

Strength of medial structures of the knee joint are decreased by isolated injury to the medial collateral ligament and subsequent joint immobilization

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Abstract

Past studies of the healing of the medial collateral ligament (MCL) in animal models have been conducted over a variety of healing intervals, some as early as 1 week. One concern with testing at early healing intervals is the difficulty in identifying and isolating the tissues that carry load. The purpose of this study was to determine if isolation of the MCL and healing time are critical factors in the assessment of structural strength in this model. Furthermore, the effect of immobilization on these critical factors was investigated. Our approach was to calculate the load-sharing ratio between the MCL and the MCL plus capsule. A 4 mm gap was created in the midsubstance of both hindlimb MCLs of 52 female New Zealand White rabbits ($n = 104$). Of these, 29 rabbits had their right hindlimb pin immobilized (immobilized group), leaving the left hindlimb non-immobilized. Testing was performed at 3 ($n = 12$), 6 ($n = 22$), and 14 ($n = 24$) weeks. The remaining 23 rabbits, which had both limbs non-immobilized (non-immobilized group), were tested at 3 ($n = 10$), 6 ($n = 12$), 14 ($n = 12$), and 40 ($n = 12$) weeks. For both groups, half of the specimens at each healing interval were used to test the MCL alone and half to test the MCL plus capsule, except for 3 week immobilized joints where only the MCL plus capsule was tested. Additionally, MCL ($n = 12$), MCL plus capsule ($n = 6$), and capsule alone ($n = 5$) were tested from normal animals. The load-sharing ratio at MCL failure for the normal joint was 89%, suggesting an MCL-dominated response. For the non-immobilized group, the load-sharing ratio was 24% at 3 weeks of healing, suggesting a capsule-dominated response. At and after 6 weeks of healing, an MCL-dominated response was observed, with the ratio being 68% or greater. Thus, at less than 6 weeks of healing, the structural strength capabilities of the joint may be better represented by the medial structures rather than the isolated MCL. Immobilization delayed the transition from a capsule-dominated response to an MCL-dominated response in this model. © 2005 Orthopaedic Research Society. Published by Elsevier Ltd. All rights reserved.

Keywords: Medial collateral ligament; Medial capsule; Failure load; Load-sharing; Immobilization

Introduction

Biomechanical and biological evaluation of the ligament healing process requires the use of animal models.

Although these are in vivo models of ligament healing, typically the mechanical testing is performed in vitro, requiring tissue dissection to isolate the ligament of interest. One concern with such an approach to the mechanical testing of healing ligaments, especially early in the healing process, is the difficulty in identifying and isolating the tissues that carry load. A further complication is that mechanical properties have been

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assessed at a variety of healing times. Studies of the rat medial collateral ligament (MCL) used healing times on the order of 2 weeks typically, but some were as short as 1 week [2,4,7,13,14,16,22]. Studies of the rabbit MCL covered a large range of healing times from 3 to 104 weeks (2 years) [3,5,6,8–11,17–20]. Likewise, studies of the canine MCL spanned 6 to 48 weeks (1 year) [12,15,21]. Attempting to isolate the healing ligament at these early intervals, with or without joint immobilization, is challenging because it can be difficult to identify and isolate tissues that can carry loads. The load-sharing between joint structures may be different in a joint healing from an isolated ligament injury compared to that in a normal uninjured joint. One reason to measure load-sharing is to avoid removal of load-carrying tissue when isolating the MCL. Another reason to measure load-sharing is to consider the whole joint response to injury rather than only considering the response of the isolated structure that was injured.

Our first purpose in this study was to evaluate a model of rabbit MCL healing to determine if isolation of the MCL and healing time were critical factors in the assessment of structural strength in this model. Our approach was to calculate the load-sharing ratio at MCL failure defined in this study as the ratio of the failure load of the isolated MCL (MCL) to the failure load of the combined medial capsule and MCL (MCL plus capsule), in which the MCL is the failing structure. Our hypothesis was that both isolation and healing time would be critical factors in the structural strength assessment of healing ligaments. Specifically, isolation would affect the strength assessment of early but not late healing liga-

ments. If the load-sharing ratio at MCL failure is decreased for healing joints compared to normal joints, isolation would be a critical factor in the assessment of structural strength of healing ligaments. If the load-sharing ratio increases with healing time, a critical minimum healing time could be defined beyond which study of isolated healing ligaments would be valid for mechanical testing in this specific model.

Our second purpose in this study was to determine the effect of immobilization on the potentially critical factors of isolation and healing time. Our hypothesis was that the load-sharing ratio at MCL failure would be altered comparing immobilized joints to normal joints. If this ratio is less for immobilized joints than for normal joints, load-sharing is affected and isolation of the MCL is a concern at later healing intervals (than for non-immobilized joints) when immobilization is performed following isolated injury to the MCL.

Methods

Sixty-four female New Zealand White rabbits were used in this study approved by the Animal Care Committee at the University of Calgary. Fifty-two animals underwent surgery to create an acute 4 mm gap in the midsubstance of both hindlimb MCLs [5,6]. Twenty-nine of these animals had their right hindlimbs pin-immobilized in full flexion [1,3] while left (contralateral to immobilized) hindlimbs were not immobilized. The remaining 23 surgical animals had no immobilization of either hindlimb.

In the group with bilateral MCL gap injury and no immobilization of either hindlimb, joints were harvested after 3 ($n = 10$), 6 ($n = 12$), 14 ($n = 12$) and 40 ($n = 12$) weeks. At each of the healing intervals, joints were allocated evenly for two different dissection techniques, leaving either the MCL plus capsule or the MCL intact (Table 1). In the group

Table 1
Test groups

Surgery	Immobilized	Healing interval	Dissection	Joints tested
Bilateral MCL gap	No	3 weeks	MCL plus capsule	5
Bilateral MCL gap	No	3 weeks	MCL	5
Bilateral MCL gap	No	6 weeks	MCL plus capsule	6
Bilateral MCL gap	No	6 weeks	MCL	6
Bilateral MCL gap	No	14 weeks	MCL plus capsule	6
Bilateral MCL gap	No	14 weeks	MCL	6
Bilateral MCL gap	No	40 weeks	MCL plus capsule	6
Bilateral MCL gap	No	40 weeks	MCL	6
Bilateral MCL gap	Immobilized	3 weeks	MCL plus capsule	6
Bilateral MCL gap	Contralateral	3 weeks	MCL plus capsule	6
Bilateral MCL gap	Immobilized	6 weeks	MCL plus capsule	6
Bilateral MCL gap	Contralateral	6 weeks	MCL plus capsule	6
Bilateral MCL gap	Immobilized	14 weeks	MCL plus capsule	6
Bilateral MCL gap	Contralateral	14 weeks	MCL plus capsule	6
Bilateral MCL gap	Immobilized	6 weeks	MCL	5
Bilateral MCL gap	Contralateral	6 weeks	MCL	5
Bilateral MCL gap	Immobilized	14 weeks	MCL	6
Bilateral MCL gap	Contralateral	14 weeks	MCL	6
Normal	No	n/a	MCL plus capsule	6
Normal	No	n/a	MCL	12
Normal	No	n/a	Capsule	5

“n/a” indicates not applicable.

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