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·专题报道·

超长重复时间三维真实重建反转恢复序列评估内耳内淋巴积水成像的价值

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［摘要］ **目的** 探讨基于调制反转角成像技术（modulated flip angle technique in refocused imaging with extended echo train, MATRIX）重复时间（repetition time, TR）为 16 000 ms 的改良三维真实重建反转恢复（three-dimensional inversion-recovery with real reconstruction, 3D-real IR）序列用于内耳内淋巴积水成像的效果，并与基于传统快速自旋回波（turbo spin echo, TSE）的经典 3D-real IR（TR 6 000 ms）对比。**方法** 前瞻性分析 2021 年 7 月至 2022 年 11 月就诊于复旦大学附属中山医院并接受经鼓室注射钆对比剂后经典和改良 3D-real IR 扫描的 27 例患者的内耳图像。主观评价两组序列的图像质量，定量分析两组序列的信噪比、对比噪声比、耳蜗和前庭内淋巴间隙和膜迷路面积比，并比较。**结果** 经典 3D-real IR 序列图像上 14（25.9%）耳的内、外淋巴间隙信号对比度不满足内淋巴积水诊断需求；改良 3D-real IR 序列图像上均能清晰显示。改良 3D-real IR 的图像质量评分、信噪比和对比噪声比均高于经典 3D-real IR（$P<0.001$），两者扫描时间相近。经典 3D-real IR 的耳蜗内淋巴间隙和膜迷路面积比高于改良 3D-real IR（$P<0.001$），两者前庭内淋巴间隙和膜迷路面积比差异无统计学意义。**结论** 经鼓室注射钆对比剂后，超长 TR 改良 3D-real IR 较经典 3D-real IR 更能清晰显示内耳内淋巴积水。

［关键词］ 内淋巴积水；梅尼埃病；3D-real IR；重复时间；鼓室注射

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Value of three-dimensional inversion-recovery with real reconstruction sequence using an ultralong repetition time for endolymphatic hydrops

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［**Abstract**］ **Objective** To evaluate the value of an optimized three-dimensional inversion-recovery with real reconstruction (3D-real IR) sequence with a longer repetition time (TR, 16 000 ms) based on modulated flip angle technique in refocused imaging with extended echo train (MATRIX) in the endolymphatic hydrops (EH) imaging after intratympanic gadolinium (Gd) administration, and to compare it with a conventional 3D-real IR based on the turbo spin echo (TSE) sequence. **Methods** From July 2021 to November 2022, twenty-seven patients received both the conventional and optimized 3D-real IR sequences after bilateral intratympanic Gd administration. Images of the two sequences were qualitativly evaluated and compared. Contrast-to-noise ratio (CNR), signal-to-noise ratio (SNR), and area ratio of endolymph against the total lymphatic space from the two sequences were measured and compared. **Results** 14(25.9%) ears with insufficient contrast for the EH diagnosis on the conventional sequence were clearly displayed on the optimized sequence. Image score, CNR and SNR of the optimized sequence were significantly higher than those of the conventional sequence ($P < 0.001$). The scanning time of two sequences was similar. The area ratio of endolymph against the total lymphatic space in the cochlear was significantly higher on the conventional 3D-real IR than that on the optimized 3D-real IR ($P < 0.001$); there was no statistical difference in the vestibule between the two sequences. **Conclusions** Compared with conventional sequence, optimized 3D-real IR sequence with a longer TR may be better for evaluation of EH after intratympanic Gd administration.

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［**Key Words**］ endolymphatic hydrops; Meniere's disease; 3D-real IR; repetition time; intratympanic injection

内耳钆造影能直观、准确显示内淋巴积水[1]，一般通过鼓室或静脉注射钆对比剂。静脉注射不需耳部操作，能同时观察双侧膜迷路[2]，但钆对比剂通过血-外淋巴屏障后，在外淋巴液中的浓度变低[3]，对磁共振扫描设备和扫描参数设置要求较高，检查成功率相对较低。鼓室注射法对比剂用量小，注射后外淋巴液中的钆对比剂浓度高，可以获得更高的信噪比（signal-to-noise ratio, SNR）和对比噪声比（contrast-to-noise ratio, CNR）[4]，且目前尚无数据表明该方法会导致远期听力损伤[5]。《内耳内淋巴积水磁共振影像评估中国专家共识（2020年）》推荐鼓室给药[6]。

对于内耳内淋巴积水的磁共振检查，目前主要采用三维液体衰减反转恢复（three-dimensional fluid-attenuated inversion recovery, 3D-FLAIR）序列及三维真实重建反转恢复（three-dimensional inversion-recovery with real reconstruction，3D-real IR）序列[7-8]。与3D-FLAIR序列相比，3D-real IR序列能同时区分内耳内、外淋巴间隙及其周围骨质[9]。但其对低浓度钆对比剂敏感性较低，同时由于圆窗膜对钆对比剂的通透性不良，以及鼓室注射后钆对比剂在迷路各部的外淋巴分布不均等，成像效果可能不佳[10-12]。

延长重复时间（repetition time, TR）能显著提高3D-real IR序列对低浓度钆对比剂的敏感性[13]。本课题组前期将基于调制反转角成像技术（modulated flip angle technique in refocused imaging with extended echo train, MATRIX）的超长TR（16 000 ms）3D-real IR序列用于静脉注射钆对比剂后内淋巴积水成像，获得了较高的内、外淋巴间隙对比度[14-15]。本研究将该方法用于鼓室注射钆对比剂后内耳内淋巴积水成像，并与基于传统快速自旋回波（turbo spin echo, TSE）的3D-real IR序列成像对比。

1　资料与方法

1.1　*研究对象*　前瞻性纳入2021年7月至2022年11月在复旦大学附属中山医院接受鼓室注射钆对比剂后经典和改良3D-real IR序列扫描的患者，其中男性6例、女性21例，年龄25～65岁，平均43.4岁。患者主要表现为眩晕、听力下降、耳鸣和耳闷等，无中耳乳突炎病史、无内耳手术史。扫描过程中无运动伪影。参照2015年Barany学会的诊断标准[16]，患者均诊断为确定的梅尼埃病或可能的梅尼埃病。

1.2　*鼓室注射钆对比剂*　由经验丰富的耳科医生用23G针头和1 mL注射器用生理盐水以8∶1稀释钆双胺注射液[（欧乃影，通用电气药业（上海）有限公司）]后，经鼓膜注入鼓室，注射量0.4～0.5 mL。注射后嘱患者以头后仰位休息1 h，尽量少说话、少做吞咽动作，注射24 h后行MRI扫描。

1.3　*磁共振成像*　用3.0 T MR扫描仪（uMR 790，上海联影医疗科技有限公司）和32通道头线圈对患者耳部进行扫描，扫描序列为经典和改良3D-real IR序列，扫描范围为双侧内耳。两组序列采用一致的定位，扫描层面互相匹配。经典3D-real IR序列主要参数：TR 6 000 ms、回波时间（echo time, TE）276 ms、反转时间（inversion time, TI）1 500 ms、层厚0.5 mm、矩阵352 × 352、视野（field of view，FOV）160 mm × 160 mm、回波链长度30、扫描层数36、扫描时间9 min 28 s。改良3D-real IR序列主要参数：TR 16 000 ms、TE 628 ms、TI 2 700 ms、层厚0.5 mm、矩阵352 × 352、FOV 160 mm × 160 mm、回波链长度180、扫描层数36、扫描时间9 min 19 s。

1.4　*图像质量主观评价*　对54耳的3D-real IR图像，均使用联影后处理工作站（uWS，上海联影医疗科技有限公司）进行图像处理和分析。两位影像医师（分别有10年和30年头颈部扫描经验）分别对经典和改良3D-real IR序列图像质量进行定性评价，评分0～5分：0分，外淋巴间隙显影不良（全部或部分未显影），内、外淋巴间隙对比度差，无法满足诊断需求；1分，外淋巴间隙轻微显影，内、外淋巴间隙之间对比度低，可勉强分辨；2分，外淋巴间隙轻度显影，内、

外淋巴间隙之间对比度较低；3 分，外淋巴间隙中度显影，内、外淋巴间隙之间对比度中等；4 分，外淋巴间隙显影良好，内、外淋巴间隙之间对比度较高；5 分，外淋巴间隙显影很好，内、外淋巴间隙及周围骨质信号分辨清晰，内、外淋巴间隙之间对比度很高[15]。两位影像医师评分不一致时，通过讨论达成一致。

1.5 图像质量定量分析 分别在两组 3D-real IR 序列上测量 27 例患者双侧耳（54 耳）的 SNR 和 CNR。同时选中两组序列，在改良 3D-real IR 序列图像上清晰显示耳蜗底周层面，在其外淋巴区域（高信号区）作面积为 5 mm^2 的圆形感兴趣区（region of interest，ROI），后处理工作站在经典 3D-real IR 序列图像上自动匹配相同 ROI；在两组序列图像上的前庭内淋巴间隙（低信号区）选取 5 mm^2 的 ROI，并在同层脑干选取 50 mm^2 的 ROI。记录由后处理工作站自动产生 ROI 的平均信号强度和信号强度标准差。将 SNR 定义为耳蜗底周外淋巴间隙信号强度与脑干信号强度标准差之比（$SI_{耳蜗底周}/\sigma_{脑干}$）；将 CNR 定义为内、外淋巴间隙之间信号差别与脑干信号强度标准差之比[（$SI_{耳蜗底周}-SI_{前庭}$）/$\sigma_{脑干}$]。

1.6 内淋巴积水的定量分析 将两组图像质量主观评价结果均符合诊断需求的耳纳入该研究。参考 Naganawa 等[17]和 Liu 等[18]提出的评价标准，分别通过在两组 3D-real IR 序列图像上手绘 ROI 测量内淋巴和膜迷路的面积（包括耳蜗和前庭，图 1），并计算两者之比。测量耳蜗时，选择耳蜗蜗轴高度最大层面，在经典或改良 3D real IR 图像上沿着高信号边缘勾画耳蜗膜迷路，测量过程中需注意避开耳蜗轴，然后在同层图像上沿中阶的低信号边缘勾画耳蜗内淋巴间隙。测量前庭时，选择显示水平半规管大于 240°的最低层面，沿高信号外缘勾画前庭的膜迷路，测量过程中需注意避开半规管和壶腹，然后沿低信号边缘勾画内淋巴间隙（包括球囊和椭圆囊）。分别计算耳蜗和前庭的内淋巴间隙与整个膜迷路的面积比。由两位影像医师分别独立完成测量，取两位医师测得的面积比平均值。

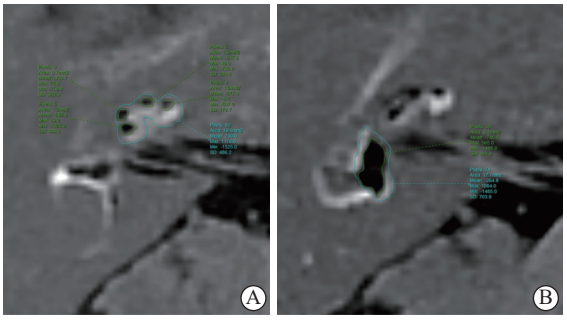

图 1 3D-real IR 序列图像上手绘 ROI 测量耳蜗和前庭的内淋巴和膜迷路面积

Figure 1 Measurement of the endolymphatic and membranous labyrinth areas of cochlea and vestibule by drawing freehand ROIs on 3D-real IR images

In the measurement of cochlea (A), choose the slice on which the cochlear modiolus is visually largest to delineate endolymph space along the margin of low signal scale media (green ROIs), and whole cochlea along the high signal margin (blue ROI). When drawing the ROI of the whole cochlea, exclude the modiolus. In the measurement of vestibule (B), choose the lowest slice where the lateral semicircular canal ring is visualized more than 240° to delineate the endolymph space along the low signal margin (green ROI), and whole vestibule along the high signal margin (blue ROI). The semicircular canal and ampulla should be excluded. ROI: region of interest.

1.7 统计学处理 采用 SPSS 16.0 软件进行统计分析，应用配对 Wilcoxon 秩和检验比较两种序列的图像质量评分。应用配对 t 检验比较两种序列的 SNR、CNR 以及耳蜗和前庭的内淋巴间隙和膜迷路面积比。应用组内相关系数（intraclass coefficient correlation, ICC）评估两位影像医师测得的耳蜗和前庭内淋巴和膜迷路面积比的一致性：ICC 为 0.00～0.19，一致性差；0.20～0.39，一致性一般；0.40～0.59，一致性中等；0.60～0.79，一致性较高；0.80～1.00，一致性很高。检验水准（α）为 0.05。

2 结 果

2.1 图像质量的主观评价 结果（表 1）显示：改良 3D-real IR 序列的图像质量评分高于经典 3D-real IR 序列（$P<0.001$）。其中，14（25.9 %）耳的经典 3D-real IR 序列图像上，外淋巴间隙呈低信号，内、外淋巴间隙信号对比度不足（14 耳

蜗、5 前庭），图像质量评分为 0，不满足内淋巴积水诊断需求。54 耳的改良 3D-real IR 序列图像质量均较高（图 2～4）。

2.2　图像质量的定量分析　结果（表 1）显示：改良 3D-real IR 序列的 SNR 及 CNR 均大于经典 3D-real IR 序列（P＜0.001）。

2.3　内淋巴积水的定量分析　23 例患者 40 耳的两组图像可用于内淋巴积水诊断；经典 3D-real IR 序列图像上 21（52.5 %）提示耳蜗内淋巴间隙的低信号区，在改良 3D-real IR 序列上部分呈高信号，近耳蜗顶周该现象更明显（图 2～4）。结果（表 1）显示：用经典 3D-real IR 序列图像测得的耳蜗内淋巴间隙与膜迷路面积比大于用改良 3D-real IR 序列图像测量的结果（P＜0.001）；两组序列测得的前庭内淋巴间隙与膜迷路面积比差异无统计学意义。两位影像医师使用改良 3D-real IR 序列测量耳蜗和前庭内淋巴间隙与膜迷路面积比的 ICC 值分别为 0.935（P＜ 0.001）、0.942（P＜0.001），高于经典 3D-real IR 序列的 0.789（P＜0.001）和 0.906（P＜0.001）。

表 1　内耳经典和改良 3D-real IR 序列图像特征比较

Table 1　Comparison of inner ear images between conventional and optimized 3D-real IR sequences

Index	n	Conventional sequence	Optimized sequence	P
Image score	54	3.11±2.06	4.72±0.60	＜0.001
CNR	54	32.07±22.80	52.28±25.20	＜0.001
SNR	54	16.06±18.34	35.91±19.96	＜0.001
Area ratio of endolymph against the total lymphatic space				
Cochlear	40	0.14±0.05	0.09±0.05	＜0.001
Vestibule	40	0.20±0.17	0.19±0.13	0.360

CNR: contrast-to-noise ratio; SNR: signal-to-noise ratio.

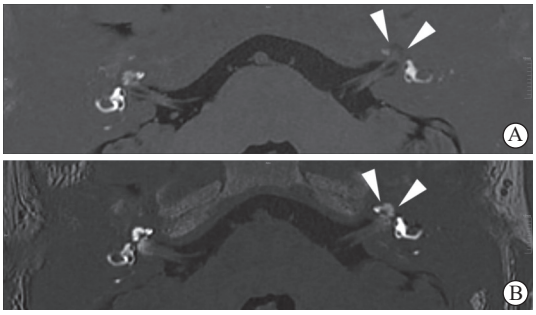

图 2　无内淋巴积水内耳经典和改良 3D-real IR 序列图像对比

Figure 2　Comparison between conventional and optimized 3D-real IR images in a patient without endolymphatic hydrops

The patient is male, 31 years old, with clinical diagnosis of left probable Meniere's disease. On conventional 3D-real IR image (A), the hypointense region in the apical turn of the left cochlear (arrowheads) shows slight endolymphatic hydrops; at the same level on the optimized 3D-real IR image (B), the region shows hyperintensity (arrowheads) without endolymphatic hydrops. In the right ear, perilymphatic space shows hyperintensity and no endolymphatic hydrops is found on both the two sequences.

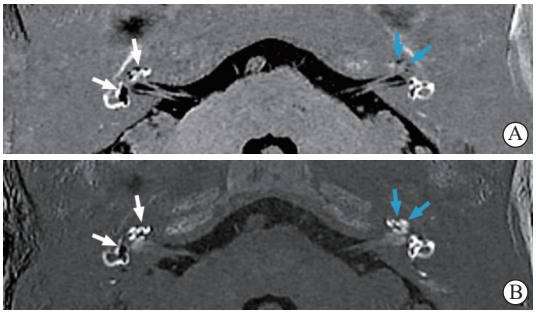

图 3　右侧耳蜗、前庭内淋巴积水内耳经典和改良 3D-real IR 序列图像对比

Figure 3　Comparison between conventional and optimized 3D-real IR images in a patient with endolymphatic hydrops in right cochlea and vestibule

The patient is male, 62 years old, with clinical diagnosis of right definite Meniere's disease. On both the conventional (A) and optimized 3D-real IR (B) images, endolymphatic hydrops in the right cochlea and vestibule is displayed well (white arrows). The apical and mid turn of the left cochlear show hypointensity (blue arrows) on the conventional 3D-real IR, but show hyperintensity (blue arrows) at the same level on optimized 3D-real IR sequence, indicating the endolymphatic hydrops degree may be over-estimated by the conventional 3D-real IR imaging.

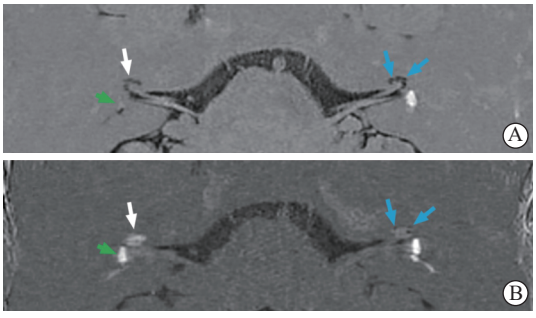

图 4 左侧耳蜗内淋巴积水内耳经典和改良 3D-real IR 序列图像对比

Figure 4 Comparison between conventional and optimized 3D-real IR images in a patient with endolymphatic hydrops in left cochlear

The patient is female, 31 years old, with clinical diagnosis of left probable Meniere's disease. On the conventional 3D-real IR image (A), both the endolymphatic and perilymphatic spaces in the left cochlear show similar hypointensity (blue arrows), and perilymphatic space shows hypointensity in the right cochlea (white arrow) and isointensity in the right vestibule (green arrow), so endolymphatic hydrops is unable to be evaluated. At the same level on the optimized 3D-real IR image (B), mild endolymphatic hydrops in the left cochlear is clearly revealed (blue arrows), and perilymphatic space shows hyperintensity in the right cochlea (white arrow) and vestibule (green arrow).

3 讨 论

3D-real IR 序列常用于鼓室注射对比剂后的延迟内耳内淋巴积水成像，保证外淋巴液中钆对比剂浓度较低时的图像质量及控制扫描时间是目前研究的难点。通过延长 TR 能增强含低浓度钆对比剂的外淋巴液和不含钆对比剂的内淋巴液的时间信号曲线在过原点时的信号差异；该方法在外淋巴液中钆对比剂浓度低时更高敏感[13, 19]。但是，延长 TR 会延长扫描时间。本研究中改良 3D-real IR 序列采用的超长 TR (16 000 ms) 基于 MATRIX 序列，能通过长回波链和短回波间隙[20-21]，使其扫描时间缩短，甚至短于 TR 为 6 000 ms 的基于传统 TSE 序列的经典 3D-real IR 序列。因此，本研究中改良 3D-real IR 序列在控制扫描时间的前提下，能有效提高图像质量。

本研究主观评价发现，改良 3D-real IR 序列的图像质量评分更高。由于内、外淋巴间隙之间的对比度不足，25.9% 内耳内淋巴积水难以通过经典 3D-real IR 序列评估，其中耳蜗尤为明显；改良 3D-real IR 序列上内耳各部分外淋巴间隙均呈明显高信号，与内淋巴间隙及内耳周围骨质有很高的对比度。定量分析中，改良 3D-real IR 序列的 SNR 和 CNR 均大于经典 3D-real IR 序列，与主观评价结果一致，表明改良 3D-real IR 序列对外淋巴液中的钆对比剂更敏感，能提高内耳内淋巴积水检查成功率。

耳蜗和前庭内淋巴间隙与膜迷路的面积比能客观反映内淋巴积水程度。3D-real IR 序列能同时分辨内、外淋巴间隙和内耳周围骨质，适用于内淋巴积水的定量分析。本研究中，经典 3D-real IR 序列的耳蜗内淋巴间隙与膜迷路面积比大于改良 3D-real IR 序列，经典 3D-real IR 序列易高估耳蜗，尤其是靠近耳蜗顶周部位内淋巴积水的程度。本研究中，经典 3D-real IR 序列图像上耳蜗内一般为内淋巴间隙的部分低信号区在改良 3D-real IR 序列图像上呈明显高信号，提示外淋巴间隙在经典 3D-real IR 序列上显影不全，此类情况即使是经验丰富的影像医师也难以察觉。在形成机制上，鼓室注射的钆对比剂在耳蜗外淋巴液中分布不均，从耳蜗底周到顶周浓度逐渐降低，经典 3D-real IR 序列对其敏感性不足导致显影不完全。该情况被影像医师发现时会评估为检查失败，未被发现时则可能造成误判，影响该项检查的可信度。本研究中改良 3D-real IR 序列具有充分的内、外淋巴间隙对比度，可有效避免上述问题。此外，两位影像医师用改良 3D-real IR 序列图像测量耳蜗和前庭内淋巴间隙与膜迷路面积比的一致性很高，高于经典 3D-real IR 序列，说明使用改良 3D-real IR 序列图像测量的结果更稳定、可靠。

本研究存在一定局限性：（1）样本量相对较小，因此采用配对研究设计提高结果可信度。（2）受限于内耳解剖位置、功能和耳源性眩晕患者的特殊性，难以获得内耳病理检查结果。未来可采用含不同浓度钆对比剂的体模研究验证本研究结论。（3）由于不同厂商生产的仪器或不同型

号仪器的成像有差异，本研究中扫描参数普适性可能受限。

综上所述，基于 MATRIX 技术和超长 TR 的改良 3D-real IR 序列用于鼓室注射钆对比剂后的内耳内淋巴积水成像能提高内、外淋巴间隙信号对比度，获得优于经典 3D-real IR 序列的内耳图像，提高检查成功率。

伦理声明 本研究经医院伦理委员会审批（B2022-255R），患者知情并签署知情同意书。

利益冲突 所有作者声明不存在利益冲突。

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