Magnetic resonance imaging (MRI) of the knee: Identiﬁcation of difﬁcult-to-diagnose meniscal lesions

Abstract This article characterizes common meniscal pathologies, reviews magnetic reso- nance imaging (MRI) diagnostic criteria for meniscal tears, and identiﬁes difﬁcult-to-detect tears and fragments and the best MRI sequences and practices for recognizing these lesions. These difﬁcult-to-diagnose meniscal lesions that radiologists should consider include tears, meniscocapsular separation lesions, and displaced meniscal fragments. Meniscus tears are either vertical, which are generally associated with traumatic injury, horizontal, which are associated with degenerative injury, or combinations of both. MRI has a high sensitivity for tears but not for fragments; MRI performance is also better for medial than lateral meniscal lesions. Fragment detection can be improved by recognizing signs secondary to migration, espe- cially signs of epiphyseal irritation and mechanical impingement. Radial and peripheral tears, as well as those close to the posterior horn insertion, have been traditionally difﬁcult to detect, but improvements in arthroscopic knowledge, identiﬁcation of common lesion patterns, and selection of the proper MRI sequence and plane for each lesion type mean that, when properly used, MRI is an invaluable tool in detecting all types of meniscal tears.   
  
Introduction

Knee pathology is one of the most common indications for musculoskeletal imaging. In particular, evaluation of meniscal lesions, whether of degenerative or traumatic origin, accounts for a large proportion of the knee exam- inations performed with magnetic resonance imaging (MRI). Knowledge of meniscal pathology and MRI appearances of degenerative and traumatic meniscal lesions has advanced over the years. Studies on the performance of MRI with sur- gical correlation have identiﬁed the most frequently missed meniscal lesions, so that radiologists and arthroscopists know where actively search for meniscal diseases [1—3]. Dis- cussions among clinicians, surgeons, and arthroscopists have advanced the clinical knowledge of the ‘‘tricky’’ lesions that should be known by radiologists. After a brief review of the typical meniscal lesions, this paper describes these ‘‘must know’’ lesions.

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Characteristics of meniscal pathology   
  
 Lesion deﬁnitions   
  
 Generally speaking, meniscal lesions manifest as:   
  
 • tears, which are characterized by abnormal intrameniscal signal that extends to the meniscus surface;   
  
 • substance loss, wherein the meniscus loses its normal tri- angular shape;   
  
 • displaced meniscal fragments which may remain attached   
 to the parent meniscus or break free from this meniscus.

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Figure 1. Illustrations of typical meniscal tears according to their orientation. Vertical tears may be longitudinal, radial, and oblique and are most often due to trauma. Horizontal tears are most often due to degeneration. Complex tears combine several orientations.

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MRI has high sensitivity and speciﬁcity for diagnosing meniscal tears. However, this diagnostic value is more lim- ited for fragment detection. Hence, meniscal fragments must be actively searched for in the common locations of displacement [4].

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meniscal apex. Lastly, complex tears show combinations of the patterns described above.

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Loss of substance   
  
 A degenerative or traumatic meniscal lesion may result in loss of meniscal tissue. Loss of substance results from migra- tion and may be followed by fragment separation. This loss of substance causes the normal triangular shape of the meniscus to be absent on MRI sections. In extreme cases, loss may be ‘‘total’’, being either chronic in the terminal phase of osteoarthritis or following extensive meniscectomy; or acute due to meniscal displacement, for example in inter- condylar ‘‘bucket-handle’’ tears).

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Meniscal tear patterns   
  
 On MRI, a tear presents as an abnormal intrameniscal signal on T2-weighted or proton density MR images that unam- biguously contacts the meniscal surface; that is, the tear is visible on at least 2 consecutive slices or on 2 images acquired in different planes [5,6].   
  
 These tears are categorized according to their patterns using the same classiﬁcations used by arthroscopic sur- geons (Fig. 1) [7]. Vertical tears are oriented perpendicularly to the tibial plateau. Vertical tears may be longitudinal (follow the long axis of the meniscus), radial (perpendic- ular to the long axis of the meniscus), or oblique/vertical ﬂap (combination of radial and longitudinal also known as ‘‘parrot beak’’ tears). Vertical tears, in particular posterior, peripheral, and longitudinal tears, are commonly caused by trauma. Horizontal tears are more typically caused by degeneration and contact with the meniscal articular sur- face. A pure horizontal tear divides the meniscus in half and runs parallel to the tibial plateau with the tear exiting at the meniscal apex. A true horizontal tear has also been referred to as a horizontal cleavage tear or a ‘‘ﬁsh mouth’’ tear, given the appearance at arthroscopy. A horizontal ﬂap tear describes horizontally oriented tears that contact either the femoral or tibial articular surface rather than the

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Fragments and displaced ﬂaps   
  
 A portion of the meniscus may become displaced. When the meniscal tissue remains attached to the parent meniscus, it is referred to as a displaced ﬂap. Detached meniscal tis- sue is referred to as a free meniscal fragment. Potential migration sites must be known and systematically checked when knee MRI are interpreted. For instance, the fragment may remain in contact with the parent meniscus, be found in a joint space, or migrate a considerable distance from the parent meniscus. The most common locations for migra- tion are the superior and inferior meniscal recesses and the intercondylar notch (Fig. 2).

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Diagnostic performance   
  
 Frequently missed meniscal tears   
  
 In degenerative meniscal pathology, the performance of MRI is noticeably poorer for detecting lateral meniscus (LM) pathology rather than medial meniscus (MM) pathol- ogy (Fig. 3). Performance also varies with the tear patterns. For example, complex and horizontal lesions are more eas- ily recognized than vertical lesions; in particular, radial tears are frequently missed (Fig. 4) [14].   
  
 Radial MM posterior horn tears (also known as root tears and root avulsions) may be overlooked. Recognition of these lesions is very important. First, their biomechan- ical prognosis is poor, and they carry signiﬁcant risks of osteoarthritis and bone complications including subchondral insufﬁciency fractures to mechanical epiphyseal necrosis (Fig. 5) [15—17]. Second, improved arthroscopic knowledge (which allows lesion categorization according to proximity to the bone insertion site and damage to the posterior tibial bone insertion site) has brought new perspectives regarding the speciﬁc treatment of radial MM posterior horn lesions [18,19].   
  
 The coronal view directly shows these radial posterior horn lesions. The lesions often show indirect signs of poste- rior detachment (i.e., meniscal subluxation on the medial side of the joint space). The sagittal view is more difﬁcult to interpret, but a subtle sign is the ‘‘disappearance’’ of the meniscus (ghost meniscus) between slices of the nor- mal posterior horn. Evaluation of thin axial images is very

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Figure 2. Illustrations of the most common types of menis- cal fragments. A ‘‘bucket-handle’’ lesion that migrated to the intercondylar notch, separated intercondylar fragments, and a ‘‘horizontal’’ ﬂap that migrated to the superior and inferior per- imeniscal recesses are shown.

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MRI technique   
  
 MRI is the modality of choice for evaluating meniscal pathol- ogy, observed either alone or in association with ligament injury in traumatic settings [8]. MRI has high diagnostic performance and is noninvasive. The examination most com- monly relies on the acquisition of two-dimensional (2D) thin slices in the axial, sagittal, and coronal planes. MRI increasingly relies on the acquisition of isotropic images using three-dimensional (3D) fast spin-echo sequences such as SPACE (Siemens-Healthinneers, Erlangen, Germany), CUBE (GE Healthcare, Milwaukee, WI, USA), and VISTA (Philips, Eindhoven, The Netherlands), which can then be used for multiplanar reconstruction. Proton density—and intermediate-weighted with fat signal suppression are the best image weightings for detecting meniscal lesions [9,10]. These sequences have the best performance and can be used to identify meniscal tears, displaced fragments, and indi- rect signs associated with migration. These sequences also have satisfactory performance for evaluating ligaments, car- tilage, peri-articular soft tissues and postoperative changes [11—13].

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Figure 3. Illustration of meniscal tears that can be missed owing to their atypical location or presentation. Meniscocapsular sepa- ration is a particular type of longitudinal tear that affects the periphery of the posterior horn of the medial meniscus; meniscocap- sular separation mainly occurs after an anterior cruciate ligament tear. ‘‘Zip’’ tears or Wrisberg rips are longitudinal vertical tears that affect the posterior horn of the lateral meniscus, thereby length- ening the extent of the separation between the meniscofemoral ligament and the posterior horn. Posterior meniscal root tears can occur at the posterior insertion site of the medial and the lateral menisci.

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Figure 4. A 43-year-old man with spontaneous knee pain and a subtle, difﬁcult-to-diagnose radial tear of the posteromedial segment of the medial meniscus. Coronal (a) and sagittal (b) proton-density images with fat signal suppression show slight high signal intensity near the free edge of the medial meniscus (arrows in a and b). On 3D T2-weighted transverse imaging (c), the high signal intensity can be properly interpreted as a radial tear perpendicular to the free edge of the posterior and medial segment of the meniscus (arrow in c).

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Figure 5. A 67-year-old woman with spontaneous knee pain and a radial tear of the posterior horn of the medial meniscus (root tear or meniscocapsular separation). Coronal (a) and transverse (b) proton-density images with fat suppression of the posterior horn of the medial meniscus show a linear tear with high signal intensity located near the expected tibial insertion site of the posterior horn.

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helpful for the detection and characterization of radial tears suspected on other imaging planes; this should become a standard approach for conﬁrming radial tears (Fig. 5). Meniscal lesions are frequently associated with anterior cruciate ligament (ACL) tears. Prevalence is around 50% to 65%, and the MM posterior horn is the most common location (> 75% of cases) [20]. In the speciﬁc case of a meniscal lesion accompanying an ACL injury, MRI performance is poorer for detecting LM lesions than MM lesions: sensitivity ranges from 50% to 60% for LM lesions but is more than 90% for MM lesions [3,21—23].   
  
 Certain clinical, morphologic, and topographic charac- teristics of meniscal lesions accompanying ACL tears are associated with an increased risk of difﬁcult or erroneous diagnosis. The factors contributing to missed meniscal tear in the setting of ACL injury are the performance of the MRI assessment shortly after the traumatic event, small of the tear (i.e., lesion involving less than one-third of the meniscal length), posterior location, peripheral longitudinal pattern, and lesions that extend from the insertion site of the meniscofemoral ligament to the LM posterior horn (rip or zip tears). These risk factors must be kept in mind [1,2]. On the posterior aspect of the MM posterior horn, no cleavage plane or recess is normally present. The presence of ﬂuid or an irregular outline on the peripheral posterior edge of the meniscus must be considered as indicative of a relevant lesion [24]. A vertical line with high signal intensity at the posterior edge of the MM posterior horn must be con- sidered as pathologic and representative of a peripheral tear

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lesion or meniscocapsular separation (Fig. 6) [24—26]. Preva- lence is estimated to be approximately 20% in knees that have ACL tears, and such lesions are believed to be more fre- quently encountered in men [27]. Longitudinal tear lesions on the posterior edge of the MM posterior horn accompa- nying ACL injuries must not be missed, especially because speciﬁc treatment options are available for meniscal ramp lesions. Treatment is justiﬁed because lesions of the MM posterior horn that accompany an ACL injury contribute to knee instability and have a signiﬁcant risk of secondary dis- placement including bucket-handle meniscal displacement into the intercondylar notch (Fig. 7) [28]. However, these lesions are likely to spontaneously cicatrize when they are not displaced. Cicatrization should be considered in cases with a vertical, longitudinal, peripheral lesion with signal that is ‘‘not frankly bright’’ on T2-weighted imaging [29]. These peripheral lesions of the MM posterior horn are often difﬁcult to diagnose on MRI, and they are sometimes even more difﬁcult to detect on arthroscopy because the medial posterior segment of the knee is practically inaccessible on anterior arthroscopy. By differentiating notable lesions on the posterior edge of the MM posterior horn, MRI may provide additional indications to perform a posterior arthroscopic approach [30].   
  
 Vertical longitudinal tears may also involve the LM posterior horn. These lesions are typically characterized by cleavage that extends from the normal junction site between the meniscofemoral ligament (Humphrey or Wris- berg ligaments) and the LM posterior horn (Fig. 8). Although

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Figure 6. A 27-year-old man with a recent history of knee trauma. Meniscocapsular separation (vertical longitudinal tear) at the posterior edge of the medial meniscus. Sagittal proton-density (a) and T2-weighted (b) images show a line with high signal intensity at the posterior edge of the posterior horn of the medial meniscus that is in contact with both surfaces (arrows). This indicates a vertical peripheral tear in association with an anterior cruciate ligament injury (ramp lesion).

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Figure 7. A 38-year-old woman with a recent history of knee trauma. Meniscocapsular separation of the posterior horn of the medial meniscus in association with an anterior cruciate ligament injury and secondary bucket-handle migration of the medial meniscus. Coronal (a) and sagittal (b) proton-density views with fat suppression show a vertical peripheral tear and detachment of the posterior horn (arrow in b) that extends into the middle segment (arrow in a) of the medial meniscus. Follow-up MRI (c and d) performed 6 months later to evaluate pain after a sudden twisting movement shows displacement of a large bucket-handle meniscal fragment into the intercondylar notch (arrowheads in c and d).

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it is normal to see a separation between the ligament and the posterior horn for a certain distance, if this separation extends 14 mm (or more than four 3-mm slices) beyond the reference point (which is the insertion site of the posterior cruciate ligament [PCL]), this indicates a longitudinal tear of the LM posterior horn. The lesion is called a ‘‘zip’’ or ‘‘rip’’ lesion based on its pathogenesis and morphology [31—33]. The Wrisberg rip is characterized by abnormal lateral exten- sion of the separation between the meniscofemoral ligament and the LM posterior horn. Separation lesions and radial tears near the roots of the medial and lateral menisci can be

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observed in traumatic settings and, in particular, in associ- ation with ACL tears [34]. These lesions and tears must not be overlooked, especially types involving the LM posterior horn, which are rarer and often missed (Fig. 9).

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Important considerations about meniscal fragments

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A meniscal tear, regardless of its pattern, may lead to a displaced ﬂap or fragment if extensive enough. In addi-

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Figure 8. A 22-year-old man with a recent history of knee trauma. A vertical longitudinal tear of the posterior horn of the lateral meniscus is shown (Wrisberg rip or zip tear). Sagittal (a) and transverse (b) proton-density views with fat suppression show separation between the meniscofemoral ligament and the posterior horn of the lateral meniscus with abnormal extension into in the posterolateral region, which represents a longitudinal tear accompanying an anterior cruciate ligament injury (arrows). Note the postcontusion bone marrow edema at the posterior margin of the lateral tibial plateau.

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Figure 9. A 39-year-old man with a recent history of knee trauma, including a radial tear of the posterior horn of the lateral meniscus in association with an anterior cruciate ligament injury. Coronal (a) and transverse (b) proton-density views with fat suppression show a deep radial tear in the free edge of the posterior horn of the lateral meniscus.

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that displace from the MM are much more common than those from the LM. The most common migration sites for these MM fragments are the intercondylar notch, in particu- lar its posterior aspect, and the medial parameniscal recess in contact with the medial femoral condyle or medial tib- ial plateau. Fragments from the LM may migrate into the intercondylar notch or lateral recesses [35].   
  
 Bucket-handle lesions can result in the migration of a large meniscal fragment into the intercondylar notch that remains attached to the anterior and posterior horns of the meniscus. Bucket-handle lesions are relatively easy to diagnose if the fragment is large: the remaining meniscal segments appear especially small with a notch-occupying fragment. However, a thin bucket-handle lesion may be missed owing to the inconspicuous loss of substance in the parent meniscus (Fig. 11). Intercondylar fragments may also present as displaced ﬂaps, which remain attached to either the posterior or anterior horn, and likely represent the loss of continuity within a previous bucket-handle tear. Meniscal fragments that have been displaced into the medial parameniscal recess are common, well known, and relatively easy to diagnose (Fig. 12). Fragments that dis- place from the LM (in particular into the recess) are rarer and more difﬁcult to diagnose (Fig. 13).   
  
 The appearance of a few speciﬁc displaced meniscal lesions on MRI have been described in the literature. Bucket- handle lesions in the intercondylar notch show a ‘‘double PCL’’ appearance on sagittal images at the intercondylar

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Figure 10. Illustration of the most common locations (direction of the green ‘‘sectors’’) and relative proportions (sizes of the green sectors) of fragments that originate from the medial (left) and lateral (right) menisci. Note the higher frequency of medial meniscal fragments and their most common locations: the poste- rior intercondylar notch and perimeniscal recess (graph adapted from reference [32]).

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tion to the extent of the tear, several tear patterns are at increased risk for displacement. Knowledge of these tear types and their common migration sites will help identify any fragments that require treatment (Fig. 10). Fragments

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Figure 11. A 32-year-old man with an old history of knee trauma. A small medial meniscus fragment with bucket-handle displacement into the intercondylar notch is shown. Coronal (a—c) and sagittal (d—f) fat-suppressed proton-density magnetic resonance images show the subtle loss of substance in the anterior horn of the medial meniscus (arrowheads in a and d) and a fragment displaced into the intercondylar notch (arrows in b, c, e, f) on the superior aspect of the medial intercondylar tubercle. Note (in b) the practically intact middle segment of the medial meniscus and the edematous inﬁltration at the margin of the medial tibial plateau (menisco-capsular separation).

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Figure 12. A 56-year-old woman with a recent history of spontaneous knee pain and locking. The coexistence of displaced fragments from the medial meniscus into the superior and inferior meniscal recesses is shown. Coronal (a and b) and transverse (c and d) proton-density views with fat suppression (a, b). Two fragments are shown: 1 fragment is in the medial superior meniscal recess (arrowheads in a and c), and 1 fragment is in the inferior recess at the medial aspect of the medial tibial plateau (arrows in b and d). Note the bone marrow edema in the medial margin of the femoral condyle and medial tibial plateau adjacent to the meniscal fragments (meniscofemoral and meniscotibial impingement).

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Figure 13. A 67-year-old man with a recent history of spontaneous knee pain and locking. A displaced fragment from the lateral meniscus is shown in the lateral paracondylar meniscal recess. Coronal (a) and transverse (b) proton-density views with fat suppression show the loss of substance in the middle segment of the lateral meniscus (arrowhead in a) with migration of a lateral paracondylar fragment (arrows in a and b).

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Figure 14. A 68-year-old man with a recent history of spontaneous knee pain and swelling. The coexistence of displaced fragments from the medial meniscus into the medial superior meniscal recess and the posterior aspect of the intercondylar notch is shown. Coronal (a and b) and transverse (c) fat-suppressed proton-density magnetic resonance images and the T2-weighted sagittal image (d) show 2 fragments: 1 fragment in the medial superior meniscal recess (arrows in a and c), and 1 fragment in the posterior aspect of the intercondylar notch (arrowheads in b and d). Note (in c) the subtle bone marrow edema of the femoral condyle adjacent to the fragment.

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notch [36—38]. Partial lesions with fragments that have been displaced into the notch close to the posterior segment of the meniscus show a ‘‘double posterior horn’’ appearance [39]. Fragments in the superior and inferior recesses may show a ‘‘double medial collateral ligament (MCL)’’ sign on axial sections of [40].   
  
 Fragments that have been displaced into the recess may be small. Signs secondary to their migration may aid detec- tion and must prompt an active search and evaluation. This especially applies to signs of mechanical impingement (meniscofemoral or meniscotibial) that result from a frag- ment located between the parent meniscus and the surface of the bone or from an irritated epiphyseal edge, which may result in osteochondral depression and bone marrow edema. Menisco-osseous impingement is characterized by a ‘‘meniscal shiny corner’’ or subchondral areas with high signal intensity [41,42]. The typical example is edema- tous inﬁltration into the medial margin of the medial tibial plateau that is in contact with a fragment that has fallen into the submeniscal recess (Fig. 12).

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Meniscal fragments and displaced ﬂaps may show changes in their location, and, for example, displaced bucket-handle tears may show spontaneous reduction. This potential variability in fragment location over time may lead to dis- crepancies between imaging and arthroscopic ﬁndings. Like other areas of diagnostic imaging, a common pit- fall is ‘‘satisfaction of search’’ error. Identiﬁcation of a displaced fragment is not a reason to actively stop evalua- tion of the preferred migration sites of meniscal fragments. Indeed, it is not uncommon to observe concurrent displaced fragments in the superior and inferior recesses or in a recess and the notch (Figs. 12 and 14).

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Conclusion

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Knowledge of difﬁcult-to-diagnose meniscal lesions is impor- tant for both radiologists and arthroscopists to avoid common diagnostic pitfalls. Radial tears and meniscocap- sular lesions of the posterior horn of the menisci near their

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tibial insertion sites are difﬁcult to diagnose and these areas require additional scrutiny on MRI interpretation. Systemat- ically reviewing common locations of these difﬁcult lesions, awareness of their morphologic characteristics, and accom- panying signs facilitate accurate diagnosis.   
  
 In posttraumatic situations, especially in association with ACL injuries, peripheral longitudinal tears may be identiﬁed in both menisci. Knowledge of the normal anatomy—–such as the absence of any recess behind the posterior horn of the normal MM and the limited extent of the anatomic sep- aration between the meniscofemoral ligament and the LM posterior horn—–ensures that these lesions are not over- looked. As a general feature, LM lesions are much less common than MM lesions, and are more challenging to identify. Their rarity contributes to their misinterpretation, though the LM may have the same lesions as those that are observed with much greater frequency in the MM. To identify displaced fragments, the intercondylar notch, periarticular recesses, and indirect bone signs must be speciﬁcally eval- uated. Multiple lesions are possible and several concurrent, displaced fragments may coexist.

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