations revealed a change in the patella's shape from spherical to elliptical, along with an increase in the width of the Trochlear Groove (Fig.3A). As development progressed, there was an observed trend of increasing in the Roughness value, which signifies that a smaller value corresponds to a deeper Trochlear Groove (Fig.3B). Moreover, there was an observed trend of decreasing in the Aspect ratio of patella value which signified that a higher value corresponds to changing the more elliptically shaped of patella shape (Fig.3C).

DISCUSSION: The purpose of this research was to investigate the temporal changes in the PF joint during early postnatal development in mice. In the early postnatal development period, a cross-section of the patella, which was surface perpendicular to the PF joint shape, changed from spherical to elliptical. At the same time, the central portion of the femoral condyle began to ossify. These changes were accompanied by an observable trend of increase in the roughness value of the Trochlear Groove. This trend was indicative of a widening of the Trochlear Groove's shape, suggesting a relative shallowing of its depth. The early postnatal mice movement is thought to be due to the transition from the open mouth kinetic chain (OKC), [11] a form of locomotion based on muscle contraction without loading in the supine position, to the closed mouth kinetic chain (CKC). [11] A form of locomotion based on muscle contraction with mechanical stress induces mechanical loading, and finally to the acquisition of walking function, which results in increased mechanical stress on the PF joint surface. Moreover, the transformation in the morphology of the patella, along with the increased width of the Trochlear Groove, is theorized to improve the PF joint's congruence, thereby facilitating the maintenance of joint stability. Our results suggest the possibility of changes in the shape of the femoral condyle associated with changed mechanical stress on the limbs during the early postnatal development of mice, paralleling the morphological changes in the patella.

SIGNIFICANCE/CLINICAL RELEVANCE: We indicated that the changes in mechanical stress specific to the early postnatal developmental process are associated with cartilaginous ossification in the PF joint and morphological changes in the Trochlear Groove. If these results are harnessed therapeutically, such as rehabilitation, it could prevent one of the major causes of patellar dislocation, which is Trochlear Dysplasia.

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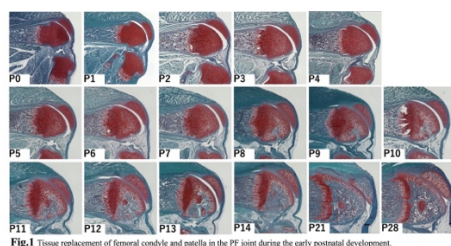


Fig.1 Tissue replacement of femoral condyle and patella in the PF joint during the early postnatal development.

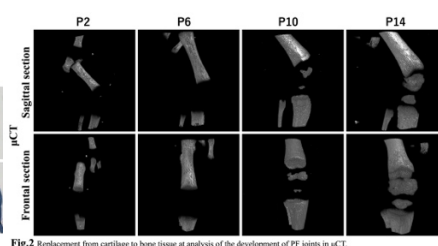


Fig.2 Replacement from cartilage to bone tissue at analysis of the development of PF joints in μ CT.

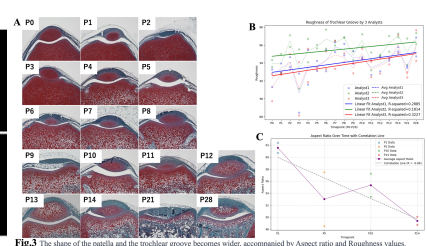


Fig.3 The shape of the patella and the trochlear groove becomes wider, accompanied by Aspect ratio and Roughness values.