京都大学	博士（ 医学 ）	氏　名	Krishna Pandu Wicaksono

論文題目	Two-Minute Quantitative Susceptibility Mapping From Three-Dimensional Echo-Planar Imaging Accuracy, Reliability, and Detection Performance in Patients With Cerebral Microbleeds （脳微小出血患者における三次元エコープラナー法を用いた二分間撮影定量的磁化率マッピングの正確性、信頼性、検出能）

（論文内容の要旨）

　Quantitative susceptibility mapping (QSM) is an MRI post-processing technique to estimate local tissue magnetic susceptibility quantitatively. QSM is commonly derived from gradient-recalled echo (GRE)-phase measurement through the deconvolution process. In evaluating cerebral microbleeds (CMB), QSM has been shown to be more sensitive and specific than susceptibility-weighted imaging (SWI). Still, QSM is rarely used in routine MR examinations, owing to the relatively long acquisition time. Echo-planar imaging (EPI) enables faster acquisition by acquiring multiple lines of imaging data after a single radiofrequency excitation. QSM derived from 3D-EPI could be scanned as short as 2 minutes, compared to 5 minutes for typical GRE QSM. This study investigated the accuracy, reliability and CMB detection performance of 3D-EPI QSM, compared with GRE QSM through phantom, healthy volunteer and patient studies.

　A gadolinium phantom study was conducted on two 3-T MR scanners employing 3D-EPI, single-TE, and multi-TE GRE sequences to assess QSM accuracy and interscanner reproducibility. From April 2018 to October 2019, 40 healthy volunteers were scanned with the three QSM sequences on one 3-T MR scanner to evaluate the QSM reliability. The linear regression analyses, intraclass correlation coefficient (ICC) and Bland-Altman analyses were performed between measured and theoretical susceptibilities in the phantom study and between QSM sequences in the volunteer's study. Thirty-eight patients with CMB who underwent both 3D-EPI and GRE QSM scans were retrospectively included. Two radiologists, blinded to image type and patient information, independently identified, counted and anatomically categorized CMB using the Microbleed Anatomical Rating Scale. Cohen κ coefficients were calculated to determine the CMB detection agreement between QSM sequences as well as the agreement between raters.

　The gadolinium phantom study demonstrated excellent accuracy between measured and theoretical susceptibilities of 3D-EPI QSM on both MR scanners (Skyra, $R^2 = 0.996$, P<.001, ICC = 0.997, mean difference -2 ppb (95% CI -45 to 40 ppb); Prisma, $R^2 = 0.992$, P<.001, ICC = 0.988, mean difference 15 ppb (95% CI -67 to 97 ppb) with a high inter-scanner consistency (R^2 = 0.984, P<.001; ICC=0.988). A human study of 40 healthy volunteers (59 ± 13 years, 25 women) showed excellent reliability with 3D-EPI QSM for both single-TE and multi-TE GRE ($R^2 = 0.981$, P<.001, ICC = 0.988; $R^2 = 0.983$, P<.001, ICC = 0.990, respectively), supported by a Bland-Altman mean difference of 4 ppb (95% CI -15 to 23 ppb) for single-TE GRE, and 3 ppb (95% CI -15 to 20 ppb) for multi-TE GRE. Visual evaluation of CMB as depicted by 3D-EPI and GRE QSM exhibited almost perfect intra-rater agreement for both raters (κ = 0.923 and 0.942, P<.001). The inter-rater agreement of 3D-EPI QSM visual assessment was slightly higher than that of GRE-QSM (κ = 0.844, P<.001; κ = 0.819, P<.001, respectively).

　These results indicated that QSM from 3D-EPI with a shorter acquisition time provided excellent accuracy, reliability, and comparable detection performance to the GRE QSM in patients with cerebral microbleeds, which may favor its clinical use.

（論文審査の結果の要旨）

　定量的磁化率マッピング（QSM）は組織の磁化率を定量的に推定可能な画像解析技術であり、脳微小出血の評価に有用であるが、比較的長い撮像時間が必要な gradient-recalled echo (GRE) 法を用いるため、日常の MR 検査ではほとんど使用されていない。3D echo planar imaging (3D-EPI) 撮像法は高速な画像取得により 2 分という短時間撮像が可能である。本研究では、ファントム、健康被験者、患者において、3D-EPI 法を用いた QSM の正確性、信頼性および微小出血の評価について GRE 法を用いた QSM と比較検討を行った。

　ガドリニウムファントムを用いて GRE 法・3D-EPI 法の撮像において、QSM から得られた磁化率と理論値の磁化率とほぼ完全に一致し($R^2 > 0.99$)、異なる MR 装置間の撮像でもほぼ同一の値を示した。40 名の健常被験者を対象とした検討では、GRE 法・3D-EPI 法の QSM から得られた磁化率はほぼ同一の値を示した。38 名の微小出血を呈した患者に対して GRE 法・3D-EPI 法の QSM を用いた視覚評価による微小出血の検出を行い、ほぼ完全な評価者内一致が見られた(κ 係数 > 0.9)。以上より、短時間撮像の 3D-EPI 法による QSM は、高い正確性を有し、従来法の QSM との間に高い信頼性を認め、微小出血の検出能も良好で、臨床応用に有用であることが示された。

　以上の研究は、短時間撮像の 3D-EPI 法による磁化率評価の臨床的有用性を示し、脳微小出血評価に寄与するところが大きい。

　したがって、本論文は博士（ 医学 ）の学位論文として価値あるものと認める。

　なお、本学位授与申請者は、令和５年１月１２日実施の論文内容とそれに関連した試問を受け、合格と認められたものである。

要旨公開可能日：　　　　　年　　　月　　　日　以降