ANDRE FUKUNISHI YAMADA

ROTURA DA PLACA PLANTAR DA SEGUNDA E TERCEIRA METATARSOFALÂNGICAS: DESEMPENHO DIAGNÓSTICO DOS SINAIS DIRETOS E INDIRETOS NA RESSONÂNCIA MAGNÉTICA, UTILIZANDO ACHADOS CIRÚRGICOS COMO REFERÊNCIA

Tese apresentada à Universidade Federal de São Paulo – Escola Paulista de Medicina para obtenção do Título de Doutor em Ciências.

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Orientador: Prof. Dr. Artur da Rocha C. Fernandes
Co-orientador: Prof. Dr. Caio Augusto de Souza Nery

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Yamada, Andre Fukunishi

Rotura da placa plantar da segunda e terceira metatarsofângicas: desempenho diagnóstico dos sinais diretos e indiretos na ressonância magnética, utilizando achados cirúrgicos como referência / André Fukunishi Yamada. -- São Paulo, 2018.

xviii, 98f.

Tese (Doutorado) – Universidade Federal de São Paulo. Escola Paulista de Medicina. Programa de Pós-graduação em Radiologia e Ciências Radiológicas.

Título em inglês: Second and third metatarsophalangeal plantar plate tears: diagnostic performance of direct and inderect MRI features using surgical findings as the reference standard

1. articulação metatarsofalângica; . 2. ressonância magnética. 3. artroscopia. 4. placa plantar

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À minha querida esposa e melhor amiga Erica,

Aos meus pais Iara e Durval, meus exemplos de pessoas e companheirismo,

Aos meus filhos Rafa e Gabi, motivos de alegria da minha vida e que me fazem sempre buscar ser uma pessoa melhor,

Aos meus irmãos Vivien e Ricardo, por sempre estarem ao meu lado.

“O seu trabalho vai ocupar grande parte da sua vida, e a única maneira de ser realmente satisfeito é fazer aquilo que você acreditar ser um ótimo trabalho. E a única maneira de realizar um ótimo trabalho é amar aquilo que você faz. Se você ainda não encontrou isso, continue procurando. Não se acomode. Assim como em todos os assuntos do coração, você vai saber quando achar. E como em qualquer grande relacionamento, só fica melhor com o passar dos anos. Portanto, continue procurando até encontrar isso. Não se acomode.”

Steve Jobs

Agradecimentos

Ao meu orientador, Prof. Dr. Artur da Rocha Correa Fernandes, exemplo como pessoa e radiologista, agradeço pelos ensinamentos, apoio e estímulo desde de minha formação na residência.

Ao meu co-orientador, Prof. Dr. Caio Augusto de Souza Nery, pela paciência e dedicação, meu agradecimento por acreditar desde o início no projeto e por confiar seu banco de dados para a execução deste estudo.

Ao chefe do Departamento de Diagnóstico por Imagem da EPM-UNIFESP, Prof. Dr. Nitamar Abdala e à coordenadora do curso de pós-graduação, Profa. Dra. Suzan Menasce Goldman, por viabilizar e dar oportunidade a realização deste projeto.

Aos docentes, Prof. Dr. Henrique M. Lederman, Prof. Dr.Sergio Ajzen, Prof. Dr. Jacob Szenfeld, Prof. Dr. Giuseppe D'Ippolito, Prof. Dr. Henrique Carrete Junior, Prof. Dr. David Shigueoka, Prof. Dr. Helio Yamashita e aos demais docentes da EPM-UNIFESP pela dedicação e ensinamentos durante minha formação.

Aos meus colegas radiologistas da UNIFESP-EPM e colegas de trabalho, pelo companheirismo e contínua troca de conhecimentos.

Aos preceptores do Departamento de Diagnóstico por Imagem da EPM-UNIFESP, pela dedicação e ensinamentos durante a residência.

Ao Dr. Abdalla Y. Skaf, por incentivar e apoiar a constante busca do conhecimento e aperfeiçoamento.

Ao colega radiologista, Dr. Michel Daoud Crema, por todo suporte desde o início do projeto.

A Sociedade Paulista de Radiologia e seus diretores por incentivar o aperfeiçoamento e divulgação do conhecimento.

Aos meus colegas de turma da Escola Paulista de Medicina (63) pela eterna amizade.

A Sra. Andrea Puchnick, Sra. Vivian Ferreira e Sra. Celia (Celinha), pela paciência e apoio desde a residência até a pós-graduação.

Ao Sr. Renan Hiagon, pela revisão e formatação da tese.

Aos demais colaboradores do Departamento de Diagnóstico por Imagem UNIFESP – EPM, pela dedicação e trabalho.

Sumário

Lista de figuras e gráficos

Lista de Quadros

Lista de Tabelas

Lista de abreviaturas e símbolos

ArtroRM	artrorressonância magnética
IC	intervalo de confiança
MTF	metatarsofalângica
OR	*odds ratio* – razão de chances
PP	placa plantar
PPFP	placa plantar – falange proximal
RM	ressonância magnética
STIR	short tau inversion recovery

Resumo

Objetivo: avaliar a performance diagnóstica dos sinais diretos e indiretos no estudo de ressonância magnética das metatarsofalângicas do segundo e terceiro dedos, supostamente relacionados à rotura da placa plantar, utilizando os achados cirúrgicos como referência.

Método: foram avaliados retrospectivamente 23 pacientes (13 mulheres e 10 homens; 60,5 +/- 8,1 anos) com quadro sintomático de instabilidade da articulação metatarsofalângica do segundo e terceiro dedos, com exame de ressonância magnética realizado em aparelho de 1,5 T e submetidos a procedimento cirúrgico. Os exames de RM foram avaliados por dois radiologistas independentes. Usando os achados cirúrgicos como referência, foram calculados sensibilidade, especificidade e acurácia de cada sinal nos estudos de RM para a detecção de rotura da placa plantar. A análise de regressão logística multivariada foi realizada para identificar quais achados na RM poderiam estar associados, independentemente, com rotura de placa plantar. A correlação interobservador foi realizada usando o teste Kappa.

Resultados: 45 articulações metatarsofalângicas foram incluídas no estudo. A presença de fibrose pericapsular apresentou alta sensibilidade (91,2%), especificidade (90,9%) e acurácia (91,1%) para o diagnóstico de rotura da placa plantar. Utilizando como valor de corte a medida de 0,275 cm, a distância placa plantar – falange proximal apresentou sensibilidade de 64,7%, especificidade de 90,9% e acurácia de 71,1% para o diagnóstico de rotura da placa plantar.

Conclusão: Em pacientes com quadro clínico compatível com instabilidade da articulação MTF, alguns sinais diretos e indiretos demonstraram de bom a excelente desempenho para o diagnóstico de rotura da placa plantar.

1 INTRODUÇÃO

A metatarsalgia é queixa comum na prática clínica, tendo como possíveis causas trauma, instabilidade, sinovite e outras patologias inflamatórias [1,2]. A articulação metatarsofalângica (MTF) do segundo dedo está frequentemente sujeita a instabilidade e é descrita como o local mais comum de luxação do antepé [3]. Devido à alta incidência de instabilidade da segunda metatarsofalângica em mulheres idosas, Coughlin elaborou a hipótese na qual o uso prolongado de calçados com salto alto determinariam forças de hiperextensão crônica, levando a um alongamento da placa plantar (PP) [1]. Por outro lado, a instabilidade da metatarsofalângica também pode afetar homens adultos jovens e atletas [1,4]. A relevância da placa plantar como restritora estática da subluxação/luxação da articulação metatarsofalângica foi bem documentada na literatura, uma vez que as lesões da placa plantar tem papel significativo no desenvolvimento da instabilidade da articulação metatarsofalângica no plano sagital [5–9]. Apesar da importância da placa plantar na estabilidade da articulação metatarsofalângica, não há consenso sobre o tratamento das lesões da placa plantar [10].

No passado, o diagnóstico de lesões da placa plantar por exames de imagem era realizado somente com artrografia. Recentemente, a ressonância magnética (RM) e o ultrassom têm assumindo esse papel [11–15]. Yao et al. observaram que focos de alto sinal nas sequências sensíveis a líquido correspondiam a rotura da placa plantar e este achado foi posteriormente confirmado com achados cirúrgicos [16]. Este achado, considerado como sinal direto para rotura da placa plantar [17,18], provavelmente representa a interposição líquida junto à área de descontinuidade parcial ou total da placa plantar. Outros estudos testaram este sinal direto em exames de RM para o diagnóstico de rotura da placa plantar, verificando-se certo grau de discrepância de desempenho no que concerne à especificidade [13,19,20]. Outras alterações morfológicas da placa plantar não foram testadas em relação a um padrão de referência. Idealmente, a performance diagnóstica da ressonância magnética deveria ser testada utilizando um protocolo de rotina para o antepé, representando a prática clínica real de nosso cotidiano. Além disso, existem poucos estudos que avaliaram o desempenho de sinais indiretos em exames de RM, principalmente no tocante às alterações das estruturas circunjacentes, que podem estar relacionados à rotura da placa plantar. Umans et al.

procuraram identificar características quantitativas e qualitativas em exames de RM sem contraste que poderiam melhorar a detecção de rotura da placa plantar [18,21]. Contudo, esses estudos não dispõem de achados cirúrgicos como padrão de referência.

1.1 Objetivos

1.1.1. Objetivo Geral

Analisar o desempenho diagnóstico da Ressonância Magnética na avaliação das lesões da placa plantar.

1.1.2. Objetivos Específicos

Avaliar o desempenho dos sinais diretos nos estudos de Ressonância Magnética que possam estar relacionados com a rotura da placa plantar.

Avaliar o desempenho diagnóstico dos sinais indiretos nos estudos de Ressonância Magnética que possam estar relacionados com a rotura da placa plantar.

2 REVISÃO DA LITERATURA

As articulações metatarsofalângicas são articulações sinoviais do tipo bola e soquete que, em conjunto com as articulações interfalângicas proximais e distais, formam as articulações do antepé. Observando suas características anatômicas e diferentes patologias relacionadas a este grupo de articulações, podemos dividi-las em dois grupos: a articulação MTF do hálux ou grande MTF e as pequenas ou menores articulações MTFs, que englobam as MTFs do segundo ao quinto dedo [(15)]. Da mesma forma, as respectivas placas plantares devem ser abordadas de maneira distinta. Neste estudo, abordaremos especificamente as alterações relacionadas às placas plantares da segunda e terceira articulações MTFs, em virtude da semelhança anatômica e da prevalência da patologia a ser analisada.

Anatomia

Ao nível da articulação MTF, a falange proximal e a placa plantar constituem uma unidade anatômica e funcional que, associadas a suas inserções e conexões, formam o principal aparato articular do antepé [(22)].

A placa plantar é uma estrutura fibrocartilagínea, constituída predominantemente de colágeno do tipo I (75% de sua composição), semelhante à composição do menisco no joelho [(7,15)]. As bandas de colágeno têm orientação longitudinal nos dois terços dorsais da placa plantar. No terço plantar distal, as fibras são orientadas no eixo transversal, ao nível do ligamento intermetatarsal e em continuidade com o mesmo [(7)]. Esta característica anatômica é consistente com sua função, qual seja, sustentar as forças de tensão no plano longitudinal [(8,15)].

A PP tem formato de retangular a trapezoidal, sua porção central logo abaixo da cabeça do metatarso é mais larga e espessa que o segmento distal. A espessura da PP pode variar entre 2 e 5 mm [(9)], sendo mais afilada no segmento proximal junto ao metatarso, onde pode atingir até 0,4 mm de espessura [(7)]. O seu comprimento no eixo longitudinal pode variar entre 16 e 23 mm e a largura entre 8 e 13 mm [(9)]. Sua inserção contém quantidade alta de condrócitos, formando uma união fibrocartilaginosa firme junto à cartilagem hialina da base da falange proximal (8,23). Em sua origem, no colo da região metafisária da cabeça do metatarso, notamos uma fixação sinovial fina e frouxa (7,8,23). Outras estruturas apresentam conexão com a placa plantar, entre elas a fáscia plantar, a bainha dos tendões flexores, o ligamento transverso intermetatarsal, os ligamentos colaterais e os tendões interósseos (7–9).

Em relação aos ligamentos colaterais, duas bandas podem ser identificadas, originando-se da cabeça do metatarso: o ligamento colateral próprio, que se insere na base da falange proximal, e o ligamento colateral acessório, que se insere diretamente na PP (7). Ambos contribuem para a estabilidade da articulação MTF, no entanto o ligamento colateral acessório, por sua relação direta com a PP, tem importância *sine qua non* para a estabilidade da articulação (1,23).

A estabilização estática da articulação MTF é realizada primariamente pela placa plantar, cápsula articular e ligamentos colaterais. Estudos com testes mecânicos demonstraram que a placa plantar é o principal componente da estabilização da articulação MTF, sendo os ligamentos colaterais a segunda estrutura mais forte nesta estabilização (24).

A estabilização dinâmica é realizada pela ação da musculatura extrínseca e intrínseca do antepé, sendo que esta função é dependente da integridade da placa plantar. Os tendões flexores longos e curtos são flexores relativamente ineficientes da articulação MTF. Em circunstâncias normais, a flexão das pequenas articulações MTFs é realizada essencialmente pelos músculos interósseos. Não obstante, com a subluxação dorsal da falange proximal pela rotura da placa plantar, os tendões interósseos migram dorsalmente em relação ao eixo central da articulação MTF, consequentemente perdendo a função de flexão da mesma. O tendão do lumbrical tem trajeto inferiormente ao ligamento transverso metatarsal profundo, permanecendo com trajeto plantar ao eixo de rotação. Entretanto, devido ao ângulo formado por essa polia, pela subluxação dorsal da falange proximal, o tendão lumbrical também perde a eficiência de flexão da MTF (25).

Prevalência

A instabilidade da articulação MTF ocorre mais frequentemente em duas populações distintas. A primeira é formada por mulheres sedentárias com mais de 50 anos de idade e a segunda por atletas jovens do sexo masculino [4,25]. Nery et al publicaram uma série de casos com instabilidade da articulação MTF na qual 71% dos casos eram do sexo feminino e a idade média de aparecimento da deformidade dos dedos foi de 58 anos. No mesmo estudo, a segunda articulação MTF foi a mais frequente, presente em 64%, seguida da terceira e quarta MTFs presentes em 32% e 4% dos casos, respectivamente [3].

Etiologia

O trauma agudo pode levar à rotura da placa plantar e instabilidade da articulação MTF, mas a principal causa é a alteração por atrito mecânico. Alterações inflamatórias crônicas podem contribuir para essas alterações de atrito, no entanto alguns autores acreditam que essa alteração inflamatória ocorra por sobrecarga mecânica da articulação MTF [23]. São causas de sobrecarga da articulação MTF: segundo metatarso longo, hipermobilidade do primeiro raio, halux valgo e pé plano. O uso de calçados com bico estreito e de salto alto também podem contribuir para a instabilidade da articulação MTF, igualmente por sobrecarga mecânica na região [1]. A proliferação sinovial relacionada à artropatia inflamatória, como a artrite reumatóide, também pode levar à degeneração e rotura das estruturas estabilizadoras, entre elas a PP [26].

Quadro clínico e exame físico

A rotura da placa plantar pode se apresentar como metatarsalgia aguda ou crônica, sendo o segundo dedo mais frequentemente envolvido. A dor focal na face plantar na base do dedo é a queixa mais comum [23]. A instabilidade leva a um espectro de sinais e sintomas, composta de sinovite, desvio do dedo, subluxação e consequente luxação. Em fases iniciais, o diagnóstico pode ser difícil por mimetizar outras patologias comuns, como o neuroma interdigital [27].

O “drawer test” ou teste de gaveta (figura 1) foi a ferramenta de exame físico mais importante detectada em estudo de Nery et al [27], sendo a mais precisa e confiável para classificar e graduar as lesões da PP antes da cirurgia. Em segundo lugar, o achado mais comum descrito no mesmo estudo foi o de dor abaixo da cabeça do metatarso (94%), mas sem capacidade de diferenciar as lesões. A deformidade com elevação dorsal do dedo também foi outro achado clínico importante, correlacionando-se com todos os graus de rotura da PP. A diminuição ou ausência de apreensão plantar do dedo (figura 2) não foi útil para a diferenciação das lesões, mas é uma boa ferramenta para controle do tratamento [27].

Diagnóstico por imagem

A avaliação da PP pelos métodos de imagem pode ser feita de diversas maneiras. Inicialmente, utilizava-se da artrografia para a avaliação da integridade da PP, bem como dos ligamentos colaterais. A presença de contraste no interior da bainha dos tendões flexores é sinal indicativo de rotura da placa plantar. Além disso, é possível a avaliação dinâmica da suficiência dos ligamentos colaterais no estudo de artrografia convencional [28].

O estudo de radiografia simples pode revelar características associadas à rotura da placa e à instabilidade da articulação MTF. Radiografias padrões no eixo anteroposterior podem dar informações sobre a magnitude das deformidades angulares, congruência das articulações, presença de alterações degenerativas ou por artropatias inflamatórias, além de poder avaliar o comprimento do segundo metatarso [25].

Até mesmo a tomografia computadorizada com “dupla energia” foi descrita como ferramenta para a avaliação da rotura da placa plantar [29], porém sem aplicação na prática clínica. A artroRM também pode ser utilizada para esta avaliação, entretanto, os métodos mais utilizados atualmente são a ultrassonografia e a RM, por serem métodos não invasivos e com bom desempenho diagnóstico.

O estudo ultrassonográfico pode ser realizado com o paciente em posição prona ou supino, utilizando transdutores lineares de alta frequência (9 a 15 MHz), para melhor caracterização de estruturas superficiais. As imagens são adquiridas preferencialmente nos planos sagital e coronal, uma vez que a avaliação dinâmica pode potencializar a detecção de eventuais roturas. Para a aquisição destas imagens dinâmicas, utiliza-se o plano sagital com extensão da MTF em até 15 graus [13]. As características da PP na ultrassonografia se assemelham às da placa volar dos dedos da mão, apresentando-se levemente ecogênica e homogênea, com aspecto fibrilar e trajeto curvo seguindo a orientação da cabeça do metatarso. A cartilagem hialina da cabeça do metatarso subjacente apresenta-se como fina imagem linear hipoecóica, junto à imagem linear hipercóica do córtex subjacente [13,19,30]. A rotura da placa plantar é descrita como perda da ecogenicidade homogênea junto à inserção, substituída por área focal hipoecogênica. Esta imagem pode ser detectada somente à manobra dinâmica com dorsiflexão da MTF [13,30].

O desempenho diagnóstico para detecção de rotura da PP utilizando a ultrassonografia foi estudada por alguns autores. Gregg et al em estudo com peças de cadáveres detectaram sensibilidade de 100%, especificidade de 0% e acurácia de 96% utilizando a ultrassonografia [19]. Posteriormente, o mesmo autor realizou estudo prospectivo, avaliando a correlação com estudos de RM e achados cirúrgicos, encontrando sensibilidade de 86%, especificidade de 64% e acurácia de 77% para diagnóstico de rotura da PP em pacientes sintomáticos e assintomáticos [13]. Klein et al realizaram estudo correlacionando os achados ultrassonográficos com achados de RM e cirúrgicos, encontrando uma melhor correlação da ultrassonografia com os achados cirúrgicos [31]. Em seus estudos, somente avaliando casos pré-operatórios com ultrassonografia, encontraram sensibilidade de 25%, especificidade de 91,1% e acurácia de 90% para rotura da PP [30]. Outros autores também constataram bom desempenho da ultrassonografia para o diagnóstico da rotura da PP [11,32], porém vale destacar que estes resultados foram obtidos com profissionais especializados e com treinamento diferenciado em relação à formação convencional de um radiologista. Fernandes et al. realizaram estudo correlacionando os achados ultrassonográficos com a instabilidade da articulação MTF verificada ao exame físico. Em 34,4% dos casos assintomáticos com aspecto normal à ultrassonografia, verificou-se grau leve de instabilidade [33]. Há ainda um forte componente operador-dependente na avaliação da

PP por ultrassonografia, sendo que sua utilização ainda é restrita na prática clínica fora de grandes centros acadêmicos.

Nos estudos de RM, a placa plantar mostra-se como estrutura bicôncava nos planos sagital e coronal, apresentando baixo sinal em todas as sequências, semelhante à característica de sinal das estruturas tendíneas normais. A origem proximal da placa apresenta-se, na maior parte das vezes, redundante e mais afilada em relação ao restante da PP. A inserção na base da falange proximal pode apresentar área mal definida de alto sinal, descritas como possível degeneração, mas sem comprovação histológica na literatura. É importante destacar a presença de um recesso na linha média desta inserção, que não deve ser confundida com rotura (figura 3), encontrada em até 47% dos casos por Mohana-Borges et al (15).

Diferentes protocolos de estudo com RM foram propostos para o estudo da PP na literatura. Klein et al. (31) e Sung et al. (20), utilizando sequências ponderadas em T1, T2 e STIR em aparelhos de RM com 0,3 T, reportaram bom desempenho diagnóstico, com sensibilidade entre 73,9% e 95% e especificidade de 100%, porém ressaltando que os protocolos utilizados foram realizados especificamente para as alterações de cada PP, focados em cada articulação MTF, o que não reflete nossa prática diária.

Atualmente em nosso país, a maior parte dos aparelhos de RM disponíveis são de 1,5 T ou 3,0 T, e esta é a configuração preferida pela maior parte dos radiologistas, inclusive para a avaliação da PP. Gregg et al. (13,19) e Umans et al. (18,21) realizaram estudos em aparelhos de 1,5 T e 3,0 T. Gregg et al. utilizaram sequências ponderadas em T2 com supressão de gordura e em densidade de prótons, nos planos sagital, axial e coronal, com área de interesse de até 10 cm e espessura de corte de 2 mm, sem espaçamento. Umans et al. utilizaram sequências ponderadas em T1 e densidade de prótons com supressão de gordura nos eixos coronal e axial e sequências ponderadas em T2 e densidade de prótons com saturação de gordura no eixo sagital; com área de interesse entre 10 e 12 cm e espessura de corte entre 2 e 3 mm no plano coronal (eixo curto) e entre 2 e 2,5 mm no eixo axial (eixo longo) (18).

Em relação à artroRM, Kier et al. (34) descreveram a utilidade da artroRM na avaliação da metatarsalgia do segundo e terceiro dedos, todavia sem comparar o desempenho diagnóstico com a RM convencional. Lepage-Saucier et al. (35) demonstraram que a associação da artroRM com a tração dos dedos é superior em relação à RM convencional para a avaliação da cartilagem e da placa plantar em um estudo com série de peças de cadáveres.

Dinoá et al. descreveram os achados nos estudos de RM com contraste relacionados à rotura da placa plantar. Segundo este estudo, uma parcela substancial das lesões da placa plantar (29,5%) foi somente caracterizada com o uso do meio de contraste paramagnético endovenoso [36]. Vale destacar que os casos deste estudo não dispunham de correlação histopatológica para o diagnóstico das roturas.

3 MÉTODO

Pacientes

Este estudo foi aprovado pelo comitê de ética de nossa instituição (UNIFESP), e o termo de consentimento foi dispensado. Foi realizada busca retrospectiva do banco de dados do departamento de ortopedia de nossa instituição entre Janeiro de 2009 e Julho de 2012. Somente foram incluídos os pacientes que se enquadravam nos seguintes critérios: *(a)* características clínicas indicando instabilidade da articulação metatarsofalângica, como história de desalinhamento progressivo dos dedos e/ou presença de espaço entre o segundo e terceiro dedos, e algum grau de instabilidade com drawer test positivo [(23)]; *(b)* ter realizado artroscopia diagnóstica da articulação metatarsofalângica; e *(c)* ter realizado um estudo pré-operatório de ressonância magnética do antepé em aparelho de 1.5 T. Assim, foram excluídos os casos com cirurgia pregressa da articulação metatarsofalângica, artropatias inflamatórias, neuropatia periférica, diabetes e doença vascular periférica. Ao final, 45 articulações metatarsofalângicas de 23 pacientes foram incluídas. Todos os pacientes incluídos apresentavam algum grau de instabilidade ao exame físico. A indicação de artroscopia foi baseada no exame físico, como descrito na literatura [(37,38)]. O estudo de ressonância magnética foi solicitado para confirmar a presença e gravidade da lesão da placa plantar antes do procedimento artroscópico.

Protocolo de Imagem

Todos os exames de ressonância magnética do antepé foram realizados em aparelhos de 1,5 T, em três serviços de radiologia independentes (Signa Excite HD 1.5T, GE Healthcare, Milwaukee, Wisconsin; Achieva 1.5T, Philips Medical Systems, Best, the Netherlands; ou Aera 1.5T, Siemens, Erlangen, Germany). Todos os exames foram realizados com bobina de extremidade dedicada, com paciente em posição supina e com o antepé em posição neutra. Como protocolo padrão, foi utilizada sequência ponderada em T1 no plano coronal (eixo curto) e sequências com ponderação intermediária com supressão de gordura, nos planos axial (eixo longo), sagital e coronal (eixo curto). Os parâmetros utilizados para essas sequências são retratados no Quadro 1.

Avaliação dos estudos de ressonância magnética

Dois radiologistas especialistas em músculo esquelético (A.F.Y. e M.D.C.), com 12 e 11 anos de experiência na área, respectivamente, avaliaram independentemente os estudos de ressonância magnética. Os radiologistas não foram informados sobre dados clínicos, relatórios iniciais das ressonâncias magnéticas e resultados da artroscopia. Somente a segunda e terceira metatarsofalângicas foram avaliadas. Os exames foram observados de forma randômica e sem os dados dos pacientes.

Uma série de achados hipoteticamente relacionados à rotura da placa plantar foram avaliados:

1. Morfologia e sinal da placa plantar (sinal direto): A placa plantar normal é descrita apresentando baixo sinal nas sequências ponderadas em T1 e T2 (19,28) (figura 4). Foram consideradas como rotura da placa plantar as seguintes alterações, quando avaliadas nos planos coronal e sagital nas sequências com ponderação intermediária: presença de afilamento da placa plantar, placa plantar não visualizada, e descontinuidade parcial ou completa com interposição líquida (figura 5) (16,17). A alteração de sinal da placa plantar sem alteração da morfologia não foi considerada como rotura. O afilamento da inserção distal da placa plantar foi determinado em comparação com a espessura de sua porção média no plano sagital: a inserção distal deveria ser mais espessa ou pelo menos igual à espessura da porção média para ser considerada normal (9). A placa foi considerada como não caracterizada nos casos com luxação/subluxação dorsal da falange proximal, com significativo desvio da placa.
2. Todos os outros achados descritos em seguida foram considerados como potenciais sinais indiretos.

2.1 Luxação ou subluxação da articulação metatarsofalângica: caracterizada como perda da congruência articular, com qualquer grau de desvio dorsal da falange proximal, avaliada nas imagens sagitais.

2.2 Edema da medular óssea: avaliado separadamente nos locais de fixação da placa plantar (cabeça do metatarso ou base da falange proximal – figura 5) e caracterizado como áreas mal definidas de alto sinal nas sequências com ponderação intermediária.

2.3 Fibrose pericapsular (sinal do “pseudoneuroma”): as alterações inflamatórias circunjacentes à placa plantar estendem-se junto ao espaço intermetatarsal, criando uma imagem que se assemelha e, portanto, pode-se confundir com um neuroma interdigital, especialmente nas sequências coronais ponderadas em T1. Entretanto, diferentemente de um verdadeiro neuroma, a fibrose pericapsular (18,36,37) relacionada aos casos de rotura da placa plantar apresenta-se, na maior parte das vezes, com limites mal definidos, assimétrica em relação ao espaço intermetatarsal, descrito por Umans et al. como de localização excêntrica pericapsular (18) e apresentando sinal alto ou intermediário nas sequências com ponderação intermediária (figura 6). Devido à frequente interpretação equivocada deste achado como neuroma, decidimos chamá-lo de “sinal do pseudoneuroma”.

2.4 A tenossinovite dos flexores foi definida com a presença de qualquer quantidade de líquido no interior de sua bainha, ao nível da articulação metatarsofalângica.

2.5 Complexo tendão interósseo e ligamento colateral: avaliamos se o complexo tendão/ligamento colateral estava afilado ou espessado, apresentando alteração de sinal no plano coronal (eixo curto) nas sequências com ponderação em T1 e intermediárias (figura 7). Avaliamos também a presença de atrofia do ventre muscular do interósseo nas sequências coronais (eixo curto) ponderadas em T1.

2.6 A presença de calosidade do coxim gorduroso plantar foi avaliada nos planos coronais com ponderação intermediária e em T1, mostrando-se como imagem de aspecto nodular, com baixo sinal em ambas as sequências, subjacente às cabeças dos metatarsais. A presença de bursite subcapital foi avaliada na mesma topografia anatômica, apresentando-se como coleção líquida bem definida com baixo sinal nas sequências ponderadas em T1 e alto sinal nas sequências com ponderação intermediária.

2.7 A bursite intermetatársica foi considerada na presença de qualquer quantidade de líquido distendendo a respectiva bursa.

2.8 A presença de derrame articular da metatarsofalângica foi observada na linha média do plano sagital em sequência com ponderação intermediária.

2.9 Distância placa plantar – falange proximal (PPFP): avaliou-se quantitativamente a distância entre a margem distal da placa plantar e a base da falange proximal, em centímetros (cm), sendo esta medida realizada no plano sagital, em sequência de ponderação intermediária e ao nível do trajeto do tendão flexor (figura 8).

Artroscopia Diagnóstica e Cirurgia Aberta

Os exames de artroscopia foram realizados por um cirurgião ortopedista (C.N.) com 30 anos de experiência em cirurgia de pé e tornozelo. O cirurgião teve acesso aos resultados das ressonâncias magnéticas pré-operatórias, mas não às avaliações retrospectivas realizadas pelos dois radiologistas. O procedimento artroscópico foi realizado por meio de dois portais (medial e lateral) localizados ao nível da articulação metatarsofalângica com artroscópio de 2,7 mm e 30 graus. As porções distal e central da placa plantar foram inspecionadas e palpadas com o probe, e as roturas das placas plantares foram avaliadas. Os relatórios cirúrgicos foram avaliados retrospectivamente para presença de rotura da placa plantar. Em todos os relatórios, houve avaliação da morfologia da placa plantar e de sua integridade, definindo-se claramente se esta apresentava-se rota (parcial ou completa) ou não.

Todas as lesões da placa plantar foram classificadas de acordo com o sistema de graduação anatômica, descrito na literatura (Quadro 2) [3,14,39]. Para cada grau de lesão, foi realizado um procedimento específico.

Para as lesões de grau 0 e I, foi realizada radiofrequência junto à área de lesão. Para todas as lesões de grau I, também foi realizado o procedimento de osteotomia de Weil. [40] Para as lesões de grau II e III, fez-se reparo direto por via aberta e posterior reinserção. Para as lesões de grau IV, realizou-se a osteotomia de Weil associada à transferência de tendão flexor para extensor [40,41].

Quando o reparo por via aberta ou a osteotomia de Weil foram realizadas, pudemos avaliar o espaço intermetatársico. Dessa forma, nas lesões com grau I, II, III e IV, foi possível a avaliação do espaço intermetatarsal.

Análise Estatística

O desempenho diagnóstico de cada um dos sinais à ressonância magnética foi avaliado, determinando-se especificidade, sensibilidade e acurácia, utilizando como referência os achados cirúrgicos para presença ou ausência de rotura da placa plantar. Além de avaliar o desempenho diagnóstico dos sinais diretos na ressonância magnética, consideramos também as alterações morfológicas da placa plantar (não-visualização, afilamento ou descontinuidade) como possíveis sinais diretos de rotura da placa plantar. O teste χ^2 e o teste exato de Fisher foram utilizados para comparação das variáveis categóricas e o teste de Mann-Whitney para avaliação de potenciais preditores contínuos de rotura da placa plantar (distância PPFP). Analisamos a curva ROC visando avaliar o desempenho diagnóstico da distância PPFP para rotura da placa plantar e a área abaixo da curva ROC foi calculada. Além disso, efetuamos análise de regressão logística multivariada para seleção das variáveis significativas, com o intuito de verificar quais sinais estariam associados com rotura da placa plantar diagnosticada durante a cirurgia. A análise multivariada incluiu somente os sinais que demonstraram significância estatística após a análise de regressão logística univariada. A significância foi definida como $P > 0.05$. A comparação das distâncias PPFP para os dois leitores foi feita com análise regressiva linear, usando o coeficiente de correlação de Pearson. A confiabilidade interobservador para todos os sinais avaliados foi realizada com estatística Kappa de Cohen. A análise estatística foi realizada com o uso de software específico (SPSS, version 22.0 for Mac; SPSS, Chicago).

4 RESULTADOS

População estudada e achados cirúrgicos

Utilizamos um grupo de estudo com 23 pacientes (13 mulheres e 10 homens) e incluímos 45 articulações metatarsofalângicas (28 no segundo dedo e 17 no terceiro). A idade média dos pacientes foi de 50,5 +/- 8,1 (DP) anos, variando entre 34 e 75 anos. O tempo médio entre a RM pré-operatória e o procedimento cirúrgico foi de 16,1 +/- 5,9 semanas, em um intervalo entre 3,9 e 26,5 semanas. Considerando as 45 PP avaliadas por artroscopia, 34 (75,6%) apresentavam rotura e 11 (24,4%) não apresentavam rotura. Ocorreram 22 casos de rotura da PP na segunda articulação MTF e nove na terceira articulação MTF (tabela 1).

Desempenho diagnóstico dos sinais nos estudos de Ressonância Magnética

As tabelas 2 e 3 retratam as articulações MTF categorizadas pelos sinais na Ressonância Magnética e a presença ou ausência de rotura da PP comprovada cirurgicamente.

Observando as 34 roturas das PP diagnosticadas à cirurgia, somente uma apresentou intensidade de sinal e morfologia normal no estudo de Ressonância Magnética. Os 33 casos de rotura da PP remanescentes apresentaram sinais positivos na Ressonância Magnética, 13 (38,2%) apresentaram descontinuidade parcial ou completa com interposição líquida, 18 (54,5%) apresentaram afilamento sem descontinuidade nítida e 2 (5,9%) apresentaram luxação dorsal da falange proximal com não visualização da placa. Em 11 casos, não foi caracterizada rotura da PP durante a artroscopia, sendo que em 5 (45,5%) observou-se alteração de sinal da PP, mas sem alteração morfológica no estudo de RM; os outros 6 casos apresentaram sinal e morfologia normais.

Considerando-se a presença de qualquer alteração morfológica da PP como sinal para diagnóstico para rotura da PP, a Ressonância Magnética apresentou sensibilidade de 97,1%, especificidade de 100%, e acurácia de 97,8%. Separadas, porém, essas alterações morfológicas exibiram baixa sensibilidade e acurácia (tabela 2).

O desempenho diagnóstico de cada sinal indireto na RM para rotura da placa plantar é apresentado na tabela 2. O sinal do pseudoneuroma demonstrou melhor desempenho diagnóstico entre os sinais testados, apresentando alta sensibilidade (91,2%), especificidade (90,9%), e acurácia (91,1%) ($p<0,001$). A presença de anormalidade do complexo tendão interósseo-ligamento colateral demonstrou de moderado a bom desempenho diagnóstico para rotura da placa plantar, com sensibilidade de 67,7%, especificidade de 72,2%, e acurácia de 68,9% ($p=0,02$). Nenhum dos outros sinais indiretos alcançaram significância estatística (tabela 3).

Associação dos sinais na RM com rotura da placa plantar

Após aplicar regressão logística univariada, encontramos uma forte associação da presença do sinal do pseudoneuroma com rotura da PP, com uma razão de chances (OR) de 103,3 (95% IC, 9,6-1108,5; $p< 0,001$). Além disso, a presença de alteração do complexo tendão interósseo/ligamento colateral também demonstrou associação com rotura da PP (OR = 5,6 [95% IC, 1,2-25,2]; $p=0,26$). A presença de edema da medular óssea na falange proximal apresentou uma tendência à associação com rotura da PP ($p=0,061$). Não constatamos associação com significância estatística para os demais sinais avaliados (tabela 4).

Utilizando o teste de Mann-Whitney, verificamos que a distância PPFP medida na RM é significativamente maior nos casos com rotura de PP comprovada à cirurgia (0,23 +/- 0,07 cm) ($p=0,02$). Fazendo uma curva ROC, encontramos uma área sob a curva (A_z) igual a 0,735, significativamente maior que 0,5 ($p=0,02$) (Gráfico 1). Por conseguinte, a medida da distância PPFP é um bom preditor para rotura da PP. Procurando um valor de corte, encontramos como melhor valor a distância de 0,275 cm, observando que medidas iguais ou maiores que este valor, apresentam sensibilidade de 64,7%, especificidade de 90,9% e acurácia de 71,1% para presença de rotura da PP. Após aplicar análise de regressão logística univariada utilizando o valor de corte mencionado, encontramos associação significativa com rotura da PP (OR = 18,3 [95% IC, 2,9-161,0]; $p=0,009$). A análise de regressão logística multivariada, incluindo somente os sinais de RM com associação significativa no modelo univariado, demonstrou que o sinal do pseudoneuroma (OR = 117,6 [95% IC, 7,2-1931,9]; p=0,001) e a distância PPFP (OR = 22,0 [95% IC, 1,1-434,7]; p=0042) são os únicos sinais independentemente associados à rotura da placa plantar, comprovada à cirurgia.

Concordância interobservador

A concordância entre os dois radiologistas em relação aos sinais avaliados nos estudos de RM foi substancial de forma geral: morfologia e sinal da PP (média k, 0,68 +/- 0,85), sinal do pseudoneuroma (média k, 0,79 +/- 0,98), e anormalidade do complexo tendão interósseo/ligamento colateral (média k, 0,75 +/- 0,80). Para a medida da distância PPFP, houve concordância substancial quando aplicamos o coeficiente de correlação de Pearson (r = 0,815; p<0,001). Para todos os outros parâmetros, encontramos concordância excelente (k > 0,80).

Associação com neuroma intermetatarsal verdadeiro

Observando as 45 PP incluídas neste estudo, 11 foram classificadas como grau 0; 4 como grau I; 10 como grau II; 18 como grau III; e duas como grau IV. Somente nos casos de grau I a IV, a intervenção cirúrgica abordada permitiu a avaliação do espaço intermetatarsal. Desse modo, em 75,6% dos casos (34/45), conseguimos verificar a presença de neuroma intermetatarsal pela cirurgia.

Analisando os 34 casos, nos quais foi possível a avaliação do espaço interdigital, dois apresentaram neuromas interdigitais (figura 9), sendo que em somente um caso houve concomitância com sinal do pseudoneuroma no exame de RM (figura 10). Outras 11 neurotomias foram realizadas, mas estes procedimentos foram realizados em articulações MTF sem instabilidade e não incluídas no estudo.

Em 11 casos, o espaço interdigital não pôde ser avaliado. Entre estes, somente em um foi caracterizado o sinal do pseudoneuroma no estudo de RM. Este é o único caso no qual a concomitância com um neuroma verdadeiro não pôde ser verificada.

5 DISCUSSÃO

A RM com protocolo de rotina do antepé, realizada em aparelho de 1,5 T, mostrou-se útil para a avaliação de rotura da placa plantar em pacientes com quadro clínico indicando instabilidade da articulação MTF. Encontramos, ainda, sinais na RM que exibiram de bom a excelente desempenho para o diagnóstico de rotura da PP e associação significativa com rotura da PP quando utilizados achados cirúrgicos como referência. Os resultados de nosso estudo demonstraram que a presença de qualquer alteração da morfologia da placa plantar e de alguns sinais indiretos na RM retrataram de boa a excelente acurácia no que diz respeito ao diagnóstico de rotura da PP. A análise de regressão logística multivariada mostrou que o sinal do pseudoneuroma e a distância PPFP são fortemente e independentemente associados com a rotura da PP verificada à cirurgia.

A PP tem posição central em cada articulação MTF e com múltiplas fixações, incluindo os ligamentos colaterais, ligamentos intermetatarsais, tendões interósseos e a bainha fibrosa dos tendões flexores. A função primária da placa plantar é a estabilização estática da articulação MTF. A estabilização dinâmica é desempenhada pela musculatura intrínseca e extrínseca do pé, porém, a habilidade dessa musculatura para a estabilidade dinâmica depende da integridade da placa plantar [(31)]. Nos casos de suspeita de anormalidade ou lesão da placa plantar, é crucial a utilização de métodos não-invasivos, como a RM, para avaliar a integridade da PP.

A utilidade da RM na avaliação da integridade da PP foi primeiramente descrita por Yao et al.[(16,30)]. Valendo-se de achados cirúrgicos como padrão de referência, verificou-se que um alto sinal focal, nas sequências sensíveis a líquido, deveria ser interpretado como rotura da placa plantar [(16)]. Este achado é considerado como sinal direto de rotura da PP [(16,17)], representando uma descontinuidade parcial ou completa da PP com interposição líquida. Gregg et al. [(13,19)] analisaram o desempenho diagnóstico da RM e da ultrassonografia para a avaliação da rotura da PP em dois estudos. Primeiramente reportaram boa correlação entre os dois métodos com achados em espécimes de cadáveres [(19)] e, posteriormente, uma alta sensibilidade, mas com baixa especificidade para os dois métodos na detecção de roturas da PP, utilizando como referência os achados cirúrgicos [(13)]. Outros estudos recentes demonstraram bom desempenho diagnóstico da RM para detecção de rotura da PP, com sensibilidade variando entre 74% e 96% e especificidade variando entre 95% e 100% [20,31].

No presente estudo, somente 13 (38,2%) roturas da PP apresentaram descontinuidade com interposição líquida nos estudos de RM, logo, este sinal por si só teve baixa sensibilidade e acurácia. Dois pontos devem ser ressaltados para justificar essa discrepância com outros estudos prévios: primeiramente, todos os casos de instabilidade da articulação MTF em nossa amostra foram avaliados com artroscopia diagnóstica que, por sua vez, potencializou um maior número de pequenas roturas incluídas no estudo; em segundo lugar, os exames de RM do antepé, em nossa pesquisa, foram realizados com protocolo padrão, sem a utilização de protocolos com alta resolução utilizados em estudos prévios. Apesar do sinal direto de rotura da PP na RM ser aceito amplamente, não há consenso sobre outras alterações morfológicas que possam estar associadas à rotura da PP. Em nosso estudo, outros casos de rotura da PP verificados à cirurgia apresentaram-se como afilamento ou não-visualização da placa nos estudos de RM. Tais casos devem alertar os radiologistas sobre outras alterações morfológicas da PP apresentadas nos estudos de RM que possam representar rotura. Quando combinadas todas as alterações morfológicas em nossa amostra, a RM mostrou excelente desempenho diagnóstico.

Este é o primeiro estudo a avaliar o desempenho diagnóstico e a associação com outros sinais na RM – a maior parte sinais indiretos de estruturas que potencialmente possam acompanhar as roturas da PP – utilizando achados cirúrgicos como referência. Alguns desses sinais foram descritos recentemente [18] e podem ser úteis no diagnóstico de rotura da PP. O sinal do pseudoneuroma mostrou-se extremamente bom para a detecção de rotura da PP. Salientamos que o sinal do pseudoneuroma se dá pela alteração inflamatória pericapsular, que se estende junto ao trajeto do nervo digital próprio plantar adjacente, lembrando um neuroma, porém diferenciando-se do mesmo por ter, na maior parte das vezes, limites mal definidos e assimétricos em relação ao espaço intermetatarsal. Alterações do complexo tendão interósseo/ligamento colateral também podem ser úteis na detecção de rotura da PP. A medida quantitativa da distância PPFP é igualmente útil nesse diagnóstico, notando que valores maiores que 0,275 cm demonstraram bom desempenho diagnóstico para detecção de rotura da placa plantar. A análise de regressão logística multivariada revelou que o sinal do pseudoneuroma e a distância PPFP maior que 0,275 cm estão fortemente e independentemente associadas à rotura da PP verificada à cirurgia. Isto posto, esses achados podem ser úteis no diagnóstico de rotura da PP e devem ser cuidadosamente avaliados nos casos com suspeita clínica, especialmente quando o sinal direto clássico não pode ser identificado nos exames de RM de rotina.

Expomos algumas limitações que nosso estudo apresenta. Por ser um estudo retrospectivo, não foi possível o controle dos diferentes protocolos de RM utilizados. Além disso, não foi aplicado protocolo de alta resolução específico com área de interesse (FOV) pequena e focada para cada articulação MTF. As aquisições dos estudos de RM foram realizadas com parâmetros técnicos que abrangeram o antepé por inteiro, portanto, isto pode ter reduzido o desempenho diagnóstico de alguns sinais avaliados. Por outro lado, os protocolos utilizados representam, de forma melhor, a realidade de nossa prática clínica. Verificamos que existe um viés de seleção inerente à amostra, pelo fato de que somente pacientes indicados para a artroscopia foram incluídos no estudo e, assim, a prevalência de rotura da PP foi alta. Em relação à fibrose pericapsular que leva ao sinal do pseudoneuroma, não temos comprovação anatomopatológica da região pericapsular, pois, infelizmente, o material não foi coletado durante a intervenção cirúrgica. À época das cirurgias, não pensávamos em estudar a origem destas alterações, como a fibrose pericapsular. Apenas em um caso, no qual verificamos a presença do sinal do pseudoneuroma, não foi possível constatar a concomitância de um neuroma verdadeiro, sendo este fato uma limitação do estudo. Por fim, a avaliação do desempenho e da associação para alguns sinais da RM, principalmente alguns indiretos, foi limitada pela baixa prevalência em nossa amostra.

Enfatizamos, no entanto, que os achados no presente estudo, especialmente o sinal do pseudoneuroma e a distância PPFP, podem melhorar o desempenho dos exames de RM de rotina para a detecção de roturas da placa plantar, quando a descontinuidade com interposição líquida (o sinal clássico e direto) não for detectada.

6 CONCLUSÕES

Concluímos que a RM mostrou-se efetiva para o diagnóstico de rotura da placa plantar.

Considerando-se qualquer alteração morfológica da placa plantar, como sinal direto de rotura, a RM demonstrou bom desempenho diagnóstico. Verificamos, todavia, que os sinais diretos, quando avaliados isoladamente, demonstraram valor limitado.

Pudemos constatar que alterações morfológicas, como afilamento e não-visualização da PP nos exames de RM de rotina, podem representar rotura.

Os sinais indiretos, como o sinal do pseudoneuroma e a distância PPFP, foram úteis no diagnóstico de rotura da PP, com bom desempenho diagnóstico, bem como forte e independente associação.

7 ANEXOS

Quadro 1 – Protocolos de ressonância magnética (1.5T): parâmetros para todas as sequências. PI: ponderação intermediária; FOV: área de interesse; SE (spin-echo); ms: milissegundos; mm: milimetros.

	T1w coronal eixo curto	**PI coronal eixo curto**	**PI Sagital**	**PI axial eixo longo**
Sequência	SE	SE	SE	SE
Tempo de repetição (ms)	400-660	2320-3270	2600-3200	2000-3100
Tempo de eco (ms)	10-15	45-55	50-60	45-60
FOV	80-100	80-100	80-100	75-100
Espessura (mm)	3.0-4.0	3.0	3.0-4.0	3.0
Número de cortes	20-24	20-24	20-24	14-16
Matrix	350 - 512	350 - 512	350 - 512	350 - 512

Quadro 2 – Classificação anatômica da lesão da placa plantar.

Grau da lesão	Achados Anatômicos
0	Atenuação e/ou luxação da placa plantar
I	Rotura distal transversa (adjacente a inserção na falange proximal <50%); medial/central/lateral e/ou intrassubstancial
II	Rotura distal transversa (>50%); medial/central/lateral e/ou intrassubstancial
III	Rotura transversa e/ou longitudinal extensa (pode envolver os ligamentos colaterais)
IV	Rotura extensa com aspecto em “button hole” (luxação)

Tabela 1 – Características demográficas da amostra.

Variável		**N**
Idade		60,5 +/- 8,1 (34 – 75)
Sexo	Masculino	10
	Feminino	13
Articulação avaliada	II MTF	28
	III MTF	17
Presença de rotura da PP	Rotura ausente	11
	Rotura presente	34
Localização rotura da PP	II MTF	25
	III MTF	9

Tabela 2 – Sensibilidade, especificidade e acurácia dos sinais diretos na RM para diagnóstico de rotura da placa plantar.

Sinais diretos da PP na RM	Ausência de rotura da PP (n=11)	Rotura da PP (n=34)	p	Sensibilidade (%)	Especificidade (%)	Acurácia (%)
Rotura parcial ou descontinuidade completa da PP com interposição líquida			0,015	38,3	100	53,3
Presente	0	13				
Ausente	11	21				
Afilamento da inserção distal comparada a espessura da porção central			0,002	52,9	100	64,4
Presente	0	18				
Ausente	11	16				
Não visualização			0,023	5,9	100	28,9
Presente	0	2				
Ausente	11	32				
Qualquer alteração da morfologia da PP			<0,001	97,1	100	97,8
Presente	0	33				
Ausente	11	1				

Tabela 3 - Sensibilidade, especificidade e acurácia dos sinais indiretos na RM para diagnóstico de rotura da placa plantar.

Sinais diretos da PP na RM	**Ausência de rotura da PP (n=11)**	**Rotura da PP (n=34)**	**p**	**Sensibilidade (%)**	**Especificidade (%)**	**Acurácia (%)**
Luxação ou subluxação dorsal			0,06	26,5	100	44,4
Presente	0	9				
Ausente	11	25				
Sinal do pseudoneuroma			<0,001 [a]	91,2	90,9	91,1
Presente	1	31				
Ausente	10	3				
Edema da medular óssea da falange proximal			0,07	44,1	90,9	55,6
Presente	1	15				
Ausente	10	19				
Edema da medular óssea da cabeça do metatarso			0,1	20,6	100	44,4
Presente	0	7				
Ausente	11	27				
Derrame da MTF			0,69	91,2	9,1	71,1
Presente	1	31				
Ausente	10	3				
Tenossinovite dos flexores			0,13	32,4	97,9	46,7
Presente	1	11				
Ausente	10	23				
Alteração complexo tendão interósseo/ligamento colateral			0,02 [a]	67,7	72,7	68,9
Presente	3	23				
Ausente	8	11				
Calosidade do coxim gorduroso plantar [b]			0,29	54,4	63,6	56,8
Presente	4	18				
Ausente	7	15				
Busite subcapital			0,57	2,9	100	26,7
Presente	0	1				
Ausente	11	33				
Busite intermetatársica			0,81	67,6	36,4	60
Presente	7	23				
Ausente	4	11				
Atrofia e lipossubstituição parcial do músculo interósseo			0,18	14,7	100	35,6
Presente	0	5				
Ausente	11	29				

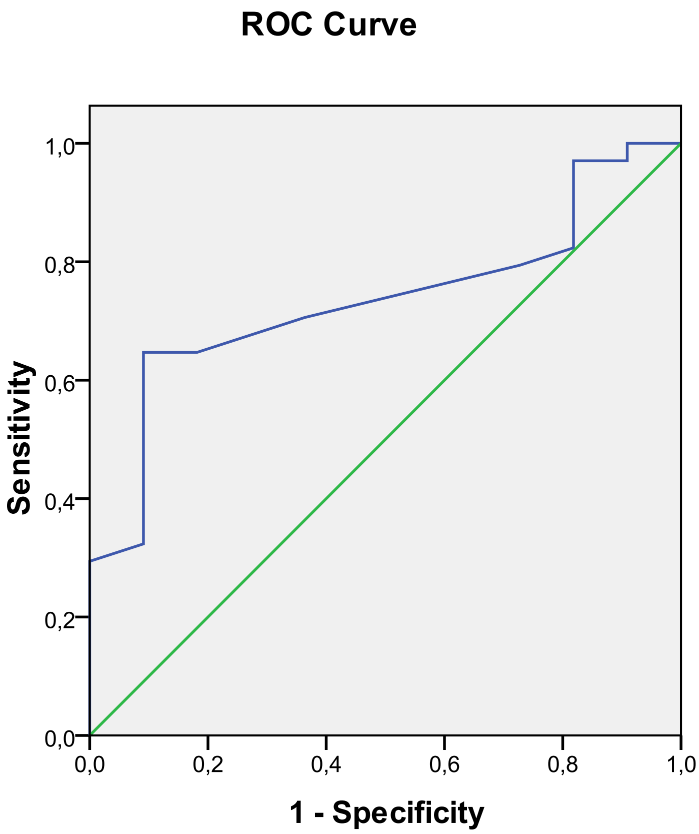
[a] Estatisticamente significante
[b] Um dos casos foi descartado devido a presença de artefato no coxim gorduroso plantar.

Tabela 4 -Associação entre sinais indiretos na RM com rotura da placa plantar na cirurgia.

Sinais indiretos da PP na RM	Ausência de rotura da PP (n=11)	Rotura da PP (n=34)	Odds Ratio (95% CI)	p
Sinal do pseudoneuroma			103,3 (9,6-1108,5)	<0,001 [a]
Presente	1	31		
Ausente	10	3		
Edema da medular óssea da falange proximal			7,9 (0,9-68,7)	0,061
Presente	1	15		
Ausente	10	19		
Tenossinovite dos flexores			4,8 (0,5-42,2)	0,159
Presente	1	11		
Ausente	10	23		
Alteração complexo tendão interósseo/ligamento colateral			5,6 (1,2-25,2)	0,026 [a]
Presente	3	23		
Ausente	8	11		
Calosidade do coxim gorduroso plantar [b]			2,1 (0,5-8,6)	0,301
Presente	4	18		
Ausente	7	15		
Bursite intermetatársica			1,2 (0,3 -5,0)	0,806
Presente	7	23		
Ausente	4	11		

[a] Estatisticamente significante

[b] Um dos casos foi descartado devido a presença de artefato no coxim gorduroso plantar.



Diagonal segments are produced by ties.

Gráfico 1 - Curva ROC da medida da distância PPFP

Area Sob a Curva

Area	Erro padrão	p	95% Intervalo de confiança para a área	
			Limite inferior	Limite superior
,735	,077	,020	,584	,887

Figura 1 – “Drawer test” ou teste da gaveta utilizado para a avaliação da instabilidade da articulação MTF, analisando o grau de subluxação sob estresse.

Figura 2 – Teste de apreensão plantar do dedo [27]

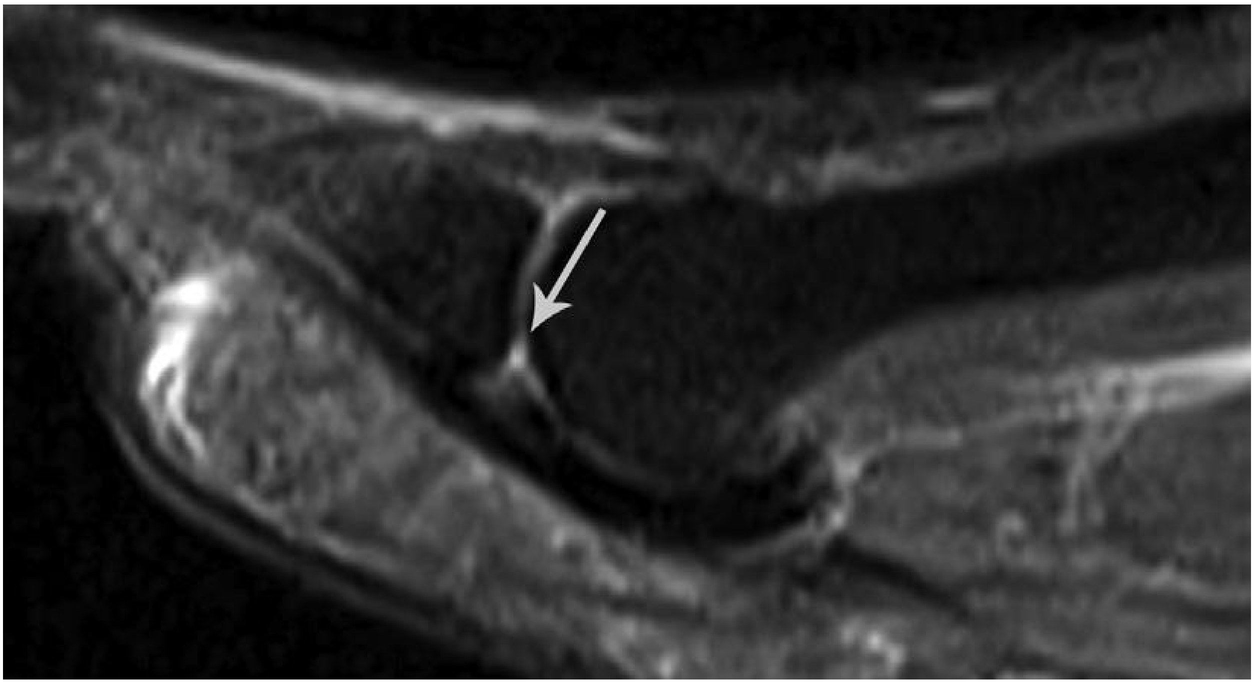


Figura 3 – Imagem no plano sagital ponderada em T2 com supressão de gordura de uma placa plantar normal. Nota-se uma área mal definida de alto sinal na região central junto a inserção da placa plantar compatível com recesso normal (seta).

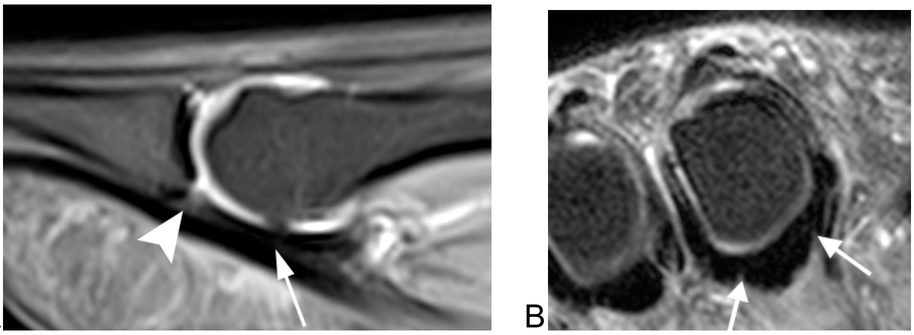


Figura 4 – Imagens no plano sagital (A) e coronal – eixo curto (B) com ponderação intermediária de placa planta normal. Placa plantar normal com formato em “C” e baixo sinal ao nível da cabeça do metatarso (seta, A e B). Um pequeno foco de alto sinal pode ser visto no plano sagital da linha média e não pode ser interpretado incorretamente como rotura (cabeça de seta, A).

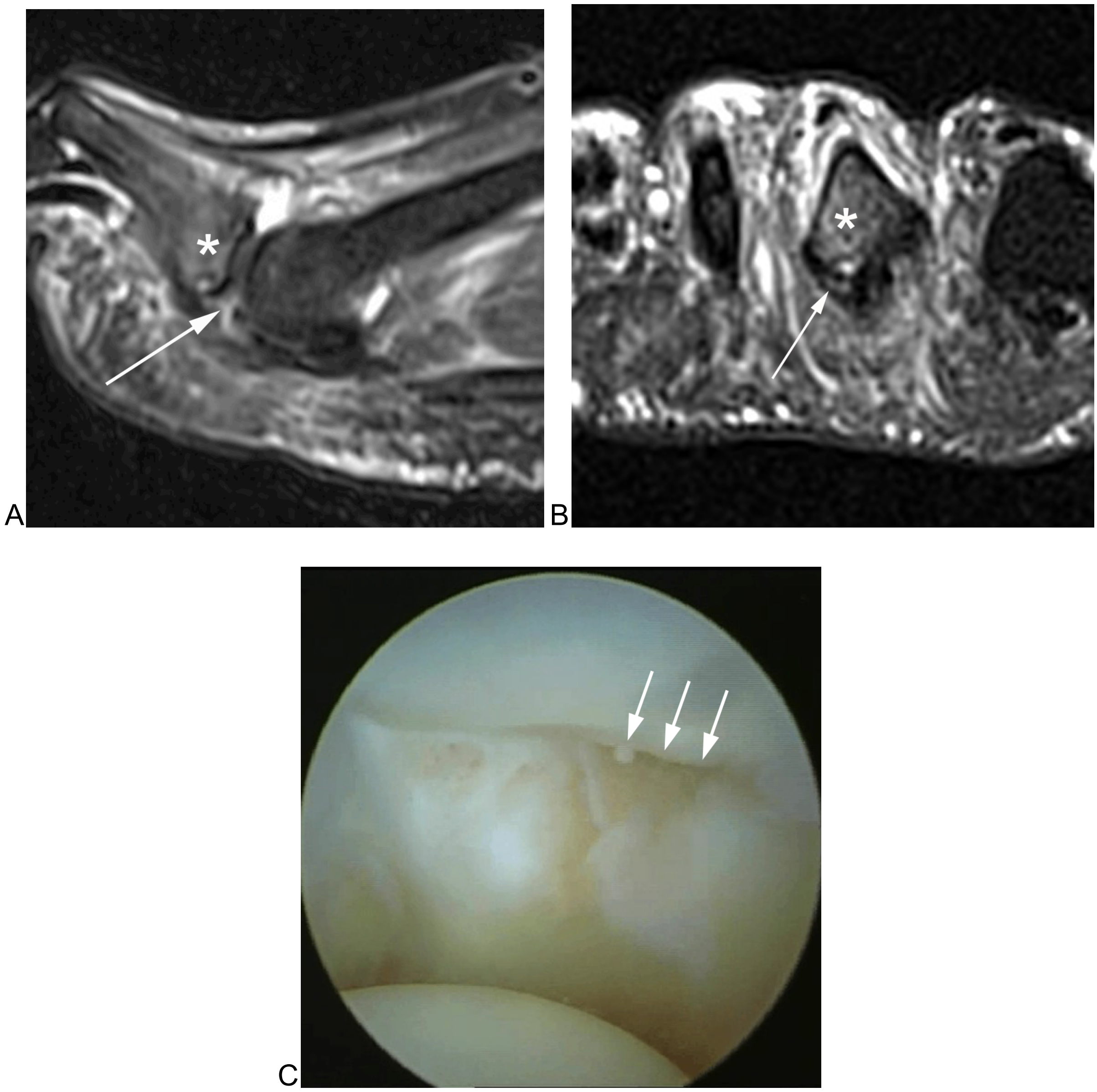


Figura 5 – Sinal direto clássico de rotura da placa plantar, apresentando-se como descontinuidade focal da placa plantar, com interposição líquida, caracterizada tanto no plano sagital (A) como no coronal – eixo curto (B) nas sequências com ponderação intermediária e com supressão de gordura (setas). Note a presença de edema da medular óssea na base da falange proximal (*), assim como a distensão líquida do recesso dorsal pelo derrame articular. Exame de artroscopia correspondente (C).

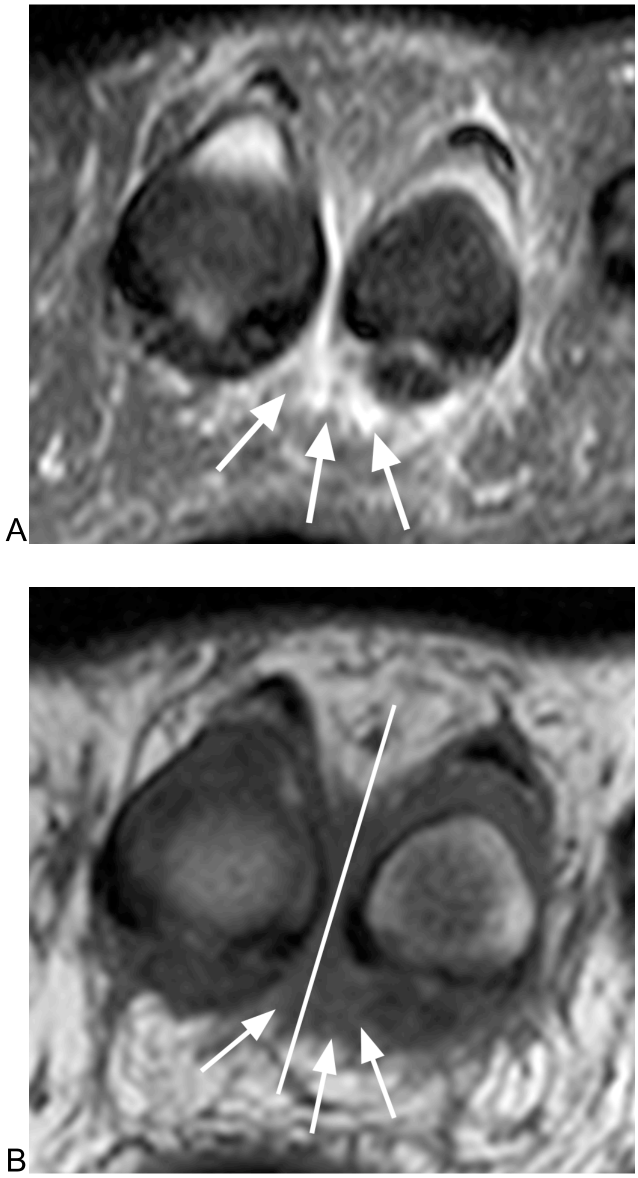


Figura 6 – Sinal do “pseudoneuroma”: alteração inflamatória de partes moles adjacente à inserção da placa plantar, estendendo-se no espaço intermetatarsal, com alto sinal nas imagens coronais – eixo curto na sequência com ponderação intermediária e com supressão de gordura (setas, A) e baixo sinal relativo nas imagens correspondentes ponderadas em T1 (setas, B). Note o aspecto nodular caracterizado no plano coronal nas sequências ponderadas em T1, mimetizando um “verdadeiro” neuroma interdigital. Porém, o pseudoneuroma é relativamente assimétrico em relação a linha vertical traçada pelo espaço intermetatarsal (B), além de apresentar limites imprecisos.

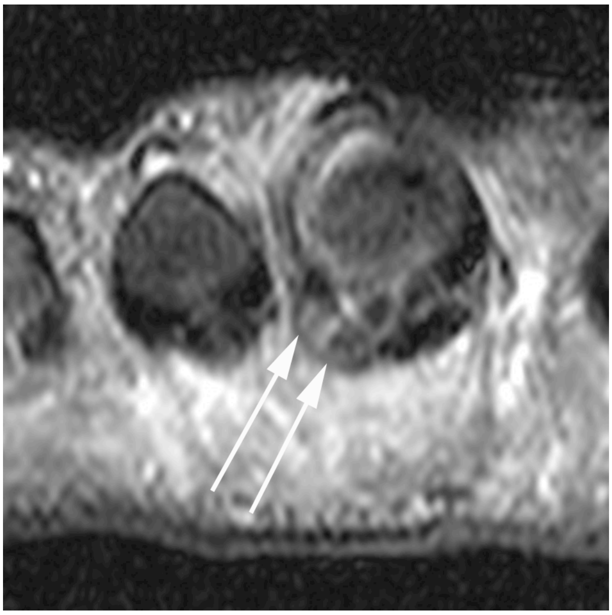


Figura 7 – Alterações morfológicas do complexo tendão interósseo/ligamento colateral associadas a rotura da placa plantar. O afilamento e alteração de sinal intrassubstancial podem ser caracterizados nesta imagem coronal – eixo curto na sequência com ponderação intermediária com supressão de gordura (setas).

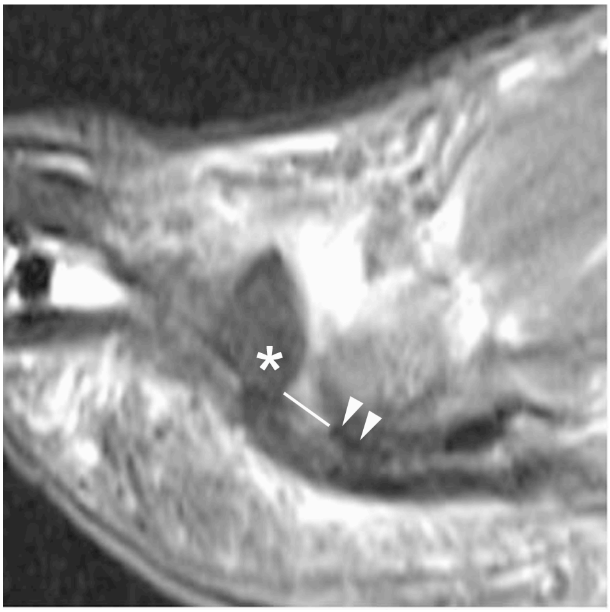


Figura 8 – Imagem sagital em sequência com ponderação intermediária, demonstrando a distância PPFP, localizada entre a margem distal da placa plantar (cabeça de setas) e a base da falange proximal (*), com indicado. Como referência para a medida desta distância, utilizou-se o plano sagital com o maior comprimento do tendão flexor. Note o espessamento e alteração de sinal do tendão flexor adjacente, assim como o derrame articular da metatarsofalângica.

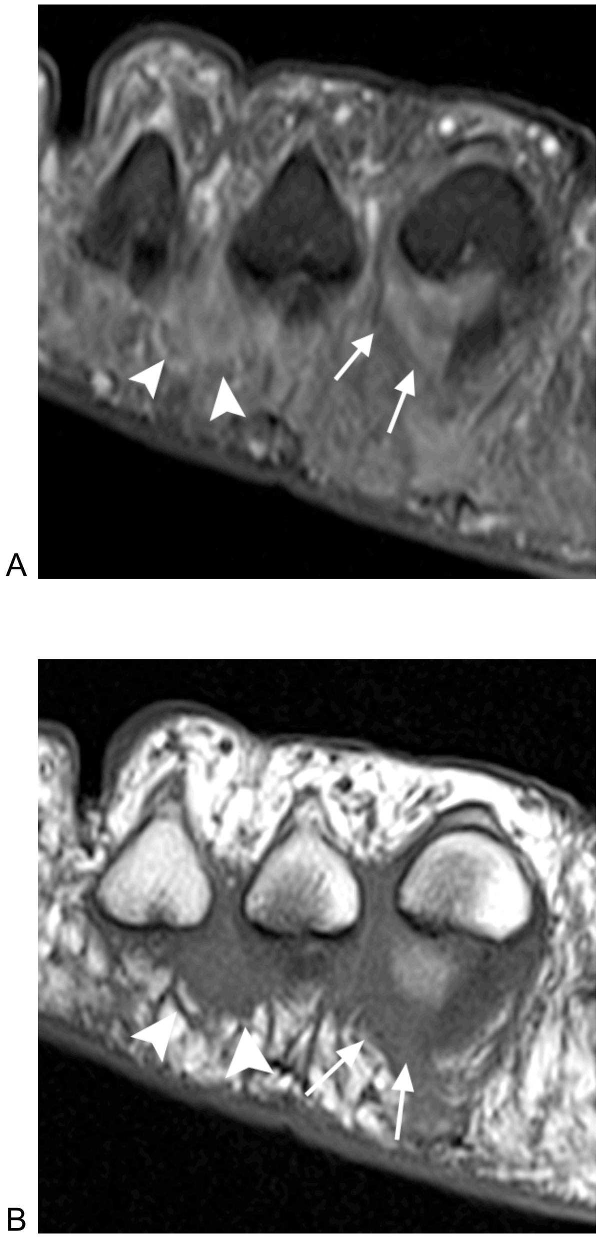
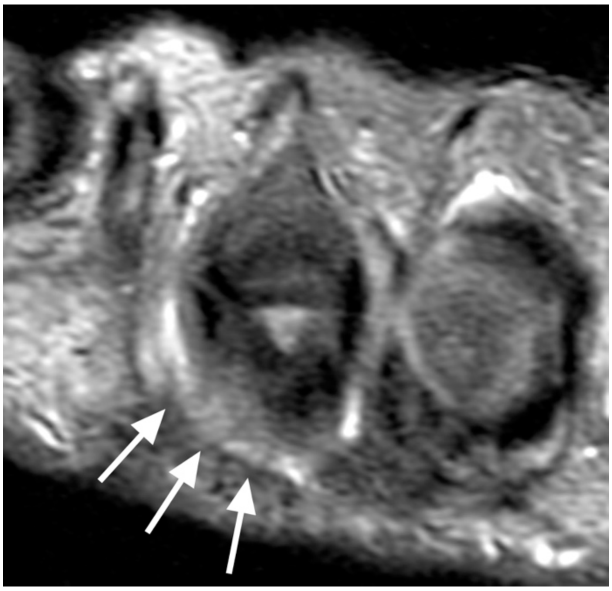


Figura 9 – Corte coronal no eixo curto em sequências em sequências com ponderação intermediária e com supressão de gordura (A) e ponderadas em T1 (B). Observa-se o sinal do pseudoneuroma no segundo espaço intermetatarsal e um neuroma verdadeiro no terceiro espaço. No terceiro espaço, nota-se imagem nodular e simétrica em relação à linha mediana do espaço intermetatarsal (cabeça de setas). Enquanto que no segundo espaço, nota-se imagem com limites imprecisos e assimétrica em relação a linha mediana do segundo espaço intermetatarsal (setas).



A

B

Figura 10 – Corte coronal no eixo curto em sequências em sequências com ponderação intermediária e com supressão de gordura (A) e ponderadas em T1 (B). Importante alteração inflamatória e fibrose pericapsular nas partes moles circunjacentes a inserção lateral da PP na base da falange proximal, estendendo-se no terceiro espaço, sendo difícil a definição de imagem nodular. A abordagem cirúrgica revelou neuroma interdigital do terceiro espaço e rotura da placa plantar em concomitância.

Aprovação Comitê de Ética

UNIVERSIDADE FEDERAL DE
SÃO PAULO - UNIFESP/
HOSPITAL SÃO PAULO

PARECER CONSUBSTANCIADO DO CEP

DADOS DO PROJETO DE PESQUISA

Título da Pesquisa: Plantar Plate Tear: Diagnostic Signs on MRI Images and Correlation with Arthroscopic Classification

Pesquisador: Andre Fukunishi Yamada

Área Temática:

Versão: 1

CAAE: 31619214.6.0000.5505

Instituição Proponente:

Patrocinador Principal: Financiamento Próprio

DADOS DO PARECER

Número do Parecer: 674.603

Data da Relatoria: 11/06/2014

Apresentação do Projeto:

A metatarsalgia é queixa frequente entre as alterações do antepé. Em 1986 Coughlin introduziu pela primeira vez o termo cross over toe descrevendo a deformidade e um algoritimo de tratamento, sendo esta alteração relacionada a instabilidade da metatarsofalângica, no caso específico, a do segundo raio. Porém a importância da placa plantar na fisiopatologia da instabilidade metatarsofalângica foi reconhecida e estudada mais recentemente.

As roturas das placas plantares ocorrem em dois grupos, o primeiro composto de adultos jovens com prática esportiva e o segundo, o mais numeroso e composto por mulheres sedentárias na 5a década de vida.

O diagnóstico é clínico e os métodos de imagem podem auxiliar nos casos duvidosos e para o planejamento terapêutico. Entres os métodos disponíveis,

os melhores métodos de imagem são a ultrassonografia e a Ressonância Magnética.

O objetivo do estudo é avaliar a acurácia dos sinais presentes nos estudos de Ressonância Magnética para deteção da rotura da placa plantar

Objetivo da Pesquisa:

Principal:

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Avaliar a acurácia dos sinais ao estudo de Ressonância Magnética para diagnóstico de rotura da placa plantar, tendo como padrão-ouro os achados do procedimento artroscópico.

Secundarios:

Avaliar a correlação da classificação das roturas pela ressonância magnética em relação com a classificação à artroscopia.

Melhorar o conhecimento da comunidade radiológica para o diagnóstico de rotura da placa plantar com estudos de Ressonância Magnética.

Avaliação dos Riscos e Benefícios:

risco mínimo, desconforto habitual

Comentários e Considerações sobre a Pesquisa:

Pesquisador: André Fukunishi Yamada

Disciplina/Depto: Departamento de Diagnóstico por Imagem Campus: São Paulo

Obj. Acadêmico: Doutorado

Patrocínio: Ausente

Orientador: Prof.Dr.Artur da Rocha Correa Fernandes

Chefe de Depto: Dr. Nitamar Abdalla

Estudo retrospectivo.

Análise dos prontuários e exames de Ressonância Magnética já realizados pelos pacientes.

MATERIAL E MÉTODOS

.1 População de estudo

Serão avaliados retrospectivamente 40 pacientes do ambulatório do grupo do pé do Departamento de Traumatologia e Ortopedia da UNIFESP com quadro clínico de instabilidade da metatarsofalângica dos pequenos dedos do pé. Serão avaliados os dados clínicos de prontuário e os estudos de Ressonância Magnética realizados por cada paciente.

.2 Amostra

Critérios de Inclusão

Pacientes com quadro de instabilidade metatarsofalângica ao exame físico que tenham realizado estudo de Ressonância Magnética e posterior intervenção cirúrgica.

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.3A valiações

Avaliação Clinica

O prontuário de todos os indivíduos será analizado quanto a parte clínica.

Avaliação por Imagem

Os estudos de Ressonância Magnética dos pacientes submetidos a artroscopia, serão avaliados por dois radiologistas com mais de 10 anos de experiência em consenso. Os seguintes parâmetros serão avaliados:

1) Distância de retração proximal da placa ao nível dos tendões flexores
2) Subluxação dorsal da falange proximal
3) Alteração inflamatória circunjacente a placa
4) Edema da medular óssea na base da falange proximal
5) Edema da medular óssea na cabeça do metatarso
6) Tecido hipertrófico proximal a rotura
7) Tenossinovite dos flexores
8) Alteração de sinal, afilamento e espessamento do tendão interósseo
9) Calosidade do coxim gorduroso plantar
10) Bursite subcapital
11) Busiteintermetatarsal
12) Lipossubstituição do ventre muscular do interósseo
13) Presença de neuroma interdigital

As roturas das placas, quando presentes, serão classificadas pela ressonância magnética, utilizando como base a classificação artroscópica proposta por Coughlin e Nery.

Será realizado estudo de concordância para a classificação das roturas pela ressonância magnética em relação a classificaçãoo determinada pela artroscopia.

Cada um dos sinais à ressonância serão avaliados quanto a sensibilidade e especificidade para a presença de rotura da placa plantar.

Considerações sobre os Termos de apresentação obrigatória:

Documentos obrigatórios apresentados (FOLHA DE ROSTO, PROJETO DE PESQUISA E TCLE)

Recomendações:

NADA CONSTA

Conclusões ou Pendências e Lista de Inadequações:

Sem inadequações

Situação do Parecer:

Aprovado

Necessita Apreciação da CONEP:

Não

Considerações Finais a critério do CEP:

O CEP informa que a partir desta data de aprovação, é necessário o envio de relatórios semestrais (no caso de estudos pertencentes à área temática especial) e anuais (em todas as outras situações). É também obrigatório, a apresentação do relatório final, quando do término do estudo.

SAO PAULO, 04 de Junho de 2014

Assinado por:
José Osmar Medina Pestana
(Coordenador)

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Artigo publicado com o material da tese apresentada

Musculoskeletal Imaging • Original Research

Second and Third Metatarsophalangeal Plantar Plate Tears: Diagnostic Performance of Direct and Indirect MRI Features Using Surgical Findings as the Reference Standard

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Caio Nery[5]
Daniel Baumfeld[6]
Tania Szejnfeld Mann[5]
Abdalla Y. Skaf[2]
Artur da Rocha Correa Fernandes[1]

OBJECTIVE. The objective of our study was to assess the diagnostic performance and associations of the direct and indirect MRI features of the metatarsophalangeal (MTP) joint that are thought to be related to tears of the plantar plate (PP) using surgical findings as the reference standard.

MATERIALS AND METHODS. We retrospectively included 23 patients with symptomatic instability of lesser MTP joints who had undergone preoperative 1.5-T MRI and surgical assessment. The MRI examinations were independently assessed by two musculoskeletal radiologists. Using the surgical data as the reference standard, we calculated the sensitivity, specificity, and accuracy of each MRI feature in the detection of PP tears. Multivariate logistic regression analysis was performed to identify which MRI features were independently associated with PP tears. Interobserver reliability was assessed using kappa statistics.

RESULTS. Forty-five lesser MTP joints were included. The presence of pericapsular fibrosis was highly sensitive (91.2%), specific (90.9%), and accurate (91.1%) for the diagnosis of PP tears. With a cutoff value of 0.275 cm, the PP–proximal phalanx distance had a sensitivity of 64.7%, specificity of 90.9%, and accuracy of 71.1% in diagnosing PP tears.

CONCLUSION. In patients with clinical features indicating lesser MTP joint instability, some direct and indirect MRI features exhibited good to excellent diagnostic performance in detecting the presence of PP tears.

Keywords: arthroscopy, imaging, metatarsophalangeal joint, MRI, plantar plate

DOI:10.2214/AJR.16.17276

Received August 24, 2016; accepted after revision January 27, 2017.

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WEB
This is a web exclusive article.

AJR 2017; 209:W1–W9

0361–803X/17/2092–W1

Pain at the lesser metatarsophalangeal (MTP) joints is a common complaint, and several causes have been described including trauma, instability, synovitis, and other inflammatory conditions [1, 2]. The lesser MTP joint of the second toe is often subject to instability and has been described as the most common site of dislocation in the forefoot [3]. The high incidence of second MTP instability in older women led Coughlin et al. [1] to hypothesize that the long-term use of high-heel shoes leads to chronic hyperextension forces, causing elongation of the plantar plate (PP). MTP instability may also affect young male athletes [1, 4]. The importance of the PP as a static restraint to lesser MTP joint subluxation and dislocation has been well documented, and injuries of the PP play a significant role in the development of sagittal plane MTP instability [5–8]. Despite the importance of the PP in terms of the stability of the lesser MTP joints, there is no consensus regarding treatment of PP injuries [9].

In the past, the imaging diagnosis of PP abnormalities consisted primarily of arthrography. More recently, MRI and ultrasound have been used [10–14]. Yao et al. [15] found that focal high signal intensity of the PP seen on fluid-sensitive sequences was consistent with PP tears, which were later confirmed by surgical assessment. This feature, which is considered to be a direct sign of a PP tear [16, 17], likely represents partial or complete discontinuity of the PP with fluid interposition. Other studies have tested MRI for detecting PP tears using direct signs, such as the one mentioned earlier, with some degree of discrepancy regarding specificity [12, 18, 19]. Some morphologic changes of the PP that could represent tears were not tested against a reference standard.

The performance of MRI in detecting PP tears should, ideally, be tested using the standard routine protocols for imaging the forefoot that are widely used in clinical practice. Furthermore, there are few studies available assessing the performance of the indirect signs or features on MRI, mainly those af-

TABLE 1: MRI Protocols (1.5 T): Parameters for All Sequences

Parameters	Coronal Short-Axis T1-Weighted SE Sequence	Coronal Short-Axis Intermediate-Weighted SE Sequence	Sagittal Intermediate-Weighted SE Sequence	Axial Long-Axis Intermediate-Weighted SE Sequence
TR (ms)	400–660	2320–3270	2600–3200	2000–3100
TE (ms)	10–15	45–55	50–60	45–60
FOV (mm)	80–100	80–100	80–100	75–100
Section thickness (mm)	3.0–4.0	3.0	3.0–4.0	3.0
No. of sections	20–24	20–24	20–24	14–16
Matrix	350–512 × 350–512	350–512 × 350–512	350–512 × 350–512	350–512 × 350–512

Note—All sequences were performed with fat suppression. SE = spin-echo.

fecting the surrounding structures at the MTP joint, that could be related to PP tears. Umans and colleagues [17, 20] sought to identify both the qualitative and quantitative features on unenhanced MRI that might improve diagnostic detection of PP tears. However, these studies lack surgical data as the reference standard.

The aim of our study was to assess the diagnostic performance of the direct and indirect MRI features hypothesized to be related to PP tears, as well as their associations with PP tears, using surgical findings as the reference standard.

Materials and Methods

Patients

This study was approved by the ethics committee at Federal University of São Paulo, and requirement for informed consent was waived. We performed a retrospective search of the patient database of the orthopedics department in our institution limited to the period from January 2009 to July 2012. Only patients who met the following criteria were included in the study: clinical features indicating instability of a lesser MTP joint, such as a history of progressive misalignment of toes or the presence of a gap between the second and third toes, and with some degree of instability as indicated by a positive drawer test [21]; patients with diagnostic arthroscopy of the lesser MTP joint; and patients with a preoperative 1.5-T MRI examination of the forefoot. We excluded patients with a history of MTP joint surgery and those with inflammatory arthropathies, peripheral neuropathy, diabetes, and peripheral vascular disease. Ultimately, 45 lesser MTP joints of 23 patients were included in the study cohort. All patients had some degree of joint instability at clinical examination. The indication for arthroscopy was based on clinical examination, as described in the literature [22, 23]. MRI was requested to confirm the presence and severity of PP lesions before arthroscopy was performed.

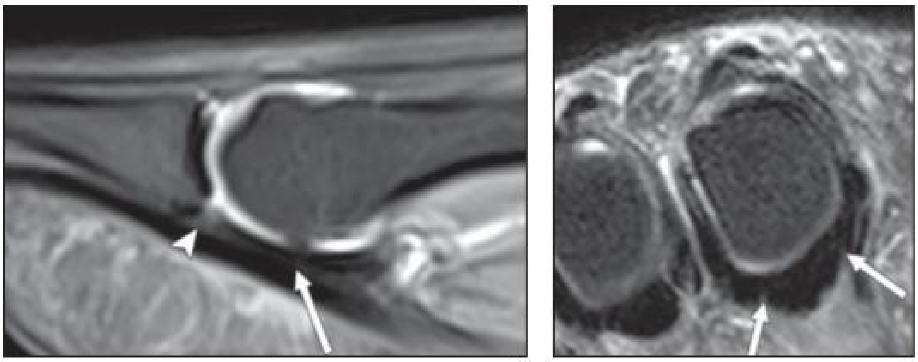
MRI Protocol

All MRI examinations of the forefoot were performed using 1.5-T units (Signa Excite HD, GE Healthcare; Achieva, Philips Healthcare; or Aera, Siemens Healthcare) at three radiology departments. For all examinations, a dedicated standard extremity coil was used, and the subject was supine with the forefoot in a neutral position for scanning. The standard protocol comprised T1-weighted spin-echo (SE) images in the coronal short axis and intermediate-weighted SE images with fat suppression in the axial long axis, coronal short axis, and sagittal plane. The parameters for all the sequences are presented in Table 1.

MRI Assessment

Two musculoskeletal radiologists who had 12 and 11 years of experience, respectively, at the time of the study independently assessed the MRI examinations. The radiologists were unfamiliar with the clinical data, the initial MRI reports, and the arthroscopic results. Only the second and third MTP joints were assessed. The MRI examinations were presented randomly and did not contain any patient information.

Ten MRI features that have been hypothesized to be helpful in diagnosing PP tears were evaluated. First, the PP morphology and signal intensity (direct features) were evaluated. The normal PP is described as having low signal intensity on both T1- and T2-weighted images [18, 24] (Fig. 1). The following PP changes were assessed on both sagittal and coronal intermediate-weighted fat-suppressed images and were considered as PP tears: the presence of PP thinning, nonvisibility of PP, and partial or complete discontinuity of the PP with fluid interposition [15, 16] (Fig. 2). The presence of signal-intensity changes in a PP with normal morphology was not considered to be a PP tear. Thinning of the distal insertion of the PP was compared with the thickness of its midportion: The distal insertion had to be thicker than or at least equal in thickness to its midportion to be considered normal [8]. The nonvisibility of the PP



A B

Fig. 1—34-year-old woman with normal plantar plate (PP). **A** and **B**, Sagittal (**A**) and coronal short-axis (**B**) intermediate-weighted images of normal PP. Normal intact PP has C shape and exhibits low signal intensity at level of metatarsal head (*arrows*). Bright signal intensity (*arrowhead*, **A**) is visible in sagittal midline plane and should not be mistaken for tear.

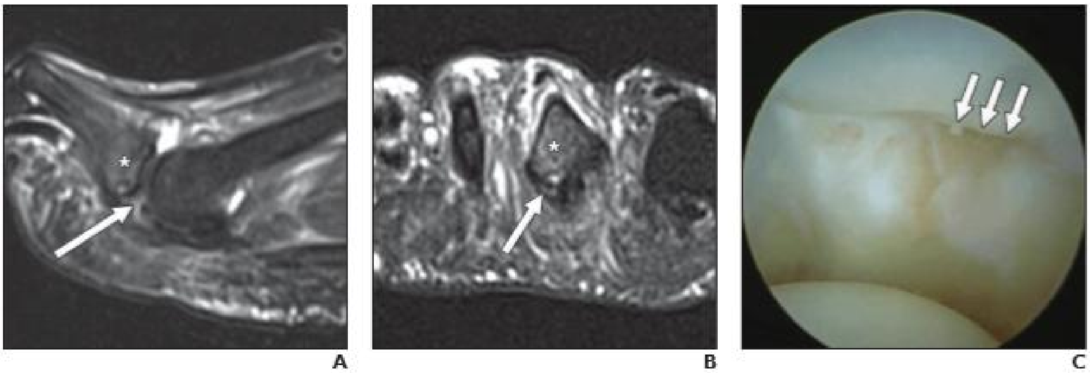


Fig. 2—54-year-old woman with plantar plate (PP) tear.
A and **B**, Sagittal (**A**) and coronal short-axis (**B**) intermediate-weighted images obtained with fat suppression show classic direct MRI feature of PP tear: focal discontinuity of PP with fluid interposition (*arrows*). Note presence of bone marrow edema at base of proximal phalanx (*asterisks*) and dorsal metatarsophalangeal joint effusion.
C, Image obtained during arthroscopic examination shows PP tear (*arrows*).

was considered in cases of dorsal dislocation of the proximal phalanx with relevant PP deviation.

All of the MRI features discussed next were considered as potential indirect signs of PP tears.

Second, dislocation or subluxation of the MTP joint, which is characterized by a loss of congruence with any degree of dorsal dislocation of the proximal phalanx, was assessed on sagittal images.

Third, bone marrow edema was evaluated separately at the sites of PP insertion (i.e., metatarsal head or the base of the proximal phalanx [Fig. 2]). Bone marrow edema was defined as ill-defined areas of high signal intensity on intermediate-weighted fat-suppressed images.

Fourth, the presence or absence of pericapsular fibrosis (i.e., the "pseudoneuroma" sign) was noted. The presence of pericapsular inflammatory changes around the PP, extending into the adjacent intermetatarsal space, creates a pattern that often mimics a true intermetatarsal neuroma, especially on coronal short-axis T1-weighted images. Unlike a true neuroma, pericapsular fibrosis [17, 22, 25] accompanying PP tears exhibits a nodular mostly ill-defined pattern; it is relatively asymmetric at the intermetatarsal space. Umans et al. [17] described pericapsular fibrosis as having an eccentric pericapsular location and as appearing as high or intermediate signal intensity on intermediate-weighted fat-suppressed images (Fig. 3). Due to frequent misdiagnosis of pericapsular fibrosis as neuroma, we decided to call this finding the "pseudoneuroma" sign.

Fifth, flexor digitorum tenosynovitis was defined as any amount of fluid within the tendon sheath adjacent to the MTP joint.

Sixth, the interosseous tendon–collateral ligament complex was assessed to determine if the tendon-ligament complex was thinned or thickened and whether it was displaying signal-intensity changes on both coronal short-axis T1- and intermediate-weighted fat-suppressed images (Fig. 4). We also evaluated for the presence of interosseous muscle atrophy on coronal short-axis T1-weighted images.

Seventh, the presence of plantar fat-pad callosities was assessed on both coronal short-axis T1- and intermediate-weighted fat-suppressed images as a nodular pattern with low signal intensity on both sequences at the level of the metatarsal heads. The presence of subcapital bursitis was assessed at the same anatomic site as well-defined fluid collections exhibiting low signal intensity on T1-weighted images and high signal intensity on intermediate-weighted fat-suppressed images.

Eighth, intermetatarsal bursitis was assessed and was considered present if any fluid distention was seen at the intermetatarsal bursae.

Ninth, the presence of an MTP joint effusion was assessed on sagittal intermediate-weighted fat-suppressed midline images.

Tenth, the PP–proximal phalanx distance was quantitatively assessed. It was defined as the distance between the distal margin of the PP and the base of the proximal phalanx in centimeters and was measured on sagittal intermediate-weighted fat-suppressed midline images displaying the adjacent flexor tendon (Fig. 5).

Diagnostic Arthroscopy and Open Surgery

Arthroscopic examinations were performed by one senior orthopedic surgeon who had 30 years of experience in foot and ankle surgery at the time of the study. The surgeon was aware of the results

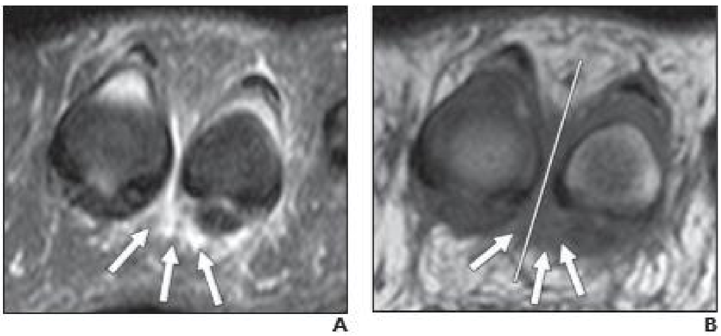


Fig. 3—48-year-old woman with plantar plate (PP) tear.
A and **B**, "Pseudoneuroma" sign appears as inflammatory changes of soft tissues adjacent to PP insertion that extend into intermetatarsal space and exhibit high signal intensity (*arrows*, **A**) on coronal short-axis intermediate-weighted image with fat suppression (**A**) and relatively low signal intensity (*arrows*, **B**) on corresponding T1-weighted image (**B**). Note nodular pattern depicted on coronal T1-weighted image is mimicking appearance of true interdigital neuroma. However, unlike neuroma, pseudoneuroma has asymmetric position with respect to vertical line (**B**) drawn through intermetatarsal space and also has ill-defined contours.

TABLE 2: Plantar Plate (PP) Lesion Anatomic Grading System

Injury Grade	Anatomic Findings
0	PP or capsular attenuation with or without dislocation
I	Transverse distal tear adjacent to insertion into proximal phalanx (≤ 50%); medial, central, or lateral area with or without midsubstance tear
II	Transverse distal tear (> 50%); medial, central, or lateral area with or without midsubstance tear
III	Transverse tear, extensive longitudinal tear, or both; may involve collateral ligaments
IV	Extensive tear with button hole (dislocation)

of the preoperative MRI examination but was not aware of the retrospective assessment of the MRI examinations performed by both radiologists. The arthroscopic procedure used two dorsal portals (medial and lateral) placed over the MTP joint with a 2.7-mm, 30° arthroscope. The central and distal portions of the PP were inspected and palpated with a probe, and the PP tears were assessed. The surgical reports were retrospectively evaluated for documentation of the presence of a PP tear. All the reviewed reports included PP morphology assessment and made clear whether the PP was torn (partially or completely) or not.

All PP lesions were classified according to an anatomic grading system that has been described in the literature [3, 13, 26] (Table 2). A specific procedure according to each grade of PP lesion was performed. For grade 0 and I lesions, radiofrequency shrinkage of the PP was performed. For grade I lesions, a Weil osteotomy was also performed. For grade II and III lesions, a direct open repair of the PP was followed by reinsertion. For grade IV lesions, a Weil osteotomy combined with a flexor-to-extensor tendon transfer was performed [27, 28].

When open repair or a Weil osteotomy was performed, we could assess the intermetatarsal space. Thus, when grade I, II, III, and IV lesions were present, we could evaluate for the presence of an intermetatarsal neuroma.

Statistical Analysis

Using the surgical data as the reference standard for whether PP tears were present or absent, we assessed the diagnostic performance of each of the MRI features and determined the sensitivity, specificity, and accuracy of each. In addition to assessing the performance of each direct MRI feature, we considered the presence of any morphologic change of the PP (i.e., nonvisualization, thinning, or discontinuity) as a sign of a PP tear. A chi-square test and a Fisher exact test were used for comparison of categoric variables, and a Mann-Whitney test was used to examine potential continuous predictors of PP tears (i.e., PP–proximal phalanx distance). ROC curve analysis was performed to evaluate the diagnostic performance of the PP–proximal phalanx distance for discriminating a PP tear, and the area under the ROC curve was calculated. In addition, multivariate logistic regression analysis with a forward stepwise method for the selection of significant variables was performed to determine which MRI features were associated with a PP tear diagnosed at surgery; the multivariate analysis included only the MRI features that showed statistical significance after univariate logistic regression analysis. Significance was defined as a $p < 0.05$. Comparisons of all PP–proximal phalanx distance measurements of both readers were performed by linear regression analysis using the Pearson correlation coefficient. Interobserver reliability for all MRI features was evaluated with Cohen kappa statistics. Statistical analyses were performed using a software package (SPSS for Macintosh [Apple Computer], version 22.0, IBM).

Results

Study Population and Surgical Findings

From the study group of 23 patients (13 women, 10 men), 45 lesser MTP joints (28 of the second toe and 17 of the third toe) were included. The mean patient age was 60.5 ± 8.1 (SD) years (age range, 34–75 years). The mean time frame between preoperative MRI and surgical assessment was 16.1 ± 5.9 weeks (range, 3.9–26.5 weeks). Of the 45 PPs evaluated arthroscopically, 34 (75.6%) had tears and 11 (24.4%) had no tear. Twenty-five PP tears affected the second MTP joint, and nine affected the third MTP joint.

Diagnostic Performance of MRI Features

Tables 3 and 4 show the MTP joints categorized by MRI feature and the presence

TABLE 3: Sensitivity, Specificity, and Accuracy of Direct MRI Features in the Detection of Plantar Plate (PP) Tears

Direct MRI Features of PP	No PP Tear at Surgery ($n = 11$)	PP Tear at Surgery ($n = 34$)	p	Sensitivity (%)	Specificity (%)	Accuracy (%)
Partial or complete discontinuity of the PP with fluid interposition			0.015	38.2	100	53.3
Present	0	13				
Absent	11	21				
Thinning of distal insertion of PP compared with thickness of midportion			0.002	52.9	100	64.4
Present	0	18				
Absent	11	16				
Nonvisualization of PP			0.023	5.9	100	28.9
Present	0	2				
Absent	11	32				
Any change in morphology of PP			< 0.001	97.1	100	97.8
Present	0	33				
Absent	11	1				

TABLE 4: Sensitivity, Specificity, and Accuracy of Indirect MRI Features in the Detection of Plantar Plate (PP) Tears

Indirect MRI Features of PP Tears	No PP Tear at Surgery (n = 11)	PP Tear at Surgery (n = 34)	p	Sensitivity (%)	Specificity (%)	Accuracy (%)
Dorsal dislocation or subluxation			0.06	26.5	100	44.4
Present	0	9				
Absent	11	25				
Pseudoneuroma sign			< 0.001[a]	91.2	90.9	91.1
Present	1	31				
Absent	10	3				
Proximal phalanx bone marrow edema			0.07	44.1	90.9	55.6
Present	1	15				
Absent	10	19				
Metatarsal head bone marrow edema			0.10	20.6	100	44.4
Present	0	7				
Absent	11	27				
MTP joint effusion			0.69	91.2	9.1	71.1
Present	1	31				
Absent	10	3				
Flexor tenosynovitis			0.13	32.4	97.9	46.7
Present	1	11				
Absent	10	23				
Interosseous tendon–collateral ligament complex abnormality			0.02[a]	67.7	72.7	68.9
Present	3	23				
Absent	8	11				
Fat-pad callosity[b]			0.29	54.4	63.6	56.8
Present	4	18				
Absent	7	15				
Subcapital bursitis			0.57	2.9	100	26.7
Present	0	1				
Absent	11	33				
Intermetatarsal bursitis			0.81	67.6	36.4	60.0
Present	7	23				
Absent	4	11				
Interosseous muscle atrophy and fatty infiltration			0.18	14.7	100	35.6
Present	0	5				
Absent	11	29				

Note—MTP = metatarsophalangeal.
[a]Statistically significant.
[b]One of the cases was discarded due to the presence of artifact in the plantar fat pad.

or absence of surgically proven PP tears. Of 34 PP tears diagnosed at surgery, only one (2.9%) exhibited normal signal intensity and morphology on MRI. Of the remaining 33 MTP joints with PP tears at surgery and positive findings on MRI, 13 (38.2%) showed partial or complete discontinuity of the PP with fluid interposition, 18 (54.5%) showed thinning of the PP without visible discontinuity, and two (5.9%) showed dorsal dislocation of the proximal phalanx with nonvisualization of the PP. Of the 11 PPs without tears observed during arthroscopy, five (45.5%) exhibited signal-intensity changes but normal morphology on MRI; the remaining six cases displayed normal signal intensity and morphology. Considering the presence of any change in PP morphology, MRI had a sensitivity of 97.1%, specificity of 100%, and accuracy of 97.8% for diagnosing PP tears. Separately, however, these features exhibited lower sensitivities and accuracies (Table 3).

The diagnostic performance of each indirect MRI feature assessed for PP tears is presented in Table 4. The pseudoneuroma sign exhibited the best performance among the indirect features tested and was highly sensitive (91.2%), specific (90.9%), and accurate (91.1%) ($p < 0.001$). An interosseous tendon–collateral ligament complex abnormality exhibited moderate to good diagnostic performance for PP tears with a sensitivity of 67.7%, specificity of 72.7%, and accuracy of 68.9% ($p = 0.02$). None of the other indirect MRI features reached statistical significance (Table 4).

Association of MRI Features With Plantar Plate Tears

After applying univariate logistic regression, we found that the presence of the pseudoneuroma sign was strongly associated with PP tears, with an odds ratio (OR) of 103.3 (95% CI, 9.6–1108.5; $p < 0.001$). Furthermore, the presence of an interosseous tendon–collateral ligament complex abnormality was also associated with PP tears (OR = 5.6 [95% CI, 1.2–25.2]; $p = 0.026$). A trend toward an association with PP tears was found for proximal phalanx bone marrow edema ($p = 0.061$). No statistically significant associations were found for the other MRI features assessed (Table 5).

Using the Mann-Whitney test, we found that the PP–proximal phalanx distance measured on MRI is significantly higher for MTP joints with PP tears at surgery (mean, 0.38 ± 0.19 cm) than for MTP joints without PP tears at surgery (0.23 ± 0.07 cm) ($p = 0.02$). Using an ROC curve to identify a cutoff value for the PP–proximal phalanx distance, we found this MRI feature to be a good predictor for PP tears (area under the ROC curve [A_z] = 0.735; $p = 0.020$). A cutoff value of 0.275 cm for the PP–proximal phalanx distance for PP tears diagnosed at surgery gave a sensitivity of 64.7%, specificity of 90.9%, and accu-

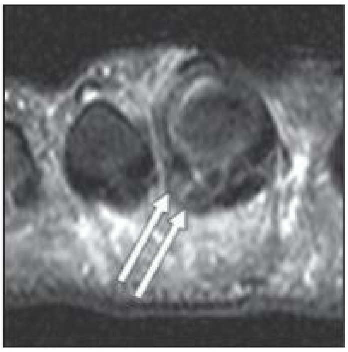


Fig. 4—Interosseous tendon–collateral ligament complex morphology changes associated with plantar plate (PP) tear in 54-year-old man. Thickening and intrasubstance signal-intensity changes of complex (*arrows*) are seen on this coronal short-axis intermediate-weighted fat-suppressed image.

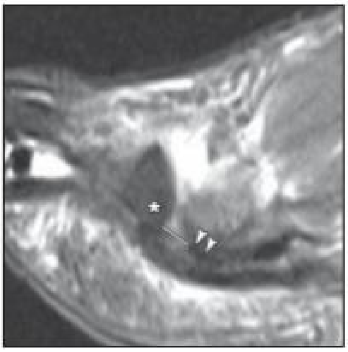


Fig. 5—Sagittal intermediate-weighted image of 49-year-old man shows plantar plate (PP)–proximal phalanx distance (*line*), which is located between distal margin of PP (*arrowheads*) and base of proximal phalanx (*asterisk*). Whole length of flexor tendon was used as reference to assess this measurement. Note thickening and signal-intensity changes of adjacent flexor tendon as well as metatarsophalangeal joint effusion.

TABLE 5: Association Between Indirect MRI Features With Plantar Plate (PP) Tears at Surgery

Indirect MRI Features of PP	No PP Tear at Surgery ($n = 11$)	PP Tear at Surgery ($n = 34$)	Odds Ratio (95% CI)	p
Pseudoneuroma sign			103.3 (9.6–1108.5)	< 0.001[a]
Present	1	31		
Absent	10	3		
Proximal phalanx bone marrow edema			7.9 (0.9–68.7)	0.061
Present	1	15		
Absent	10	19		
Flexor tenosynovitis			4.8 (0.5–42.2)	0.159
Present	1	11		
Absent	10	23		
Interosseous tendon–collateral ligament complex abnormality			5.6 (1.2–25.2)	0.026[a]
Present	3	23		
Absent	8	11		
Fat-pad callosity[b]			2.1 (0.5–8.6)	0.301
Present	4	18		
Absent	7	15		
Intermetatarsal bursitis			1.2 (0.3–5.0)	0.806
Present	7	23		
Absent	4	11		

Note—These results are from univariate logistic regression. Due to insufficient numbers, the other MRI features that we assessed could not be tested for associations using logistic regression models.
[a]Statistically significant.
[b]One of the cases was discarded due to the presence of artifact in the plantar fat pad.

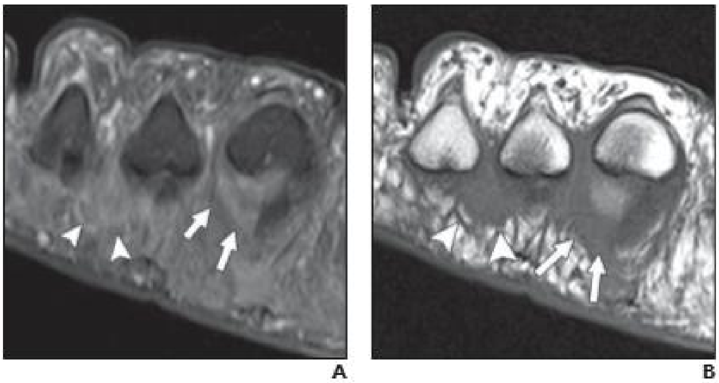


Fig. 6—Concurrent "pseudoneuroma" sign on second intermetatarsal space and true neuroma on third intermetatarsal space in 56-year-old woman.
A and **B**, Coronal short-axis T1-weighted images. Nodular pattern (*arrowheads*) and symmetry in relation to intermetatarsal midline are seen in third intermetatarsal space, whereas ill-defined margins and asymmetry in relation to midline (*arrows*) are seen in second intermetatarsal space.

racy of 71.1%. After a univariate logistic regression analysis was applied using the same cutoff value, the PP–proximal phalanx distance showed a significant association with PP tears (OR = 18.3 [95% CI, 2.9–161.0]; $p = 0.009$). A multivariate logistic regression analysis including only the MRI features that showed significant associations on univariate models revealed that the pseudoneuroma sign (OR = 117.6 [95% CI, 7.2–1931.9]; $p = 0.001$) and the PP–proximal phalanx distance (OR = 22.0 [95% CI, 1.1–434.7]; $p = 0.042$) were the only features independently associated with PP tears at surgery.

Interobserver Reliability

Reliability between both radiologists regarding the MRI features assessed was substantial overall: PP morphology and signal intensity (mean κ, 0.68 ± 0.85), pseudoneuroma sign (mean κ, 0.79 ± 0.98), and interosseous tendon–collateral ligament complex abnormality (mean κ, 0.75 ± 0.80). For the PP–proximal phalanx distance, there was a substantial agreement when applying the Pearson correlation coefficient ($r = 0.815$; $p < 0.001$). For all other parameters, we found excellent agreement ($\kappa > 0.80$).

Association With True Intermetatarsal Neuroma

Of the 45 PP injuries in the study group, 11 were grade 0 lesions; four, grade I lesions; 10, grade II lesions; 18, grade III lesions; and two, grade IV lesions. Therefore, in 75.6% (34/45 lesions), we could verify the presence of an intermetatarsal neuroma.

Among the 34 cases for which it was possible to evaluate the interdigital space, two presented interdigital neuromas (Fig. 6) and the pseudoneuroma sign occurred in concomitance in only one case (Fig. 7). Another 11 neurectomies were performed, but these procedures were performed in MTP joints without instability and were not included in the study. None of these cases had the pseudoneuroma sign detected on the MRI studies.

In 11 cases, it was not possible to evaluate the intermetatarsal space. Among these cases, the pseudoneuroma sign was identified in only one. This case was the only case in which the concomitance of a true neuroma could not be surgically verified.

Discussion

We found that routine MRI of the forefoot at 1.5 T is useful in the assessment of PP tears when performed in patients with clinical features indicating lesser MTP instability. We also found that some MRI features exhibit good to excellent diagnostic performance for PP tears and significant associations with PP tears when using surgical data as the reference standard. In particular, our results showed that the presence of any morphologic change in the PP and the presence of some indirect features exhibited good to excellent accuracy in the diagnosis of PP tears. Multivariate logistic regression analysis showed that the pseudoneuroma sign and the PP–proximal phalanx distance are strongly and independently associated with PP tears detected at surgery.

The PP has a central location in each MTP joint, with multiple attachments including the collateral ligaments, intermetatarsal liga-

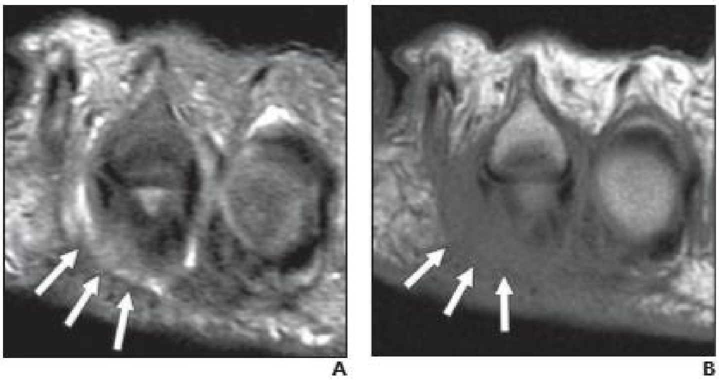


Fig. 7—**A** and **B**, Coronal short-axis intermediate-weighted fat-suppressed (**A**) and coronal short-axis T1-weighted (**B**) images show inflammatory and pericapsular fibrosis changes of soft tissues adjacent to PP insertion extending into third intermetatarsal space (*arrows*).

ments, interosseous tendons, and the fibrous sheath of the flexor tendons. Static stabilization of the MTP joint is the primary function of the PP, and dynamic stabilization is provided by the extrinsic and intrinsic musculature of the foot. However, the ability of these muscles to stabilize the joint relies on the integrity of the PP [29]. When an abnormality or injury of the PP is suspected, it is crucial to rely on noninvasive methods, such as MRI, to assess the integrity of the PP.

Yao and colleagues [15, 24] first described the usefulness of MRI in the evaluation of PP integrity. Using surgery as a reference, they found that focal high signal intensity of the PP visualized on fluid-sensitive sequences should be interpreted as a PP tear [15]. This finding is considered to be a direct sign of a PP tear [15, 16], representing partial or complete discontinuity of the PP with fluid interposition. Gregg and colleagues [12, 18] assessed the performance of MRI and ultrasound in the evaluation of PP tears in two studies. They reported, first, a good correlation between both methods and direct inspection of cadaveric feet [18] and, second, a high sensitivity but low specificity of both methods for the detection of PP tears with surgical correlation [12]. Other recent studies showed good diagnostic performance of MRI in the detection of PP tears, with sensitivities ranging from 74% to 96% and specificities ranging from 95% to 100% [19, 30].

In the current study, only 13 (38.2%) PP tears showed discontinuity of the PP with fluid interposition on MRI, so this sign by itself had poor sensitivity and accuracy. Two points must be considered regarding this discrepancy between our results and those of previous studies: First, all cases of instability of the MTP joint in our sample were evaluated using diagnostic arthroscopy, which potentially increased the number of small tears included in our study group. Second, in our study, the MRI examinations of the forefoot were performed using standard protocols, not high-resolution dedicated protocols as were used in some previous studies. Although the direct signs of PP tears on MRI are widely accepted, there is no consensus regarding other morphologic changes of the PP that could be related to tears. In the current study, other cases of torn PPs at surgery exhibited thinning or nonvisualization of the PP on MRI. These cases should alert radiologists that other morphologic changes in the PP seen on MRI may represent tears. When combining all of the morphologic changes seen in our sample, MRI showed excellent diagnostic performance.

This study is the first to assess the diagnostic performance and the associations of other MRI features—most of which are indirect signs related to other structures that may potentially accompany PP tears—with surgical findings as the reference standard. Some of these features were described recently [17] and may be useful in diagnosing PP tears. The pseudoneuroma sign was extremely good for the detection of PP tears. Changes at the interosseous tendon–collateral ligament complex may also be useful for the detection of PP tears. We also found that the quantitative measurement of the PP–proximal phalanx distance is useful, and values greater than 0.275 cm exhibited good diagnostic performance in the detection of PP tears. Multivariate logistic regression analyses revealed that the pseudoneuroma sign and a PP–proximal phalanx distance greater than 0.275 cm are strongly and independently associated with PP tears detected at surgery. Thus, these findings may be useful in diagnosing PP tears and must be carefully assessed in clinically suspect cases, especially when the classic direct sign cannot be detected at routine MRI.

This study had some limitations. First, because of its retrospective nature, we could not control for differences in MRI protocols. Also, we did not apply high-resolution protocols with small FOVs focused on each MTP joint; the MRI acquisitions were conducted with technical parameters to cover the entire forefoot. This may have reduced the diagnostic performance of some features. However, the protocols we used better represent the reality of clinical practice. Second, there was an inherent bias in that only patients referred to arthroscopy were included in this study and the prevalence of PP tears was high, introducing an additional selection bias. Regarding the pericapsular fibrosis that leads to the pseudoneuroma sign, we do not have anatomopathologic analysis of the pericapsular region because, unfortunately, the material was not collected at the surgical interventions. At the time of the surgeries, it was not our idea to study the origin of these alterations as pericapsular fibrosis. In only one case that showed the pseudoneuroma sign, the concomitance of a true neuroma could not be verified and this is a limitation of the study. Finally, the assessment of performance and of associations for some of the MRI features, mainly some of the indirect signs, was limited by their low prevalence in our sample.

Our study showed that other morphologic changes such as thinning or nonvisualization of the PP at routine MRI may also represent PP tears. Furthermore, other MRI features such as the pseudoneuroma sign and the PP–proximal phalanx distance were useful for the diagnosis of PP tears, with good diagnostic performance and strong and independent associations. Assessment of these features may increase the performance of routine MRI for the detection of PP tears whenever discontinuity, the classic direct sign, cannot be detected.

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AMERICAN ORTHOPAEDIC FOOT & ANKLE SOCIETY

Foot & Ankle International
34(3) 315–322
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DOI: 10.1177/1071100712470918
http://fai.sagepub.com

MRI Evaluation of the MTP Plantar Plates Compared With Arthroscopic Findings: A Prospective Study

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Abstract

Background: Instability of the lesser metatarsophalangeal (MTP) joints has been widely reported and plantar plate insufficiency is a key part of this pathologic process. The diagnosis is made clinically but can be aided by imaging studies, particularly magnetic resonance imaging (MRI); however, the sensitivity and accuracy of this method compared to direct visualization of these lesions has not yet been established, nor has interobserver accuracy of MRI been assessed for evaluation of plantar plate pathology. In this study, our goals were to identify the accuracy of the MRI in describing plantar plate tears when compared to direct arthroscopic visualization using an anatomic grading system and to test the influence of an anatomic grading system in the accuracy of the MRI readings.
Methods: We evaluated the clinical exam, MRI scans, and arthroscopic findings of 35 patients with lesser MTP instability.
Results: Using an anatomic grading system, a distinct improvement in the radiological evaluation and interpretation occurred. Knowledge of the pattern of plantar plate tears by a radiologist enabled them to locate and describe the type of tears of the plantar plate on the MRI. The amount of training and the experience of the radiologist were also important factors in our study. The senior radiologists had much better levels of accuracy (Group A, 77.0%; Group B, 88.5%) than less experienced radiologists.
Conclusion: Prior knowledge of the pathophysiology and morphological types of lesions of the plantar plates was helpful for accurate identification and description of the tears by the radiologist.
Level of Evidence: Level II, prospective comparative study.

Keywords: MRI, MTP plantar plate, arthroscopy

Instability of the lesser metatarsophalangeal (MTP) joint has been widely reported,[1,2,4,6-11,13,14,28] and plantar plate insufficiency may indeed be the central cause of this pathologic condition.[1,3,14,16,22,23,28,29,31] The plantar plate is centrally located on the plantar aspect of the lesser metatarsophalangeal joint, with multiple important attachments. This fibro-cartilaginous structure has an average length of 16 mm, width of 9 mm, and is 1.8 mm thick.[14,22,35] The proximal origin of the plantar plate attaches loosely to the metatarsal shaft, just proximal to the metaphysis of the metatarsal head. Distally, the plantar plate inserts firmly and directly into the plantar lip of the proximal phalanx, just distal to the articular surface.[1,11,20,31] Dysfunction of the plantar plate can lead to major morbidity.[11,16,18,28,38] Previous reports[23,26,38] indicate that frequent use of high-heeled or ill-fitting footwear is a major predisposing factor for lesser metatarsophalangeal joint instability. The instability pattern has been classified with clinical staging and anatomic grading of plantar plate tears.[11,15,28]

The diagnosis of instability is made clinically but can be improved by imaging studies.[17,19,35,37] Radiographic evaluation, arthrography, sonography, and magnetic resonance imaging (MRI) have been used previously to assess the plantar plate.[17,27,35] Radiographs may be helpful in evaluating the magnitude of the MTP joint angular deformity, assessing joint congruity, ascertaining the presence of MP joint arthritis, and determining the metatarsal parabola.[25]

Arthrography of the second MTP joint has been described by several authors[26,27,29] and may be helpful in assessing capsular deterioration or instability of the lesser MTP joint.

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Dissemination of contrast into the tendon sheath can indicate a plantar plate rupture. [7,11,26,29]

Yao et al[37] and others[19,24,27,35] have reported that magnetic resonance imaging is useful and reliable in the diagnosis of plantar plate abnormalities and may improve the specificity of thorough history and clinical examination. MRI is a noninvasive alternative to arthrography and helps to differentiate articular and nonarticular diagnoses.[17,19,24,27,35,37]

A study of the metatarsophalangeal joint in cadavers using MRI arthrography described excellent anatomic detail of the metatarsophalangeal joint capsule and plantar plate.[19] Gregg et al reported the sensitivity of MRI to be up to 87%, and this finding can be upgraded with the use of intra-articular contrast or an MRI combined with sonographic evaluation.[17,18]

In the current study, our primary purpose was to identify the accuracy of MRI in describing plantar plate ruptures when compared to direct arthroscopic visualization using an anatomic grading system.[11,28] A secondary purpose of this study was to test the influence of an anatomic grading system in the accuracy of the MRI readings. While it has been used in open procedures, it has not been used to define arthroscopic lesions or used to compare arthroscopic findings with the MRI images.[11,28] In a previous work we demonstrated that each type of tear should be treated differently with different results.[11,28]

We hypothesized that previous knowledge of the anatomic grading system would help the clinician to treat the plantar plate lesion. The evaluation using a noninvasive method such as MRI may influence therapeutic decisions, allowing more precise preoperative planning for each type of tear.

Material and Methods

Patients

Between January 2009 and June 2010, 35 symptomatic patients with instability of lesser MTP joints were prospectively studied and treated with preoperative MRI, arthroscopic evaluation, and open surgical treatment of 62 lesser metatarsophalangeal joints. All patients that had complaints of forefoot pain and some element of lesser MTP joint deformity and instability were enrolled in the study. Instability was noted by history with a progressive malalignment of the toe, gap between the second and third toes, or medial, lateral, or dorsal deviation of the lesser toes, and all patients had some degree of clinical instability on examination. All patients that had a positive drawer sign then had a preoperative MRI examination. The positive drawer test was related to a pathological laxity of the joint when compared to the opposite foot or adjacent MTP joints associated with pain.

Excluded from the study were 7 patients with previous MTP joint surgery, inflammatory arthropathies, peripheral neuropathy, diabetes, or peripheral vascular disease. Twenty-eight patients with instability of 55 lesser metatarsophalangeal joints met the inclusion criteria and were enrolled in this study. We received approval by our institutional ethics and research board.

Twenty patients were female (71%) and 8 were male (29%). The average age at the time of the surgery was 61 years (range, 43-75). Eight patients had bilateral involvement (16 feet) and 20 had a unilateral deformity (20 feet). In this study we focused on the evaluation and treatment of the second, third, and fourth metatarsophalangeal joints. Of the 36 feet, we counted 55 affected and 53 unaffected lesser MTP joints. Of the 55 affected MTP joints, the second was involved in 35 joints (64%), the third 18 joints (32%), and the fourth 2 joints (4%).

MRI Imaging

All patients had an MRI. Some MRI studies were obtained at outside hospitals prior to the referral to our facility, however, all magnets used in the MRI studies were 1.0 to 1.5T, and MRI scans were performed without contrast or an arthrogram.

We asked 4 radiologists to analyze the images: 2 attending staff radiologists, with more than 10 years of MRI experience, and 2 radiology residents in training. None were informed of the surgical findings or of each other's impressions. They were divided in 2 groups (Group A and Group B) matching 1 attending radiologist and 1 resident in each group.

Each radiologist received a set of CDs with the MRI images of all patients but were unaware of the pathology. The 2 radiologists in Group A were presented a report sheet for them to describe the types of plantar plate lesions (morphology, length, width) for them to record upon. The radiologists in Group B were presented a drawing with the Anatomical Grading System (Appendix 1). Both groups were asked to describe and report the pattern of the plantar plate lesion.

The reports of Group A were analyzed by one of the authors (TSM), who reviewed the descriptions of the radiologists and then classified each lesion according to the Anatomical Grading System.

The radiologists in Group B reported the classification of each lesion according the Anatomical Grading System presented[11,28] (Appendix 1).

Arthroscopy

All patients underwent diagnostic MTP joint arthroscopy by the senior author (CN). Only the symptomatic lesser MTP joints were evaluated.

The arthroscopic procedure used 2 dorsal portals (medial and lateral) placed over the MTP joint, and a 2.7 mm, 30 degree arthroscope was used. With light manual traction applied to the digit, the central and distal portions of the plantar plate were visualized, inspected, and palpated with a probe (see Figure 1).

At the arthroscopy the author reported the type of plantar plate tear using the same grading system previously mentioned.[11,28]

Figure 1. Arthroscopy of the MTP joints: A, dorsal medial and lateral portals for the 2nd MTP joint of the right foot; B, positioning of the 2.7 mm, 30 degree arthroscope in the medial dorsal portal of the 2nd MTP; C, arthroscopic image of a normal plantar plate obtained with the same positioning showed in B.

There were 9 MTP joints classified as Grade 0, 8 as Grade 1, 5 as Grade 2, 27 as Grade 3, and 6 as Grade 4. For the purpose of this study the arthroscopic findings and the definition of the plantar plate lesion using this method were considered as the landmark for the MRI observations.

Statistical Analysis

We compared the findings of the 2 groups of radiologists and the diagnostic arthroscopy. Lesions detected by the surgeon during the arthroscopic procedure but not by the radiologist were counted as missed.

The number of radiologists in each group was determined by statistical criteria and was considered sufficient to permit statistical conclusions.

To test the correlation and reliability between the observations of the radiologists on the plantar plate lesions, we used the Correlation Kappa Test.

The Weighted Kappa Test was used in the correlation analysis of the MRI observations and the arthroscopic findings. The sensitivity and specificity were also determined using this same test. We used a 95% confidence interval in the calculation of the interrater agreement statistic Kappa (alpha error = 0.05).

Results

Using MRI, radiologists were able to detect plantar plate pathology at the lesser MTP joints. Additionally, prior knowledge of the anatomic grading system increased the identification and accuracy of the description of the pathology by both the resident and attending radiologists.

Table 1 and Figure 2 display the correlation interval values for each observer between plantar plate lesions identified on MRI and those described at the time of the arthroscopy. When given the anatomic grading system before the MRI, evaluations by both the resident and attending radiologists were nearly twice as likely to have a positive correlation with arthroscopic findings as their uninformed counterparts.

Table 1. Correlation Between Magnetic Resonance Imaging (MRI) and Arthroscopic Findings (Kappa) by Observer

		95% Confidence Interval	
Radiologist	Kappa	Lower	Upper
Attending radiologist, Group A	.328	.168	.447
Attending radiologist, Group B	.693	.585	.800
Resident, Group A	.152	.033	.272
Resident, Group B	.305	.147	.443

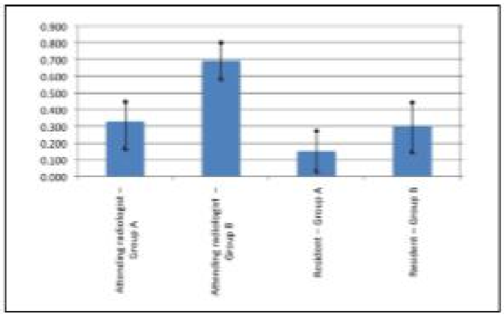


Figure 2. Correlation intervals values for each observer. The error bars represents 95% confidence intervals of the mean.

Table 2. Sensitivity, Specificity, Predictive Values (positive and negative) and Missed Lesion by Observer

Radiologist	Sensitivity 95% Confidence Interval	Specificity 95% Confidence Interval	Balanced Accuracy	Missed Lesions	Positive Predictive Value 95% Confidence Interval	Negative Predictive Value 95% Confidence Interval
Attending radiologist (Group A)	29% (17%, 42%)	97% (92%, 99%)	77%	43%	80% (56%, 94%)	75% (68%, 82%)
Attending radiologist (Group B)	96% (87%, 99%)	81% (72%, 87%)	89%	7%	69% (57%, 79%)	98% (93%, 99%)
Resident (Group A)	14% (6%, 26%)	97% (93%, 99%)	56%	52%	73% (39%, 94%)	72% (64%, 78%)
Resident (Group B)	36% (23%, 50%)	90% (84%, 95%)	63%	37%	62% (43%, 78%)	76% (68%, 82%)

In Table 1, we present the results of the statistical analysis of the correlation between the MRI and arthroscopic findings (Kappa) relative to each observer, which shows the improvement in the agreement in Group B. In Group A, both the senior radiologist and the resident had a fair correlation between MRI images and arthroscopic findings.

Table 2 demonstrates the results of sensitivity, specificity, and missed lesions as well as the positive and negative predictive values of each observer. Again, the low sensitivity obtained by the attending radiologist and the resident of Group A contrasts with high level of sensitivity observed in Group B, specifically by the attending radiologist (96.2%).

Considering the results in Table 2, we calculated the balanced accuracy for each observer. The attending radiologists had better accuracy: Group A, 77.0%; Group B, 88.5%. The resident observers had less accuracy: Group A, 56.0%; Group B, 63.0%. The total accuracy for the radiologists of Group B (who were knowledgeable of the anatomic pattern of plantar plate tears) was higher than those for Group A (who had no notion of the patterns of plate tears). The same pattern was found in the analysis of missed lesions.

Discussion

The plantar plate is a fibro-cartilaginous structure that provides MTP joint stability.[5,11,14,15,20,22,28] The contribution of the plantar plate to metatarsalgia can be assessed and diagnosed with physical examination.[12,23,26,28,33,34] At the onset of plantar plate deterioration, there are no digital deformities and the joint instability can be very difficult to detect.[11,26] As the condition progresses, separation of the toes can occur, with eventual progression to a multiplanar deformity.[21,30,32,38] The progressive instability of the MTP joint can result from different patterns of tears of the plantar plate.[5,36]

Each type of plantar plate tear has a particular treatment and different postoperative results.[11,28] With that we believe that the previous knowledge of the Anatomic Grading System helps the foot and ankle surgeon to do more precise preoperative planning.

The MRI appearance of the normal plantar plate has previously been reported as a smooth, curvilinear, low-signal structure abutting the plantar aspect of the metatarsal head and attaching to the proximal phalangeal base adjacent to the joint surface.[19,35,37] In the sagittal plane, proton density–weighted sequences depict the normal plantar plate as a uniform hypo-intense structure inserting onto the proximal phalanx. The plantar plate cradles the metatarsal head, providing a matching articular surface. The hypo-intense flexor tendon, coursing beneath the plantar plate, appears to blend with it, making the cleavage plane indiscernible. The origin of the plantar plate at the level of the metatarsal shaft just proximal to the flare of the metatarsal head is poorly delineated from the flexor tendon. The insertional fibers are well delineated when compared to the articular cortex of the proximal phalanx.[19]

Coronal proton density–weighted and T2-weighted fat-suppressed images of the plantar plate reveal a C-shaped low-signal-intensity band centrally beneath the metatarsal heads. On the plantar surface, a central groove on the plantar plate accommodates the flexor tendons. The collateral ligaments blend with the plantar plate at the base of the proximal phalanx. On T2-weighted fat-suppressed images, the plantar plate appears as a uniformly hypo-intense structure. The insertional fibers are also hypo-intense adjacent to the articular cortex of the proximal phalanx. This latter finding is important in deciphering the normal plantar plate. In its distal central portion, it is possible to see a hyperintense area of 1 to 2 mm that represents the recess for the flexor tendons[19,35,37] (Figure 3A–3D).

The MRI findings of plantar plate pathology have also been well described. Increased signal intensity in the sagittal and coronal planes and the identification of a discontinuity of the plantar plate at the base of the proximal phalanx are the most common images.[35,37] Tears appear hyperintense on both proton density–weighted and T2-weighted fat-suppressed images.

Retraction of a tear is best assessed on the sagittal images. The coronal images assist in demarcating its location in relation to the collateral ligaments and the flexor tendon. The tears are best evaluated through the coronal plane,

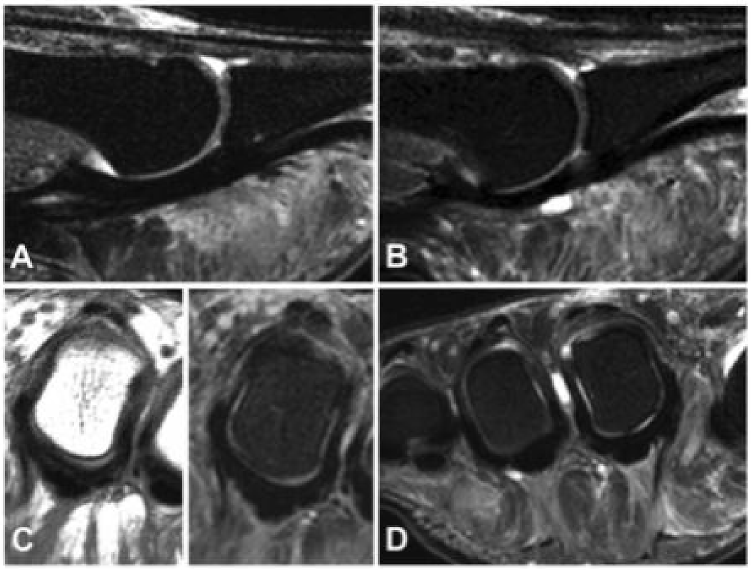


Figure 3. MRI appearance of the normal MTP plantar plate: A, smooth, curvilinear, low-signal structure abutting the plantar aspect of the metatarsal head and attaching to the proximal phalangeal base adjacent to the joint surface; B, the hypo-intense flexor tendon, coursing beneath the plantar plate appears to blend with it, making the cleavage plane indiscernible. The origin of the plantar plate at the level of the metatarsal shaft just proximal to the flare of the metatarsal head is poorly delineated; C, coronal proton density–weighted and T2-weighted fat-suppressed images of the plantar plate reveal a C-shaped low-signal-intensity band centrally beneath the metatarsal heads. On the plantar surface, a central groove on the plantar plate accommodates the flexor tendons; D, the collateral ligaments blend with the plantar plate at the base of the proximal phalanx.

as it is easy to detect all portions of the plate at the base of the distal proximal phalanx. It is more difficult to visualize tears in the sagittal plane as the MRI slices are not always well aligned with the metatarsal longitudinal axis.[35] Partial- or full-thickness tears can be assessed in both planes.

With a Grade 0 lesion, there is attenuation of the plantar plate, which is seen as laxity of the plantar plate during the arthroscopic visualization. In this grade, there was not a partial- or full-thickness plate tear; only an attenuation of the plate could be seen using both methods (arthroscopy and MRI). Partial transverse distal ruptures of either the medial or lateral aspects of the distal plantar plate were classified as Grade 1 tears. Complete distal transverse tears were classified as Grade 2 tears. When a complete tear extended proximally into the medial, lateral, or central aspects of the plantar plate, it was classified as Grade 3 tear. Extensive disruption of the plantar plate (manifested as a cruciform hyperintensity in the center of the plantar plate) resembled a "plus" shape, and this was classified as a Grade 4 tear (Figure 4A–4D). However, cases of advanced plate degeneration could be difficult to distinguish from frank rupture.[17]

To enhance the diagnosis of this condition, MRI is recommended, but the sensitivity and specificity of this method compared to direct visualization has not yet been established.[19,24,25,35,37] Gregg et al[19] reported in 2006 that the MRI can detect 71% of the full-thickness tears and 25% of the partial-thickness tears occurring at the plantar plate insertion onto the base of the proximal phalanx. With chronic tears, the plantar plate can be retracted, and the tear is easily diagnosed because of the low signal intensity. This may be one of the factors that can explain the low sensitivity on MRI findings.[17,24,27] In this study, a tear was defined only when there was hyperintensity of the signal in the plantar plate with thickening. We believe plantar plate pathology represents a continuous process of degeneration beginning with a thickening phase due to disorganization of the collagen fibers followed by an attenuation phase and then finally a rupture occurs.

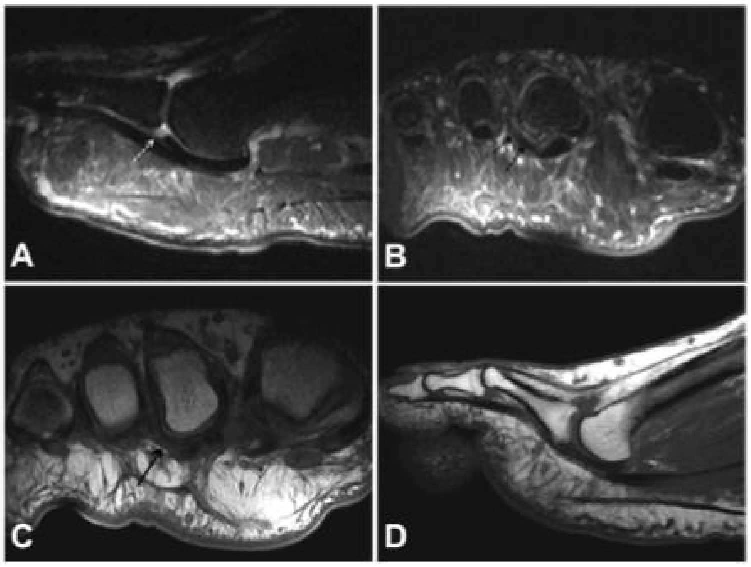


Figure 4. MRI appearance of the abnormal MTP plantar plate: Increased signal intensity in the sagittal and coronal planes and the identification of a discontinuity of the plantar plate at the base of the proximal phalanx are the most common images, A and B (arrows); C, tears (solid black arrow) appear hyperintense on both proton density–weighted and T2-weighted fat-suppressed images. D, in the Grade 0 lesion, there is attenuation of the plantar plate, which is represented by an altered signal intensity of this structure.

In our study, the use of the anatomic grading system significantly aided the radiological evaluation. Prior knowledge of the typical patterns and classifications of tears helped the radiologists to describe more accurately the type of tear visualized. Correlation between the MRI and arthroscopic findings was increased in Group B where the anatomic grading system was given beforehand. The time of training and the experience of the radiologist were also important predictors in our study. The attending radiologist had better levels of accuracy in Group A, 77.0%, and in Group B, 88.5% (Table 2).

Although there was an improvement in the description of the plantar plate tears when the anatomic grading system was given beforehand, only fair correlation existed between the plantar plate lesions in the MRI studies and the arthroscopic findings when all the observers were analyzed together.

Although MRI may aid in the identification of plantar plate pathology at the MTP joint, use of an anatomic grading system was helpful in improving descriptions of MRI findings and to better establish correlations between image findings and the anatomic lesions.

We conclude that a prior knowledge of the anatomic grading system of lesions of the plantar plates improved identification and description of plantar plate tears by the radiologist. We further conclude that this improvement in diagnostic accuracy holds true for both novice and experienced radiologists. We therefore propose that the Anatomic Grading System be included in foot and ankle fellowship training and in the radiology curricula and that by doing so, MRI may become a more powerful and useful diagnostic tool in the treatment of plantar plate pathology.

Appendix 1

Anatomic Grading of Plantar Plate Tear

Grade	Description
0	Plantar plate or capsular attenuation, and/or discoloration
1	Transverse distal tear (adjacent to insertion into proximal phalanx [<50%]; medial/lateral/or central area) and/or midsubstance tear (<50%)
2	Transverse distal tear (>50%); medial/lateral/or central area and/or midsubstance tear (>50%)
3	Transverse and/or longitudinal extensive tear (may involve collateral ligaments)
4	Extensive tear with button hole (dislocation).

Scheme of the Anatomic Grading System

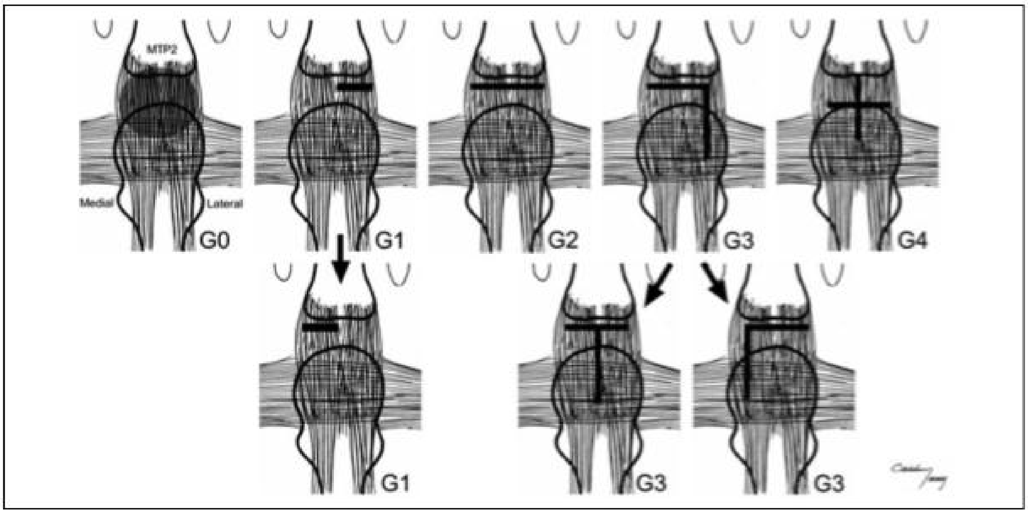
GO - Attenuation of the plantar plate.

G1 - Partial distal transverse rupture - medial or lateral halves: "minus" tear.

G2 - Complete distal transverse rupture

G3 - Complete distal transverse rupture, extended proximally: lateral = "seven" tear; central = "T" tear; medial = inverted "seven" tear.

G4 - Extensive disruption of the plantar plate (cruciform): "plus" tear.



Declaration of Conflicting Interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: Michael J. Coughlin is a consultant of Arthrex.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

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MR Imaging of the Plantar Plate
Normal Anatomy, Turf Toe, and Other Injuries

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KEYWORDS

• Metatarsophalangeal joints • Turf toe • Sand toe • Plantar plate tears
• Magnetic resonance imaging • Instability • Forefoot

KEY POINTS

- Acute and traumatic injuries are more common at the first MTP joint and degenerative injuries are the main cause of lesser MTP plantar plate tears.
- MR imaging is the most powerful imaging tool to evaluate soft tissue and cartilaginous damage related to the turf toe and plantar plate injuries.
- Familiarity with typical patterns and classifications of plantar plate tears of the lesser MTP joints enhances detection and characterization of the lesions by the interpreting radiologist.
- Lesser metatarsal supination and second metatarsal protrusion may correlate with plantar plate tears.

INTRODUCTION

Forefoot pathology is a most challenging orthopedic subject owing to the anatomic complexity, the sophistication of its biomechanics, and the range of pathology, stressors, and injury that may occur over the course of a lifetime. The fine-tuned balance of the human forefoot can be disturbed by subtle forces, repetitive trauma, and degenerative conditions that set off a deleterious chain of events that lead to pain, overload, and, finally, permanent deformities.

Recognition that injuries to the greater and lesser metatarsophalangeal (MTP) joints can be terribly disabling has inspired increased interest in research and treatment of MTP joint pathology. The onset of new and efficient diagnostic and therapeutic alternatives for forefoot pathology must be based on robust knowledge of the regional anatomy, clinical observation, and an understanding of the range of conditions that affect the MTP joints.

Disclosures: Dr C. Nery is consultant of Arthrex, USA. Drs D. Baumfeld, H. Umans, and A.F. Yamada have nothing to disclose.

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Magn Reson Imaging Clin N Am 25 (2017) 127–144
http://dx.doi.org/10.1016/j.mric.2016.08.007

ANATOMY OF THE METATARSOPHALANGEAL JOINTS

Although the general structure of MTP joints of the great and lesser toes follows a similar pattern, important anatomic differences exist between the first and the second through fifth rays. All 5 metatarsal heads are rounded and convex in the sagittal plane, but the head of the first metatarsal has a larger transverse than vertical dimension, which results in a slightly flattened appearance. Conversely, the heads of the lesser metatarsals (second to fifth) are larger in the vertical than the transverse dimension, resulting in a more slender appearance in the coronal plane.[1]

The first metatarsal head has 2 different articular surfaces. The superior surface, which articulates with the proximal phalanx, is convex and wide, extending to the dorsal aspect of the metaphysis. A sagittal plane crest (the "crista") divides the plantar articular surface into 2 grooves, one for each hallucal sesamoid. The medial groove is deeper and wider than the lateral groove to accommodate the larger tibial sesamoid (Fig. 1).

Sagittal plane stability of the first ray MTP joint is provided by the glenosesamoid apparatus, a gliding and pressure-absorbing mechanism formed by the 2 sesamoids embedded in a thick fibrous tissue (Gillette, 1872)[1]—in combination with the intrinsic and extrinsic muscles of the hallux. The medial plantar tubercle at the base of the proximal phalanx of the hallux is the insertion site for the medial head of the flexor hallucis brevis (medial) and abductor hallucis tendons. The plantar plate anchors to the adjacent inferior margin of the proximal phalanx. The lateral head of the flexor hallucis brevis (lateral) and conjoint tendon of the adductor hallucis muscle (adductor hallucis oblique and transverse bellies) all insert onto the lateral plantar tubercle of the proximal phalanx. Both sesamoids are embedded in the plantar plate, which receives fibers from flexor hallucis brevis tendons, lateral deep intermetatarsal ligament, plantar fascia, and suspensory ligaments (Table 1).

Of the hallucal sesamoids, the medial one is slightly larger. A strong intersesamoid ligament binds the tibial and fibular sesamoids and forms the roof of a fibrous tunnel for the flexor hallucis longus tendon (Figs. 2 and 3).

At the dorsal aspect of the first MTP joint, the extensor system includes the extensor hallucis longus and extensor hallucis brevis tendons and the extensor hood that is composed of oblique and transverse aponeurotic fibers that extend around the capsule and blend on the plantar aspect with the plantar plate and deep transverse intermetatarsal ligament.

The lesser metatarsal distal articular surfaces are bicondylar, with 2 plantar articular segments separated by a central concavity; typically, the lateral condyle is larger. In rare instances (1.8%),[1] there are sesamoids of the lesser MTP joints.

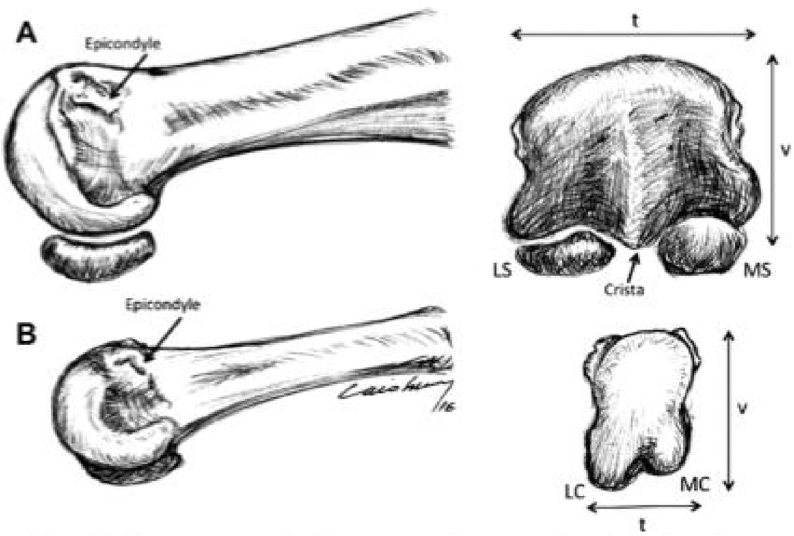

Fig. 1. Metatarsal heads. (*A*) First metatarsal—the transverse dimension (*t*) is larger than the vertical dimension (*v*). (*B*) Lesser metatarsals—the vertical dimension (*v*) is larger than the transverse dimension (*t*). LC, lateral condyle; LS, lateral sesamoid; MC, medial condyle; MS, medial sesamoid.

Table 1
Anatomy of the first MTP joint plantar plate ligaments and tendons

Anatomic Structure	Special Characteristics
FHB tendon (medial head)	Inserts on medial plantar tubercle at base of proximal phalanx of the hallux
Abductor hallucis tendon	Inserts on medial plantar tubercle at base of proximal phalanx of the hallux (together with FHB)
Plantar plate	Formed by fibers from the FHB tendon, lateral deep intermetatarsal ligament, plantar fascia, and suspensory ligaments, with contribution from aponeurotic fibers of extensor hood Extends from distal margin of the intersesamoidal ligament Inserts on inferior plantar margin of the proximal phalanx Often difficult to visualize as distinct structure unless thickened or surrounded by edema
FHB tendon (lateral head)	Inserts on lateral plantar tubercle of the proximal phalanx of the hallux
Adductor hallucis tendon (conjoint tendon from oblique and transverse muscle bellies)	Inserts on lateral plantar tubercle of the proximal phalanx of the hallux (together with FHB)
Proper collateral ligaments (medial and lateral)	Course obliquely to insert on medial and lateral phalangeal tubercles
Accessory collateral ligaments (medial and lateral)	Insert broadly along medial and lateral borders of the MTP joint plantar plates
Hallucal sesamoids (tibial and fibular)	The medial sesamoid is slightly wider and larger than the lateral
Intersesamoid ligament	Transverse ligament that runs between the tibial and fibular sesamoids
Metatarsal–sesamoid ligaments (medial and lateral)	Thickened portions of the plantar capsule that may be hard to distinguish from capsule Originate with joint capsule from plantar aspect of first metatarsal and attach to proximal margin of respective sesamoid
Sesamoidal–phalangeal ligaments (medial and lateral)	Extend from distal margin of sesamoids to plantar base of the proximal phalanx

Abbreviations: FHB, flexor hallucis brevis; MTP, metatarsophalangeal.

On each side of the lesser metatarsal heads, there are bony tubercles (epicondyles) that provide insertion sites for the MTP collateral ligaments (proper collateral ligaments) and for the fan-shaped suspensory metatarsoglenoid ligaments (accessory collateral ligaments).[2,3] The MTP joint proper collateral ligaments, which course obliquely to insert onto the medial and lateral

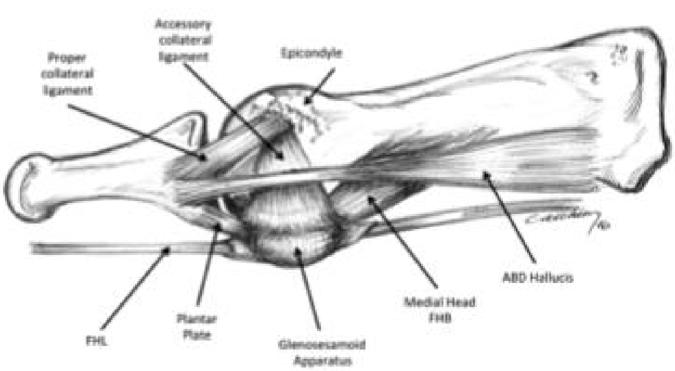

Fig. 2. Anatomy of the first metatarsophalangeal joint, medial view. ABD, abductor; FHB, flexor hallucis brevis; FHL, flexor hallucis longus.

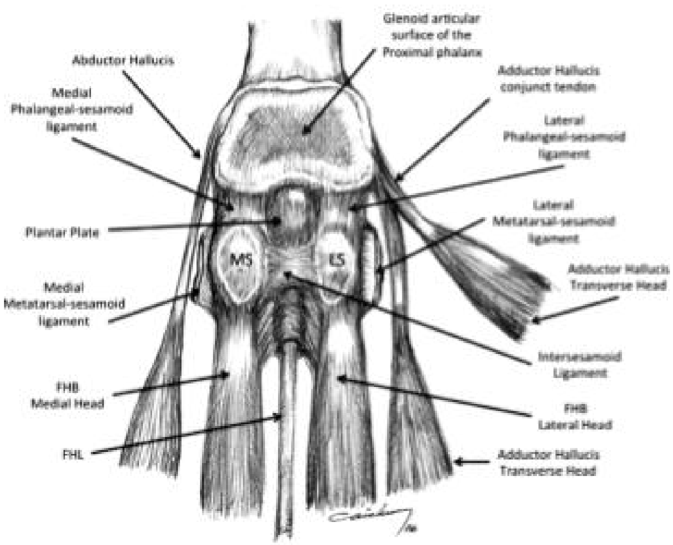

Fig. 3. Anatomy of the first metatarsophalangeal joint, dorsal view (the first metatarsal was removed). FHB, flexor hallucis brevis; FHL, flexor hallucis longus; LS, lateral sesamoid; MS, medial sesamoid.

phalangeal tubercles, play an important role in stabilization of the joint in the transverse plane. The suspensory (accessory collateral) ligaments broadly insert along the medial and lateral borders of the MTP joint plantar plates, which they stabilize.

The rounded metatarsal heads articulate with shallow, ovoid, concave bases of the proximal phalanges. These "glenoid" cavities are smaller than the articular surfaces of the metatarsal heads, conferring a degree of inherent instability to the MTP joints.

The anatomy of the lesser MTP joints is somewhat simpler than that of the first ray. The fibrocartilaginous plantar plate is now recognized as the primary stabilizer of the lesser MTP joints, especially in the dorsal–plantar direction.[2,4–6] The plantar plate firmly inserts onto the plantar bases of the lesser toe proximal phalanges. Along with its connections from the distal plantar fascia, accessory collateral ligaments (suspensory ligaments) and deep transverse intermetatarsal ligament, it acts as a cradle for the metatarsal head.[2,7] Dorsal and plantar interossei and lumbrical tendons insert onto the bases of the proximal phalanges, helping to maintain balance and function of the lesser MTP joints. At the central plantar surface of the plantar plate, a fibrous tunnel accommodates the flexor digitorus longus and brevis tendons (Table 2).

Both the extensor digitorum longus and brevis tendons cross the dorsal surface of the lesser MTP joint inside a fibroaponeurotic sling—the extensor hood—that helps to maintain joint balance (Figs. 4 and 5).

TURF TOE (FIRST METATARSOPHALANGEAL JOINT)

Hyperextension injury of the first MTP joint was first reported by Ryan and colleagues in 1975. The following year, Bowers and Martin coined the term "turf toe" owing its prevalence in American football players injured while wearing flexible shoes on artificial turf.[8–10]

Unfortunately, varied pathologies of the first MTP joint have been incorrectly bundled along with the diagnosis of turf toe, creating some confusion in the literature.[10] The classic "turf toe" lesion occurs when an axial force is applied to the foot while the great toe is fixed to the ground with hyperextension of the MTP joint (Fig. 6). The glenosesamoid apparatus and the plantar ligaments are the most frequently injured structures.[8,9,11] Depending on the intensity of the force applied to the foot, injuries can range in severity from mild sprain to complete disruption of the plantar structures (Table 3).

In contradistinction to turf toe, "sand toe" was described as an injury resulting from hyperplantarflexion of any of the MTP joints. This most commonly occurs in barefoot beach volleyball players. The most frequently affected structures in sand toe are the extensor tendons, the extensor hood and the articular capsule.[12]

Diagnosis

The diagnosis of the first MTP joint injuries is based not only on an accurate history, but also thorough physical examination and imaging studies. It is important to identify the points of

Table 2
Intrinsic muscles acting in the dynamic stabilization and function of the metatarsophalangeal joints

	Proximal	Phalanx
	Medial Plantar Tubercle (1) Medial Metatarsophalangeal Joint Capsule (2)	Lateral Plantar Tubercle
Great toe	Abductor hallucis + medial head of flexor hallucis brevis (1)	Adductor hallucis + lateral head of flexor hallucis brevis
Second toe	First dorsal interosseous (1) First lumbrical (2)	Second dorsal interosseous
Third toe	First plantar interosseous (1) Second lumbrical (2)	Third dorsal interosseous
Fourth toe	Second plantar interosseous (1) Third lumbrical (2)	Fourth dorsal interosseous
Fifth toe	Third plantar interosseous (1) Fourth lumbrical (2)	Abductor digitus V + digitus V short flexor

tenderness, ecchymosis, and swelling to correlate them with the deep anatomic structures potentially involved in the lesion.

The MTP joint drawer test is very useful to establish and grade joint instability. It is important to test the joint stability in different directions—varus stress/valgus stress/hyperflexion—because of the possibility of coexisting lesions in multiple planes. Comparison with the asymptomatic contralateral foot is extremely helpful.

Weight-bearing anteroposterior and lateral radiographs may show avulsion fractures of the proximal phalanx and sesamoids as well as proximal migration of the sesamoids, which may accompany complete rupture of the distal insertion of the glenosesamoid apparatus.[13] Waldrop and colleagues[10] showed that, when the distance between the sesamoids and the proximal phalanx differed by 3 mm or more between the right and left feet, then that was a significant and predictive of severe injury to the hallucal plantar plate (Fig. 7).

A dorsiflexed lateral radiograph of the hallux or fluoroscopic imaging can easily assess proximal migration of the glenosesamoid apparatus, diastasis of sesamoids, fractures or other coexisting lesions.

MR imaging is the most powerful diagnostic tool for assessment of soft tissue and cartilaginous injuries related to turf toe. By comparison, radiography, arthrography, and computed tomography have limited tissue contrast resolution, which is necessary to delineate the fine anatomic structures of the MTP joint of the great toe.[14] Although high-resolution ultrasonography can delineate soft

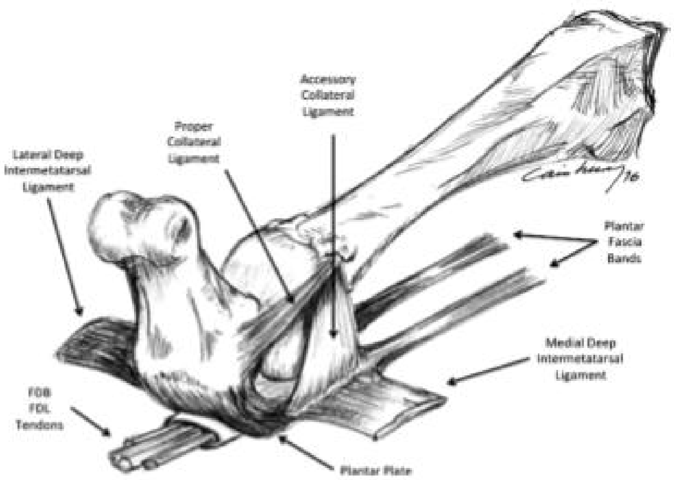

Fig. 4. Anatomy of the lesser metatarsophalangeal joints, dorsomedial view. FDB, flexor digitorus brevis; FDL, flexor digitorus longus.

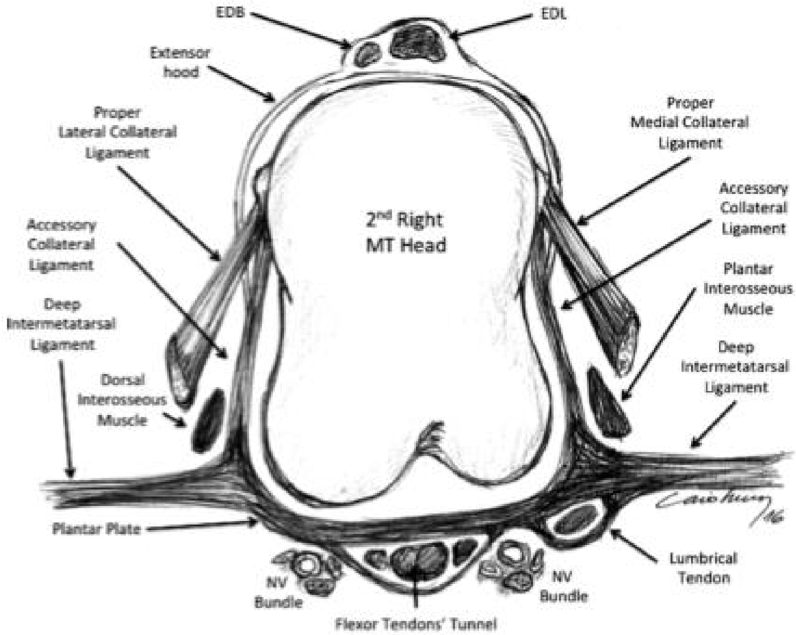

Fig. 5. Anatomy of the lesser metatarsophalangeal joints, coronal cut. EDB, extensor digitorus brevis; EDL, extensor digitorus longus; NV, neurovascular.

Fig. 6. Hyperextension injury to the first metatarsophalangeal (MTP) joint. "Turf toe" injury occurs when an axial force (*black arrow*) is applied to the foot while the great toe is fixed on the ground, with hyperextension of the MTP joint and rupture of the glenosesamoid apparatus (*gray arrow head*).

tissue structures about the first MTP joint, it is not useful for the evaluation of the associated osseous and cartilaginous injuries.[15]

The MR imaging protocol should include at least 1 non–fat-suppressed T1-weighted or proton density-weighted sequence to delineate the anatomy (Figs. 8 and 9).[16] Some authors prefer proton density weighted sequences because of the superior detail of the ligaments and tendons and the improved delineation of the chondral surfaces.[17] In addition, fat-suppressed proton density-weighted sequences or short tau inversion recovery sequences in the coronal, axial, and sagittal planes are recommended for optimal evaluation of fluid and edema associated with acute pathology.[16]

The plantar plate and hallucal sesamoids are analyzed best in sagittal and coronal short axis planes. MR imaging can show variable patterns related to heterogeneous signal intensity resulting from a partial or complete tear of the plantar plate.[18] The lateral deep intermetatarsal ligament is visualized only in the coronal short axis plane.[14] Main collateral ligaments and sesamoid ligaments are analyzed best in the axial long axis and coronal short axis plane. Although it is not commonly performed, and unnecessary in the context of acute

Table 3
Classification and grading system for turf toe injury according to Anderson and Shawen

Injury	Grade	Description
Hyperextension (turf toe)	I	Attenuation of the glenosesamoid complex Local tenderness, minimal swelling and ecchymosis
	II	Partial tear of the glenosesamoid complex Diffuse tenderness, moderate swelling and ecchymosis Restricted painful movement
	III	Complete disruption of the glenosesamoid complex Severe tenderness, marked swelling and ecchymosis Limited painful movement + positive MTP drawer test
Hyperflexion (sand toe)		Hyperflexion injury of MTP or interphalangeal joint Lesser MTP joints may be involved
Dislocation	I	Dislocation of the hallux with the sesamoids No lesion of the intersesamoid ligament
	IIA	Associate disruption of the intersesamoid ligament
	IIB	Associate transverse fracture of one of both sesamoids
	IIC	Complete disruption of the intersesamoid ligament with fracture of one of the sesamoids

Abbreviation: MTP, metatarsophalangeal.
Data from Anderson RB, Shawen SB. Great-toe disorders. In: Porter DA, Schon LC, editors. Baxter's the foot and ankle in sport. 2nd edition. Philadelphia: Elsevier Health Sciences; 2007. p. 411–33.

Fig. 7. (*A*) Plain standing radiograph of the right foot of a patient after acute hyperextension injury to the great toe or "turf toe." The lateral sesamoid is grossly displaced proximally suggesting a partial tear of the glenosesamoid apparatus. (*B*) Magnified view of the first metatarsal. The tibial sesamoid is in its normal position 3 mm proximal to the phalangeal border and the fibular sesamoid lies 15 mm proximal in relation to the phalangeal border indicating a significant injury.

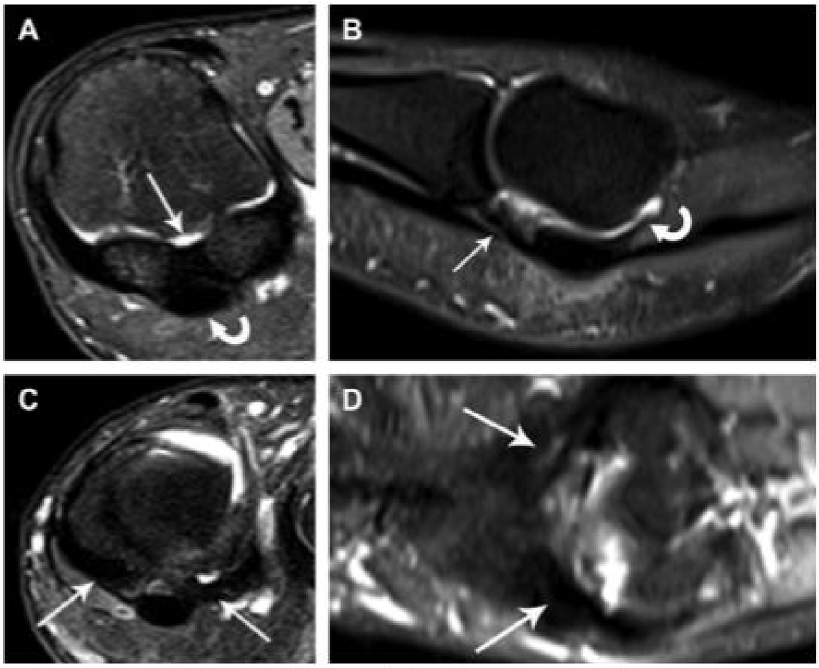

Fig. 8. MR images of a normal metatarsophalangeal hallucal complex. Coronal T2-weighted fat-suppressed image (*A*) demonstrate intersesamoid ligament with low signal intensity (*straight arrow*), deep to the normal flexor hallucis longus tendon (*curved arrow*). Sagittal T2-weighted fat suppressed image (*B*): normal anatomy of the sesamoid phalangeal ligament (*straight arrow*) and metatarsosesamoid ligament (*curved arrow*). Sesamoid phalangeal ligament (*straight arrow*) can also be identified on coronal (*C*) and axial (*D*) planes.

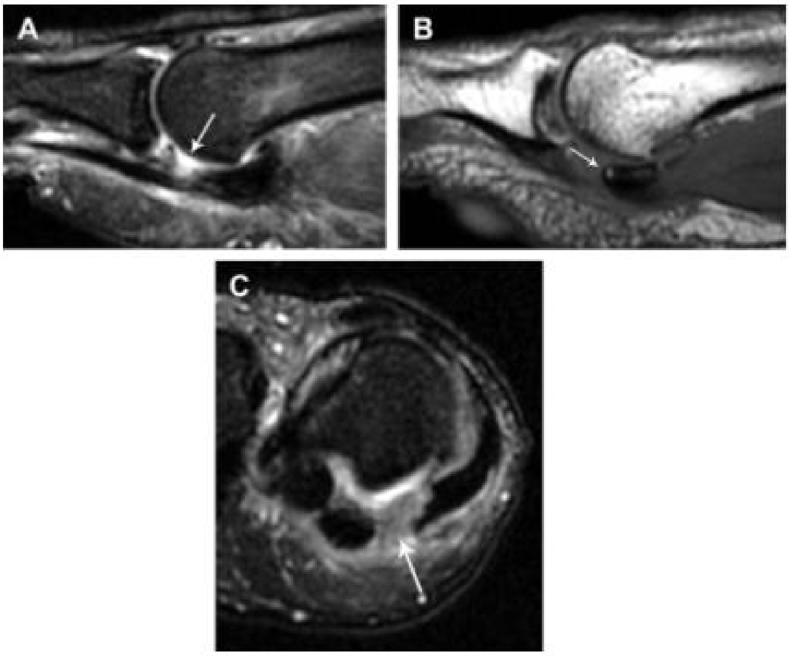

Fig. 9. Squash player injury. Sagittal fat-suppressed T2-weighted MR image (*A*) of the first metatarsophalangeal (MTP) illustrates a complete tear of the proximal medial sesamoid phalangeal ligament (*arrow*). Sagittal T1-weighted MR image (*B*) of the first MTP. Note the proximal retraction of the medial sesamoid (*arrow*). Coronal short axis fat-suppressed T2-weighted (*C*), demonstrates sesamoid-phalangeal ligament tear with adjacent edema (*arrow*).

injury with posttraumatic fluid signal distention of the joint, MR arthrography has been reported to enhance visualization of many of these structures.[14]

Treatment

First-line treatment of turf toe is conservative based on "RICE" (rest, ice, compression, and elevation). Non–weight-bearing protection or immobilization of the joint is essential to control pain and prevent additional tissue damage in the acute posttraumatic period. After a few days, as pain subsides, careful rehabilitation commences. The challenge lies in finding the balance between the restoring the physiologic range of motion and protecting the healing tissues. Taping and rigid insoles are often used to protect the great toe MTP joint, until recovery is complete.

All grades of turf toe can be treated conservatively; however, higher grade injuries take longer to heal, with greater delay in return to full activity. Fortunately, few cases of turf toe require surgical treatment. According to McCormick and Anderson,[8,9] there are strict indications for surgical treatment of turf toe that include (Box 1): (1) large capsular avulsion with unstable joint (coronal, sagittal or transverse planes), (2) diastasis and/or retraction of the sesamoids (fracture or bipartite), (3) traumatic hallux valgus/varus deformity, (4) osteochondral injury (including loose bodies), and (5) failed conservative treatment.[8]

Box 1
Indications for turf toe surgical treatment

Strict indications for surgical treatment of the turf toe lesions

1. Large capsular avulsion with unstable metatarsophalangeal joint (coronal, sagittal or transverse planes)
2. Diastasis and/or retraction of the sesamoids (fracture or bipartite)
3. Traumatic hallux valgus/varus deformity
4. Osteochondral injury (first metatarsal head), including loose bodies
5. Failed conservative treatment (unstable and painful joint)

Data from McCormick JJ, Anderson RB. The great toe: failed turf toe, chronic turf toe, and complicated sesamoid injuries. Foot Ankle Clin 2009;14:135–50; and McCormick JJ, Anderson RB. Turf toe: anatomy, diagnosis, and treatment. Sports Health 2010;2:487–94.

LESSER METATARSOPHALANGEAL JOINT INSTABILITY

Although acute trauma can lead to lesser MTP joint instability (16%), instability of the lesser MTP joints is more commonly a chronic, degenerative condition.[5] Compressive and tensile forces chronically applied to the hyperextended MTP joint contribute to attenuation and insufficiency of the stabilizing structures, which ultimately results in a painful, deformed, and dysfunctional toe.[19] The "crossover toe" is the end-stage disabling deformity, which was first described by Coughlin in 1987[20] (Fig. 10). Although the normal function of the lesser MTP joints depends on an intricate balance between bones, articular ligaments, and tendons, the deterioration and rupture of the plantar plate seems to be the most important fact in the genesis of lesser MTP joint instability.[4]

Acute pain under the affected metatarsal head and the sensation of plantar swelling are the very first clinical signs. A few days later, widening of the interdigital space can be seen. Clinical distinction of acute metatarsalgia owing to plantar plate tear, intermetatarsal bursitis, interdigital (Morton) neuroma, and stress fracture may be very challenging.

The affected toe progressively loses "ground touch" and "toe purchase" (the dynamic ability of the toe to push against the ground, which connotes normal muscle balance and function), that can be detected and measured using the "paper pull out test."[21] The most predictive and reliable test to identify and quantify MTP joint instability is the Hamilton-Thompson MTP drawer test, which measures the degree of subluxation or dislocation at the MTP joint (Fig. 11).[5]

Coughlin and colleagues[6] proposed a Clinical Staging System for MTP joint instability that correlates toe alignment with the most important

Fig. 10. The classic crossover toe deformity. This represents end-stage deformity resulting from plantar plate injury of the second metatarsophalangeal joint.

Fig. 11. Hamilton-Thompson MTP drawer test is a predictive and reliable clinical test for MTP joint instability, assessing the degree of subluxation or dislocation under stress. $P<.0001$. MTP, metatarsophalangeal.

Correlation	Grade 0 (%)	Grade 1 (%)	Grade 2 (%)	Grade 3 (%)	Grade 4 (%)
MTP drawer test: grade I (<50%)	100	72	60	35	0
MTP drawer test: grade 2 (>50%)	0	8	40	42	35
MTP drawer test: grade 3 (dislocatable)	0	0	0	13	29
MTP drawer test: grade 4 (dislocated)	0	0	0	0	35

(*From* Nery C, Coughlin MJ, Baumfeld D, et al. Classification of metatarsophalangeal joint plantar plate injuries: history and physical examination variables. J Surg Orthop Adv 2014;23:218; with permission.)

physical findings (Table 4). Based on cadaveric studies and a surgical series, an Anatomic Grading System for the plantar plate lesions was proposed[6,22,23] (Figs. 12 and 13, Table 5). This anatomic grading has been shown to correlate strongly with the clinical staging system. The comparison of the ability to identify and describe lesser toes plantar plate tears by 2 groups of radiologists (one who were knowledgeable of the anatomic pattern of plantar plate tears and another that had no notion of the anatomic patterns of the tears) showed that familiarity with the anatomic grading system improved radiologists' diagnostic accuracy in characterizing plantar plate tears, which is an important help to the surgeons in preoperative planning.[5,24]

Diagnosis

The primary evaluation of plantar plate injury is based on the clinical examination with adjunctive diagnostic imaging. Radiographs, ultrasound imaging, and MR imaging have been the primary diagnostic imaging tools used by clinicians to assist in their evaluation.[25] There has even been reported utility of dual-energy computed tomography in a recent case report.[26]

At initial presentation, foot standing radiographs are obtained to rule out other osseous pathology, including fracture, dislocation, and advanced osteonecrosis,[27] keeping in mind that both fracture and early stage osteonecrosis are commonly radiographically occult. Radiography is helpful for assessment of MTP joint arthritis, hallucal sesamoid position, metatarsal length, phalangeal deviation, subluxation, and hyperextension.

There are both developmental anatomic factors that might predispose to, and acquired deformities that may result from, plantar plate tears. Three measurements based on anteroposterior weight-bearing radiographs (an increased first metatarsal declination angle, and increased second metatarsal declination angle, and a second metatarsal protrusion distance of >2 mm) were shown to correlate with plantar plate tear in greater than 75% of cases in a series reported by Klein and colleagues.[27] This indicates that a long second metatarsal likely predisposes to plantar plate tear. In a

Table 4
MTP joint instability: Clinical staging system

Grade	Alignment	Physical Examination
0	MTP joint alignment; pain with no deformity	Plantar pain, thickening or swelling under MTP joint, reduced toe purchase, negative drawer test
1	Mild misalignment, widening of web space, medial toe deviation	MTP joint pain and swelling, loss of toe purchase, mild positive drawer test (<50% subluxable)
2	Moderate misalignment, medial, lateral, dorsal or dorsomedial deformity, hyperextension of toe	MTP joint pain, reduced swelling, no toe purchase, moderate positive drawer test (>50% subluxable)
3	Severe misalignment, dorsal or dorsomedial deformity, crossover toe or flexible hammertoe	MTP joint and toe pain, little swelling, no toe purchase, very positive drawer test (dislocatable MTP joint) and flexible hammertoe
4	Dorsomedial or dorsal dislocation, severe deformity, fixed hammertoe	MTP joint and toe pain, little or no swelling, no toe purchase, dislocated MTP joint, fixed hammertoe

Abbreviation: MTP, metatarsophalangeal.

recent publication by Umans and colleagues[28] based on MR imaging, second metatarsal protrusion of greater than 4 mm was also found to trend toward correlation with plantar plate tear (Fig. 14).

Related predisposing morphology includes subtle cavus foot structure, mildly increased metatarsus adductus, a supinated foot, or a forefoot varus deformity, all of which result in a plantarflexed "shortened" position of the first ray. With relative shortening of the first ray, the second metatarsal is relatively "lengthened." Resultant overload of the second metatarsal head and plantar structures, including the plantar plate, predisposes to tissue deterioration. As the supporting soft tissue structures deteriorate, toe deformity ensues and manifests radiographically as transverse plane splaying of the digits (tibial deviation of the second toe and fibular deviation of the third

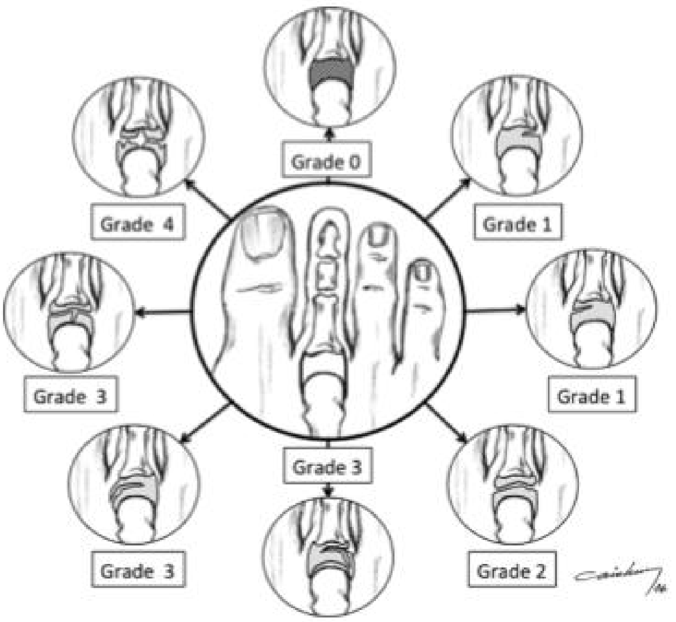

Fig. 12. Anatomic grading system of lesser metatarsophalangeal joint plantar plate tears: grade 0 = attenuation; grade 1 = partial transverse distal tear (<50%)—lateral or medial; grade 2 = complete transverse distal tear (>50%–100%); grade 3 = combination of transverse and longitudinal tears – "7," "T," or "inverted 7" shapes; grade 4 = extensive tear with buttonhole.

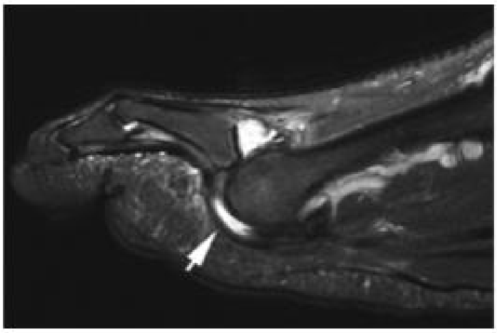

Fig. 13. Sagittal MR image of the second metatarsophalangeal joint, showing an extensive plantar plate tear with the characteristic buttonhole appearance (*arrow*).

toe), sagittal plane instability (varus angulation of the second MTP joint angle >6°), or both.

The metatarsal parabola is an old, but useful, concept that aims to understand the physiologic relationship between the lengths of the metatarsals in a normal subject. According to Maestro, "in the normal parabola the metatarsal heads were positioned according to a geometric progression by a factor of 2."[27] This concept defines forefoot radiologic images where one can see the second metatarsal 3 mm longer than the third that is 6 mm longer than the fourth that is 12 mm longer than the fifth metatarsal (the harmonic morphotype).[27,29] It can be assessed according to 3 methods: (1) the arc method described by Hardy and Clapham, (2) the second metatarsal protrusion distance, and (3) the harmonious morphotype method described by Maestro and colleagues. All methods were found to be of equal usefulness by Klein and colleagues.[27] This description is useful for assessing disharmonious morphotypes that are associated with pathology, and for surgical planning to correct the metatarsal parabola. In radiologic evaluation, weight-bearing anteroposterior and lateral views suffice, without the need for special forefoot or toe views.[29]

Table 5
Anatomic grading system of plantar plate tears

Grade	Patterns of Soft Tissue Evolvement
0	Plantar plate and capsular attenuation and/or discoloration
1	Transverse distal tear adjacent to insertion to the proximal phalanx (<50%, more frequently at the lateral area)
2	Transverse distal tear (>50%, almost 100%)
3	Transverse distal tear (>50%, frequently 100%) combined with a longitudinal extensive tear: Medial (inverted "7" shape), Central ("T" shape) or Lateral ("7" shape)
4	Extensive tear with buttonhole (dislocation) resulting from the combination of transverse and longitudinal tears. Little or no plantar plate tissue to repair

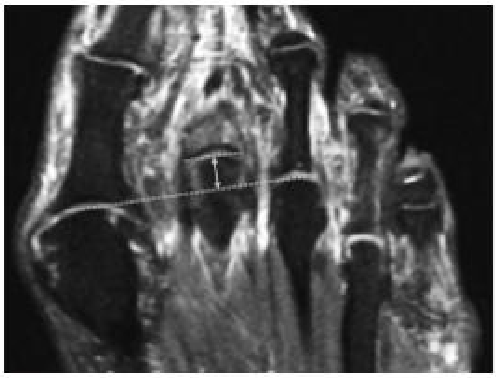

Fig. 14. Second metatarsal protrusion. A line tangent to the most distal points of the first and third metatarsals heads is drawn. The "second metatarsal protrusion" is the perpendicular distance (in millimeters) from this baseline to the distal tip of the second metatarsal head. Note that the landmarks of the distal borders of the metatarsal heads may lie on adjacent images and may be necessary to scroll between them to determine exactly your references.

MR imaging and ultrasound examination provide further details in the diagnostic evaluation of plantar plate pathology. The plantar plate is a superficial fibrocartilaginous structure which is easily accessible and visible in its entirety by ultrasound[30,31] (Figs. 15 and 16). Gregg and colleagues[30] compared ultrasound and MR imaging detection of plantar plate pathology in both symptomatic and asymptomatic feet and found only fair correlation between MR imaging and intraoperative findings, whereas longitudinal and transverse plane sonographic images showed moderate to high correlation, respectively.[30] It should be noted, however, that operative correlation was available in only 10 of the 160 symptomatic joints.[32] Klein and colleagues[32] also compared plantar plate ultrasound and MR imaging with a surgical gold standard and showed that MR imaging and ultrasound examination were both highly sensitive (73.9% and 91.5%, respectively), but MR imaging offered 100% specificity, whereas ultrasound examination was poorly specific. In all series, sonography is extremely sensitive for detection of plantar

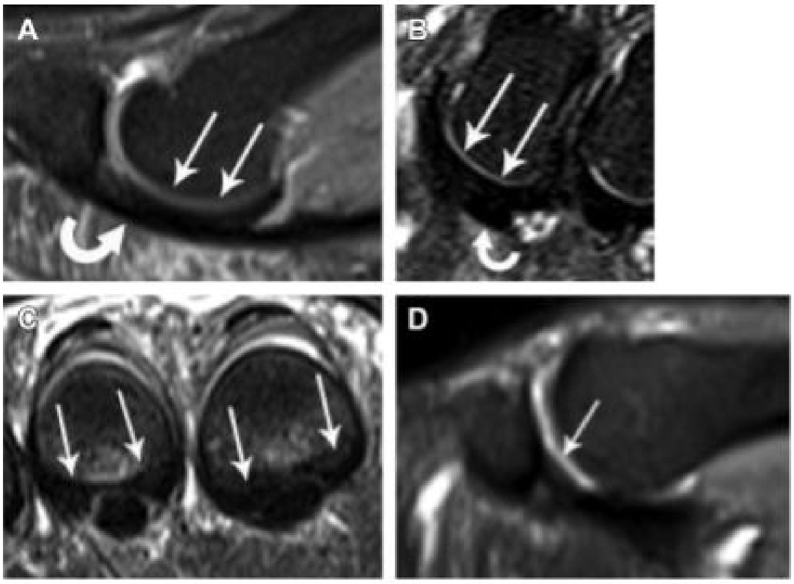

Fig. 15. MR images of a normal lesser metatarsophalangeal joint. Sagittal T2-weighted fat-suppressed image (*A*): normal appearance of the plantar plate (PP; *straight arrow*) with low signal intensity, deep to the normal flexor tendons (*curved arrow*). Coronal T2-weighted fat-suppressed image (*B*) of the central portion of a normal PP (*straight arrow*) at the level of the metatarsal head. In the same image, one can see the normal flexor tendons (*curved arrow*). Distally it is possible to see normal insertion of PP (*straight arrow*) at the base of proximal phalanx (*C*). This insertion can also be seen in the sagittal plane (*straight arrow*) (*D*).

plate pathology, but is relatively nonspecific in distinguishing between degeneration and tear.

Although MR imaging and ultrasound examination are appropriate modalities for the evaluation of plantar plate, ultrasound performance is strongly user dependent, and reproducible only in the hands of highly skilled professionals. Based on our experience, MR imaging is affords a greater degree of reproducibility between different institutions.

Different MR imaging protocols for evaluation of the plantar plate have been reported in the literature. Podiatrists Klein and colleagues[32] and Sung and colleagues[25] reported good diagnostic performance using 0.3 T MR imaging, imaging in 3 orthogonal planes using T1, T2 and short T1 inversion recovery sequences. Most radiologists, however, favor imaging of small parts using high field strength MR imaging, given the inherent superiority in spatial resolution and practical advantage of more rapid imaging time. Gregg and colleagues[33] and Umans and colleagues[34] used 1.5 T and 3.0 T MR imaging. Gregg and colleagues[33] performed proton density fast-spin echo sequences and T2-weighted fat-suppressed fast-spin echo sequences in the coronal, axial, and sagittal

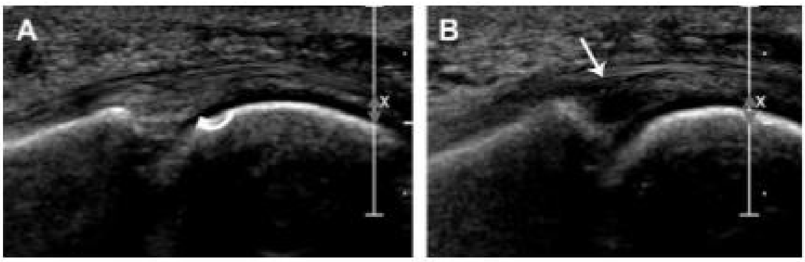

Fig. 16. Plantar plate (PP) ultrasound image of the second metatarsophalangeal, sagittal plane. (*A*) Normal appearance of PP as a labral-like, slightly echogenic and homogeneous structure (*curved arrow*). (*B*) Hypoechoic area of discontinuity (*arrow*) in the distal attachment of the PP, adjacent to the base of the proximal phalanx, compatible with PP tear.

planes using a 10 cm field of view and 2-mm slices with no gap. Umans and colleagues[34] performed axial long axis and coronal short axis T1-weighted and fat-suppressed proton-density, T2-weighted and sagittal fat-suppressed proton-density, or T2-weighted images using 10- to 12-cm field of view and 2- to 3-mm slice thickness in the short axis and sagittal plane and 2- to 2.5-mm slice thickness in the long axis images.

Although arthrography is not widely used in the evaluation of plantar plate tears, it has been reported as a useful adjunct to MR imaging. Yao and colleagues[18] first reported pathologic communication of MTP intraarticular contrast with the flexor tendon sheath as diagnostic of plantar plate tear using conventional arthrography. Subsequently, using a cadaveric model, Mohana-Borges and colleagues[35] showed MR arthrography to be superior to standard MR imaging for depiction of the articular surface of plantar plate, proximal and distal attachments, and the connections of plantar plate with collateral ligaments. Kier and colleagues[36] later described the use of MR arthrography for the evaluation of painful conditions of second and third MTP joints, but did not compare the relative diagnostic performance of conventional MR imaging to MR arthrography. Recently, Lepage-Saucier and colleagues[36] reported the combination of toe traction and MR arthrography to be superior to conventional MR imaging in assessment of articular cartilage and plantar plate pathology in a small cadaveric series.

In our experience, MR imaging of the plantar plate is ideally performed using high field units, typically without intraarticular contrast using a small field of view and small surface coil. Axial long axis and coronal short axis T1-weighted, sagittal, axial long axis, and coronal short axis fat-suppressed T2-weighted or proton-density images should be obtained, with contiguous thin slices no thicker than 3 mm in the sagittal and coronal short axis. It is important to achieve high spatial resolution, because tears can be quite small and the plantar plate measures only 12 mm in the transverse plane.

MR IMAGING OF THE NORMAL PLANTAR PLATE

In the sagittal plane, proton-density and T2-weighted sequences depict the normal plantar plate as a uniform dark signal. The plantar plate cradles and articulates with the metatarsal head. The hypointense flexor tendon courses beneath the plantar plate and seems to blend with it, with a typically nondiscernable intervening cleavage plane. The origin of the plantar plate at the level of the metatarsal shaft, just proximal to the flare of the metatarsal head, is poorly delineated from the flexor tendon. The insertional fibers are well-delineated against the articular cortex of the proximal phalanx.[31]

Umans and Elsinger reported a normal, discretely marginated, high signal intensity zone at the midsagittal phalangeal insertion of the plantar plate that measures up to 2.5 mm.[34] Mohana-Borges and colleagues[35] subsequently clarified that this represents an anatomic recess, which they identified in the midsagittal plane in 47% of imaged MTP joints. This normal capsular recess must not be mistaken for a plantar plate tear (Fig. 17).

In coronal short axis proton density and T2-weighted fat-suppressed images, the plantar plate appears as a C-shaped low signal intensity band centered under the metatarsal head. On the plantar surface a central groove accommodates the flexor tendons. The plantar plate is of low signal intensity, similar to the flexor tendons. The proper collateral ligaments blend with the plantar plate at their insertion bilaterally onto the base of proximal phalanx. The insertional fibers are also hypointense adjacent to the articular cortex of the proximal phalanx.[31] Collateral ligaments have a close relationship with the interosseous, abductor digiti minimi, and flexor digiti minimi brevis tendons. Distally, these complexes are attached both to the base of the proximal phalanges and the plantar plate. Axial long axis images are best for evaluating the attachment of collateral ligaments onto the bilateral base of the proximal phalanges, but coronal short axis and sagittal images are necessary for evaluating the integrity of the plantar plate.[35]

MR IMAGING OF PLANTAR PLATE TEARS

Yao and colleagues[18] first described the utility of MR imaging in evaluating plantar plate tear.[34,38] Using a surgical gold standard, they found that

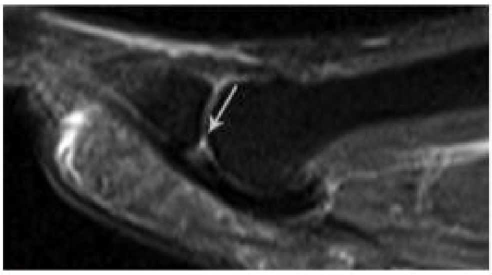

Fig. 17. T2-weighted fat-suppressed MR image of a normal plantar plate (PP), sagittal plane. Poorly defined area of moderately increased signal intensity, compatible with normal PP recess (*arrow*).

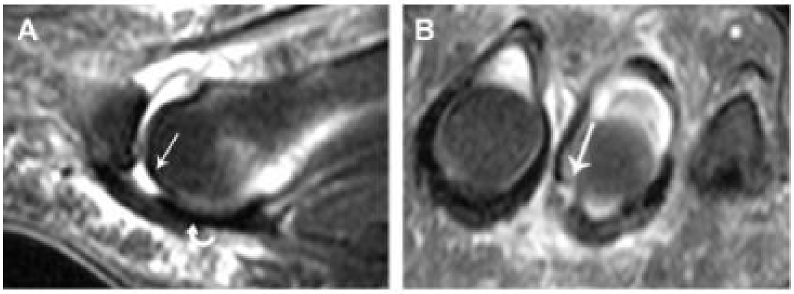

Fig. 18. T2-weighted fat-suppressed MR image of direct sign of plantar plate (PP) tear, sagittal (*A*) and coronal (*B*) planes of the third metatarsophalangeal. Replacement of normal low signal PP fibers with a hyperintense focus (*arrow*), compatible with PP tear. The intact proximal portion of the plantar plate is seen on the sagittal image (*curved arrow*).

focal high signal intensity of the plantar plate identified on fluid-sensitive sequences correlated with plantar plate tear.[39] A bright T2 signal defect at the insertion of the plantar plate is accepted as a direct sign of a plantar plate tear[28,39](Fig. 18). Tears appear hyperintense on both proton density-weighted and T2-weighted fat-suppressed images. Retraction of a torn plantar plate is best assessed in the sagittal plane. Coronal short axis images best delineate the location of tear in relation to the collateral ligaments and flexor tendon. Although the distinction can be difficult, partial versus full-thickness tears can be assessed in both the sagittal and coronal planes.

Umans and colleagues[34] reported intermetatarsal space nonneuromatous lesions in association with plantar plate tear. Pericapsular fibrosis accompanies most cases of plantar plate tear and, like some Morton neuromas, it is intermediate signal on T1- and T2-weighted images[34] (Fig. 19). The key difference is that pericapsular fibrosis is eccentrically located within the interspace and broadly abuts the plantar lateral and lateral aspect of the MTP joint, whereas Morton neuroma is centrally located within the interspace, typically extending plantar to the level of the deep transverse intermetatarsal ligament. The importance of this finding is 2-fold. Eccentric pericapsular fibrosis is now recognized as a useful correlate, which may be more readily apparent than a small defect, for the diagnosis of plantar plate tear. It has also been recognized that many cases of plantar plate tear with associated pericapsular fibrosis have been misdiagnosed and mistreated as neuroma. Misdiagnosis of plantar plate tear and pericapsular fibrosis and mistreatment; neuroma can prolong pain and dysfunction, permit development of progressive deformity, and possibly adversely affect outcomes of definitive surgery.

Although the classic direct sign of plantar plate tear on MR imaging is widely accepted, represented by partial or complete discontinuity of the plantar plate on fluid-sensitive sequences with fluid interposition, there is no consensus regarding other morphologic changes of the plantar plate seen on MR imaging studies. In our experience, other changes include thinning or nonvisualization of the plantar plate, pericapsular fibrosis, increased distance between the distal margin of plantar plate and the base of the proximal phalanx, and distortion of the interosseous tendon and collateral ligament complex, all of which might help in the diagnosis of plantar plate tear. In our unpublished data (André F. Yamada and colleagues, 2016), pericapsular fibrosis was strongly associated with plantar plate tears, with an odds ratio of 103.3 (95% confidence interval, 9.6–1108.5; $P<.001$). In addition, these data indicated that the distance between the distal margin of plantar plate and the base of the proximal phalanx, with a cutoff value of 0.28 cm, showed a significant association with plantar plate tears (odds ratio, 18.3; 95% confidence interval, 2.9–161.0; $P = .009$).

TREATMENT

The acute posttraumatic form and early stages of chronic, degenerative lesser MTP joint instability can be treated conservatively. The main purpose of noninvasive treatment is pain control, combined with protection and stabilization of the forefoot. This is achieved with taping of the central lesser toes in slight flexion, temporary suspension of weight bearing and reduction of the range of motion of the affected joints. Corticosteroid injections must be avoided because of the potential damage to the soft tissues of the region.

Successful treatment lies in the balance between joint rehabilitation and the protection of

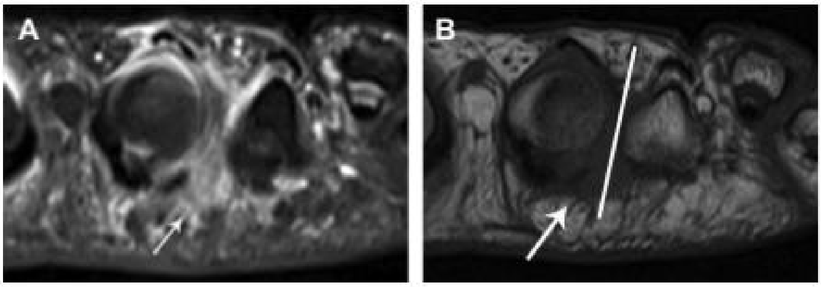

Fig. 19. Coronal short axis fat-suppressed T2-weighted (*A*) and T1-weighted (*B*) images. Pericapsular fibrosis accompanies most cases of plantar plate tear and, like some Morton neuromas, it is intermediate signal on T1 and T2 weighted images (*arrow*). Unlike neuromas, pericapsular fibrosis is positioned eccentrically within the intermetatarsal space (*line*), abutting the second metatarsophalangeal lateral capsule and PP.

the healing tissues. Unfortunately, outcome studies suggest that although conservative therapy may reduce or eliminate pain, deformity and MTP instability tend to worsen over time. When conservative therapy fails to reduce discomfort and deformities worsen, surgery is indicated.

Older surgical techniques focused on restoration of joint function through soft tissue transfers and reconstruction, but did not attempt to repair the main anatomic structures. Based on unpublished research by Dr Garry P. Jolly, Ford and colleagues[37] in 1998, demonstrated that direct plantar plate repair was a viable alternative for stabilization of the lesser MTP joints. Ever since, repair and reinsertion of the plantar plate onto the base of the phalanx has been considered the surgical treatment of choice. Controversy remains as to whether or not there is a need to combine plantar plate repair with Weil osteotomy and how to address grade 4 lesions in which there is no salvageable soft tissue.

New treatment alternatives must focus on the early stages of MTP joint instability to achieve better patient outcomes. Based on the literature[19,20,33,39–41] and our own experience,[5,42,43] our goals in the treatment of patients with plantar plate tear are to:

1. Correct the metatarsal parabola (to correct lesser metatarsal head protrusion);
2. Reduce pressure under the metatarsal head (to alleviate metatarsalgia);
3. Create room to permit access to the plantar plate (to reinsert it and repair it); and
4. Repair the original anatomic structures and tissues.
5. Consider the impact on the whole forefoot (pay attention to PIP and DIP joints)

In our service, we are using a treatment algorithm[43] for the lesser MTP joint instability based on the Anatomic Grading System that can be summarized as follows:

- Grade 0 and 1 tears—arthroscopic radiofrequency shrinkage plus Weil osteotomy.
- Grades 2 and 3 (all variants)—plantar plate repair and reinsertion through the dorsal approach plus capsular and ligament reefing plus Weil osteotomy.
- Grade 4—flexor digitorus longus tendon transfer to the extensor hood plus Weil osteotomy.

In our practice, all joints are first evaluated by MTP joint arthroscopy. This enables us to grade the tear and treat according to the algorithm as described. The direct repair and reinsertion of the plantar plate in the proximal phalanx can be performed via dorsal or plantar approaches. The dorsal approach is greatly preferred because it permits evaluation and correction of the dynamic and static anatomic structures. Lengthening of the extensor tendons, repairing and balancing the proper and accessory collateral ligaments and joint capsule, and shortening an elongated metatarsal is almost impossible through a plantar approach. Repair of the plantar plate via a dorsal approach has only been made possible by innovations in surgical instruments and techniques, which have only been available in the last 5 years.

Generally, the transverse component of the tear is debrided and reinserted onto the base of the proximal phalanx. Once sutures secure the plantar plate at its phalangeal insertion, they are passed through bone holes and tied in the dorsal aspect the proximal phalanx. Longitudinal tears are repaired using two or three 4-0 or 5-0 nonabsorbable sutures. Lateral soft tissue reefing may be performed as needed to improve toe alignment and stability.

The most common postoperative complications are arthrofibrosis and joint stiffness. This is likely owing to the extent of dissection and soft tissue release in a small anatomic area. It is essential, therefore, to perform all the surgical steps as gently as possible to minimize scarring and retraction of the transected structures. Reefing and balancing the joint and careful hemostasis in all dissected planes at the end of the procedure helps prevent these complications.

POSTOPERATIVE

Healing occurs within 6 weeks but requires another 4 to 6 months for complete maturation. It is important to protect the toes during this period. We recommend keeping the toes in 20° of flexion in a postoperative shoe for 6 weeks. An aggressive rehabilitation program starts at the end of the first week to reduce scarring at the incision site, strengthen the flexor tendons, and maintain joint mobility. It is crucial to prevent passive and active dorsiflexion of the toes for 6 weeks to avoid damaging the plantar plate sutures. Low-heeled shoes with wide toe boxes are advised for 6 months after the surgery, during which time high-impact sports activities should be avoided. Return to play should occur gradually and carefully, to protect the surgical repair and prevent reinjury.

EXPECTATIONS

Direct plantar plate repair using a dorsal approach are promising. Some studies reported excellent pain relief with improved digital strength and realignment at an average follow-up of 1.5 years.[42] Recently, authors have reported favorable results in the treatment of early stages of plantar plate injuries with better postoperative results when compared with correction of later stages with gross instability. These results suggest that surgical treatment of MTP joint instability in the early stages might yield better outcomes.

SUMMARY

The complex anatomy of the MTP joints is critical for proper balance and biomechanics. Imaging studies, particularly MR imaging, play a crucial role in diagnosing plantar plate tear and turf toe injury and for the heterogeneous group of disorders affecting the first and the lesser MTP joint. Equipped with knowledge of local anatomy and the diverse pathologies that can affect this complex, the radiologist can help the referring clinician or surgeon to determine the appropriate treatment plan to minimize morbidity and facilitate faster recovery and rehabilitation.

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