The Not-So Definitive Guide to Meniscal Root Repairs

Research Review and Commentary

Meniscus Root Repair Background

Medial meniscus root tears account for 10% of all meniscus tears and 21% of all medial meniscus tears; posterior medial and posterior lateral root tears account for 52% and 41% of all meniscal root tears, respectively.[1] The most common subtype of medial meniscus root tears (MMRT) being degenerative tears with 80% of these seen in obese sedentary individuals over the age of 50.[2] Acute injuries, typically caused by deep knee flexion or deep squatting with rotation, make up the remaining 20%. As opposed to most MMRTs, Hantouly et al. reported lateral root tears were more commonly seen in males, those with chronic ACL insufficiency, or in multi-ligamentous injuries.[3]

Table 1 Risk factors for meniscus root tear

Medial meniscus root tear	Lateral meniscus root tear
Female	Male
Obesity	Multi ligament injury
Older age > 50	Chronic ACL deficient knee
Sedentary lifestyle	Physically active lifestyle
Frequent squatting and kneeling	
Middle East and Asian populations	

Fig. 1 (Hantouly et al, 2024)

Up until about the last decade or so, meniscectomy was the primary surgical intervention for root tears although these yielded poor results due to the inability to restore the essential load distribution qualities of the intact meniscus root. When the meniscal root is torn, it disrupts the hoop tension qualities of the meniscus which is essential for balanced distribution of axial-loading forces within the knee joint and subsequent protection of the articular cartilage.[4] Disruption of this hoop tension leads to extrusion of the meniscus, increased articular contact stress, and decreased medial compartment contact.[2,4] (Figure 2) A reduction of contact area by 40-75% may increase joint stresses by 200-300%, significantly increasing stress to the articular cartilage and rapidly progressing degenerative joint changes.[5] Allaire et al. completed biomechanical studies showing an untreated MMRT to be biomechanically similar to *complete* meniscectomy [5] although repair of the MMRT has been shown to bring peak contact pressures back to numbers similar to normal, native knees.[6-7]

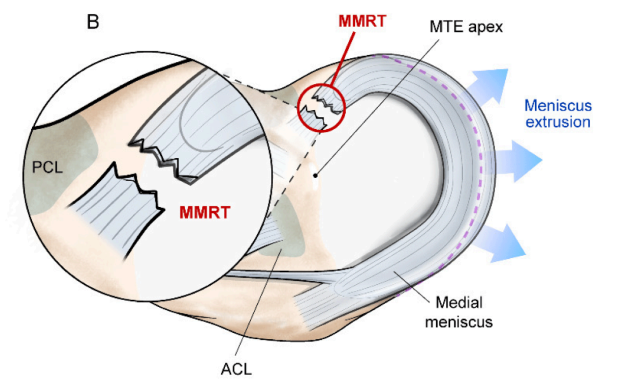


Fig 2 (Moon et al, 2023)

Currently, three treatment options exist for Meniscus Root Tears: Repair, Meniscectomy, and Conservative management. Gold standard is generally considered to be transtibial repair; either twin tunnel or single tunnel all-inside repair. (Figure 3) Ideal candidates for surgical repair are 1) young and physically active, 2) without severe arthritic changes, 3) without severe valgus mal-alignment, 4) without a high BMI and 5) willingness to comply with a strict rehab protocol.[8]

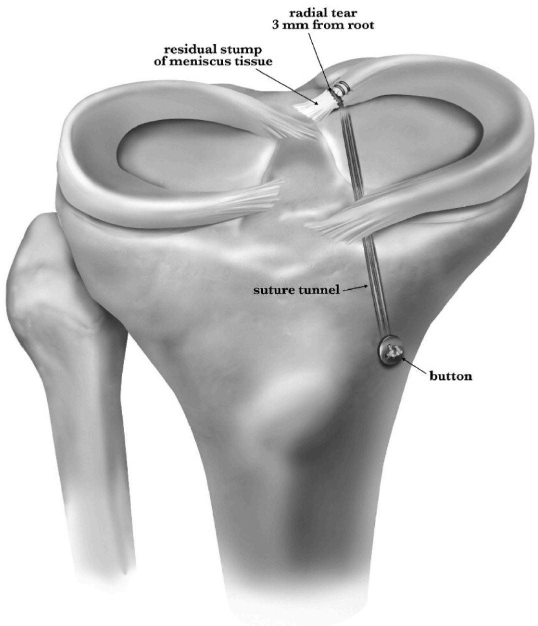


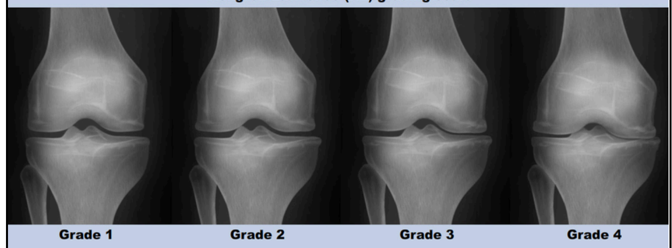
Fig. 3 (Padalecki et al., 2014)

Conservative Vs. Surgical Management:

In a recent paper by Kumar et al.[9] published in 2024 comparing functional and radiological outcomes in conservatively managed vs surgically repaired MMRTs, the surgical group significantly outperformed the conservative group in all metrics measured. Specifically, Lysholm Scores improved from 53.8 to 81.4 pts and IKDC scores from 41.1 to 70.7 pts in the surgical group compared to 50.2 to 61.9 pts for the Lysholm and 36.4 pts to 47.2 pts with the IKDC in the conservative group.

Additionally, radiological assessment revealed Kellgren-Lawrence (KL) grade progressions were seen in 60% of the surgical group and 100% of the non-op group. In the surgical group, 10% had significant joint space narrowing (>2mm) and 5% progressed more than 2 grades on the KL grading scale. In the conservative group, those numbers were 25% and 80% respectively.[9]

Kellgren-Lawrence (KL) grading scale



CLASSIFICATION	Normal	Doubtful	Mild	Moderate	Severe
DESCRIPTION	No features of OA	Minute osteophyte: doubtful significance	Definite osteophyte: normal joint space	Moderate joint space reduction	Joint space greatly reduced: subchondral sclerosis

Fig 4.
(http://www.adamondemand.com/clinical-management-of-osteoarthritis/)

Conservative management showed short term improvements although these plateaued quickly and long term preservation of these improvements may not persist. The surgical group continued to improve over time although 33.5% of those who underwent MMRT repairs transitioned to TKA in 10 years (however authors note, this may be an overprediction).[10]

Weight Bearing Protocols

"There are as divergent opinions about the WB period as ROM. WB can cause damage on suture-meniscal tissue and bone-to-meniscus interface, which can result in unfavorable meniscal healing and meniscal extrusion.[27] However, excessive delays in WB can have a negative effect on the clinical outcome as some studies have confirmed that hoop stresses associated with WB actually facilitate meniscal healing in general meniscus repair.[34]"- Kim et al. 2023

The purpose of this review is primarily focused on the research surrounding weight bearing after meniscal root repair; however, prior to that discussion we need to establish context on the current postoperative rehabilitation trends in this area. In a systematic review completed by Kim et al. in 2023, they found that of the 13 included studies:[11]

- 2 studies had low-level PWB started 1 day after surgery with a gradual increase of WB intensity until 6 weeks
- PWB was started at postoperative week 2 in 2 studies
- PWB was started at postoperative week 4 in 1 studies
- PWB was started at postoperative week 6 in 6 studies,
- FWB was allowed at 6 weeks in 7 studies and 8 weeks in 4 studies
- One study suggested that PWB should be started after 6 weeks of the NWB period and gradually increased to FWB until there is no pain or swelling
- One study suggested TTWB should be initiated at postoperative week 2 and WB intensity should be gradually increased to 50% until postoperative week 4
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Summary findings from Kim et al., 2023

The current published literature is fraught with heterogeneity. If the search is extended to include online protocols shared by large academic institutes, we see similar findings: Ohio State University recommends 4 weeks of NWB with the goal of crutch discharge by 6 weeks post-op for meniscus root repairs.[12] For meniscus repairs (MMRR not specified) Mass General Brigham recommends partial weight bearing for 3-6 weeks dependent on surgeon approval with potentially discharging crutches at 6 weeks if cleared by surgeon.[13] University of Virginia recommends 25% WB for 6 weeks after meniscus root repair with discharge goal over the following 2 weeks.[14]

Research Foundations

Weight bearing precautions for postoperative management of meniscus root repairs are largely based on a half dozen research papers investigating repair strength of various fixation strategies in cadaver knees. The most commonly cited references are broken down below but before we can examine the findings of these studies, we need to begin with the cyclic loading protocol itself and its origins. All of these investigations utilize a protocol that applies 500 N of tibiofemoral compression for 1000 cycles at .5 Hz (1 rep every 2 seconds) with an applied tensile load of anywhere from 5-30 N depending on the author. This is reported to be "*reflective of rapid loading*" with some authors adding language like "*as expected in postoperative rehabilitation*". I'll save you the pain of reading every citation provided for those statements (and the citations for the citations) but for those of you who are interested, you can scroll through the breakdown here. A word of caution, it's tedious and is akin to following the yellow brick road only to find an old man behind the curtain.

The hallmark origin story of weight bearing precautions begins with Starke et al. who completed an investigation on repaired meniscal root tears and the tensile force experienced in vitro. Their group investigated the change in medial meniscus root forces with flexion, flexion + external rotation, and flexion + internal rotation under either a 100 N or 500N tibiofemoral compression load. Human cadaver knee joints with ligaments intact were tested in each plane under 100 N or 500 N of tibiofemoral compression. (**Quick math: 1 lb = 4.44 N so 500 N = approx 112 lbs of force).** Their *specific* findings were that peak pressure to the posterior meniscus root was seen with loaded knee flexion to 60 degrees combined with internal rotation.[15] (Figures 5-6).

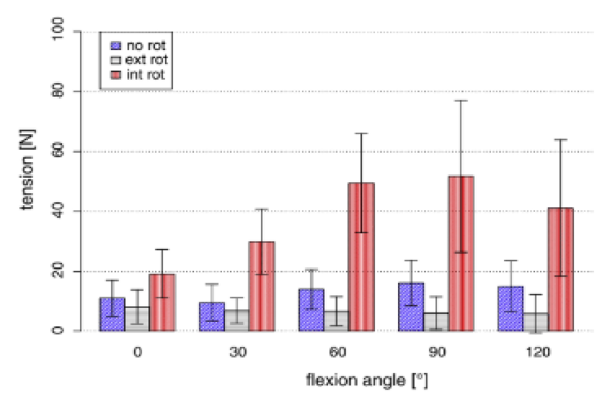

Fig 6. Root tension (mean and standard deviation) for each combination of flexion (0°, 30°, 60°, 90°, 120°) and rotation of the femur (no rotation, internal, external) at 100 N femorotibial load.

Fig. 5 (Starke et al., 2013)

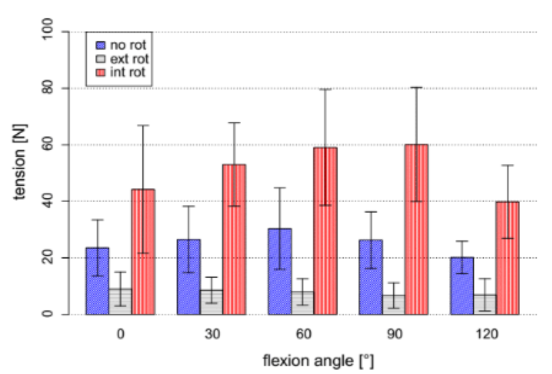

Fig 7. Root tension (mean and standard deviation) for each combination of flexion (0°, 30°, 60°, 90°, 120°) and rotation of the femur (no rotation, internal, external) at 500 N femorotibial load.

Fig.6 (Starke et al., 2013)

A couple takeaways: 1) the loading schemes used effectively equate to 22lbs and 112 lbs of femoral-tibial compression, 2) in neutral flexion-extension under both load exposures, the meniscus root experiences 15-33 N of force, and 3) loaded flexion did not seem to make significant differences in stress to the meniscus root repair when controlled for tibial rotation. The authors do make the typical correlation to their study design and real world application:

"The femorotibial load used in this study is below what would be expected during activities of daily living." (Kutzner et al., 2010)

- Kutzner et al. (2010)- an investigation into knee loading with ADL movements like standing, stairs, walking, etc.; toe touch weight bearing and partial weight bearing were not investigated.[16]

"This implies certain limitations in terms of the conclusions. Nevertheless, these forces are in a range that would be expected postoperatively" (citation needed)

For the sake of argument, we will agree that the forces used by Starke et al. are below the forces expected with ADLs and we can accept that 100 to 500 N can represent toe touch/partial weight bearing (although 500 N is likely >50% bodyweight for the average adult if we use the Kutzner paper as reference). However, the authors go on to make a few additional opinion statements that warrant discussion:

"Despite the use of moderate loads, the data collected in this study indicate that the tensile force at the repaired root could easily reach a magnitude that exceeds the strength of fixation materials used to repair meniscal horn tears, if weight bearing and range of motion are not restricted." (Kopf et al, 2011, Moon et al., 2012, Asik & Sener, 2001)

This appears to be a reasonable statement as it is doubtful clinicians are advocating for unrestricted weight bearing or range of motion in the early post-operative rehab phases for meniscus root repairs. Even less so for combined flexion and rotation under load as these were the only parameters where values approach the load to failure thresholds described below. Alas, it wouldn't be a research review if we didn't take a look the citations provided and what *those* papers actually say:

- [Kopf et al. (2011)](#)- Investigation in load to failure for native meniscal roots as well as repaired root tears utilizing 3 different suture types. Relevant findings: native meniscus roots averaged 594 +/- 241 N load to failure and depending on the suture type, repaired meniscal root tears demonstrated 64-142 N load to failure. It is beyond the scope of this review to go into current gold standards for suture type in MMRR but we can safely say that current guidelines are using the best proven suture/fixation strategies based on the current state of the literature.[24] Of note, Kopf et al. actually share their early phase rehab recommendations:

  "*Our rehabilitation strategy limits the patients to partial weight bearing for 1 week, wearing a brace locked in full extension for 4 weeks, and passive range of motion exercises from 0° to 90° of knee flexion while wearing the brace.*" [17]

- [Moon et al. (2012)](#): Investigated prognostic factors for favorable outcomes after MMRR which were: low BMI, less than 5 deg varus and grade 2 or less osteoarthritic changes. They did *not* investigate weight bearing or rehabilitation at all and their key finding was that MMRR did not prevent further excursion in the majority of case:

  "Meniscus extrusion increased in 20 of 31 patients, decreased in 8, and stayed the same in 3…Nevertheless, the results of the present study show that the progression of extrusion had no detrimental effect on clinical outcomes.[18]

- [Asik & Sener (2001)](#): Investigation on load to failure of various sutures (horizontal and vertical) with ranges between 49N and 106N as well as rigid implant devices. No reference to in vivo loading or rehabilitation.The authors conclude:

  "*These drawbacks keep us from concluding relevant clinical outcomes. All of our experimental results should be confirmed by long-term clinical studies, because factors affecting the meniscus in vivo are numerous than in vitro situation.*"[19]

Starke et al. leave us with this conclusion:

*"Our results have potential implications for postoperative rehabilitation. **The data suggest that weight bearing should be prohibited after repair of meniscal root tears until a sufficient strength can be assumed**. Internal rotation of the femur should be avoided as it generates high tensile forces in the posterior meniscal root. Range of motion exercises are less critical when external rotation of the femur relative to the tibia is applied.*"(citation needed)

No citations provided for the above and we are left wondering what "*until sufficient strength can be assumed*" means. I think it's fair to say "prohibited" is a solid jump in language here based on the authors' citations provided. It is unclear how the authors reference papers suggesting progressive partial weight bearing[17]- if they discuss it at all- and then conclude that weight bearing should be prohibited? Additionally, we have yet to establish that being non-weight bearing improves meniscal root healing or outcomes as discussed later in this review. Despite these concerns, this is a hallmark paper used in the meniscal root repair literature and establishes context on the subsequent papers below.

The most commonly cited paper when researching meniscus root repair loading was published by Feucht et al. in 2014.[20] The authors completed a biomechanical investigation of the difference between suture anchor (SA) and transtibial pullout (TP) repairs for medial meniscus root repairs. Twenty-four pig cadavers were split into three groups- native, suture anchor repair, and transtibial repair with each undergoing cyclic loading of the suture fixation for 1000 cycles at .5 Hz with a perpendicular load between 5 and 20 N. This is not the origin of the cyclical loading protocol used in MMRR research although nearly all cyclical loading protocols use some variation of this scheme. This protocol was chosen as it *"**is believed to simulate in vivo loads to which repaired menisci are subjected early after surgery.**"*

Sidenote: when we actually chase the citations down for this statement we ultimately find ourselves either at a dead end that this protocol is "reflective of rapid loading forces" without any additional citations or we land in the ACL research realm with references to unpublished data by Havig who states "1000 cycles represents one week of rehabilitation". You can see the breakdown here if interested. LINK

After an in-depth review of the citations provided (and the citations' citations), we fail to establish that this loading protocol represents forces we can expect the meniscus root repair to experience in early postoperative rehabilitation. In fact, the only paper we can loosely draw conclusions from is the Starke et al.[15] paper discussed previously.

We are just going to have to agree that the commonly used repetitive cyclical loading protocol represents rapid loading forces and, for the purposes of this portion of the review, we will assume Starke et al. as our contextual framework for the loading parameters. It is important to note, however, that we just have not established that these parameters are a reliable proxy for in vivo forces experienced in the postoperative setting.

Returning to the Feucht et al. article, their group found that both repairs demonstrated significantly increased displacement with the SA outperforming the transtibial pull out repair as shown in figure 7.

Why does displacement matter? In a 2010 study completed by Starke et al. comparing non-anatomic repair fixation, the authors demonstrated that a 3 mm change in fixation site "*decreased the resultant tensile force by 49% to 68%, depending on the flexion angle and femorotibial load.*" [21] As previously mentioned, restoring the hoop tension stress to allow normal distribution of tibiofemoral compressive load to the meniscus rather than articular cartilage is the primary goal of meniscus root repairs.[5-7]

The next most commonly cited paper for meniscus root repairs and early post-operative weight bearing was completed in 2014 by Cerminara et al.[22] The authors investigated transtibial pull-out repair response to cyclic loading. Eighteen porcine cadavers were allocated to 3 groups: the full repair construct group, button-bone interface group, and meniscus-suture interface group.

Fig. 7 (Feucht et al. 2014)

TABLE 1
Displacement During Cyclic Loading[a]

	Displacement, mm		
	After 100 Cycles	After 500 Cycles	After 1000 Cycles
Native	$0.2 \pm 0.1^{b,c}$ (0.1-0.3)	$0.4 \pm 0.2^{b,c}$ (0.3-0.5)	$0.5 \pm 0.2^{b,c}$ (0.3-0.6)
SA technique	0.6 ± 0.2^{c} (0.4-0.7)	1.0 ± 0.3^{c} (0.8-1.3)	1.3 ± 0.3^{c} (1.0-1.5)
TP technique	1.0 ± 0.3 (0.8-1.2)	1.8 ± 0.4 (1.5-2.2)	2.2 ± 0.5 (1.8-2.6)

[a]Data are shown as mean ± standard deviation (95% confidence interval). SA, suture anchor repair; TP, transtibial pull-out repair.
[b]Significant difference compared with SA (100 cycles: P = .003; 500 cycles: $P < .001$; 1000 cycles: $P < .001$).
[c]Significant difference compared with TP (100 cycles: $P < .001$; 500 cycles: $P < .001$; 1000 cycles: $P < .001$).

The purpose was to isolate the different structures that comprise the TP root repair and subsequent response to cyclic loading. The authors used the standard 1000 cycles at .5 hz with a slightly higher loading of 10 to 30 N.

"This protocol was chosen to approximate the tensile forces that the posterior medial meniscal root may experience under neutral rotation, knee flexion to approximately 30 to 60 degrees, and 500 N of tibiofemoral load, which are believed to be the standard range of motion and toe-touch weight bearing protocols over the course of a typical 6-week postoperative rehabilitation regimen after meniscal root repair." (Starke et al., 2013)

The most obvious point here is that while we can accept that the knee flexion angles suggested generally represent TTWB, 500 N of tibiofemoral loading (approx. 112 lbs) limits the ability to apply these findings to toe-touch and potentially even partial weight bearing in the clinic. The authors found an overall displacement of 3.28 mm after cyclic loading with "*the primary contributor to the increase in displacement due to suture cut-out at the meniscus-suture interface*". The authors again report the validity of this loading protocol as:

"*previous studies have evaluated cyclic displacement under similar loading conditions to represent the loads that may be experienced by the posterior medial meniscal root during a typical postoperative regimen*." (Feucht et al., 2014, Ropke et al., 2013, Starke et al. 2013)

- Feucht et al.[20] discussed previously, references Starke et al.[15] for protocol
- Ropke et al.[23]- a repetitive load with a magnitude of 10 N was then applied 100 times (frequency 1 Hz). "*This magnitude of tension was chosen according to earlier studies, which determined forces on repaired meniscal roots for a possible post-op rehabilitation scenario*.[15]"
- Starke et al.[15]

While this paper demonstrated suture cut-out as a primary contributor to increased repair displacement with their loading protocol, the same issues persist with drawing conclusions that the application of these forces is what we can expect in the early postoperative rehabilitation phases (despite the many references to the contrary). The references, with the exception of the Starke et al. paper, are all secondary references that ultimately cite…the Starke et al. paper. Cerminara et al. conclude their report with the following opinion statement:

"Therefore, we believe that these results give further credence to the theory that partial toe-touch weightbearing for 6 weeks, followed by a slow progression to full weight bearing at approximately 8 weeks, is necessary to allow for adequate soft tissue healing."

Concerns abound with the language "*necessary for adequate soft tissue healing*" as it is not supported by these first few studies. Both of the previously discussed papers simply establish the response in porcine cadavers to cyclic loading in a range we think might happen with repetitive loading in the clinic. Extrapolation to in vitro should be cautioned until better understanding is established.

Our next and final paper before we move on is also heavily cited in the weight bearing justification research. In 2015, LaPrade et al.[24] investigated different suture types for transtibial pull-out meniscus root repairs in human cadaver knees using the same cyclic loading protocol (10-30 N) as above. At the time of the study, the TSS suture was the clinical standard suture type and demonstrated the least amount of displacement (1.78 mm) compared to the other

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TABLE 1
Cyclic Displacement and Ultimate Failure Load of Meniscus-Suture Fixation Techniques[a]

Group	Displacement, mm: 1 Cycle	100 Cycles	500 Cycles	1000 Cycles	Ultimate Failure Load, N
TSS	0.53 ± 0.31	1.11 ± 0.47	1.55 ± 0.57	1.78 ± 0.64	192 ± 52
MMA	0.54 ± 0.19 (2.45)	1.31 ± 0.43 (18.0)	1.88 ± 0.59 (21.3)	2.14 ± 0.65 (20.2)	325 ± 77 (69.9)[b]
S-DLL	0.73 ± 0.19 (39.2)	2.09 ± 0.45 (88.3)[b]	3.27 ± 0.67 (111)[b]	3.81 ± 0.78 (114)[b]	217 ± 51 (13.5)
D-DLL	0.61 ± 0.06 (14.7)	1.67 ± 0.24 (50.5)[b]	2.53 ± 0.44 (63.2)[b]	2.97 ± 0.57 (66.8)[b]	320 ± 50 (67.1)[b]

[a]Data are reported as mean ± SD. Values in parentheses are the percentages of greater displacement or ultimate failure load compared with the two simple sutures (TSS) technique. D-DLL, double-locking loop; MMA, modified Mason-Allen; S-DLL, single-locking loop.
[b]$P < .05$ compared with TSS.

Fig. 8 (LaPrade et al., 2015)

suture types (although a lower load to failure) as shown in figure 8. In regard to postoperative weight bearing, the authors give the following opinion:

"Based on the results of this study, the authors reiterate the importance of a slow and careful postoperative rehabilitation program to prevent significant displacement at the root repair site, similar to recommendations in previous studies.[3,5,6,9]…

…."Even under a cyclic loading protocol of 1000 loading cycles of 10 to 30 N at 0.5 Hz, chosen to approximate the tensile forces on the posterior medial meniscal root under neutral rotation, a range of motion program from 0 to 90 of knee flexion, and 500 N of tibiofemoral load,[19] a considerable amount of displacement occurred for each meniscus-suture fixation technique."

To review, the references provided for this statement are largely circular, filled with secondary citations and in some cases, tertiary. The majority of these references simply establish that this loading protocol has been used previously and while there is often the additional statement that these loads are "representative of rapid loading", which seems fair, our ability to use this data as it relates to in vivo applications seems limited at best. Instead, these protocols represent a supposed "worst case" scenario and the authors themselves often mention that caution should be applied in comparing these results to in vivo loading.

Once you have read these papers and the supporting citations, you'll see that these constitute the foundation of references provided on meniscus root repairs and drive most of the weight bearing protocol origins. For the sake of argument, we will assume that this cyclic loading protocol reproduces the tensile forces at the repaired meniscal root with toe-touch/partial weight bearing (for now). This brings us to the next phase of the investigation- **but is that what we *actually* experience?**

Actual Weight Bearing Research

In 2024, an investigation was completed by Sukopp et al. to evaluate loading scenarios to the posterior medial meniscus root in ACL-intact human cadavers during different weight bearing scenarios- TTWB, PWB, normal gait, gait with rotation, sit to stand and stand to sit.[25] The authors tested each cadaver with the MMPR intact, torn, and then repaired. They reported increases in force experienced by the repair suture (compared to TTWB): PWB + 18%; Gait + 152%; GaitRotation +144%; SitToStand + 161%; and StandToSit + 201%. Peak forces seen at TTWB and PWB were 77 N and 91 N, respectively (Figure 9).

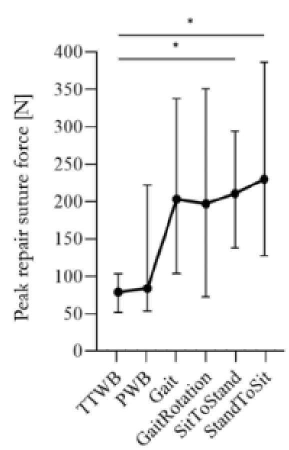

Fig. 9 (Sukopp et al. 2024)

The authors go on to remark:

"Moreover, a study by Lee et al.[26] showed good clinical outcomes with only 5% (1/21) re-tearing root repairs when avoiding partial WB for 6 weeks postoperatively, which is in line with current rehabilitation recommendations.[28]"

Over 80% of the participants in the Lee et al. study[26] had KL grades of 2 or less which has been established as a predictor for post-surgical success whereas we have *not* established differing weight bearing precautions as a prognostic for favorable MMRR outcomes.[32] Additionally, the statement that NWB for 6 weeks is "*in line with current rehabilitation recommendations*" references a clinical commentary published by in 2016 by Mueller et al.[27]

Mueller et al. demonstrate justification for NWB for the first 6 weeks with the same Lee et al. paper above and one study by Kim et al. [28] that showed 35% of the small sample pool that were allowed PWB immediately (N=14) showed loose healing or failed healing of the MMRR. While the results shared by Mueller et al. are accurate for the two studies they reference, it is unclear how two total studies with a combined 24 participants is indicative of current rehab guidelines.

Returning to the paper by Sukopp et al., the authors share their postoperative rehabilitation recommendations as below:

"These biomechanical findings suggest the implementation of partial weight bearing in the early post-operative period with a gradual transition to full weight bearing,[11] which appears to be essential to promote adequate soft tissue healing in the case of MMPRA [1, 22, (Hamer et al. 2009)], because the hoop stress caused by weight bearing can improve meniscal healing in meniscal repair."

Very few studies have been completed comparing MMRR outcomes and weight bearing protocols. Recently, Tamura et al. allocated 55 subjects to either a conservative protocol or an accelerated protocol (figure 10) with no significant differences observed in any category between groups.[29]

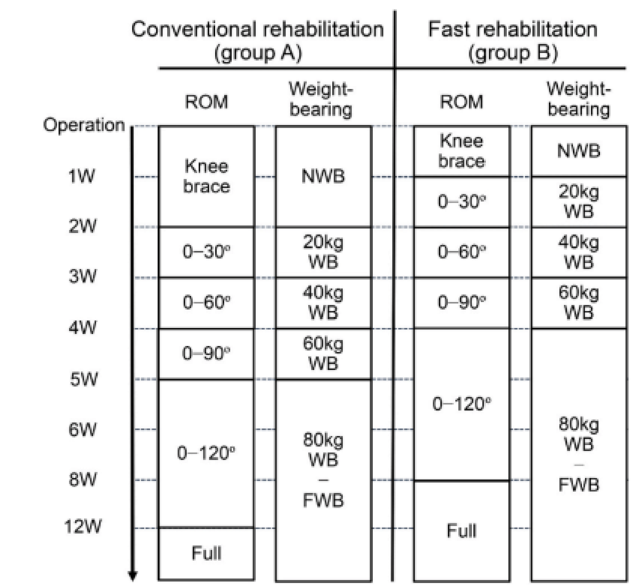

Fig. 3. Postoperative rehabilitation protocols. Range of motion, ROM. Non-weight-bearing, N.W.B. Weight-bearing, W.B. Full weight-bearing, F.W.B.

Fig. 10 (Tamura et al. 2024)

"The most important finding of the current study was that early weight-bearing and knee ROM exercises initiated 1 week post-operatively (group B) did not have a negative effect on postoperative clinical scores, postoperative MME progression, and arthroscopic meniscal healing status 1 year postoperatively compared to conventional rehabilitation (group A). Our results suggest that a fast rehabilitation regimen is clinically safe to perform." -Tamura et al. 2024

They go on to discuss the importance of balancing the risk of compromising the repair compared to the risks of prolonged immobilization such as decreased collagen formation and decreased strength.[29]

The Role of The ACL

One problem with using these studies to dictate postoperative rehabilitation protocols is that these are all cadaver studies which inherently limits application to living tissue. Another point to consider, other than the Starke et al. paper,[15] these investigations were in ACL-deficient knees which additionally decreases confidence points that the forces investigated are what we would expect to see in human ACL-intact knees let alone with supporting musculature.

To this point, several papers have been published investigating changes in medial meniscus loading in ACL-deficient knees. Papageorgiou et al. tested 10 human cadaveric knees with intact ACLs, deficient ACLs and reconstructed ACLs with a combined load of 134 N anterior tibial and 200 N axial compression. They demonstrated an increased force of 126% at 30 degrees of knee flexion and 113% at 60 degrees compared to ACL-intact knees.[30] (Figure 11).

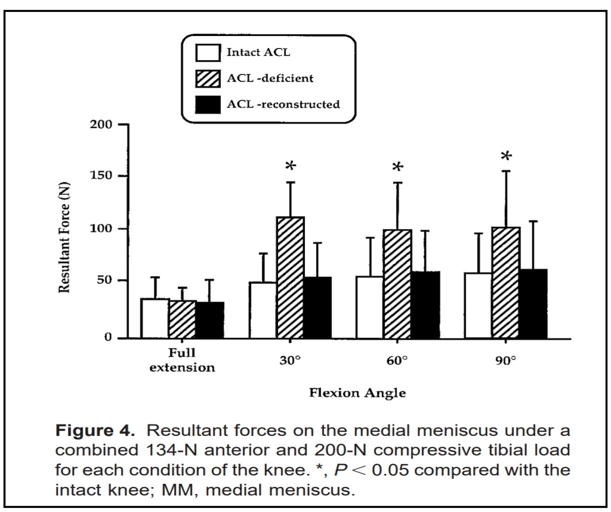

Fig. 11 (Papageorgiou et al. 2010)

Similarly, Markolf et al. tested 12 human cadavers with 500 N joint load initially with the ACL intact and again with it removed to assess changes in force experienced at the medial meniscus horn attachment. In ACL-deficient knees, the authors found a force increase of 55% (21.47 +/-15.88 N to 35.89 +/- 19.93 N) to the posterior horn compared to an ACL-intact knee at 50 degrees of knee flexion.[31] (Figure 12) Allen et al. performed a similar study with a 134 N anterior tibial force applied to ACL-intact and deficient human cadavers. They reported, "*The largest increase occurred at 60 degrees of flexion, when the resultant force in the medial meniscus of the anterior cruciate ligament-deficient knee* ***nearly tripled*** *that in the medial meniscus of the intact knee.*"[32]

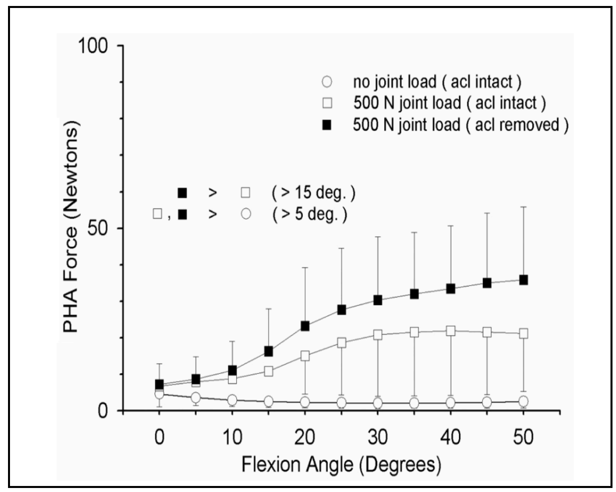

Fig. 12 (Markolf et al. 2012)

While these studies are limited in their comparative nature to the biomechanical loading papers reviewed above, it does suggest the tensile forces experienced at the medial meniscus in an ACL-deficient knee should be interpreted cautiously when extrapolating these findings to in vivo experience.

Does Any of it Matter?

To answer this, we have to first establish how we are measuring meniscus repair success. This typically lands in three main areas: resolution of meniscal extrusion, biological healing, and patient reported outcomes.

Meniscus Extrusion

In regard to medial meniscal extrusion (MME), the general trend in the research is that more often than not we still see increased MME even after surgical repair but there is quite a bit of heterogeneity in the amounts observed post-surgically.

In 2012, Moon et al. found MME increased in 20 of 31 (64.5%) patients with a mean increase from 3.6 ± 1.2 mm to 5.0 ± 1.7 mm; extrusion decreased in 8 participants and remained the same in 3 participants with "good healing status" reported in >90% of the subjects.[18] More recently, Sundararajan et al. showed >57% of patients had "good correction of meniscal extrusion" after transtibial pull out repair for MMRTs with only 38% showing an increase in postoperative MME.[33] The authors reported age <50, low level cartilage damage, low KL grade, and varus alignment less than 2.5 degrees were correlated with positive correction of MME postoperatively. They shared their post operative rehab protocol as below:

"Postoperatively, toe-touch weight bearing was allowed for the first 6 weeks. Knee mobilisation was started on postoperative day 2 and progressed to 90° flexion by 4 weeks. Full flexion of knee was achieved by 6 weeks and partial weight bearing was started after 6 weeks and progressed to full weight-bearing by the end of 8 weeks. Weight-resisted exercise and half squat exercise were started from third month onwards. Patients were allowed to participate in sports, running, squatting for eastern comourd, sitting cross legged on the floor and other heavy activities, only after 6–8 months of rehabilitation."

In 2017, Chung et al. assessed outcomes in patients having undergone transtibial pullout repair of meniscus root tears at a mean follow up of 68.9 months post-op with 23 of 39 (56%) patients demonstrating increased MME (3.5 mm +/- 0.9 mm preoperatively to 5.1 +/- 1.4 mm at 1-year follow up) and 16 of 39 demonstrating decreased MME (4.1 mm +/- 1.3 mm pre-op to 3.5 mm +/- 1.4 mm at 1-year follow up).[34] Chung et al. shared their early postoperative rehab protocol as below:

"Toe-touch weightbearing with the use of crutches and a knee brace locked in extension was required for 3 weeks postoperatively. Progressive knee range of motion (ROM) exercises using a continuous passive motion machine and isometric exercise were initiated at 2 or 3 days postoperatively. Crutches were continued, and the motion allowed in the brace was progressively increased starting at 3 weeks. The brace was discontinued, and full weight bearing and closed kinetic chain exercises were started at 6 weeks postoperatively. Patients were asked to permanently avoid deep flexion to decrease the risk of reinjuries to the posterior root."

Outside of the previously reported risk factors for successful outcomes regarding correction of MME, Kawada et al. recently demonstrated increased quad strength was associated with decreased medial meniscus extrusion progression. Participants included thirty patients having previously undergone MMRR tested pre- and postoperatively for knee extension strength as well as second-look arthroscopy to assess root tear healing.

Fig. 13 (Kawada et al., 2023)

Table 8 Comparison of high and low postoperative quadriceps muscle strength groups

	Low postoperative quadriceps muscle strength (< 375 N)	High postoperative strength (≥ 375 N)
Patients, *n*	15	15
Sex, male/female	3/12	7/8
Age, years	64.9 ± 8.8	62.6 ± 8.6
[range]	[50–77]	[41–77]
Height, m	1.57 ± 0.07	1.59 ± 0.08
[range]	[1.50–1.72]	[1.46–1.71]
Body weight, kg	65.2 ± 7.3	67.5 ± 9.7
[range]	[54.0–77.2]	[54.0–79.0]
Body mass index, kg/m^2	26.5 ± 3.6	26.6 ± 2.5
[range]	[22.2–31.4]	[22.6–30.1]
Time from injury to surgery, days	144.0 ± 149.9	149.7 ± 143.4
[range]	[23–644]	[19–622]
Preoperative quadriceps muscle strength, N	226.8 ± 76.4	317.0 ± 95.2
[range]	[100–375]	[126–541]
ΔMME, mm	1.34 ± 1.07	0.58 ± 0.84
[range]	[0.28–3.77]	[-0.85–1.81]

Values are presented as means ± standard deviations or numbers

p-values were derived using Wilcoxon's signed-rank test or Fisher's exact test

ΔMME change in medial meniscus extrusion

* Statistically significant

Patients with higher postoperative knee extension strength demonstrated .58 mm +/- 0.84 increased MME compared to the low strength group at 1.34 +/- 1.07.[35] (Fig. 13)

Their group published a paper the following year looking at the change in MME at multiple timeline points following meniscus root repair and showed that while MME was not able to be prevented, the largest changes were seen in the first 3 months and decreased over time concurrently with improvement in patient reported outcomes:

"*The ΔMME from the preoperative measurement point to 3 months postoperatively, from 3 months to 1 year postoperatively, and from 1 to 3 years postoperatively were 0.89 ± 0.94, 0.41 ± 0.66, and 0.16 ± 0.58 mm, respectively"* [36]

Interestingly, they reported males having an average of .53 +/- .55 mm increased MME compared to the 1.45 mm +/- 1.43 mm seen in women. In both papers, they share the early postoperative rehab protocol as below:

"The rehabilitation protocol consisted of extension immobilization of the affected limb for the 1st postoperative week with no loading allowed. The range of motion of the knee joint increased to 30°, 60°, 90°, and 120° at 1, 2, 3, and 4 weeks postoperatively, respectively. The load was 20 kg at 1 week, 40 kg at 2 weeks, 60 kg at 3 weeks, and full at 4 weeks postoperatively."

In summary, medial meniscus extrusion is observed in postoperative patients anywhere from 38% of the time on the low end to 100% on the high end.[33, 35] While increased MME is observed in the majority of cases, the amount varies widely despite marked heterogeneity in postoperative rehab protocols. Circling back to the original biomechanical studies, it seems that the real world response to loading is markedly less than that seen in cadaveric studies. Risk factors for increased MME seem to be age >50, high BMI, increased valgus angles, more advanced chondral changes and increased joint space narrowing.[32] Despite the increased MME, all of the studies demonstrated significant improvements to patient reported outcome measures as discussed below.

Meniscus Repair Healing

When we look at healing, which for the purposes of this review is measured with second look arthroscopy and probing of the meniscal root repair, Lee et al. found that of the 33 subjects having undergone MMRR, approximately 69.7% of those were classified into the "stable healed" group.[37] Similar to the Sundararajan et al. paper referenced above, "*higher BMI and the presence of grade 3 or 4 chondral lesions in the medial compartment were significant factors leading to poor healing after pullout suture for MMRTs*".

Sundararajan et al. reported 41 of the 54 (76%) subjects in their study demonstrated fully healed or partially healed (16.6%) MMRR although this was assessed via MRI and not arthroscopically.[33] More recently, Zhou et al. investigated outcomes for lateral meniscus root tears and found stable healing in 78% of the 23 subjects participating in their study. Additionally, they categorized "lax healing" in 5 of the 23 subjects.[38] Lax healing was defined as "*presence of a connection between the meniscus root and tibial insertion site with maintenance tension to a certain extent, despite lifting of the meniscus on probing.*" Zhou et al. shared their postoperative early phase rehab protocol as below:

"Postoperatively, the leg was immobilized using a knee brace in full extension. Quadriceps strengthening exercises were started on the second day. Flexion was restricted between 0° and 90° during the first 4 weeks of rehabilitation and gradually advanced as tolerated. Partial

weight bearing was started at 6 weeks, and full weight bearing was started at 8 weeks. Squatting was allowed at 3 months. Running and bicycling were allowed at 6 months. A full return to a competitive level of sports activities with contact was allowed at 12 months.

Interestingly, this NWB protocol yielded markedly different results than the Lee et al. paper referenced previously by Mueller et al. as their foundation for postoperative weight bearing recommendations. Of note, Zhou et al. had the youngest age of subjects (average age 28.8 +/- 8.5 years old) than any of the previously discussed papers.

Healing rates are varied in the literature but generally speaking, we see 70-80% of meniscal root tears demonstrate satisfactory healing with second look arthroscopy. It is worth mentioning that the majority of these studies were completed with participants over the age of 60 (other than Zhou et al.) and healing rates in younger patients may be different. Regardless, risk factors for suboptimal healing seem to be high BMI and advanced chondral changes.[33]

A quick note about healing: Cui et al. completed a study investigating anterior horn meniscus healing with the transtibial repair and the TP repair + platelet-rich plasma gel (PRG) injections. While they demonstrated improved healing markers across all timepoints for the PRG group, it is beyond the scope of this review to investigate biologics or adjunct treatments as they relate to meniscus repair healing. However, they did show that in the meniscus repair group without PRG, maximum tensile fracture strength of the repaired meniscus began to increase by 8 weeks after surgery and had doubled by 12 weeks.[39] In an older paper, investigating tensile strength of meniscus repairs in dogs, the authors reported ratios of maximum tensile strength were *"25% at two weeks, 54% at four weeks, 42% at six weeks, 77% at eight weeks, and 80% at 12 weeks postoperatively."*[40]

Meniscus Root Repair Outcomes

Despite mixed results in changes observed with meniscal extrusion and healing rates, subjective patient reporting seems to consistently improve in all groups. Moon et al. showed mean Lysholm scores increased from 48.3 preoperatively to 83.2 postoperatively[8] and Kim et al. showed similar changes of 56.8 to 85.1 at follow up. [18] In the Chung et al. paper referenced above, they found that patient reported outcome measures improved significantly *regardless of change in medial meniscus extrusion*. In the group that experienced *increased* MME, mean Lysholm scores improved from 50.3 +/- 6.8 preoperatively to 81.0 +/- 9.0 points at final follow-up and mean IKDC scores improved from 39.1+/- 6.8 points preoperatively to 71.1+/- 7.8 pts. Those with decreased MME after surgery demonstrated even more significant improvement in PROs compared to preoperative scoring.[38]

Similarly, Lee et al. showed that regardless of the patients being categorized into the stable healed or unhealed groups, PROMs improved in all areas with more significant improvements seen in the healed group.[37] (Figure 15)

Summary of Findings:

Meniscus root tears deserve unique consideration in the knee arthroscopy realm due to the deleterious consequences of injury to these keystone structures. While many orthopedic surgeries are hard pressed to show significant benefit compared to conservative management, the meniscal root repair consistently shows improvements in nearly all metrics compared to nonoperative cohorts. Restoring the integrity of the meniscus root is integral to normalizing load distribution in the knee and without it, we see marked increases in articular cartilage stress

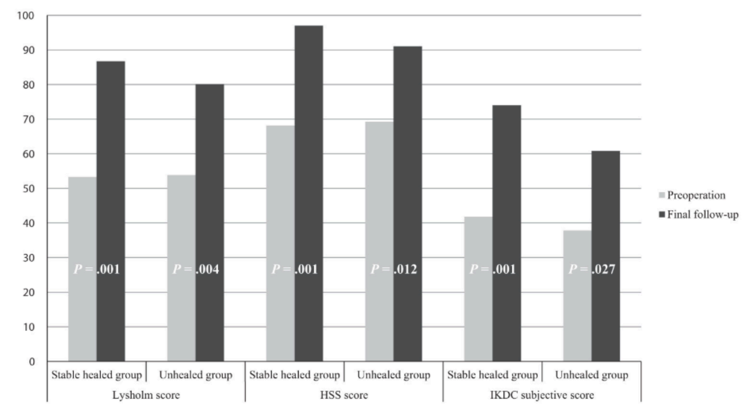

Figure 3. Preoperative and final follow-up clinical scores in each group. HSS, Hospital for Special Surgery; IKDC, International Knee Documentation Committee.

Fig. 15 (Lee et al. 2018)

stress and accelerated osteoarthritis. Despite the consensus that meniscal root tears should be surgically corrected in patients with low BMI, minimal arthritis, less than 2.5 degrees of valgus alignment, and KL grades of 2 or less, there is no consensus on postoperative management, specifically in regards to weight bearing.

The majority of the clinical framework for postoperative weight bearing is built off several biomechanical studies in ACL-deficient cadavers having undergone cyclic loading protocols thought to replicate the stress these structures may experience in early rehabilitation phases. Increased displacement is seen consistently in these investigations with suture elongation and suture cut-out being the primary contributors identified in most studies. There is little debate as to the response to meniscal root repairs when subjected to these protocols in vitro, which in turn are largely built off a single paper or replicating variations of cyclic protocols used in the ACL literature.

In regard to the weight bearing precautions commonly seen in typical early postoperative rehab, minimal research is available to guide decision making with MMRRs. The single paper shared seems to suggest the in vivo forces may actually be higher than those reported in these early cyclic loading publications. Specifically, Starke et al. showed the meniscus root, regardless of knee flexion angle, experiences less than 20 N of tension and up to 33 N of tension under a compressive force of approximately 22 lbs to 112 lbs respectively. Comparatively, Sukopp et al. demonstrated approximately 77-91 N of tensile force to the meniscus repair sutures with TTWB and PWB respectively. Despite these results, no differences were seen in the single study investigating fast versus slow early phase rehabilitation protocols for meniscus root repairs. Despite the high heterogeneity seen in weight bearing protocols, the research has failed to identify weight bearing restrictions as a prognostic marker for postoperative success.

Meniscus repair outcomes show resolution of meniscal extrusion occurs in the minority of cases while meniscus healing, defined as stable fixation under probing in second-look arthroscopy, is seen in the majority of cases in the current literature. Despite the wide range of these findings, patient reported outcome measures consistently improve after meniscal root repair surgery.

Taking all currently published research into consideration, it seems reasonable to protect the MMRR from repetitive loading early on although the risks of prolonged unloading, ie. persistent muscle weakness, do not seem to be justified at this time. In fact, recent research actually demonstrated improved knee extension strength was associated with decreased meniscal excursion whereas prohibited early weightbearing has not. Decision making should be guided by surgeon recommendations and individualized for the patient profile as we have previously outlined those prognostics for improved outcomes. Further research is needed to better develop the clinical framework for weightbearing as it relates to meniscal root repair healing and outcomes.

Closing Opinion and Ruminations:

Based on what research we have available, it is difficult to support NWB in patients for 6 weeks as this seems to be built on an overabundance of caution. That being said, I don't think it's a bad plan either as we have so little to go off of when making these decisions. After completing this review, I can't help but get late 90s/early 2000s ACL vibes. The investigations (and conclusions) are almost identical: a bunch of papers on cyclic loading of the ACL, a few studies on strain with exercises, and two decades of avoiding knee extensions as a consequence.

While my current opinion is that we need to minimize excessive cyclical loading to the ACL with gait until adequate quad control is established, the current ACL research supports early knee extensions for ACL rehab as it relates to better clinical outcomes without increased laxity as previously believed.[41] I suspect we'll see a similar evolution of MMRR weight bearing protocols as better research is completed and it's likely to land somewhere in the middle of NWB and WBAT.

It is abundantly clear we need more research on postoperative management for MMRTs. For context, while we've been doing ACL reconstructions for over a century, they didn't rise in popularity until the 1970s and subsequently thousands upon thousands of publications exist to guide ACL rehabilitation guidelines. In contrast, up until about a decade ago, most meniscus root repairs were debrided rather than repaired.[41] Our recommended protocol, which is likely to change as more information becomes available is shared below:

Week 0-1	**NWB**	**Brace locked in extension, PROM 0-90 degrees**
Weeks 1-2	**TTWB (<20% BW)**	**Brace locked in extension, PROM 0-90 degrees**
Week 3-5	**PWB (<50% BW)**	**Brace locked in extension, PROM 0-90 degrees**
Week 6	**WBAT**	**Brace unlocked 0-30 degrees, PROM 0-110 degrees**
Weeks 7-8	**FWB, no brace**	**PROM to WNL**

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42. Noehren, B., & Snyder-Mackler, L. (2020). Who's Afraid of the Big Bad Wolf? Open-Chain Exercises After Anterior Cruciate Ligament Reconstruction. *The Journal of orthopaedic and sports physical therapy*, *50*(9), 473–475. https://doi.org/10.2519/jospt.2020.0609

Appendix 1

Outcomes of Weight Bearing precautions in Kim et al. Review

2 studies had low-level PWB started 1 day after surgery with a gradual increase of WB intensity until 6 weeks

- [28]Kim SB, Ha JK, Lee SW, et al. Medial meniscus root tear refixation: comparison of clinical, radiologic, and arthroscopic findings with medial meniscectomy. Arthroscopy. 2011;27(3):346-54.
    - Fixation strength measured by arthroscopic probing was normal in 9, loose in 3, and lost in 2
    - 17 (56.7%) showed complete healing of the meniscus, 11 (36.7%) had partial healing, and 2 (6.7%) had repeat tears. MME decreased in 26 patients (86.7%)
- Lee, D. W., Kim, M. K., Jang, H. S., Ha, J. K., & Kim, J. G. (2014). Clinical and radiologic evaluation of arthroscopic medial meniscus root tear refixation: comparison of the modified Mason-Allen stitch and simple stitches. *Arthroscopy : the journal of arthroscopic & related surgery : official publication of the Arthroscopy Association of North America and the International Arthroscopy Association*, *30*(11), 1439–1446. https://doi.org/10.1016/j.arthro.2014.05.029
    - The medial meniscal extrusion in the M (modified mason allen) group decreased by 0.6+/- 0.9 mm after surgery, whereas the extrusion increased by 1+/- 0.6 mm in the S (simple suture) group
    - Of the 25 patients in the M group, 15 (60%) showed complete healing, 9 (36%) had partial healing, and 1 (4%) showed no healing. In contrast, 8 (32%) of the 25 patients in the S group showed complete healing, 16 (64%) had partial healing, and 1 (4%) showed no healing

PWB was started at postoperative 2 weeks in 2 studies

- Furumatsu, T., Miyazawa, S., Fujii, M., Tanaka, T., Kodama, Y., & Ozaki, T. (2019). Arthroscopic scoring system of meniscal healing following medial meniscus posterior root repair. *International orthopaedics*, *43*(5), 1239–1245. https://doi.org/10.1007/s00264-018-4071-z
    - A median of second-look arthroscopic scores was 6.5 (5.75–8). In the meniscal healing status, filamentous anteroposterior width of bridging tissues and detached posterior root were not observed at second-look arthroscopy
- Seo, H. S., Lee, S. C., & Jung, K. A. (2011). Second-look arthroscopic findings after repairs of posterior root tears of the medial meniscus. *The American journal of sports medicine*, *39*(1), 99–107. https://doi.org/10.1177/0363546510382225
    - On the second-look arthroscopy, complete healing was not observed in any of the patients. Five knees had lax healing (symptomatic in 2 and

asymptomatic in 3) and 4 had scar tissue healing (asymptomatic in all 4). The other 2 patients had failed healing (symptomatic in 1 and asymptomatic in 1). The lax healing, scar tissue healing, and failed healing were found in the 3 patients who had a high tibial osteotomy

PWB was started at postoperative 4 weeks in 1 studies

- Lee, S. S., Ahn, J. H., Kim, J. H., Kyung, B. S., & Wang, J. H. (2018). Evaluation of Healing After Medial Meniscal Root Repair Using Second-Look Arthroscopy, Clinical, and Radiological Criteria. *The American journal of sports medicine*, *46*(11), 2661–2668. https://doi.org/10.1177/0363546518788064
  - Among the 33 patients, 23 (69.7%) were in the stable healed group and 10 (30.3%) in the unhealed group. The clinical outcomes at the final follow-up were significantly improved, and the medial joint space became significantly narrower than that preoperatively, regardless of the healing status of the MMRTs

PWB was started at postoperative 6 weeks in 6 studies,

- Dragoo, J. L., Konopka, J. A., Guzman, R. A., Segovia, N., Kandil, A., & Pappas, G. P. (2020). Outcomes of Arthroscopic All-Inside Repair Versus Observation in Older Patients With Meniscus Root Tears. *The American journal of sports medicine*, *48*(5), 1127–1133. https://doi.org/10.1177/0363546520909828
  - Compared non-op to arthro, did not report healing rates
- LaPrade, R. F., Matheny, L. M., Moulton, S. G., James, E. W., & Dean, C. S. (2017). Posterior Meniscal Root Repairs: Outcomes of an Anatomic Transtibial Pull-Out Technique. *The American journal of sports medicine*, *45*(4), 884–891. https://doi.org/10.1177/0363546516673996.
  - Did not report healing rates
- Jung, Y. H., Choi, N. H., Oh, J. S., & Victoroff, B. N. (2012). All-inside repair for a root tear of the medial meniscus using a suture anchor. *The American journal of sports medicine*, *40*(6), 1406–1411. https://doi.org/10.1177/0363546512439181.
  - Follow-up MRI was performed in 10 patients. Five (50%) patients showed complete healing; 2 of these 5 patients showed complete healing with isointense signal of a normal meniscus (Figure 8), and 3 showed intermediate signal tissue at the previous tear site without any high signal cleft or ghost sign. Four (40%) patients showed partial healing, and 1 (10%) showed no healing.
  - Mean extrusion of the midbody of the medial meniscus was 3.9 mm (range, 2.2-7.1 mm) preoperatively and 3.5 mm (range, 1.2-6.1 mm) postoperatively. Extrusion was not significantly decreased
- Lee, J. H., Lim, Y. J., Kim, K. B., Kim, K. H., & Song, J. H. (2009). Arthroscopic pullout suture repair of posterior root tear of the medial meniscus: radiographic and clinical results with a 2-year follow-up. *Arthroscopy : the journal of arthroscopic & related surgery : official publication of the Arthroscopy Association*

of North America and the International Arthroscopy Association, *25*(9), 951–958. https://doi.org/10.1016/j.arthro.2009.03.018.
  - ➢ Second Look arthroscopy was performed in 10 knees (47.6%), and all of the repaired menisci had healed completely without additional chondral lesions in the knee

❖ Kim, J. H., Chung, J. H., Lee, D. H., Lee, Y. S., Kim, J. R., & Ryu, K. J. (2011). Arthroscopic suture anchor repair versus pullout suture repair in posterior root tear of the medial meniscus: a prospective comparison study. *Arthroscopy : the journal of arthroscopic & related surgery : official publication of the Arthroscopy Association of North America and the International Arthroscopy Association*, *27*(12), 1644–1653. https://doi.org/10.1016/j.arthro.2011.06.033
  - ➢ On follow-up MRI at 2 years postoperatively, complete structural healing was seen in 11 cases in group 1 (pullout) and 12 cases in group 2 (suture anchor) without statistical significance (P .05). However, incomplete structural healing was seen in 6 cases in group 1 and 2 cases in group 2 with statistical significance (P .05) (Table 5).
  - ➢ Mean preoperative meniscal extrusion, 4.3 0.9 mm in group 1 and 4.1 1.0 mm in group 2, was significantly decreased postoperatively in both groups (to 2.1 1.0 mm in group 1, and 2.2 0.8 mm in group 2)

❖ Kim, C. W., Lee, C. R., Gwak, H. C., Kim, J. H., Park, D. H., Kwon, Y. U., & Jung, S. H. (2019). Clinical and Radiologic Outcomes of Patients With Lax Healing After Medial Meniscal Root Repair: Comparison With Subtotal Meniscectomy. *Arthroscopy : the journal of arthroscopic & related surgery : official publication of the Arthroscopy Association of North America and the International Arthroscopy Association*, *35*(11), 3079–3086. https://doi.org/10.1016/j.arthro.2019.05.051
  - ➢ Of the 30 patients (75%) who received second-look arthroscopy, 21 patients were finally enrolled in the repair/lax healing group, 2 patients were classified as having complete healing, and 7 patients were classified as having failed healing

One study suggested that PWB should be started after 6 weeks of the NWB period and gradually increased to FWB until there is no pain or swelling

❖ LaPrade, R. F., Matheny, L. M., Moulton, S. G., James, E. W., & Dean, C. S. (2017). Posterior Meniscal Root Repairs: Outcomes of an Anatomic Transtibial Pull-Out Technique. *The American journal of sports medicine*, *45*(4), 884–891. https://doi.org/10.1177/0363546516673996
  - ➢ Did not report healing rates

One study suggested TTWB should be initiated at postoperative 2 weeks and WB intensity should be gradually increased to 50% until postoperative 4 weeks

❖ Seo, H. S., Lee, S. C., & Jung, K. A. (2011). Second-look arthroscopic findings after repairs of posterior root tears of the medial meniscus. *The American journal of sports medicine*, *39*(1), 99–107. https://doi.org/10.1177/0363546510382225
  - ➢ Reported above

Appendix 2

Outcomes of Weight Bearing Protocols of Referenced Articles

- Kawada, K., Furumatsu, T., Yokoyama, Y., Higashihara, N., Tamura, M., & Ozaki, T. (2024). Meniscal healing status after medial meniscus posterior root repair negatively correlates with a midterm increase in medial meniscus extrusion. *Knee surgery, sports traumatology, arthroscopy : official journal of the ESSKA*, *32*(9), 2219–2227. https://doi.org/10.1002/ksa.12245
    - MME significantly progressed from 4.1 ± 1.1 mm preoperatively to 5.3 ± 1.9 mm at 3 years post-operatively
- Moon, H. K., Koh, Y. G., Kim, Y. C., Park, Y. S., Jo, S. B., & Kwon, S. K. (2012). Prognostic factors of arthroscopic pull-out repair for a posterior root tear of the medial meniscus. *The American journal of sports medicine*, *40*(5), 1138–1143. https://doi.org/10.1177/0363546511435622
    - After surgery, a cylinder splint was applied for 2 weeks with the knee inextension, and during this period, only partial weightbearing with toe touching was permitted. After the splint was dis-carded, gentle motion exercise combined with physical therapy was encouraged up to 90 flexion. Full weight bearing was allowed at 6 weeks postoperatively and full flexion and squatting at 12 weeks postoperatively
        - Good healing status was observed in 28 (90.3%) of the 31 patients who underwent MRI.
        - On MRI, mean medial meniscus extrusion increased from 3.661.2 mm to 5.061.7 mm (P\.001). Meniscus extrusion increased in 20 of 31 patients, decreased in 8,and stayed the same in 3.
- Sundararajan, S. R., Ramakanth, R., Sethuraman, A. S., Kannan, M., & Rajasekaran, S. (2022). Correlation of factors affecting correction of meniscal extrusion and outcome after medial meniscus root repair. *Archives of orthopaedic and trauma surgery*, *142*(5), 823–834. https://doi.org/10.1007/s00402-021-03870-8
    - However, correction of extrusion was not significant in our cohort (p > 0.05). 57.4% (31 patients of 54) showed good correction of extrusion (Fig. 5) (in which most of the patients- 25 patients out of 31 i.e. 80.64% were less than 50 years of age) and 3.7% (two patients of total 54) showed no change in extrusion correction In remaining cohort of patients 38.8% (21 patients of 54) showed increase in extrusion postoperatively
    - 41 patients (75%) showed healed meniscus in all the three MRI sections, 9 (16.6%) showed partially healed meniscus, that is healing in at least one MRI section (either coronal/sagittal/axial sections), and 4 (7.4%) showed non healed meniscus at the 6-month follow-up. Healing status of root repair was not significantly associated with IKDC or Lyshom's scores (Table 1). However, patients with healed root repair (0.63± 0.97 mm) and partially healed repairs (0.59 ±1.03 mm) had better extrusion correction than those with non-healed repairs (− 1.25 ± 0.89 mm, p<0.001).

- Chung, K. S., Ha, J. K., Ra, H. J., Nam, G. W., & Kim, J. G. (2017). Pullout Fixation of Posterior Medial Meniscus Root Tears: Correlation Between Meniscus Extrusion and Midterm Clinical Results. *The American journal of sports medicine*, *45*(1), 42–49. https://doi.org/10.1177/0363546516662445
    - Of the 39 patients included in the study, 23 demonstrated increased meniscus extrusion and were included in group A. Sixteen patients demonstrated decreased meniscus extrusion and were included in group B. Neither the preoperative data nor the patient characteristics differed significantly between the 2 groups (Table 1). The mean (±SD) follow-up duration was 67.2 ± 14.7 months in group A and 73.5 ± 13.3 months in group B (*P* = .228). Meniscus extrusion in group A increased significantly from a mean of 3.5 ± 0.9 mm preoperatively to 5.1 ± 1.4 mm at 1 year postoperatively (*P* < .001), whereas in group B, it decreased significantly from 4.1 ± 1.3 mm preoperatively to 3.5 ± 1.4 mm at 1 year postoperatively (*P* < .001).
    - In terms of meniscal healing, there were 13 patients (57%) with complete healing and 10 patients (43%) with partial healing in group A. Complete and partial healing in group B were observed in 9 (56%) and 7 (44%) patients, respectively. There was no significant difference between the 2 groups
- Zhuo, H., Pan, L., Xu, Y., & Li, J. (2021). Functional, Magnetic Resonance Imaging, and Second-Look Arthroscopic Outcomes After Pullout Repair for Avulsion Tears of the Posterior Lateral Meniscus Root. *The American journal of sports medicine*, *49*(2), 450–458. https://doi.org/10.1177/0363546520976635
    - For the stable healing group (n = 18), all patients were classified as having complete healing based on MRI scans. However, for the lax healing group (n = 5), 3 patients were classified as having partial healing, while 2 patients were classified as having complete healing, based on MRI scans. This indicated that some patients with lax healing were classified as having complete healing based on MRI scans.
    - A total of 23 patients underwent second-look arthroscopic surgery. The mean time from index surgery to second-look arthroscopic surgery was 17.17 ± 3.03 months (range, 13-22 months). According to the classification criteria, stable healing occurred in 18 patients (78.3%), lax healing occurred in 5 patients (21.7%), and failed healing occurred in 0 patients (Figure 6).