Coating of Nitinol Guidewire with Manganese Ion Chelated Natural Melanin Nanoparticles for MRI

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***Abstract*—Interventional procedures are performed for treating lesions, preventing their development, or for pathological diagnosis under the guidance of imaging methods where MRI (Magnetic Resonance Imaging) is the key imaging modality. However, performing interventional procedures under MRI has many challenges such as RF heating, MRI safety and visibility. In this study, a custom-designed dip coating method was utilized to deposit Mn^{2+} chelated natural melanin nanoparticles (MNPs) onto MRI-compatible nitinol guidewires. To enhance the coating quality, a specialized dip coating apparatus was developed with the help of Arduino and a step motor. Images of SEM (Scanning Electron Microscope) and MR demonstrated that optimizing the coating parameters could achieve more homogeneous Mn^{2+} chelated natural MNPs coated invasive instruments, presenting a promising approach for the advancement of interventional MRI.**

Keywords—Dip Coating, Natural Melanin Nanoparticles, Interventional Magnetic Resonance Imaging, Nitinol Guidewire.

I. INTRODUCTION

Interventional procedures are performed to diagnose, treat, and prognosis of a lesion, with the guidance of imaging methods and MRI (Magnetic Resonance Imaging) can be a tool for this observation [1]. MRI is one of the preferred diagnostic imaging methods today due to ionizing radiation free nature and providing cross-sectional images and physiological information including perfusion, diffusion, temperature, pressure, etc. [2]. One of the primary methods for designing MRI-compatible interventional tools based on passive techniques, which inherently eliminate MRI safety concerns due to the lack of a connection to the MR scanner and the ease of reproduction [2]. Passive methods provide MRI visibility by using diamagnetic, paramagnetic and ferromagnetic materials over the tip or shaft of the devices like guidewires, catheters, needles, etc. [3, 4]. However, interventional instruments fabricated with passive techniques still need additional improvement for commercialization in terms of MRI safety and visibility. For interventional MRI imaging procedures, MNPs (Melanin Nanoparticles) are potential candidates when chelated with metal ions because they provide adequate contrast similar to gadolinium containing solutions [5-10]. Our previous research has showed T1 shortening effect of ferric ion chelated natural MNPs under 3T MR scanner [8, 9]. In another study, MNPs presented negligible toxicity when they are incubated Human umbilical vein endothelial cells (HUVECs) and fibroblast (NIH 3T3) cells using MTT assay test for 24 h. [10]. The aim of this study was coating of Mn^{2+} chelated MNPs over MRI-compatible guidewires (nitinol, titanium and 316-L stainless steel) using a

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modified dip coating method. The quality and uniformity of the coating over nitinol guidewire was confirmed using SEM (scanning electron microscope) and acquired MR images.

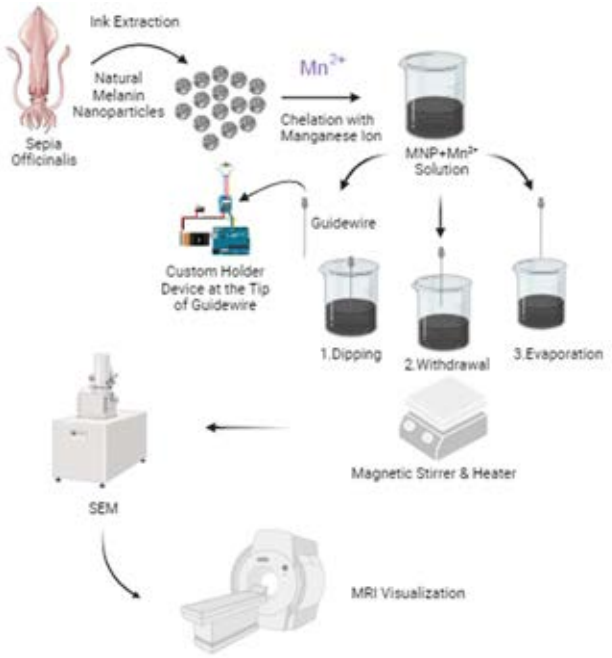


Fig 1. Schematic illustration of the study, this figure was created using https://app.biorender.com/

II. MATERIALS AND METHODS

A. Extraction of MNP & Chelation with Mn^{2+}

Natural MNPs were extracted from freshly dissected the ink sacs of squid (*Sepia officinalis*) [8-12]. The process involved washing and centrifuging at 10,000 rpm for 20 minutes, repeated three times, followed by redispersing the MNPs in water using a bath-type sonicator [8, 9, 12]. A simple mixing technique was employed to facilitate the chelation of Mn^{2+} ions with MNPs. Specifically, a solution of MNPs (1 mg/mL) was mixed with an Mn^{2+} solution (1 mg/mL) in a ratio of 100:1 (v/v) [8, 9]. The mixture was subsequently centrifuged at 10,000 rpm to remove any unbound Mn^{2+} ions [8, 9]. The supernatant was collected using a membrane filter with a pore size of 0.45 µm for analysis by inductively coupled plasma mass spectrometry (ICP-MS) using a Perkin-Elmer Optima-5300-DV to determine the Mn^{2+} content in the MNPs [13]. Scanning electron microscopy was used to monitor the effect of Mn^{2+} chelation on the morphology of the MNPs [8, 9].

B. Dip Coating Method with Custom Holder Apparatus

The system used a 28BYJ-48 step motor and an L298N motor driver to enhance precision and control. This provided more stable and reproducible results, with the step motor ensuring precise dipping and withdrawal. This improved the quality and reliability of the coatings and experimental results.

TABLE I. CUSTOM HOLDER COMPONENTS FOR COATING

Components	Description	Quantity
Arduino Uno	Microcontroller board	1
28BYJ-48 Step Motor	Motor for dipping and extraction movement	1
L298N Motor Driver	Provides strong and accurate control for step motor	1
Jumper Cables	Cables for connections	-
Flexible Coupling	Connection between the step motor and chuck	1
Wire or Cord (Messenger)	Wire for dipping and extraction movement	1
9V Battery	Power source for the system	1

The L298N motor driver ensures robust and accurate control of the step motor. It enables precise step-by-step control, allowing for the accurate execution of dipping and extraction movements as per the desired parameters. Moreover, the L298N motor driver is designed to supply the necessary power to meet the requirements of the step motor.



Fig 2. Dip Coating with Custom Holder Apparatus

C. Coating of Nitinol Guidewire Samples

In dip coating experiments, the variables included the duration, RPM, and the MNP+Mn^{2+} ratio in the solution were same. The dipping-withdrawing method was performed using custom designed holder. The simple dipping method was carried out by immersing the sample material in the solution for a specified duration, temperature, and RPM.

TABLE 2. DIP COATING METHOD PARAMETERS

MNP+Mn^{2+}	Dip Coating		
	Duration	***Temperature***	***RPM***
Nitinol	10 h	75 ºC	150
316-L Stainless Steel	10 h	75 ºC	150
Titanium	10 h	75 ºC	150

Nitinol, titanium, and stainless-steel guidewires were subjected to a dip-coating process in the MNP solution at 150 rpm for 10 hours using a specially designed holder apparatus. After the experiments were completed, guidewires were placed in an oven at 75 ºC for approximately 8 hours to dry. Coated guidewires were examined under SEM, and it was observed that the nanoparticles adhered best to the nitinol guidewire. Consequently, only the nitinol guidewire was subjected to MRI examination.

D. Visualization of Coated Nitinol Sample with MR Scanner

MNPs+Mn^{2+} coated nitinol guidewire samples positioned into a custom-made phantom incorporates falcon tube filled with saline solution. Axial image of guidewires was acquired using a 7.0 T MRI scanner at Boğaziçi University (MR Solutions, MRS*DRYMAG by performing a spin echo sequence with TR/TE:500/11 ms, slice thickness:1 mm, flip angle: 90º.

III. RESULTS

A. SEM Images

MNP+Mn^{2+} observed through SEM reveal their distinct morphological characteristics, appearing as uniformly spherical or irregularly shaped particles. Agglomeration was observed as a result of the predominance of Van der Waals forces at the nanoscale.

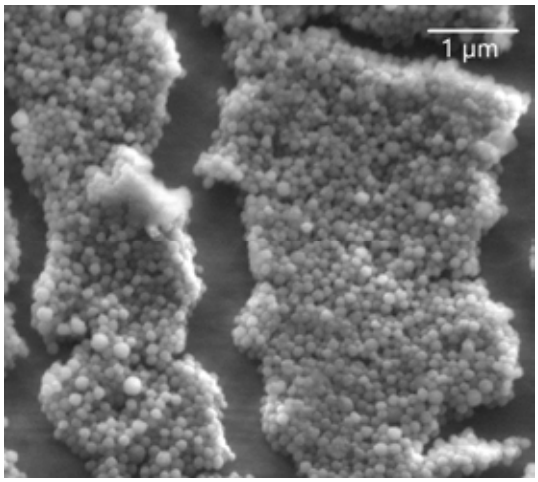


Fig 3. SEM image of MNP+Mn^{2+} coated nitinol guidewire, at 5.00 kV, 1 µm

B. MR Images

Sagittal, coronal and axial images of MNP-Mn ion-coated nitinol guidewire sample in custom saline solution phantoms and T1-W images acquired with Spin Echo sequence, TR (Repetition Time): 500 ms, TE (Echo Time): 11 ms, Slice Thickness: 1.0 mm, Flip Angle: 90º, WW (Window Width) and WL (Window Length) are also changed depending on the contrast. Considering the coatings made by dip coating method with holder (10 hours dipping-withdrawing method), a nitinol guidewire sample was imaged in MRI.

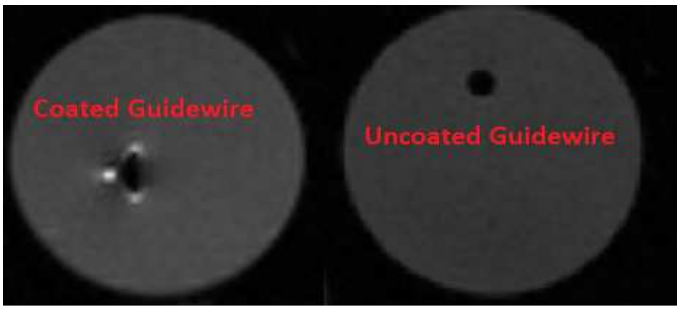


Fig 4. Axial images of MNP-Mn^{2+} ions coated and uncoated nitinol guidewire were acquired when TR:500 ms, TE:11 ms, slice thickness:1 mm, matrix size: 280x220, Flip angle:90º, WL:4859, WW:9719.

IV. DISCUSSION

MNPs chelated with Mn^{2+} provide a potential passive MR imaging material together with their biocompatible and biodegradable characteristics. In this study, we investigated MRI visibility of nitinol, stainless-steel and titanium made guidewire coated with Mn^{2+} chelated MNPs using a modified dip coating method. Experimental results showed that dipping-immersion method provided the most durable and homogenous deposition of Mn^{2+} chelated MNPs over nitinol guidewire for 8-10 hours. The quality of the coating over nitinol guidewire was confirmed using SEM (scanning electron microscope) and acquired MR images.

V. CONCLUSION

Up to date, development of commercial and MRI compatible invasive instruments were mostly based on passive, active and semi-active methods [14, 15, 16]. Although, semi-active and active technique-based prototypes are very promising in terms of visibility under MRI, they are still suffering from ease of fabrication due to incorporating rigid and bulky electronical components and MRI safety due to RF heating for routine clinical use. In this study, we used a custom designed MNP+Mn^{2+} dip coating method to obtain a uniform thin layer over a nitinol guidewire, to enhance MRI traceability. The MRI visibility test of coated guidewire revealed that fabrication of MRI traceable interventional instruments using MNP+Mn^{2+} coating over MRI compatible materials is possible. To conclude, our study showed that the deposition of Mn^{2+} chelated MNPs over the surface of MRI compatible instruments presents a promising and feasible manufacturing method for mass production of MRI compatible and traceable interventional medical devices.

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