Superb Micro-vascular Imaging (SMI): Clinical Advantages of a Novel US Flow Technique in Pediatric Diagnostic Imaging

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ABSTRACT

During blood flow evaluation in young children, assessment of subtle blood flow is limited by motion artefacts when using conventional US blood flow methods (color Doppler imaging, power Doppler imaging, and advanced dynamic flow), in particular for evaluation of respiratory fluctuating organs or in restless non-sedated children. In the conventional methods, a wall filter is usually employed to remove motion artifacts, which resulting in reduction not only of motion artifacts but also of low velocity flow components. In contrast, Superb Microvascular Imaging (SMI) provides excellent blood flow images because it uses a new adaptive algorithm that effectively separates blood flow signals from overlying tissue motion artifacts. The algorithm removes only motion artifacts while preserving low velocity blood blow components without sacrificing high resolution and high frame-rate image quality.

Attention should be paid to the pitfall, that high velocity blood flow signals might be overlooked on SMI. Because SMI is specifically adjusted to demonstrate low velocity blood flow signals in the manufacturer default, high velocity blood flow signals are relatively weak and might be overlooked. Therefore, the combination of both conventional methods and SMI is highly recommended in evaluation of blood flow in clinical application. In conclusion, SMI is particularly useful in evaluation of non-sedated children.

Keywords: Microvascular imaging, SMI, ultrasound technique, vascular imaging

INTRODUCTION

Superb Microvascular Imaging (SMI) is a novel sonography technique for detecting subtle vascular blood flow. Until recently, conventional color Doppler imaging (CDI), power Doppler imaging (PDI), and advanced dynamic flow (ADF) have been widely used to demonstrate tissue vascularity. These methods are very useful to detect hypervascular blood flow of lesions such as malignant tumors, metastatic or inflammatory lymph nodes, or vascular malformations. However, they could not be applied to evaluation of small vessel or low velocity blood flow in conditions such as normal and undescended testes in young children [1]. However, these conventional techniques have limitations in demonstrating vascularity in moving tissues because they are vulnerable to motion artifacts. Therefore, US vascular or blood flow evaluation has been difficult in young children who cannot stay still.

SMI is characterized by a novel intelligent algorithm that effectively separates flow signals from overlying motion artifacts, and provides high quality vascular image not only in lesions with subtle blood flow but also in mobile organs in non-sedated children. Because SMI is a recently developed technique, its application to children has not yet been well documented. Here, we demonstrate some clinical examples of SMI in various diseases of children, and discuss its advantages and pitfalls in clinical setting.

CASE PRESENTATION

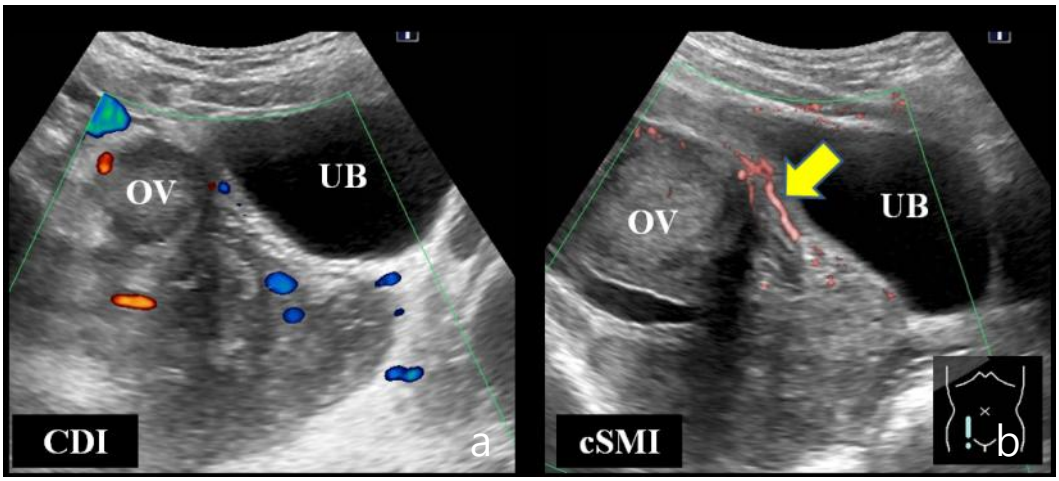

Figure 1: adnexal vessels in ovarian torsion

(a) CDI: a round structure adjacent to the urinary bladder and the uterus shows decreased blood flow. (b) cSMI: Intralesional vascularity is significantly decreased compared with favorable visualization of the surrounding adnexal vessels (arrow). Right ovarian torsion. UB: urinary bladder, OV: ovary

CASE 1: adnexal vessels in a girl suspected to have ovarian torsion [Fig 1]

An adolescent girl with acute abdominal pain was suspected to have ovarian torsion, and underwent ultrasonography. On CDI (a), a round structure is noticed adjacent to the urinary bladder and the uterus, showing decreased intralesional blood flow. But the origin of the lesion is difficult to confirm. On SMI (b), feeding adnexal artery is clearly demonstrated, tentatively warranting that the lesion arises from the right ovary. Intralesional vascularity is significantly decreased compared with favorable visualization of the surrounding vessels, suggesting torsion of the right ovary. The diagnosis was confirmed on surgery.

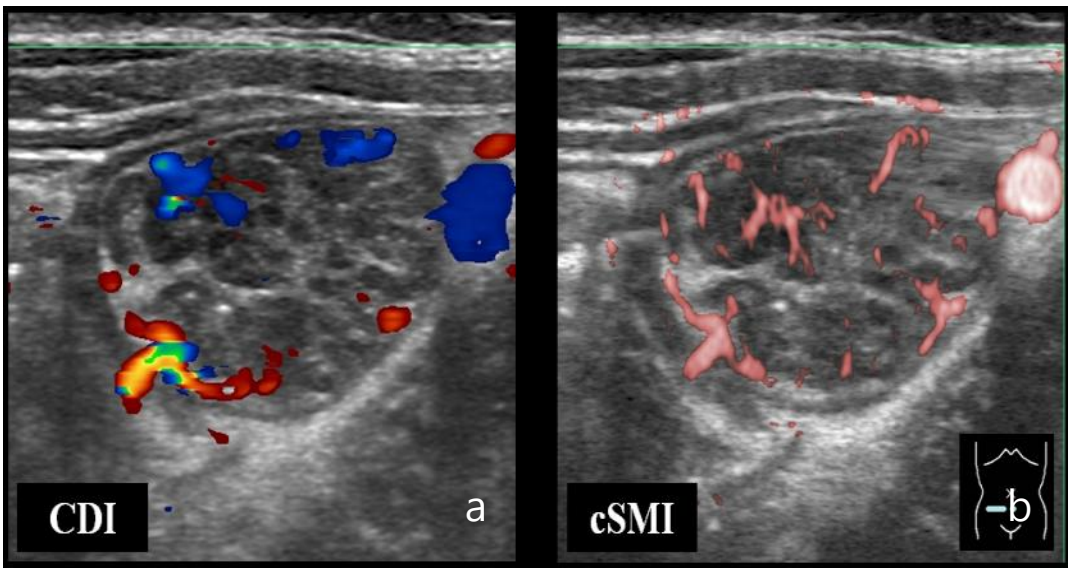

Figure 2: ileal wall thickening in IgA vasculitis

(a) CDI: significant circumferential intestinal wall thickening of the terminal ileum with increased blood flow. (b) cSMI: demonstration of small, low velocity blood flow signal that are not discerned on CDI.

CASE 2: ileal wall thickening in a boy with IgA vasculitis [Fig 2]

A boy with IgA vasculitis (formerly Henoch-Schoenlein purpura) shows significant circumferential intestinal wall thickening of the terminal ileum. Both CDI (a) and SMI (b) depict increased blood flow in the intestinal wall; however, SMI demonstrates small, low velocity blood flow signal that are not discerned on CDI. Also, SMI has higher spatial resolution. Although these intestines are peristaltic, motion artifacts are negligible.

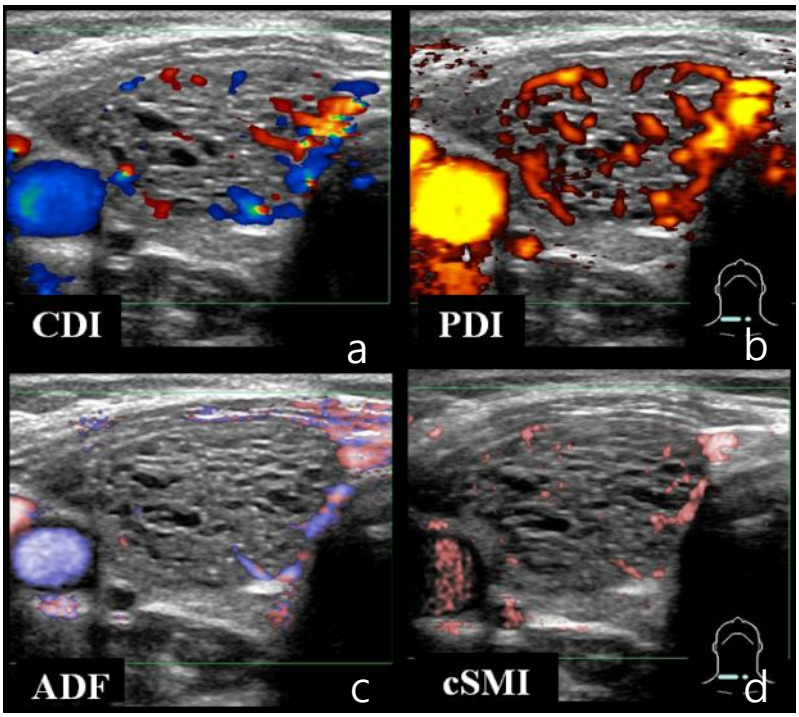

Figure 3: a thyroid nodule

(a) CDI and (b) PDI: a well-defined thyroid mass with heterogeneous intralesional texture shows hypervascularity; however, motion and blooming artifacts are conspicuous. These artifacts are less conspicuous on ADF (c) and the least on SMI (d).

Small vessels are clearly depicted on SMI without increase of motion or blooming artifacts. Adenomatous hyperplasia.

CASE 3: a thyroid nodule in an adolescent girl [Fig 3]

An adolescent girl with palpable anterior neck mass was suspected to have a thyroid tumor and underwent ultrasound. A well-defined mass with heterogeneous intralesional texture is noticed in the right lobe of the thyroid gland on US. The lesion shows hypervascularity on CDI (a) and PDI (b); however, motion and blooming artifacts are conspicuous because of neck motion and swallowing. These artifacts are less conspicuous on ADF (c) and the least on SMI (d). Small vessels are clearly

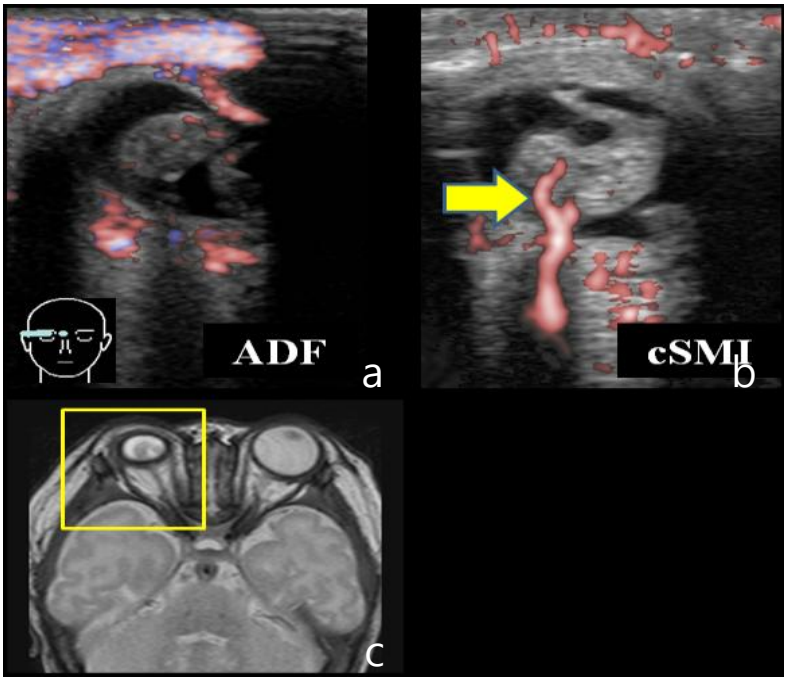

Figure 4: hyaloid vessel in PHPV

(a) ADF: The right eye shows significant microphthalmia with echogenic vitreous content. (b) cSMI: The hyloid vessel is clearly depicted on cSMI from the optic nerve sheath to the posterior aspect of the lens beyond the vitreous (arrow), but not on ADF. A diagnosis of PHPV is supported by MR (c).

PHPV: persistent hyperplastic primary vitreous

CASE 4: the hyaloid vessel in a newborn with persistent hyperplastic primary vitreous (PHPV) [Fig 4]

A newborn with multiple anomalies underwent US for evaluation of small right orbital fossa without opening of palpebral fissure, with a high frequency linear transducer. The right eye shows significant microphthalmia with echogenic vitreous content. The presence or absence of the hyloid vessel is difficult to confirm on ADF (a), which is the most important diagnostic hallmark of PHPV. On SMI (b), the hyloid vessel can be clearly depicted from the optic nerve sheath to the posterior aspect of the lens beyond the vitreous. The finding is consistent with PHPV, and MR of the orbit (c) supports the diagnosis.

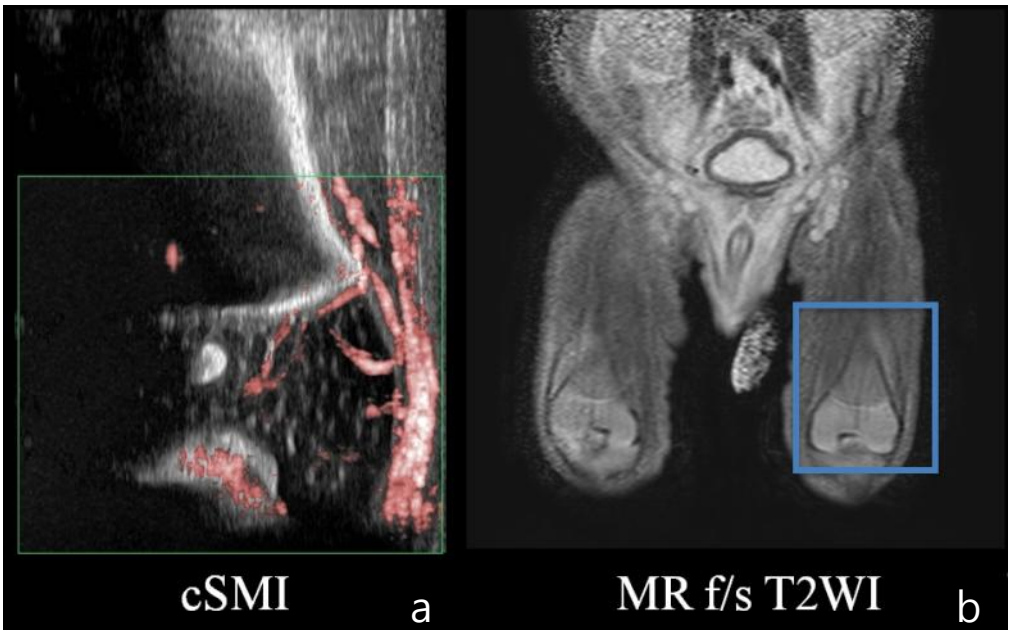

Figure 5: distal femoral epiphysis of a newborn

(a) cSMI: small vessels are depicted penetrating from the periosteal/subperiosteal regions into the unossified cartilage of the distal femoral epiphysis. Excellent visualization with higher resolution compared with MR (b).

f/s T2WI: fat saturated T2 weighted image

CASE 5: cartilage of the distal femoral epiphysis in a newborn with leg swelling [Fig 5]

US (a) and MR (b) failed to define any pathologic condition in a newborn with soft tissue swelling of the leg. As incidentally found on SMI (a), small vessels are depicted penetrating from the periosteal/subperiosteal regions into the unossified cartilage of the distal femoral epiphysis. Such visualization of the cartilaginous vascular structure has never been documented.

DISCUSSION

During blood flow evaluation in young children, conventional US blood flow methods (CDI, PDI, and ADF) have limitations in subtle blood flow evaluation especially in respiratory fluctuating organs or in restless non-sedated children. In contrast, SMI provides excellent blood flow images and is significantly useful even in the aforementioned situations. The difference mainly depends on processing algorithm. US Doppler signal is formed by blood flow as a pixel-to-pixel moving material, as well as tissue movement. Therefore, US blood flow methods have been vulnerable to motion artifacts, and require some reduction of motion artifacts to obtain high quality blood flow images. To remove motion artifacts, conventional US blood flow methods use a wall filter. A wall filter acts as a cutter of low velocity components, resulting in reduction not only of motion artifacts but also of low velocity flow components. However, SMI does not use such a wall filter. SMI uses a new adaptive algorithm that effectively separates blood flow signals from overlying tissue motion artifacts, and removes only motion artifacts while preserving low velocity blood blow components. Thus, SMI is capable to visualize low velocity blood flow signals that conventional methods have never achieved.

The clinical efficacy of SMI has been documented in evaluation of breast cancer [2-6], thyroid lesions [7], metastatic lymph nodes [8], and hepatobiliary diseases [9-12] in adults; however, its application to children has been rarely described to date. In 2016, Karaca et al. [13] reported comparison of SMI and CDI for evaluating children's testicular blood flow, and concludes that SMI yields more detailed vascular information in blood flow in testicles in small children than either CDI or PDI, and that SMI decreases the duration of the examination at a significant level. In another article, Lee et al. [14] reported that SMI can detect perfusion difference between normal and undescended testis in young children better than PDI. In 2017, Ohno et al. [15] analyzed 56 pediatric patients with hepato-gastrointestinal disorders, and stated that SMI can aid in the diagnosis and treatment planning for pediatric patients with hepato-gastrointestinal disorders. To date, we could not find any other English literature related to clinical usefulness of SMI in evaluation of children; however, we believe that SMI is expected to demonstrate more useful blood blow

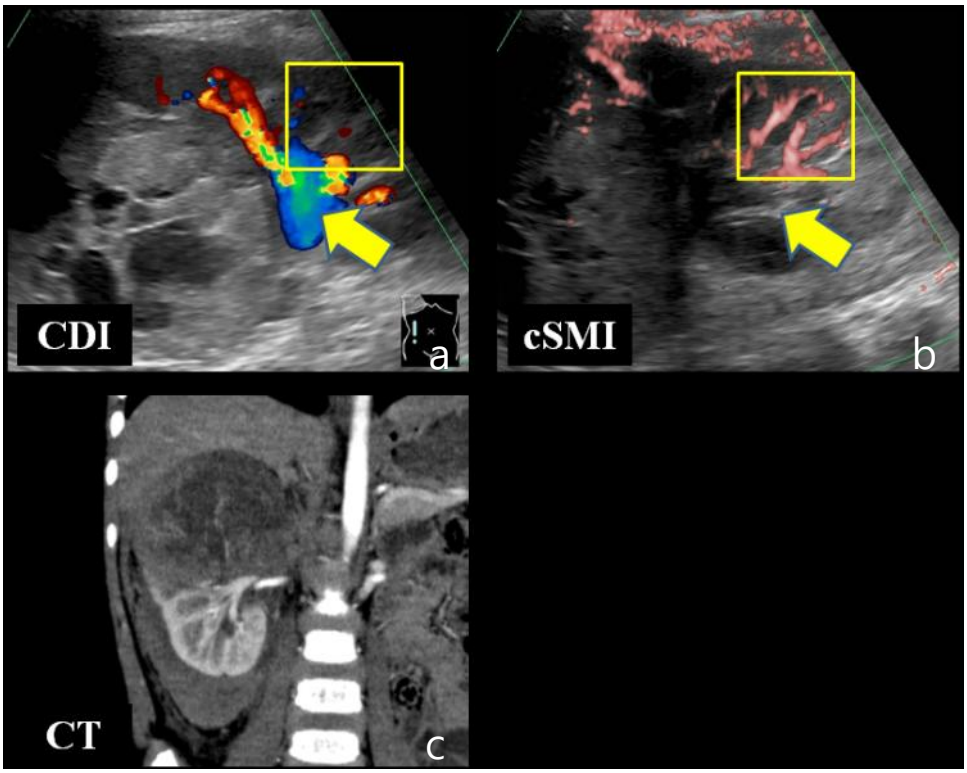

Figure 6: Loss of large vessel flow signal

In a boy with Wilms' tumor, small vessels (yellow square) in the normal kidney parenchyma are clearly demonstrated on SMI (b), while they are not clear on CDI (a). However, high velocity blood flow signals of large vessels (arrow) are missing on SMI. Contrast CT (c) demonstrates large vessels as well.

information not only in evaluation of the testis, but also in evaluation of other organs or pathologies in children.

In addition to the aforementioned points, SMI has several advantages. First, SMI does not sacrifice image quality to obtain low velocity blood flow signals. It possesses comparable or even more excellent spatial resolution and frame rates, and less blooming artifacts compared with conventional methods. So, it demonstrates excellent low velocity blood flow signal in small vessels, as well as that in large vessels. Second, it can be applied on various transducers, including high frequency (ex. 20MHz) convex and linear transducers. Third, two different imaging modes are available depending on the situation, colored SMI (cSMI) and monochrome SMI (mSMI) modes. The former demonstrates blood flow signals as colored signals (usually red) and provides excellent visualization, while the latter does not have color information but is more sensitive to low velocity blood flow. To improve visualization, the latter can be demonstrated as a fused image with a gray-scale sonography.

Currently, SMI has a few pitfalls or points to be improved. (1) SMI can be applied on various latest transducers, but not on microconvex transducers frequently used for a newborn. (2) In exchange for high sensitivity to low velocity blood flow, very subtle motion artifacts might be observed. Such artifacts are not observed on conventional methods because they would be omitted by a wall filter. (3) Attention should be paid to the last pitfall, that high velocity blood flow signals might be overlooked on SMI. SMI is specifically adjusted to demonstrate low velocity blood flow signals in the manufacturer default. In this setting, low velocity blood flow signals can be clearly demonstrated; however, high velocity blood flow signals are relatively weak and might be overlooked [Fig 6]. Therefore, the combination of both conventional methods and SMI is highly recommended in evaluation of blood flow in clinical application.

CONCLUSION

SMI provides low velocity blood flow information with an excellent high resolution and high frame-rate image, and is especially useful in evaluation of non-sedated children because of its invulnerability to motion artifacts.

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REFERENCES

1. Ingram S, Hollman AS: Colour Doppler sonography of the normal paediatric testis. Clin Radiol. 1994 Apr;49(4):266-7.
2. Xiao XY, Chen X, Guan XF et al: Superb microvascular imaging in diagnosis of breast lesions: a comparative study with contrast-enhanced ultrasonographic microvascularimaging. Br J Radiol. 2016;89(1066):20160546.
3. Park AY, Seo BK, Cha SH et al: An Innovative Ultrasound Technique for Evaluation of Tumor Vascularity in Breast Cancers: Superb Micro-Vascular Imaging. J Breast Cancer. 2016;19(2):210-3.
4. Yongfeng Z, Ping Z, Wengang L et al: Application of a Novel Microvascular Imaging Technique in Breast Lesion Evaluation. Ultrasound Med Biol. 2016;42 (9):2097-105.
5. Zhan J, Diao XH, Jin JM et al: Superb Microvascular Imaging-A new vascular detecting ultrasonographic technique for avascular breast masses: A preliminary study. Eur J Radiol. 2016;85 (5):915-21.
6. Ma Y, Li G, Li J et al: The Diagnostic Value of Superb Microvascular Imaging (SMI) in Detecting Blood Flow Signals of Breast Lesions: A Preliminary Study Comparing SMI to Color Doppler Flow Imaging. Medicine (Baltimore). 2015;94 (36):e1502.
7. Machado P, Segal S, Lyshchik A et al: A Novel Microvascular Flow Technique: Initial Results in Thyroids. Ultrasound Q. 2016;32(1):67-74.
8. Ryoo I, Suh S, You SH et al: Usefulness of Microvascular Ultrasonography in Differentiating Metastatic Lymphadenopathy from Tuberculous Lymphadenitis. Ultrasound Med Biol. 2016;42(9):2189 -95.
9. Kuroda H, Abe T, Kakisaka K et al: Visualizing the hepatic vascular architecture using superb microvascularimaging in patients with hepatitis C virus: A novel technique. World J Gastroenterol. 2016 14;22(26):6057-64.
10. Koyama N, Hata J, Sato T et al: Assessment of hepatic fibrosis with superb microvascular imaging in hepatitis C virus-associated chronic liver diseases. Hepatol Res. 2016 Jul 19.
11. Lee DH, Lee JY, Han JK. Superb microvascular imaging technology for ultrasound examinations: Initial experiences for hepatic tumors. Eur J Radiol. 2016;85(11):2090-2095.
12. Tomizawa M, Shinozaki F, Motoyoshi Y et al: Signal Intensity of Superb Microvascular Imaging Correlates with the Severity of Acute Cholecystitis. Case Rep Gastroenterol. 2016;10(2):452-458.
13. Karaca L, Oral A, Kantarci M et al: Comparison of the superb microvascular imaging technique and the color Doppler techniques for evaluating children's testicular blood flow. Eur Rev Med Pharmacol Sci. 2016;20(10):1947-53.
14. Lee YS, Kim MJ, Han SW et al: Superb microvascular imaging for the detection of parenchymal perfusion in normal and undescended testes in young children. Eur J Radiol. 2016;85(3):649 -56.
15. Ohno Y, Fujimoto T, Shibata Y: A New Era in Diagnostic Ultrasound, Superb Microvascular Imaging: Preliminary Results in Pediatric Hepato-Gastrointestinal Disorders. Eur J Pediatr Surg. 2017;27(1):20-25.

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