论 著

3D view 序列联合压缩感知技术精准诊断踝周韧带损伤

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【摘要】**目的** 应用3D view序列联合压缩感知(Compressed Sensing, CS)技术观察踝关节扭伤患者韧带损伤情况，探讨3D view序列与常规2D序列相比能否提高诊断效能。**方法** 前瞻性分析2021年2月至2021年11月来我院急诊就诊的踝关节急性扭伤患者共26例(26个踝关节)。上述受试均行MRI检查，扫描序列包括常规2D及3D view T2联合压缩感知序列。应用Mann-Whitney U检验评价常规序列及3D view序列的扫描时间、跟腱的信噪比及对比噪声比及评估患者在两序列下腓距前韧带、腓跟韧带、三角韧带、分歧韧带的损伤程度比较有无区别。应用Fisher确切概率法比较两序列对腓距前韧带、腓跟韧带、三角韧带、分歧韧带损伤的检出率有无差别。**结果** 共纳入踝关节扭伤患者26例，3D view+CS序列的扫描时间为376.2 ± 0s，略短于常规序列(381.479 ± 7.3s)，两者无明显差别(Z = -1.396，P = 0.163)。3D view 序列跟腱信噪比明显高于2D常规序列(Z = -3.441, *P*= 0.001)；对比噪声比明显高于2D常规序列(Z = -6.094，*P*<0.01)；跟腓韧带和分歧韧带的损伤程度明显高于2D常规序列(Z = -2.67, *P*= 0.008；Z = -2.67, *P*<0.001)。两序列对于距腓前韧带和内侧三角韧带的损伤程度差异无统计学差别(*P*<0.05)。3D View+CS序列对分歧韧带损伤的检出率明显高于2D常规序列(*P*<0.001)。3D View+CS序列较2D常规序列对距腓前韧带、跟腓韧带、内侧三角韧带损伤的检出率无明显差别(*P*>0.05)。**结论** 在3D View+CS序列与常规2D序列扫描时间相当的情况下，3D View+CS序列图像质量较常规2D序列更高，踝周韧带的检出率更高，并更准确地评估韧带损伤程度。

【关键词】3D View；压缩感知；踝关节；韧带损伤
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3D VIEW Sequence Combined with Compressed Sensing Technology to Accurately Diagnose Malleolus Injury

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ABSTRACT

Objective 3D View sequence combined with Compressed Sensing (CS) was used to observe the ligament injury of ankle sprain patients, and to explore whether 3D View sequence can improve the diagnostic efficiency compared with conventional 2D sequence. ***Methods*** A total of 26 cases (26 ankles) of acute ankle sprain in our hospital from February 2021 to November 2021 were prospectively analyzed by using 3D VIEW sequence combined with Compressed Sensing (CS) technology to observe the ligament injury of patients with ankle sprain. All the above subjects underwent MRI examination, and the scanning sequence included conventional 2D and 3D View T2 combined compressed sensing sequence. Mann-whitney U test was used to evaluate the difference in scanning time, signal-to-noise ratio and contrast noise ratio of the Achilles tendon between the conventional sequence and 3D View sequence, and to evaluate the difference in injury degree of the anterior fibular ligament, anterior fibular ligament, deltoid ligament and divergent ligament between the two sequences. Fisher's exact probability method was used to compare the detection rates of anterior fibular ligament, anterior fibular ligament, deltoid ligament and divergent ligament. ***Results*** A total of 26 patients with ankle sprain were included, and the scanning time of 3D VIEW +CS sequence was 376.2 ± 0s, slightly shorter than that of conventional sequence (381.479 ± 7.3s), with no significant difference between them (Z = -1.396, *P*= 0.163). The Achilles tendon SNR of 3D VIEW sequence was significantly higher than that of 2D conventional sequence (Z = -3.441, P= 0.001). The contrast noise ratio was significantly higher than that of 2D conventional sequence (Z = -6.094, *P*<0.01). The injury degree of calcaneal ligament and divergent ligament was significantly higher than that of 2D conventional sequence (Z = -2.67, *P*= 0.008; Z = -2.67, *P*< 0.001). There was no significant difference in the injury degree of anterior talofibular ligament and medial deltoid ligament between the two sequences (P > 0.05). The detection rate of 3D View+CS sequence was significantly higher than that of 2D conventional sequence (*P*<0.001). There was no significant difference in the detection rate of anterior talofibular ligament, calcaneal fibular ligament and medial deltoid ligament injuries with 3D View+CS sequence compared with 2D conventional sequence (*P*>0.05). ***Conclusion*** When the scanning time of 3D View+CS sequence is the same as that of conventional 2D sequence, the image quality of 3D View+CS sequence is higher than that of conventional 2D sequence, and the detection rate of malleolar toughness band is higher, and the degree of ligament injury can be assessed more accurately.

Keywords: 3D View; Compressed Sensing; Ankle Joints; Ligament Injuries

踝关节活动度较大，是最易损伤的关节之一，运动损伤中有40%的患者为踝关节损伤，其中踝周韧带损伤更为多见[1]。最常损伤的踝周韧带包括腓距前韧带(Anterior Talofibular Ligament，ATL)、跟腓韧带(Calcaneofibular Ligament，CFL)、内侧三角韧带(Medial Deltoid Ligament，MDL,包括胫距前韧带、胫距后韧带、胫跟韧带)、分歧韧带等(Bifurcate Ligament，BL)[2-4]。在踝关节急性损伤后，如果对踝周韧带损伤诊断不及时、不准确，易导致残留疼痛、肿胀、僵硬感和踝关节不稳定等后遗症，严重影响患者生活质量甚至致残[5]。

目前，常规踝关节MRI检查多使用2D检查序列，存在扫描视野小和层厚较厚等不足，图像容易受部分容积效应干扰，从而影响诊断的准确性。且足踝部韧带走行迂曲，2D检查无法实现沿韧带走行的扫描或重建，容易漏诊或误诊韧带损伤[6]。3D各向同性薄层MRI序列在进行韧带扫描时优势明显，图像受部分容积效应影响小，并可进行多平面重建，即可沿韧带走行重建图像以清晰显示细小韧带[7-9]。临床研究表明，3D序列成像诊断关节疾病的能力好于常规2D序列成像[10-11]。

压缩感知(Compressed Sensing，CS)技术[12]是由图像的稀疏采样、K空间输出的非相干性采集和非线性的小波重建这几种技术共同完成，极大缩短检查时间。3D MRI序列结合CS技术克服了既往3D MRI检查时间较长的不足，将扫描时间从以往至少 15~20分钟缩短至4~5分钟左右。目前CS技术已在全身各部位的MRI检查中有较广泛的应用[13-16]。但其在显示韧带的图像质量和评估韧带损伤的临床价值，尚需进一步研究验证。

本研究旨在应用3D View序列联合CS技术进行踝关节MRI检查。探讨如下三个方面的问题：(1)踝关节3D View序列联合CS技术的扫描时间与常规2D序列相比有无差异；(2)3D View序列联合CS技术的踝关节MRI图像信噪比和对比噪声比与常规2D序列进行有无提高；(3)与常规2D序列相比，3D View序列联合CS技术对踝周韧带的检出率及损伤诊断能力有无提高。

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1 资料和方法

1.1 伦理 本研究经医院伦理委员会批准，所有患者均签署知情同意书。

1.2 入排标准 本研究连续收集于2021年2月~2021年11月来我院急诊就诊的踝关节急性扭伤患者54例，排除既往踝关节扭伤、足踝部感染、风湿免疫及代谢、肿瘤等病史患者28例，最终纳入急性踝关节扭伤患者共26人(共26个踝关节)。

1.3 影像学检查 所有患者均采用3.0T MRI扫描仪(Ingenia CX, Philips Healthcare, Best, the Netherlands)和8通道的足踝专用线圈。扫描体位为仰卧位足先进，患侧踝关节置于足踝专用线圈中心。患者行踝关节常规2D MRI检查及3D VIEW T2+CS序列检查。常规2D MRI及3D VIEW T2+CS序列参数见表1。

1.4 图像质量评价 在Philips公司星云工作站(ISP 9, Philips Healthcare, Best, the Netherlands)上，测量所有患者的常规2D检查序列及3D view+CS序列图像的信噪比和对比噪声比。具体方法为；选取踝关节正中矢状位图像，在跟腱上手动设定感兴趣区(Region of Interest, ROI)，面积为15~17mm²，连续测量3次取平均值作为该ROI的信号强度值。以相同大小ROI测量图像周边4角的背景噪声标准差(Standard Deviation, SD)，取其平均数。采用NEMA测量法计算跟腱的信噪比(Signal to Noise Ratio, SNR)：在胫骨远端和跟腱分别设置ROI, 面积为3-5mm²，连续测量3次取平均值，获得ROI信号强度值(Signal Intensity, S)。d为层厚(图1)。采用如下公式计算图像的信噪比和对比噪声比。

$$SNR = \frac{0.66 \times S}{SD} \times \sqrt{10}\,\mathrm{d}$$

$$CNR = \frac{|SNR(\text{韧带}) - SNR(\text{骨髓})|}{SD}$$

1.5 踝周韧带损伤评价 由2位医师(XHM，副主任医师，从事骨肌影像11年；HZZ，技师，从事骨肌影像工作7年)分别在常规2D MRI序列及3D VIEW+CS序列上诊断ATL、CFL、MDL、BL有无损伤，并对损伤程度按国际标准分为0~3度，0度：韧带轮廓、走形、信号均未见异常；1度：韧带局灶性或弥漫性肿胀，信号增高，韧带连续性尚好，轮廓尚完整光滑无切迹；2度：不完全断裂，表现为韧带增粗，局部有切迹，韧带损伤中心部位轮廓不完整，韧带连续性不佳，但仍可见部分连续显示韧带；3度：完全断裂，表现为韧带连续性中断，断端蜷曲呈切状或断端移位，韧带起止点挛缩或断端溶解吸收。两人经会诊对韧带损伤程度达成一致意见。

1.6 统计学处理 采用SPSS 23.0(IBM公司，美国)统计软件包进行统计学分析。计数以数字表示，计量资料以均数±标准差表示。应用Mann-Whitney U检验评价常规2D检查序列及3D view+CS序列的扫描时间、信噪比及对比噪声比有无区别，患者在两序列下ATL、CFL、MDL、BL损伤程度比较有无区别。应用Fisher确切概率法比较两序列对ATL、CFL、MDL、BL损伤的检出率有无差别。*P*<0.05提示有统计学差别。

2 结 果

2.1 常规2D序列与3D View+CS序列进行踝关节MRI检查的扫描时间比较结果 3D view+CS序列的扫描时间为376.2±0s，略短于常规踝关节序列扫描时间(381.4±7.3s)，两者无明显统计学差别(Z=-1.396，*P*=0.163)。

2.2 2D常规序列与3D View+CS序列图像信噪比和对比噪声比的结果比较 3D view+CS序列图像的信噪比和对比噪声比均高于2D常规序列，具体结果见表2。

2.3 2D常规序列与3D View+CS序列对韧带损伤检出率和损伤程度的比较结果 2D序列对ATL损伤的检出率为92.3%(24/26)，3D View+CS序列的检出率为92.3%(24/26)，二者无明显差别(*P*=1.000)；2D序列对CFL损伤的检出率为46.2%(12/26)，3D View+CS序列的检出率为73.1%(19/26)，两者无明显差别 (*P*=0.089)；2D序列对MDL损伤的检出率为26.9%(7/26)，3D View+CS序列的检出率为46.2%(12/26)，两者无明显差别(*P*=0.249)；2D序列对BL损伤的检出率为0%(0/26)，3D View+CS序列的检出率为50%(13/26)，3D序列较2D序列能显示更多的BL损伤(*P*<0.001)；3DView+CS序列对CFL和BL损伤程度的诊断较2D序列更重， 而对ATL和MDL，两者诊断无明显差别，具体结果见表3。(图2~图3)。

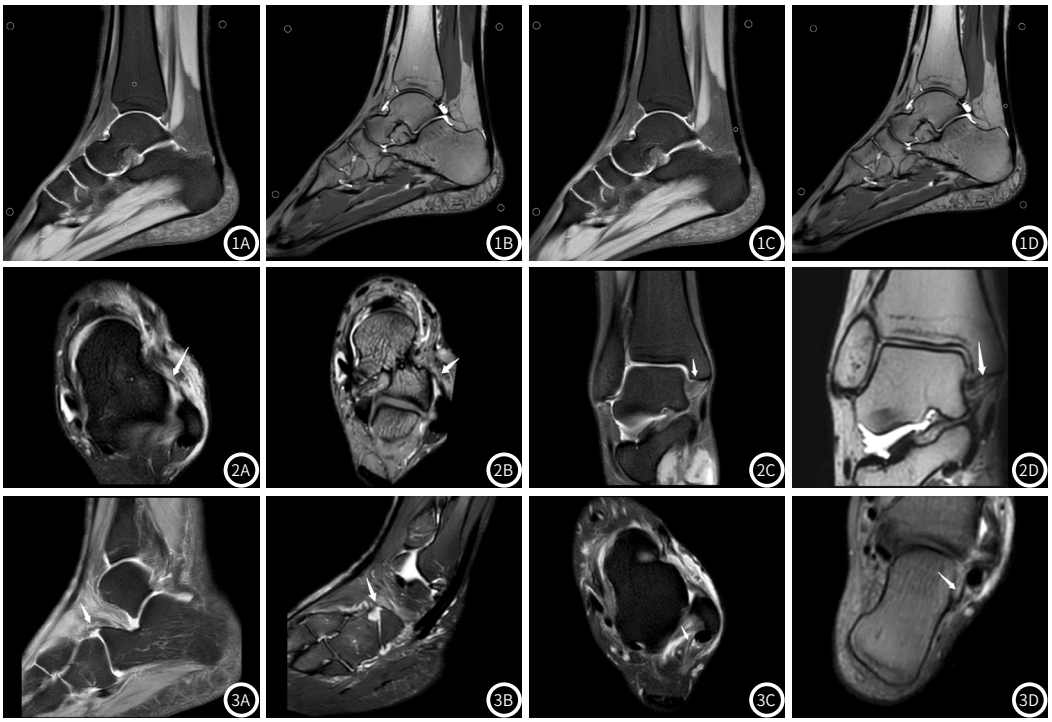

图1，2D常规序列和3D View+CS序列信噪比和对比噪声比测量的感兴趣区设置。**图1A** 常规2D序列胫骨远端及背景噪声ROI选取；**图1B** 常规2D序列跟腱及背景噪声ROI选取；**图1C** 3D View+CS序列胫骨远端及背景噪声 ROI选取；**图1D** 3D View+CS序列跟腱及背景噪声ROI选取。图2，常规序列和3D View+CS序列显示距腓前韧带和内侧三角韧带损伤情况。**图2A** 常规轴位T_2W_SPAIR显示距腓前韧带损伤Ⅱ°；**图2B** 3D View T_2显示距腓前韧带损伤Ⅱ°，与图2A诊断一致；**图2C~图2D** 常规冠状位T_2W_SPAIR与3D View T_2显示内侧三角韧带损伤差异不大。图3，常规序列和3D View+CS 序列显示分歧韧带和跟腓韧带损伤情况。**图3A** 常规矢状T_2_SPAIR显示分歧韧带模糊；**图3B** 3D View T_2显示分歧韧带信号增高，提示部分撕裂Ⅱ°(骰骨侧)；**图3C** 常规轴位T_2W_SPAIR显示跟腓韧带无损伤；**图3D** 3D View T_2显示跟腓韧带跟骨附着端走行迂曲，信号增高，提示损伤Ⅱ°。

3 讨 论

3D View+CS序列在检查时间与常规2D序列相当的情况下，图像的信噪比与对比噪声比更高，提示3D View+CS序列图像质量较常规2D序列更高，而且3D View+CS序列对踝周韧带的检出率及损伤诊断更为准确。

常规2D序列无法进行容积数据采集，在矩阵和视野一定的条

表1 常规踝关节2D MRI检查序列及参数

序列名称	重复时间(ms)	回波时间(ms)	视野(mm)	矩阵	层厚(mm)	层间距	激励次数	扫描时间(s)
矢状PDW_SPAIR	1800	25	160x160	248x222	3.8	0.36	1	98
矢状T_1W_TSE	500	15	160x160	248x222	3.8	0.5	1	78
冠状PDW_SPAIR	1800	25	160x100	248x145	3.5	0.36	1	96
轴位T_2W_SPAIR	1600	65	100x120	144x157	3.5	1	1.3	112
矢状3D view+CS	2000	110	169x179	212x224	0.8	-0.4	2	376

表2 2D常规序列与3D View+CS序列图像信噪比和对比噪声比的比较

	信噪比	对比噪声比
2D常规序列	63.4±36.0	173.5±135.6
3D view+CS	100±43.5	1699.7±651.1
Z值	-3.441	-6.094
*P*值	0.001	<0.001

表3 2D常规序列与3D View+CS序列对韧带损伤程度的比较

	ATL	CFL	MDL	BL
2D 序列	1.58±0.86	0.5±0.58	0.5±0.9	0.5±0.58
3D view+CS序列	2.0±0.85	1.08±0.8	0.88±1.14	1.08±0.8
Z值	-1.936	-2.672	-1.396	-4.111
*P*值	0.053	0.008	0.163	<0.001

件下，只能通过提高层厚，来获得较高的信噪比。但过大的层厚必然导致Z轴空间分辨力的降低，部分容积效应无法避免，降低了小病变的检出率，对病变分级的评价产生了影响[17]。相比之下，采用了容积采集技术的3D view序列可以实现零间隔的连续薄层扫描，大幅度提高了Z轴空间的分辨力，本研究的3D view薄层序列达到了完全各向同性，图像可进行三维多平面重建，沿韧带走行重建韧带，对细小韧带损伤的检出能力明显高于常规2D序列[18-19]。

2007年，Lustig等最先将CS理论应用于MRI成像领域，通过K空间部分数据成功重构出原始图像，减少了MRI的成像时间。认为与传统MRI的采集k空间信号，CS-MRI先将信号进行空间变换，使其成为稀疏或可压缩信号，再利用一个与变换基本不相干的测量矩阵将变换所得高维信号投影至一个低维空间，并对所获取的少量测量值进行解凸优化，从而实现信号的精确重构[20]。2019年，CS被马培旗等用于3.0T膝关节MRI，对评估膝关节半月板损伤有较好的价值，保证图像质量的前提下，缩短了扫描时间[21]。本研究结果表明应用CS的3D view图像的SNR及CNR优于常规2D序列，与既往研究结果相似[22]。

踝关节扭伤往往为多韧带合并损伤，因此，全面、准确诊断踝周韧带损伤的部位和程度对临床及时治疗非常关键[23-24]。目前采用的常规2D踝关节MR检查序列不能沿韧带走行进行扫描或重建、扫描层厚较厚，部分容积效应重，对跟腓韧带和分歧韧带等走行迂曲或细小的韧带显示能力不足，容易导致漏诊或低估韧带损伤。而3D View+CS序列在可接受的检查时间内大幅提升图像质量，可沿韧带走行对图像进行任意平面重建，层厚薄(<1mm)，对显示足踝部走行迂曲和细小韧带有天然优势[25]。本研究即发现3D View序列可更准确地显示跟腓韧带和分歧韧带损伤，值得推广应用。

本研究尚存在一些不足。首先，本研究的患者数量较少，需今后进一步大量搜集踝关节损伤的患者以研究3D View+CS序列对踝关节各结构损伤诊断的准确性。其次，本研究证实3D view序列对跟腓韧带和分歧韧带的诊断能力较常规序列确有提升，但并未对足内其他小韧带进行诊断分析，今后还需加强足踝小韧带损伤的3D检查和诊断能力。第三，本研究选用的CS的并行采集次数为9，采集次数固定，但是不同并行采集次数得到图像的信噪比及对比噪声比不同，今后应尝试各种不同的并行采集次数，以在最短的时间内获得最佳的图像质量。

3D view序列在CS技术的协助下，获得了临床和患者均能接受的扫描时间，提高了图像质量及足踝部韧带损伤诊断的准确性，为临床医师准确治疗提供了影像学检查基础。

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