Cross-sectional Effects of Isolated Meniscal Tears on in vivo Biomechanics of the Knee

A Systematic Review of Motion Analysis Studies

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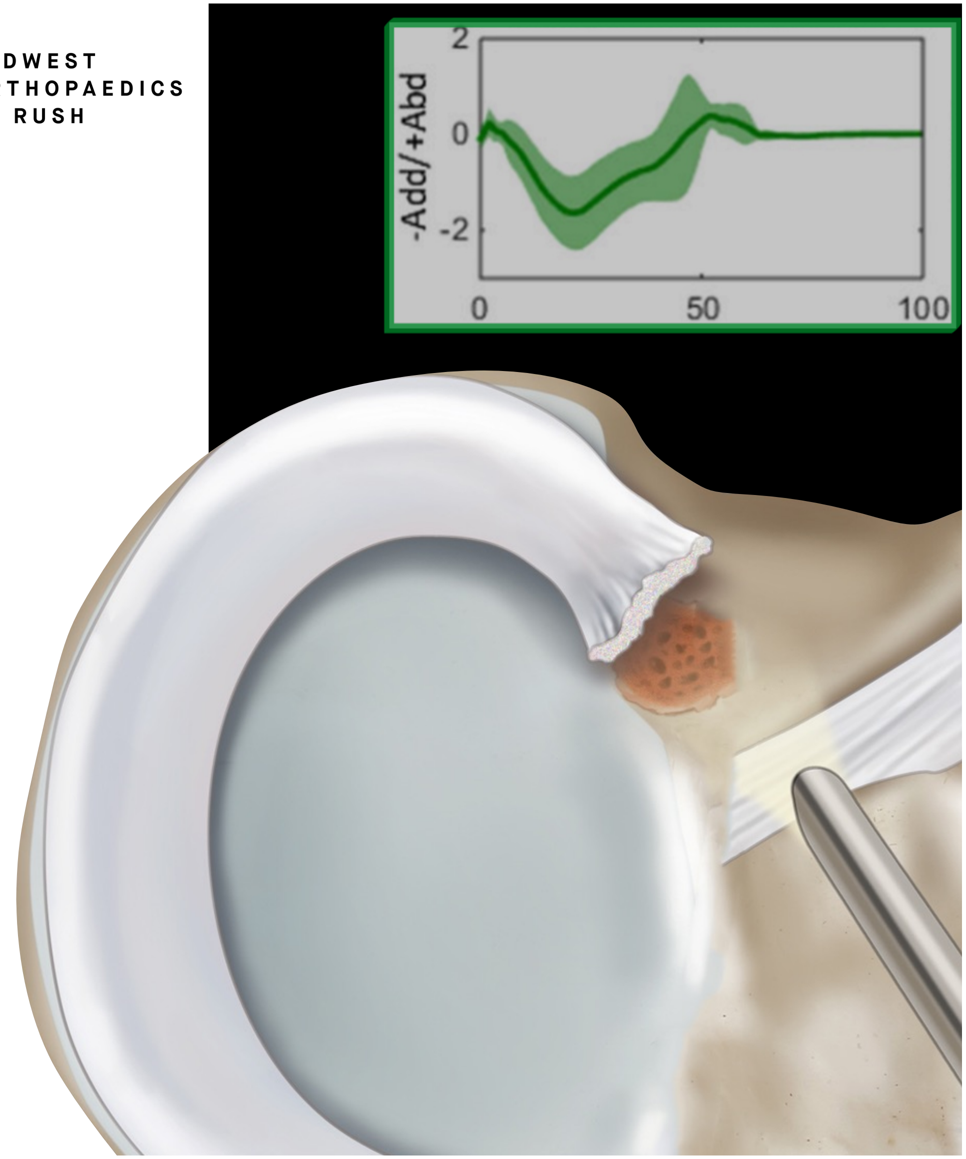

DISCLOSURES

- Enzo Mameri *MD MSc* [1,2,3] - NONE
- Garrett Jackson MD [1] - NONE
- Harkirat Jawanda BS [1] - NONE
- Jonathan Gustafson PhD [1] - NONE
- Gustavo Leporace, *PhD* [2] - NONE
- Leonardo Metsavaht *MD MSc* [2] *– Paid Consultant: APTISSEN*
- Jorge Chahla *MD PhD* [1] *- Paid Consultant: CONMED, LINVATEC, OSSUR, SMITH & NEPHEW;*

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BACKGROUND

Improved understanding of the role of the meniscus in load transmission and knee stability paved the way for the current point of emphasis on meniscus repair

Current knowledge-base stems from *in vitro* studies

- Limited to time-zero condition
- Effects of dynamic/functional weight-bearing activities?
- Impact on other joints (e.g. hip, ankle)?

Motion analysis studies: assessment of dynamic *in vivo* biomechanics

OBJECTIVES

To systematically review the literature on the cross-sectional impact of meniscal tears on *in vivo* biomechanics of the knee

Tears of the menisci would significantly alter *in vivo* knee biomechanics

METHODS

SEARCH TERMS

MENISCUS	DISORDER	IN VIVO BIOMECHANICS
Meniscus	Tear	Kinematics
Menisci	Injury	Kinetics
Meniscal	Avulsion	Motion Analysis
	Extrusion	Gait
	Discoid	Angle
	Abnormal	Moment

ELIGIBLITY CRITERIA

Level I-IV
(1) in vivo motion analysis
(2) isolated meniscus disorder
(3) kinetics, kinematics outcomes

DATA EXTRACTION

Lvl of Evidence
Sample and Control Group characteristics
System used for Motion Analysis
Marker set used for Motion Analysis
Tasks Performed
Kinetics / Kinematics Outcome Measures

DATA ANALYSIS

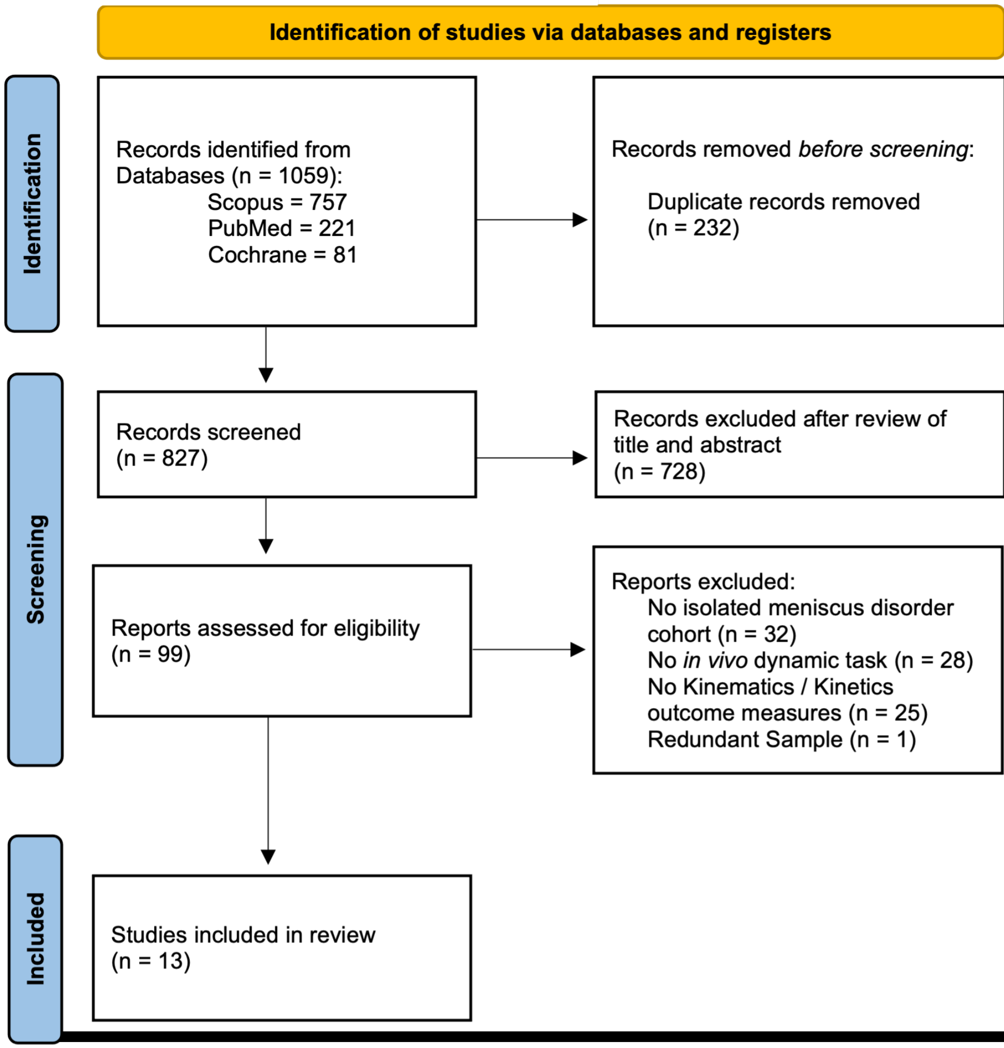
Qualitative Synthesis
(Meniscus disorder, motion analysis methods, outcomes)

Metanalysis - SMD and Effect Estimates of numerical variables
(Random effects inverse variance model)

RISK OF BIAS

MINORS criteria (8 questions for non-comparative studies; 12 for comparative studies)

FIGURE 1 – PRISMA Flowchart



RESULTS

13 STUDIES (16 TOTAL COHORTS)

MEAN AGE 13.9-68.0 yo

176 MEDIAL MENISCUS; 74 LATERAL MENISCUS

HETEROGENEITY IN TYPE OF TEAR (ROOT, BUCKET, DISCOID, NON-SPECIFIED)

MINORS score: mean 19/24 (79%); range 15-22

RESULTS

TASKS PERFORMED

- GAIT (n = 11)
- DECLINE WALKING (n = 1)
- SQUAT (n = 1)
- FORWARD LUNGE (n = 1)
- STEP-DOWN (n = 1)

METHOD OF MOTION ANALYSIS

KINETICS

- FORCE PLATES (n = 6)

KINEMATICS

- INFRARED CAMERAS + REFLECTIVE MARKERS (n = 9)
- BIPLANE FLUOROSCOPY + CT (n = 2)
- INERTIAL MOTION SENSORS (n = 1)
- ULTRASOUND-BASED (n = 1)

MARKER SET

- HELEN-HAYES (n = 1)
- ST PLUG IN (n = 4)
- RIGID CLUSTER (n = 3)
- POINT CLUSTER (n = 1)

KINETICS - MEDIAL MENISCUS

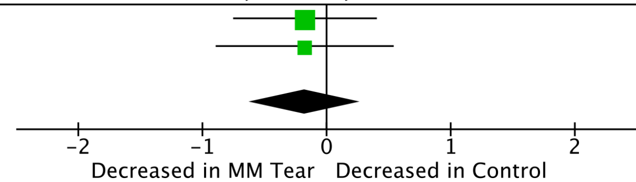
RESULTS

Peak Knee Flexion Moment (KFM) during Gait

	MM Tear			Control				Std. Mean Difference	
Study or Subgroup	**Mean**	**SD**	**Total**	**Mean**	**SD**	**Total**	**Weight**	**IV, Random, 95% CI**	**Year**
Thorlund et al., 2016	3	0.57	23	3.13	0.87	23	60.5%	−0.17 [−0.75, 0.41]	2016
Russell et al., 2017	0.33	0.12	15	0.35	0.1	15	39.5%	−0.18 [−0.89, 0.54]	2017
Total (95% CI)			**38**			**38**	**100.0%**	**−0.17 [−0.63, 0.28]**	

Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 0.00$, df = 1 (P = 1.00); $I^2 = 0\%$
Test for overall effect: Z = 0.76 (P = 0.45)

Std. Mean Difference
IV, Random, 95% CI



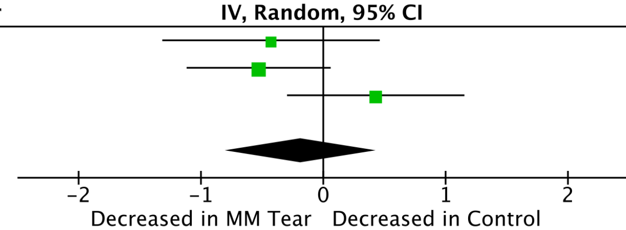
NO SIGNIFICANT DIFFERENCE ($p \geq 0.05$)

Peak Knee Adduction Moment (KAM) during Gait

	MM Tear			Control				Std. Mean Difference	
Study or Subgroup	**Mean**	**SD**	**Total**	**Mean**	**SD**	**Total**	**Weight**	**IV, Random, 95% CI**	**Year**
Bulgheroni et al., 2007	1.96	1.17	10	2.458	1.06	10	27.1%	−0.43 [−1.32, 0.46]	2007
Thorlund et al., 2016	2.43	1.17	23	3.03	1.06	23	39.6%	−0.53 [−1.12, 0.06]	2016
Russell et al., 2017	0.39	0.19	15	0.32	0.12	15	33.4%	0.43 [−0.30, 1.15]	2017
Total (95% CI)			**48**			**48**	**100.0%**	**−0.18 [−0.80, 0.43]**	

Heterogeneity: $Tau^2 = 0.16$; $Chi^2 = 4.33$, df = 2 (P = 0.11); $I^2 = 54\%$
Test for overall effect: Z = 0.58 (P = 0.56)

Std. Mean Difference
IV, Random, 95% CI



NO SIGNIFICANT DIFFERENCE ($p \geq 0.05$)

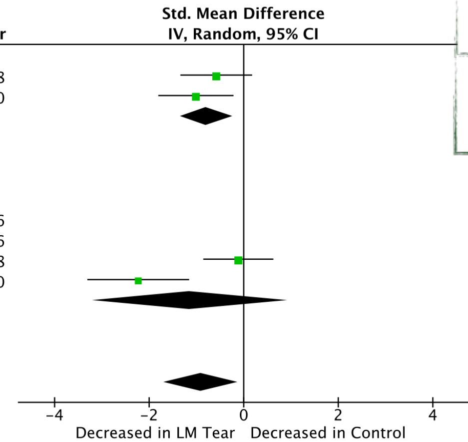
KINEMATICS - LATERAL MENISCUS

RESULTS

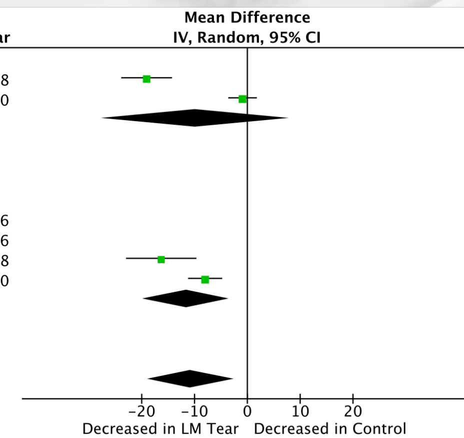
Peak KFA during Stance

Significant Decrease
$p < 0.05$

Study or Subgroup	LM Tear Mean	LM Tear SD	LM Tear Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI	Year
2.1.1 Lateral Meniscus									
Lin et al., 2018 - SLM cohort	10.38	5.52	14	13.19	3.69	14	26.4%	-0.58 [-1.34, 0.18]	2018
Li et al., 2020 - SLM Cohort	18.77	5.52	13	23.59	3.69	15	25.8%	-1.01 [-1.81, -0.22]	2020
Subtotal (95% CI)			**27**			**29**	**52.2%**	**-0.79 [-1.34, -0.24]**	
Heterogeneity: Tau² = 0.00; Chi² = 0.59, df = 1 (P = 0.44); I² = 0%									
Test for overall effect: Z = 2.81 (P = 0.005)									
2.1.2 Discoid Lateral Meniscus									
Harato 2016 - Asymptomatic DLM	18.2	4.2	10	18.33	4.7	10		Not estimable	2016
Harato 2016 - Symptomatic DLM	19.27	3.5	10	18.33	4.7	10		Not estimable	2016
Lin et al., 2018 - DLM Cohort	12.73	4.13	14	13.19	3.69	14	26.7%	-0.11 [-0.86, 0.63]	2018
Li et al., 2020 - DLM Cohort	14.68	4.13	9	23.59	3.69	15	21.1%	-2.23 [-3.31, -1.15]	2020
Subtotal (95% CI)			**23**			**29**	**47.8%**	**-1.14 [-3.21, 0.94]**	
Heterogeneity: Tau² = 2.02; Chi² = 10.07, df = 1 (P = 0.002); I² = 90%									
Test for overall effect: Z = 1.07 (P = 0.28)									
Total (95% CI)			**50**			**58**	**100.0%**	**-0.92 [-1.70, -0.13]**	
Heterogeneity: Tau² = 0.45; Chi² = 10.66, df = 3 (P = 0.01); I² = 72%									
Test for overall effect: Z = 2.29 (P = 0.02)									
Test for subgroup differences: Chi² = 0.10, df = 1 (P = 0.75), I² = 0%									



Study or Subgroup	LM Tear Mean	LM Tear SD	LM Tear Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random, 95% CI	Year
2.2.1 Lateral Meniscus									
Lin et al., 2018 - SLM cohort	42.01	4.44	14	61.08	8.04	14	24.8%	-19.07 [-23.88, -14.26]	2018
Li et al., 2020 - SLM Cohort	69.96	4.38	13	70.87	2.55	15	26.3%	-0.91 [-3.62, 1.80]	2020
Subtotal (95% CI)			**27**			**29**	**51.1%**	**-9.88 [-27.67, 7.92]**	
Heterogeneity: Tau² = 160.93; Chi² = 41.56, df = 1 (P < 0.00001); I² = 98%									
Test for overall effect: Z = 1.09 (P = 0.28)									
2.2.2 Discoid Lateral Meniscus									
Harato 2016 - Asymptomatic DLM	0	0	10	0	0	10		Not estimable	2016
Harato 2016 - Symptomatic DLM	0	0	10	0	0	10		Not estimable	2016
Lin et al., 2018 - DLM Cohort	44.77	9.87	14	61.08	8.04	14	22.9%	-16.31 [-22.98, -9.64]	2018
Li et al., 2020 - DLM Cohort	62.88	4.54	9	70.87	2.55	15	26.0%	-7.99 [-11.22, -4.76]	2020
Subtotal (95% CI)			**43**			**49**	**48.9%**	**-11.62 [-19.70, -3.53]**	
Heterogeneity: Tau² = 27.46; Chi² = 4.84, df = 1 (P = 0.03); I² = 79%									
Test for overall effect: Z = 2.82 (P = 0.005)									
Total (95% CI)			**70**			**78**	**100.0%**	**-10.78 [-18.95, -2.61]**	
Heterogeneity: Tau² = 64.19; Chi² = 51.45, df = 3 (P < 0.00001); I² = 94%									
Test for overall effect: Z = 2.59 (P = 0.010)									
Test for subgroup differences: Chi² = 0.03, df = 1 (P = 0.86), I² = 0%									



Peak KFA during Swing

Significant Decrease
$p < 0.05$

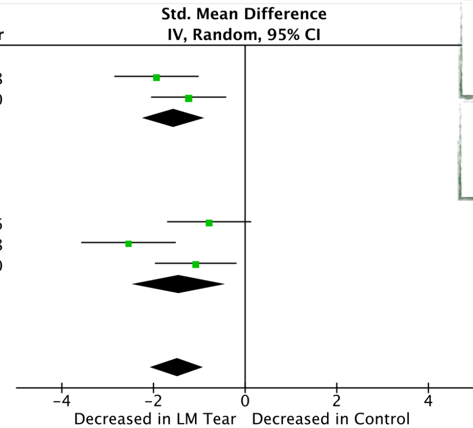
KINEMATICS - LATERAL MENISCUS

RESULTS

Range of Adduction-Abduction during Gait

Significant Decrease $p < 0.05$

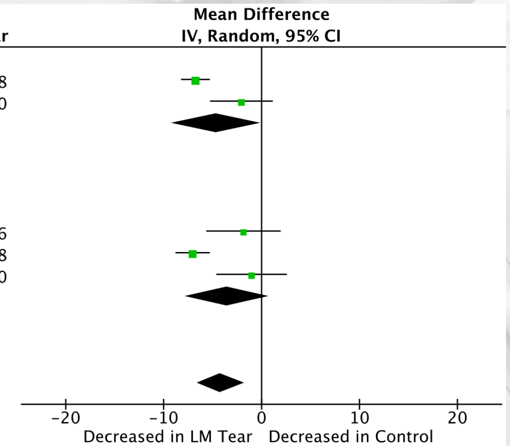
Study or Subgroup	LM Tear Mean	LM Tear SD	LM Tear Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI	Year
2.3.1 Lateral Meniscus									
Lin et al., 2018 - SLM cohort	6.6	1.19	14	9.89	2.01	14	19.9%	-1.93 [-2.85, -1.01]	2018
Li et al., 2020 - SLM Cohort	9.06	2.09	13	11.91	2.37	15	22.1%	-1.23 [-2.05, -0.41]	2020
Subtotal (95% CI)			**27**			**29**	**41.9%**	**-1.55 [-2.24, -0.87]**	
Heterogeneity: $Tau^2 = 0.05$; $Chi^2 = 1.24$, df = 1 (P = 0.26); $I^2 = 20\%$									
Test for overall effect: Z = 4.44 (P < 0.00001)									
2.3.2 Discoid Lateral Meniscus									
Harato 2016 - Symptomatic DLM	8.9	2.3	10	11	2.8	10	19.9%	-0.78 [-1.70, 0.13]	2016
Lin et al., 2018 - DLM Cohort	5.58	1.17	14	9.89	2.01	14	17.7%	-2.54 [-3.58, -1.51]	2018
Li et al., 2020 - DLM Cohort	9.4	2.02	9	11.91	2.37	15	20.5%	-1.08 [-1.97, -0.19]	2020
Subtotal (95% CI)			**33**			**39**	**58.1%**	**-1.44 [-2.46, -0.42]**	
Heterogeneity: $Tau^2 = 0.57$; $Chi^2 = 6.95$, df = 2 (P = 0.03); $I^2 = 71\%$									
Test for overall effect: Z = 2.78 (P = 0.005)									
Total (95% CI)			**60**			**68**	**100.0%**	**-1.48 [-2.07, -0.89]**	
Heterogeneity: $Tau^2 = 0.23$; $Chi^2 = 8.34$, df = 4 (P = 0.08); $I^2 = 52\%$									
Test for overall effect: Z = 4.93 (P < 0.00001)									
Test for subgroup differences: $Chi^2 = 0.03$, df = 1 (P = 0.86), $I^2 = 0\%$									



Range of Internal-External Rotation during Gait

Significant Decrease $p < 0.05$

Study or Subgroup	LM Tear Mean	LM Tear SD	LM Tear Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random, 95% CI	Year
2.4.1 Lateral Meniscus									
Lin et al., 2018 - SLM cohort	8.64	1.51	14	15.39	2.37	14	24.6%	-6.75 [-8.22, -5.28]	2018
Li et al., 2020 - SLM Cohort	16.76	4.38	13	18.82	4.25	15	18.4%	-2.06 [-5.27, 1.15]	2020
Subtotal (95% CI)			**27**			**29**	**43.0%**	**-4.63 [-9.21, -0.06]**	
Heterogeneity: $Tau^2 = 9.38$; $Chi^2 = 6.78$, df = 1 (P = 0.009); $I^2 = 85\%$									
Test for overall effect: Z = 1.98 (P = 0.05)									
2.4.2 Discoid Lateral Meniscus									
Harato 2016 - Symptomatic DLM	10.21	4.43	10	12.06	4.25	10	16.3%	-1.85 [-5.65, 1.95]	2016
Lin et al., 2018 - DLM Cohort	8.35	2.38	14	15.39	2.37	14	23.7%	-7.04 [-8.80, -5.28]	2018
Li et al., 2020 - DLM Cohort	17.8	4.43	9	18.82	4.25	15	17.0%	-1.02 [-4.63, 2.59]	2020
Subtotal (95% CI)			**33**			**39**	**57.0%**	**-3.55 [-7.87, 0.76]**	
Heterogeneity: $Tau^2 = 12.02$; $Chi^2 = 12.33$, df = 2 (P = 0.002); $I^2 = 84\%$									
Test for overall effect: Z = 1.61 (P = 0.11)									
Total (95% CI)			**60**			**68**	**100.0%**	**-4.18 [-6.63, -1.73]**	
Heterogeneity: $Tau^2 = 5.78$; $Chi^2 = 19.52$, df = 4 (P = 0.0006); $I^2 = 80\%$									
Test for overall effect: Z = 3.35 (P = 0.0008)									
Test for subgroup differences: $Chi^2 = 0.11$, df = 1 (P = 0.74), $I^2 = 0\%$									



QUALITATIVE EVIDENCE
[Heterogeneity/ Limited Data precluded Metanalysis]

RESULTS

KINETICS - LATERAL MENISCUS

LM Tear (Semilunar or Discoid) = decreased peak KFM
Semilunar LM tear = decreased peak KAM
(1 study)

KINEMATICS - MEDIAL MENISCUS

Root Tear = Increased Lateral Tibial Translation + increased in total contact path in the medial compartment (1 study); increased lateral tibial thrust acceleration (1 study)

Bucket-Handle Tear = increased variability across gait parameters; contralateral increase in Hip and Knee ROM, pelvic obliquity (1 study)

Unspecified Tears: conflicting evidence of effect on gait kinematics (3 studies); evidence of limited pKFA and range of F-E, Add-Abd during step-down task

DISCUSSION

Lateral Meniscus Tears Significantly impair all three planes of knee kinematics (limited peak KFA, range of Add-Abd, range of Int-Ext rotation)

Hypothesis

Limited Sagital Plane excursion = “Joint Stiffening” pattern: compensatory mechanism similar to ACL tears

Limited Knee Flexion during Swing phase in Discoid Menisci patients may be a protective mechanism to prevent snapping

Limited Axial Rotation: avoid non-physiological horizontal shear forces in the setting of damaged LM (secondary rotational stabilizer)

Varus deformity secondary to discoid meniscus may explain the limited range of coronal plane motion during gait

Paucity of Data on the impact of Lateral Meniscus Tears on knee kinetics

DISCUSSION

Medial meniscus tear cohorts exhibited similar kinetics to control groups

Hypothesis ✗

- **Abundance of in vitro evidence of significant impact of MM tears on knee biomechanics**
- **Cohorts included different types of tears, including “more benign" tears (while tears that disrupt the circumferential fibers and hoop stress mechanism would be more significant) likely underestimating the effect**
- **Analysis was largely limited to simple overground gait**
- **Assessing more demanding functional tasks likely would result in more prominent differences (as evidenced by Nicolas et al. during a step-down task)**

CONCLUSION

LM Tears significantly impair *in vivo* knee kinematics in all three planes.

There is still no evidence in the literature of significant impact of MM Tears on *in vivo* kinetics, although potentially due to methodological limitations in prior studies.

Analysis of more demanding functional tasks beyond simple gait are likely necessary to detect the true impact *in vivo* effects of meniscus tears, reflecting prior *in vitro* findings.