Systematic Review With Video Illustrations

Open Tibial Inlay Versus Arthroscopic Transtibial Posterior Cruciate Ligament Reconstructions

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Purpose: The optimal method of posterior cruciate ligament (PCL) reconstruction is not known. The purpose was to evaluate the biomechanical and clinical literature comparing open tibial inlay and arthroscopic transtibial PCL reconstructions and determine which method of reconstruction is superior. **Methods:** A systematic review of the literature was performed on PubMed. Biomechanical and clinical studies comparing the outcomes of open tibial inlay and arthroscopic transtibial PCL reconstructions were selected and reviewed. **Results:** Biomechanical studies evaluating posterior stability found no difference or increased stability with open inlay reconstruction. Graft degradation at the killer turn after arthroscopic transtibial reconstruction was described in some of the biomechanical studies. Biomechanical studies found no significant difference in graft forces after cyclic loading between the 2 groups. Biomechanical studies were influenced by methodologic limitations of graft fixation, power analysis, graft tensioning protocol, and magnitude of load applied for cyclic loading. Clinical studies with some methodologic limitations found no significant difference in maintaining posterior stability between the 2 reconstruction groups at short-term follow-up. **Conclusions:** The advantage of open inlay or arthroscopic transtibial PCL reconstruction techniques remains uncertain in the setting of conflicting biomechanical studies, with notable limitations in clinical studies. The arthroscopic tibial inlay technique may provide benefits of both open inlay and transtibial reconstruction techniques and comparable stability to the conventional PCL reconstruction methods according to several biomechanical studies. **Level of Evidence:** Level IV, systematic review.

The posterior cruciate ligament (PCL) is the primary restraint to posterior translation in an intact knee. The incidence of PCL injuries varies from 3% to 38% of all acute knee injuries.[1-3] These injuries can be isolated or combined multiligament injuries.

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One of the key controversies in the surgical management of PCL injuries is whether to perform surgery using the open tibial inlay technique or arthroscopic transtibial tunnel reconstruction. Graft fixation through an arthroscopic transtibial technique creates an acute angle on the posterior aspect of the tibial tunnel, which is known as the "killer turn." The PCL graft can be weakened at this killer turn because of the repetitive force at this angle.[4] Some of the studies have shown the advantages of the transtibial tunnel technique, which include lower morbidity, easier patient positioning, and reliable clinical results with satisfactory return of function and improvement in symptoms.[5,6] Open tibial inlay reconstruction avoids creating the killer turn and has been shown to be advantageous biomechanically.[7]

The purpose was to evaluate the biomechanical and clinical literature comparing open tibial inlay and arthroscopic transtibial tunnel PCL reconstruc-

tions and determine which method of reconstruction is superior.

METHODS

A PubMed search was performed with the terms "posterior cruciate," "tibial inlay," and "tibial tunnel" that identified 31 publications. We identified 2 Level III clinical studies and 6 biomechanical studies comparing the results of open tibial inlay and arthroscopic transtibial PCL reconstruction. "Related articles" to these publications were also searched on PubMed. The references used in these publications were searched to identify more studies on PCL reconstruction techniques. An additional search was performed using the phrases "posterior cruciate transtibial" and "posterior cruciate open inlay." This did not identify additional studies comparing open tibial inlay and arthroscopic transtibial reconstruction PCL reconstructions. The biomechanical studies were reviewed first, followed by the clinical studies, in order of year of publication.

RESULTS

Biomechanical Studies

Bergfeld et al.[8] published the first biomechanical study comparing PCL reconstruction by open inlay and arthroscopic transtibial techniques in cadaveric knees, in 2001. The reconstruction was performed with central one-third bone–patellar tendon–bone (BPTB) grafts. Grafts were pre-tensioned with 156 N of anterior tibial force. The authors performed 72 cycles of repetitive loading with a 150-N anteroposterior (AP) force with the knee flexed at 90° and in neutral tibial rotation. Knee laxity was compared at 4 angles: 0°, 30°, 60°, and 90° of flexion with the tibia in neutral rotation, internal rotation, and external rotation. Graft conditions were compared between both reconstruction groups after cyclic loading. The results showed that the AP laxity was significantly less at 30° to 90° of knee flexion in the inlay group compared with the tunnel group. After 72 loading cycles at 90° of flexion with a 150-N AP force, the arthroscopic transtibial group had a statistically significant increase in mean laxity compared with the inlay group. Mechanical degradation of the graft was significant in the tunnel group compared with the inlay group. The authors suggested that the mechanical degradation may be 1 of the causes of clinical failure after tunnel reconstruction. Another possible cause of failure with the tunnel technique could be inconsistency in the placement of the tunnel outlet in the posterior tibia. The study suggests that the open tibial inlay techniques for PCL reconstruction may better correct abnormal posterior laxity and could potentially result in lower graft forces compared with the arthroscopic transtibial reconstruction.

Markolf et al.[9] compared the open inlay and arthroscopic transtibial reconstructions in 62 cadaveric knees using BPTB grafts from the medial and lateral halves of patellar tendons. Reconstructed knees were subjected to 2,000 cycles of tensile force of 50 to 300 N with the angle of pull at 45° to the tibial plateau. Graft conditions were compared after the reconstructions. In this study, 10 of 31 grafts (32%) fixed with the transtibial technique failed at the killer turn before 2,000 cycles. All grafts fixed with the inlay method survived. The authors found that the percent change in the graft thickness was significantly less for the inlay group compared with the transtibial group. The percent change in the mean elongation of the graft was significantly greater in the transtibial group compared with the inlay group during the first loading cycle. After 2,000 loading cycles, the difference in graft elongation was not significant between the 2 groups. The percent change in the mean graft length after 2,000 cycles was significantly greater in the transtibial group compared with the inlay group. The authors suggested that the permanent length changes in the graft could be reduced substantially if they were cyclically preconditioned in situ before final pre-tensioning and fixation. This study showed that the open inlay technique for PCL reconstruction was superior to the arthroscopic transtibial technique with respect to graft failure, graft thinning, and permanent increases in graft length.

McAllister et al.[10] investigated the open tibial inlay and arthroscopic transtibial tunnel reconstruction techniques in 12 fresh-frozen cadaveric knees using BPTB grafts. Both reconstructions were performed in the same specimens. Arthroscopic transtibial reconstruction was followed by open tibial inlay reconstruction. Tibial defects created by the tunnel reconstruction were filled with a press-fit cylinder of high-density polyurethane foam. Grafts were pre-tensioned with 25 N of anterior tibial force. Both groups underwent 50 cycles of 200 N of anterior and posterior tibial force. AP laxities were compared between both reconstruction groups at angles of 0°, 30°, 60°, 90°, and 120° of knee flexion. There was no significant difference in mean laxity between the 2 reconstruction groups before and after cyclic loading (Table 1). After 50 pos-

Table 1. *Effects of Cyclic 200-N Posterior Tibial Loading on Anteroposterior Laxity - Eccentric Femoral Tunnel**

Condition	Anteroposterior laxity (mm)				*P* value
	Before cyclic loading		After 50 loading cycles		
	mean	(SD)	mean	(SD)	
Tunnel	9.6	(1.6)	10.3	(1.9)	<0.0013
Inlay	9.3	(1.9)	9.9	(1.9)	<0.0001

*Reprinted with permission.[10]

terior tibial cycles, mean AP laxity at 90° of flexion increased significantly in both reconstruction groups. There was no significant difference in the graft pre-tensioning necessary to restore normal laxity at 90° of knee flexion between tibial inlay and transtibial reconstructions when the graft was placed in the eccentric femoral tunnel. When the graft was placed in the central femoral tunnel, the arthroscopic transtibial reconstruction required significantly more pre-tensioning than the tibial inlay reconstruction. After 50 posterior tibial cycles, mean graft pre-tensioning decreased significantly for both reconstruction techniques, but there was no significant difference between the 2 techniques. There were 2 graft failures in the tibial tunnel group and none in the inlay group after cyclic loading. In both of the failures, the graft ruptured at the killer turn near the tibial attachment of the graft. The authors suggested that if the femoral tunnel is drilled at the site of the anterolateral bundle of the femoral insertion of the PCL (the eccentric tunnel in this study), slightly less graft pre-tensioning will be required to restore normal AP laxity at 90° of flexion compared with the more central site at time 0. It is interesting to note that the potential stretch of the graft around the killer turn after the transtibial technique could represent an important advantage for the inlay technique in terms of postoperative outcome if the graft is cycled such as with knee range-of-motion exercises.

Oakes et al.[11] studied open tibial inlay and arthroscopic transtibial tunnel reconstructions using BPTB grafts in 12 fresh-frozen cadaveric knees. The proximal ends of all grafts were pre-tensioned to a level of force that restored intact knee laxity at 90° of flexion. A series of constant tibial loading tests was performed during knee flexion from −5° to 120° at 100 N of posterior tibial force, 5 Nm of varus and valgus moment, and 5 Nm of internal and external tibial torque. Mean graft forces did not significantly differ between the 2 reconstructions with 100 N of posterior tibial force, 5 Nm of varus and valgus moment, and 5 Nm of internal and external tibial torque. However, forces were significantly higher with both reconstruction techniques than forces in the native PCL when the knee was flexed beyond approximately 90° (Fig 1). The authors recommended that regardless of the type of reconstruction, loading of the knee at a flexion angle greater than approximately 90° should be avoided during the early postoperative period to prevent abnormally high forces on the graft. This study suggests that neither reconstruction technique appeared to have a substantial advantage over the other in terms of graft forces generated by the loading modes.

Margheritini et al.[12] evaluated open tibial inlay and arthroscopic transtibial tunnel reconstructions in 10 cadaveric knees using Achilles tendon allografts. Both reconstructions were performed on the same knee. The tibial defect created in the first reconstruction was filled with polymethyl methacrylate. Posterior tibial loads of 134 N were applied at angles of 0°, 30°, 60°, 90°, and 120° of flexion. The authors did not find a significant difference in posterior translation between the 2 reconstruction techniques. In situ forces in the grafts reconstructed by both techniques were not significantly different in response to the posterior tibial load (Figure 1). No cyclic loading was performed during testing. This study suggests that both techniques provide similar biomechanical outcomes in terms of AP laxity and graft forces in response to a posterior tibial load at time 0.

Hiraga et al.[13] studied open tibial inlay and arthroscopic transtibial tunnel reconstructions in 12 cadaveric knees. In each specimen, 4 PCL reconstruc-

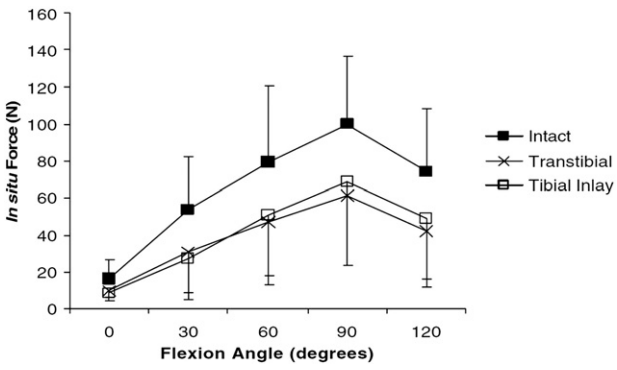

Figure 1. In situ forces in the intact PCL, transtibial graft, and tibial inlay graft. (Reprinted with permission.[12])

tions were performed in randomized order (open inlay reconstruction with single-bundle BPTB graft, transtibial reconstruction with single-bundle BPTB graft, and transtibial reconstruction with double-bundle hamstring graft fixed by EndoButton technique [Smith & Nephew Endoscopy, Andover, MA] and by EndoPearl technique [ConMed Linvatec, Largo, FL]). Posterior tibial translation was measured under a posterior tibial load of 100 N in the intact knee and each reconstructed knee. This was followed by 1,000 cycles of 100-N posterior tibial loads to determine the increase in laxity and change in posterior tibial translation in the reconstructed knees. There was no significant difference in posterior tibial translation between the intact knee and each of the reconstruction techniques. After cyclic loading, posterior tibial translation significantly increased in all reconstruction techniques. The change in posterior tibial translation before and after cyclic loading was significantly greater in the knees with double-bundle hamstring tendon transtibial reconstruction fixed by the EndoButton compared with knees undergoing open inlay–BPTB reconstruction. Posterior tibial translation was not significantly different between open inlay reconstruction and the other 2 transtibial reconstruction techniques. After cyclic loading, AP laxity increased significantly in the knees with transtibial double-bundle hamstring tendon reconstruction fixed by the EndoButton compared with knees undergoing single-bundle open inlay–BPTB reconstruction. There was no significant difference in AP laxity found between the open inlay reconstruction and the other 2 transtibial reconstruction techniques. After transtibial reconstruction, none of the grafts ruptured at the killer turn or pulled out from the bone tunnel. The advantage of the inlay technique compared with the arthroscopic transtibial technique with respect to posterior stability could not be shown in this study. The authors believe that fixation of the double-bundle hamstring tendon graft by the EndoPearl technique might be preferable to the EndoButton technique in transtibial PCL reconstruction to prevent excessive posterior laxity in the early phase of postoperative rehabilitation.

TABLE 2. *Comparison of Knee Stability According to the Posterior Drawer Test at 90° Knee Flexion**

TABLE 1. Comparison of Knee Stability of the 2 Groups According to the Posterior Drawer Test at 90° Knee Flexion

	Transtibial Tunnel Group (n = 21)		Tibial Inlay Group (n = 22)	
Grade	Preoperative	Last Follow-up	Preoperative	Last Follow-up
I (0-5 mm)	0	19	0	20
II (6-10 mm)	5	2	7	2
III (>10 mm)	16	0	15	0

*Reprinted with permission.[6]

Clinical Studies

In the first clinical study, Seon and Song[6] compared an isolated PCL reconstruction using open inlay and arthroscopic transtibial techniques in 41 patients with grade II injuries or greater confirmed by posterior drawer test. Patients with objectively detectable posterolateral corner, posteromedial corner, or anterior instability were excluded. Twenty-one knees were reconstructed by the arthroscopic transtibial technique with quadrupled hamstring autograft. Twenty-two knees were reconstructed by the open inlay technique with BPTB autograft. The results were evaluated using clinical and stress radiographic tests with a minimum 2-year follow-up. Improvements in Lysholm knee score and Tegner score showed no significant difference between the 2 groups ($P = .259$ for Lysholm score and $P = .264$ for Tegner score). At the final follow-up, normal or grade I laxity was observed on the posterior drawer test in 19 patients after transtibial reconstruction and in 20 patients after open inlay reconstruction (Table 2). Mean side-to-side differences measured by instrumented posterior laxity testing using a Telos device (Telos, Marburg, Germany) at 20 lb were significantly improved in both groups without a significant difference between them. The authors found no significant differences between the transtibial and open inlay techniques, and satisfactory clinical and stress radiologic results were obtained in both groups. This study had several limitations such as an absence of randomization and the use of different graft types for each of the groups.

MacGillivray et al.[14] retrospectively investigated the results of open tibial inlay and arthroscopic transtibial tunnel reconstructions in 20 patients with isolated PCL injury and no other ligamentous injury detected by physical examination and confirmed by magnetic resonance imaging. Patients were followed up for a mean of 5.7 years (range, 2 to 15 years). Thirteen patients underwent arthroscopic transtibial reconstruction with a single-bundle BPTB autograft, BPTB allograft, or Achilles tendon allograft. Seven patients underwent open inlay reconstruction with single-

Table 3. *Physical Examination and Radiographic Comparison in Knees Reconstructed by Open Tibial Inlay and Arthroscopic Tibial Tunnel Techniques**

	Follow-up (mo)	Posterior Drawer	Corrected KT-1000	Radiographic Changes	Tegner Score	Lysholm Score	AAOS Score
Tibial tunnel group							
Patient 1	29	C	10	1	9	95	98
Patient 2	90	B	8.5	0	7	79	82
Patient 3	181	B	2.5	2	4	87	84
Patient 4	48	C	9.5	2	6	51	73
Patient 5	84	A	2.5	2	5	76	92
Patient 6	89	B	2	0	7	66	92
Patient 7	67	A	2.5	1	9	100	98
Patient 8	30	B	4	1	5	89	91
Patient 9	69	B	NA	2	NA	NA	NA
Patient 10	110	C	10.5	2	5	82	94
Patient 11	114	B	3.5	2	6	85	92
Patient 12	29	C	10	0	5	86	92
Patient 13	37	A	5	0	NA	NA	NA
Mean	75		5.9	1.15	6	81	90
Tibial inlay group							
Patient 1	48	A	4.5	0	8	85	91
Patient 2	52	A	5	0	8	59	45
Patient 3	76	A	1	1	5	87	93
Patient 4	58	B	10	0	10	74	84
Patient 5	24	C	7.5	0	5	100	96
Patient 6	55	B	4.5	1	4	83	89
Patient 7	85	C	6	0	2	42	40
Mean	57		5.5	0.28	6	76	77
P value	.39	.48	.97	.06	.96	.54	.23

Abbreviations: AAOS, American Academy of Orthopaedic Surgeons; NA, not applicable.
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bundle BPTB autograft or allograft. No significant differences were found on posterior drawer testing, KT-1000 assessment (MEDmetric, San Diego, CA), or functional testing or in Lysholm, Tegner, and American Academy of Orthopaedic Surgeons knee scores at a minimum of 2 years' follow-up (Table 3). The results of the postoperative posterior drawer test improved in 4 of 7 patients (57%) after the open inlay reconstruction and in 5 of 13 (38%) after the arthroscopic transtibial reconstruction. The mean corrected KT-1000 measurement was 5.7 mm overall, 5.5 mm in the open inlay group, and 5.9 mm in the arthroscopic transtibial group. The mean preoperative Tegner score was 6.86 in the open inlay group and 6.92 in the arthroscopic transtibial group. The mean postoperative Tegner score was 6.00 in both groups. The mean Lysholm score was 76 in the open inlay group and 82 in the arthroscopic transtibial group. The mean American Academy of Orthopaedic Surgeons knee score was 77 in the inlay group compared with 90 in the arthroscopic transtibial group. This study suggests that neither of the 2 reconstruction techniques consistently restores AP stability to its original state by use of a single-bundle graft. The authors did not find a significant difference in outcomes between the 2 reconstruction techniques. However, this study did have several limitations such as a small number of patients studied retrospectively without randomization and a lack of preoperative data; moreover, the type of graft was not controlled (autograft *v* allograft).

DISCUSSION

Biomechanical Outcome

Is There an Advantage in AP Stability of Tibial Inlay Reconstructions Compared With Transtibial Tunnel Reconstructions? McAllister et al.[10] and Margheritini et al.[12] found no difference in AP laxity between the tibial inlay and transtibial tunnel reconstruction groups, whereas Bergfeld et al.[8] found better AP stability after open inlay reconstruction. The results of Hiraga et al.[13] varied with the type of the graft and method of graft fixation. They did not find a significant difference between open inlay and tibial

tunnel reconstruction with similar graft types. However, a significant difference was found when BPTB single-bundle open inlay reconstruction was compared with double-bundle transtibial reconstruction with hamstring graft fixed by the EndoButton technique but not when fixed by the EndoPearl technique. The improvement in AP stability after open inlay reconstruction shown in some of these biomechanical studies could be a result of multiple factors, such as variation in the method of graft fixation between the 2 reconstruction techniques, graft tensioning protocol, and low power of the study. In reality, there may not be any difference in AP laxity achieved by the arthroscopic transtibial and open tibial inlay PCL reconstructions at time 0.

Is There a Graft Degradation/Failure Around the Killer Turn With Cyclic Loading? Biomechanical studies by Bergfeld et al.,[8] Markolf et al.,[9] and McAllister et al.[10] found graft degradation and failure whereas Hiraga et al.[13] did not find graft failure after cyclic loading with the arthroscopic transtibial technique. Hiraga et al. used a lower magnitude of load (100 N) in contrast to the other 3 studies (>150 N). The results of these biomechanical studies show that there is likely an effect due to the magnitude of load applied in cyclic loading on failure at the killer turn with the arthroscopic transtibial tunnel reconstruction. With repeated loading at a higher magnitude, the open inlay technique may provide a more durable reconstruction than the arthroscopic transtibial tunnel technique.

Is There an Advantage in Graft Tension/Forces of Tibial Inlay Reconstruction Relative to Transtibial Tunnel Reconstruction? Several studies measured graft forces in tibial inlay and tibial tunnel reconstructions. Biomechanical studies by Oakes et al.[11] and Margheritini et al.[12] showed no significant differences in graft forces after cyclic loading between the 2 reconstructions. McAllister et al.[10] showed that lower graft pre-tensioning was required to restore normal laxity with a central femoral tunnel after open inlay reconstruction compared with the transtibial technique. However, at the end of cyclic loading, graft pre-tensioning decreased in both groups, but the percentage of decrease in pre-tensioning was not significantly different between the open inlay and transtibial reconstruction groups. The results of these biomechanical studies suggest that there may be no difference in graft tension and forces between open tibial inlay and arthroscopic transtibial tunnel reconstructions.

Clinical Outcome

Is There a Clinical Improvement in Functional Outcome or AP Stability in Patients With Tibial Inlay Versus Transtibial Tunnel PCL Reconstructions? Clinical studies found no significant differences in knee scores and AP stability between the 2 PCL reconstruction techniques at short-term follow-up.

Seon and Song[6] performed isolated PCL reconstruction for grade II and grade III PCL injuries evaluated by the posterior drawer test. At a minimum of 2 years' follow-up postoperatively, 91% of patients had grade I laxity and 9% of patients had grade II laxity in both reconstruction groups. AP laxity was not restored to normal in any patient after isolated PCL reconstruction. This suggests that there may be associated injuries in patients with PCL injury, and in this situation greater laxity may not be restored to normal with just an isolated PCL reconstruction. Several studies found that grade III PCL injuries on posterior drawer testing correlate with the presence of combined injuries including posterolateral or posteromedial corner injuries in addition to a complete disruption of the PCL.[15-17] This is a possible explanation for the greater postoperative AP laxity after isolated PCL reconstruction described by Seon and Song.

The clinical studies have several limitations. MacGillivray et al.[14] performed a retrospective study that may have confounding factors. Seon and Song[6] treated grade III PCL injuries with isolated PCL reconstruction. Clinical evidence suggests that grade III PCL injuries are combined injuries associated with posterolateral or posteromedial corner injuries.[15-17] These corner injuries were not addressed by Seon and Song. There was no randomization performed in both clinical studies, which likely have significant selection bias. Power analysis was not performed in either of the clinical studies, so a β error could be present. Postoperative follow-up was short-term. Graft type was not controlled in either reconstruction group. Therefore it is difficult to conclude whether a significant clinical difference exists between the open tibial inlay and arthroscopic transtibial tunnel reconstruction techniques.

Future Directions

Some of the biomechanical studies discussed previously have shown no difference between the 2 reconstruction techniques, and others have shown graft elongation, thinning, and graft failure around the killer turn after cyclic loading after transtibial PCL reconstruction. There is potential to combine the benefits of both arthroscopic and open techniques and avoid the complications of each procedure, such as graft wear from the killer turn

that occurs with arthroscopic tunnel reconstruction and the morbidity associated with the posteromedial dissection with open inlay reconstruction. Several studies have described a tibial inlay technique performed arthroscopically[18-24] (Video 1, available at www.arthroscopyjournal.org). The arthroscopic tibial inlay procedure has been shown to provide comparable knee stability to these conventional techniques in biomechanical studies and with early clinical experience.[5,20-23] In an acute partial PCL rupture where there is significant PCL tissue remaining, PCL augmentation can be performed (Video 2, available at www.arthroscopyjournal.org). This technique preserves the native PCL tissue that may heal and provide support to the reconstructed graft bundle.

CONCLUSIONS

Biomechanical studies show that there may be no difference in AP laxity and graft forces between open inlay and tibial tunnel reconstruction techniques at time 0. The graft loading protocol may likely have an effect on graft degradation and failure at the killer turn with transtibial tunnel reconstruction. However, the advantage of the open inlay or tibial tunnel reconstruction technique remains uncertain in the setting of conflicting biomechanical studies and notable limitations in clinical studies, including a lack of randomized clinical trials including power analyses, as well as limited follow-up periods and variable graft types. Biomechanical studies addressing the conflicting issues listed in this review followed by well-designed prospective clinical studies with appropriate surgical techniques, well-powered sample sizes, and long-term follow-up would help to definitively answer these questions. A novel all-arthroscopic approach combines the benefits of both open inlay and transtibial reconstructions. This technique has been shown to provide comparable stability to the conventional PCL reconstruction methods in several biomechanical studies, but clinical studies on the outcome of this procedure are needed.

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