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Synthesis, Characterization and Evaluation of NiFe₂O₄/Cr₂O₃ Nano Composite as T1-T2 Contrast Agents for High-Field MRI

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Abstract

Synthesis, Characterization and Evaluation of NiFe₂O₄/Cr₂O₃ Nano composites as promising class of T1-T2 contrast agents for high-field MRI Compared to conventional contrast agents like gadoliniumbased chelates, this composite possesses several benefits, such as improved biocompatibility, lower toxicity, and increased relativity In current study, we used a straightforward hydrothermal process to synthesis NiFe₂O₄/Cr₂O₃ nanocomposites, and X-ray diffraction, and scanning electron microscopy were among the methods we employed to describe them. They were also evaluated for their effectiveness as T1-T2 contrast agents in vivo and in vitro. NiFe, O_4/Cr_2O_3 nanocomposites have low toxicity and great relaxivity, according to the results. The nanocomposites could considerably improve the contrast of MRI images in both the T1 and T2 weighted modes, according to in vivo investigations. The NiFe₂O₄/Cr₂O₃ NCPs ` T1 and T2 relaxivities were tested at 3 T and 7 T. The T1 and T2 relaxivities of the nanocomposites rose as the Cr.O. content increased, according to the results. The NiFe2O4/Cr₂O₃ nanocomposites with a 50% Cr₂O₃ concentration had the maximum T1 relaxivity of 22.5 mM⁻¹ s⁻¹ and T2 relaxivity of 52.8 mM⁻¹ s⁻¹.Overall, these findings point to NiFe₂O₄/Cr₂O₃ nanocomposites as a potential T1-T2 high-field magnetic resonance imaging contrast agent. They may enhance the identification and tracking of numerous illnesses, including stroke and cancer. For high-field MRI, NiFe₂O₄/Cr₂O₂ NCPs are very effective T1- T2 contrast agents. Our approach is easy to use, scalable, and reasonably priced. The NCPs can dramatically improve the contrast of MRI images in both T1 and T2 weighted modes in vivo. They also have a high relaxivity and low toxicity. Our NCPs are distinct in various aspects. Initially, they consist of two distinct spinel ferrite oxides, NiFe₂O₄ and Cr²O₃, which work in concert to enhance relaxivity. Second, the NCPs consist of a NiFe₂O₄ core and a Cr₂O₃ shell, forming a coreshell structure. The NCPs 'T2 relaxivity is improved by this structure. Third, the NCPs are suited for in vivo applications because they are covered with a biocompatible layer of polyethylene glycol (PEG). Our nanocomposites may help with the detection and tracking of numerous illnesses, including stroke and cancer. Our NCPs, for instance, could be applied to the assessment of stroke damage or the detection and tracking of brain tumor development. Our nanocomposites have the potential to be employed for therapeutic applications in addition to diagnostic ones. Our nanocomposites could be applied, for instance, to enhance tissue regeneration following a stroke or to deliver therapeutic medications to Cancers. In general, our novel class of T1-T2 contrast agents for high-field MRI using NiFe₃O₄/Cr₃O₃ NCPs shows promise. They may enhance the identification, management, and observation of numerous illnesses. The cytotoxicity and in vivo magnetic resonance imaging performance of the NiFe₂O₄/Cr₂O₃ nanocomposites were also assessed. The human embryonic kidney (HEK293) cells were not harmed by the nanocomposites, according to the cytotoxicity data. The T1 and T2 contrast of mice livers may be markedly improved by the NiFe₃O₃/Cr₃O₃ NCPs, according to the in vivo MRI results.

Introduction

Clinical diagnostics and research use magnetic resonance imaging (MRI), a potent non-invasive imaging modality, extensively. By increasing the contrast of MRI images, MRI contrast agents facilitate the visualization and diagnosis of abnormalities and disorders. Based on gadolinium (Gd), traditional MRI contrast agents have been associated with substantial adverse effects, including nephrogenic systemic fibrosis (NSF). New high-performing, safer MRI contrast agents are required. Wang, J. (2020) [1]. With exceptional T1 and T2 relaxivity, NiFe₂O₄/Cr₂O₃ NCPs represent a promising



new class of MRI contrast agents. Two significant factors that influence the contrast of MRI images are the T1 and T2 relaxation durations. Because the NCPs have high T1 and T2 relaxivity, they can shorten the water molecules' T1 and T2 relaxation durations, resulting in, respectively, a darker and brighter contrast. The synthesis, characterization, and assessment of NiFe₂O₄/Cr₂O₃ NCPs as T1-T2 contrast agents for high-field MRI will be the main topics of the thesis. To create NCPs with the required size, shape, and content, the synthesis of NiFe₂O₄/Cr₂O₃ will be optimized. X-ray diffraction (XRD) and scanning electron microscopy (SEM) will be among the methods used to characterize the NCPs. We will assess relaxivity of the NCPs both in vitro and in vivo. It is anticipated that the thesis will significantly advance the creation of novel, high- performing, and safe MRI contrast agents for highfield MRI. Li, Z., et al. (2019) [2,3].Better image quality: Compared to conventional T1 or T2 contrast agents, T1-T2 dual contrast agents can offer greater image contrast and resolution.Lesser doses may be used.Multimodal imaging: For T1 and T2 weighted MRI, T1-T2 dual contrast agents can be utilized, which can be helpful for multimodal imaging investigations. For high-field MRI, the NiFe₂O₄/Cr₂O₃ NCPs are a promising T1-T2 contrast agent. Compared to conventional contrast agents like GBCAs, it offers a number of benefits, such as increased relaxivity, decreased toxicity, extended blood circulation duration, adaptability, and scalability.

Material and Method

Material

Nickel Nitrate Hexahydrate (Ni(NO₃)₂·6H₂O), Iron (III) Nitrate Nonahydrate (Fe(NO₃)₃·9H₂O), Chromium (III) Nitrate Nonahydrate (Cr(NO₃)₃·9H₂O), Sodium Hydroxide (NaOH) and all other chemicals were purchased from sigma Aldrich.

Synthesis of NiFe₂O₄/Cr₂O₃ Nanocomposites:

The NiFe₂O₄/Cr₂O₃ NCPs were hydrothermally synthesized using nickel nitrate, iron (III) nitrate, and chromium (III) nitrate as precursors. In a standard synthesis, twenty milliliters of deionized water were used to dissolve two milligrams of nickel nitrate hexahydrate, one milligram of iron (III) nitrate nonahydrate, and one milligram of chromium (III) nitrate nonahydrate. To guarantee the full dissolution of the precursors, the solution was agitated for duration of one hour. The solution was then treated with 4 M NaOH solution until the pH reached 11. After that, the mixture was moved to a 50 mL autoclave with a Teflon lining and sealed. After that, the autoclave was heated to 200 °C and kept there for 12 hours. The autoclave was permitted to naturally cool to room temperature when the reaction was finished. After that, the final product was dried at 60 °C and cleaned with water. The NiFe₂O₄/Cr₂O₃ NCPs were made via a straightforward two-step hydrothermal process. Using deionized water and a molar ratio of 1:2:1, we first created a homogenous solution of Ni (NO₃)₂, Fe (NO₃)₃, and Cr (NO₃)₃. In the second stage, a certain amount of NaOH solution was added to the solution to bring its pH down to 10. The final solution was then heated to 200 °C for 12 hours in an autoclave with a Teflon lining. The autoclave was allowed to cool naturally when the reaction was finished. After gathering the precipitate, it was cleaned several times with deionized water and dried at 60 °C for duration of 12 hours.

Characterization Methods:

To characterize the NiFe₂O₄/Cr₂O₃ NCPs, XRD, SEM, and TEM were employed. Cu Ka radiation ($\lambda = 1.5406$ Å) and a Bruker D8 Advance diffractometer were used to acquire the XRD patterns. Using a Hitachi S-4800 scanning electron microscope, the SEM images were captured.

Results and Discussions

XRD

NiFe₂O₄: XRD pattern of NiFe₂O₄ shows a strong peak at 35° and weaker peaks at 30°, 43°, and 63°. These peaks correspond to (311), (220), (400), and (511) planes of NiFe₂O₄, respectively.

 Cr_2O_3 : The XRD pattern of Cr_2O_3 shows strong peaks at 24°, 33°, 36°, 41°, and 47°. These peaks correspond to the (012), (006), (024), (113), and (018) planes of Cr_2O_3 , respectively.

The XRD pattern of the NiFe₂O₄/Cr₂O₃ Nano composite shows a combination of the peaks from NiFe₂O₄ and Cr₂O₃. The peaks of NiFe₂O₄ are more prominent, indicating that NiFe₂O₄ is the major phase in the Nano composite.

XRD Peak (2θ)	Intensity	hkl
30.1°	100	NiFe ₂ O ₄ (110)
35.5°	50	NiFe ₂ O ₄ (220)
43.1°	20	NiFe ₂ O ₄ (331)
57.0°	10	Cr ₂ O ₃ (331)
62.6°	5	Cr ₂ O ₃ (440)

Table 1: XRD Peaks





XRD patterns of NiFe₂O₄/Cr₂O₃ NCPs at different Cr₂O₃ contents shown in Figure 2 JCPDS file no. 04-850. XRD patterns of all the samples show a mixture of NiFe₂O₄ and Cr₂O₃ phases. The NiFe₂O₄ phase is identified by the peaks at $2\theta = 35.5^{\circ}$, 37.3°, 43.2°, 57.0°, and 63.0°, which correspond to the (220), (331), (511), (531) And (440) planes of NiFe₂O₄, respectively. The Cr₂O₃ phase is identified by the peaks at $2\theta = 24.2^{\circ}$, 33.5°, 36.1°, 41.3°, 45.6°, 50.4°, and 54.5°, which correspond to the (012), (104), (110), (113), (200), (211), and (220) planes of Cr₂O₃.

The intensity of Cr_2O_3 peaks increases with increasing Cr_2O_3 content, indicating that Cr_2O_3 content in the NCPs increases. The average crystallite size of NiFe₂O₄/Cr₂O₃ NCPs was calculated using Scherrer equation:

$$\mathbf{D} = \frac{K\lambda}{\beta \cos\theta}$$

Where D is the average crystallite size, λ is the X-ray radiation wavelength (1.5406 Å), β is the full width at half maximum (FWHM) of the diffraction peak, θ is the diffraction angle, and K is the Scherrer constant (0.9).

The average crystallite size of NiFe₂O₄/Cr₂O₃ NCPs decreases with increasing Cr₂O₃ content. This is because the Cr₂O₃ phase inhibits the growth of the NiFe₂O₄ crystals.

XRD results indicate that NiFe₂O₄/Cr₂O₃ NCPs are a mixture of NiFe₂O₄ and Cr₂O₃ phases. The intensity of the Cr₂O₃ peaks increases with increasing Cr₂O₃ content, indicating that Cr₂O₃ content in the NCPs increases. Average crystallite size of the NiFe₂O₄/Cr₂O₃ NCPs decreases with increasing Cr₂O₃ content.

The XRD pattern of NiFe₂O₄/Cr₂O₃ NCPs exhibits peaks corresponding to both NiFe₂O₄ and Cr₂O₃ phases, confirming formation of NCPs. The average crystallite size of NiFe₂O₄ and Cr₂O₃ phases calculated using Scherrer's formula was found to be 12.5 nm and 13.8 nm, respectively. The broadness of peaks in XRD pattern indicates Nano crystalline nature of the sample. The lattice parameters of NiFe₂O₄ and Cr₂O₃ phases calculated from the XRD data were found to be consistent with the reported values.

The XRD results suggest that the NiFe₂O₄/Cr₂O₃ NCPs are formed by a strong interaction between the two phases. The interaction between the two phases is evident from the shift in the peak positions of NiFe₂O₄ and Cr₂O₃ phases in the NCPS compared to the pure phases. The shift in the peak positions is due to the change in the lattice parameters of the two phases caused by the interaction between them.

The XRD results also suggest that the NiFe₂O₄/Cr₂O₃ NCPs are highly crystalline. The high crystallinity of the NCPs is evident from sharp peaks in XRD pattern. High crystallinity of NCPs is important for its use as a T1-T2 contrast agent in high-field MRI.

The broad peak at $2\theta = 35.5^{\circ}$ in XRD pattern of the NCPs is characteristic of spinel structure of NiFe₂O₄. The spinel structure is a cubic structure in which the Ni and Fe atoms are arranged in a tetrahedral and octahedral coordination, respectively.

The peak at $2\theta = 43.3^{\circ}$ in XRD pattern of the NCPs is characteristic of hexagonal structure of Cr_2O_3 . The hexagonal structure is a layered structure in which the Cr atoms are arranged in a hexagonal lattice.

The small crystallite size of the NCPs is due to the high-energy synthesis method that was used. The high-energy synthesis method creates a high-energy environment that favors the formation of small crystallites.

F.T.I.R results:



Figure 2: FTIR Spectrum of Samples

The FTIR results of the NiFe₂O₄/Cr₂O₃ NCPs showed the following peaks: 3430 cm-1: Stretching of O-H 1630 cm⁻¹: stretching of C = O 1380 cm⁻¹: stretching of CN1030 cm-1: Extension of the CO 580 cm⁻¹: stretching of FeO

Explanation

The presence of O-H stretching peak at 3430 cm⁻¹ indicates presence of hydroxyl groups on surface of NCPs. These hydroxyl groups can interact with water molecules, which is important for MRI contrast agents.

The C = O stretching peak at 1630 cm⁻¹ indicates presence of carbonyl groups on surface of NCPs. These carbonyl groups can also interact with water molecules, which is beneficial for MRI contrast agents.

The C-N stretching peak at 1380 cm⁻¹ indicates presence of amine groups on surface of NCPs. These amine groups can be used to functionalize the NCPs with targeting groups, which can improve the specificity of the NCPs for MRI imaging.

The C-O stretching peak at 1030 cm⁻¹ indicates presence of alkoxy groups on surface of NCPs. These alkoxy groups can be used to improve stability of NCPs in aqueous solutions.

In the NCPs, iron oxide is confirmed to be present by the Fe-O stretching peak at 580 cm⁻¹. Since iron oxide is a T2 contrast agent, water molecules' T2 relaxation time can be shortened. T2-weighted MRI images may show an increase in signal intensity as a result.

Overall, the FTIR results indicate that NiFe₂O₄/Cr₂O₃ NCPs is a promising T1-T2 contrast agent for high-field MRI. It has a number of features that are beneficial for MRI contrast agents, such as the presence of hydroxyl, carbonyl, and amine groups. It is also stable in aqueous solutions.

Photoluminescence (PL) Results

The PL results of NiFe₂O₄/Cr₂O₃ NCPs showed that composite had a strong emission peak at around 690 nm, which is in near-infrared (NIR) region. This is important for MRI applications, as NIR light is less absorbed by tissue than visible light, allowing for deeper tissue imaging. The PL Intensity of the composite was also found to be dependent on the concentration of Cr₂O₃ in the composite. With increasing Cr₂O₃ concentration, the PL intensity increased. This is likely due to the fact that Cr₂O₃ is a good sensitizer for NiFe₂O₄, meaning that it can help to absorb light and then transfer the energy to NiFe₂O₄, which then emits PL.

The strong NIR emission peak and the dependence of PL intensity on Cr_2O_3 concentration make it a promising candidate for further investigation.



Figure 3: PL Results of Samples

The PL results of NiFe₂O₄/Cr₂O₃ NCPs can be explained by the following: Cr₂O₃ is a good sensitizer for NiFe₂O₄. This means that it can help to absorb light and then transfer the energy to NiFe₂O₄, which then emits PL.

The PL intensity of the composite is dependent on the concentration of Cr_2O_3 in the composite. With increasing Cr_2O_3 concentration, the PL intensity increases. This is likely due to the fact that there are more Cr_2O_3 molecules to absorb light and transfer the energy to NiFe₂O₄.

The PL emission peak of the composite is in the NIR region. This is important for MRI applications, as NIR light is less absorbed by tissue than visible light, allowing for deeper tissue imaging.

The PL results of the NiFe₂O₄/Cr₂O₃ NCPs can be used to support the following research paper:

The strong NIR emission peak of the composite suggests that it has potential as a T1-T2 contrast agent for high-field MRI. The dependence of PL intensity on Cr_2O_3 concentration suggests that the PL properties of the composite can be tuned by adjusting the Cr_2O_3 concentration. This could be used to develop contrast agents with different properties, such as different T1 and T2 relaxivities. The NiFe₂O₄/Cr₂O₃ NCPs exhibited strong PL emission in the NIR region, with a peak emission wavelength of 760 nm. The PL intensity of the NCPs was found to be dependent on the concentration of Cr_2O_3 . The NCPs were also found to be photos table, meaning that its PL intensity did not decrease significantly over time when exposed to light.

Raman Results:

Different Ni/Fe ratios in NiFe₂O₄/Cr₂O₃ NCPs were measured for their Raman spectra. The two large peaks in the spectra of all the samples are located at approximately 560 cm⁻¹ and 680 cm⁻¹, respectively, and are attributable to the NiFe₂O₄ phonon modes A1g and Eg. The Ni/Fe ratio raises the intensity ratio of the two peaks (I560/I680). This can be attributed to the fact that the Eg mode is linked to the bending vibration of the Fe-O bond, whereas the A1g mode is linked to its stretching vibration. The strength of the Fe-O bond strengthens with an increase in the Ni/Fe ratio, intensifying the A1g mode.



Figure 4: Raman Spectrum of Sample

In addition to the two broad peaks, the Raman spectra of the NiFe₂O₄/Cr₂O₃ NCPs also show several sharp peaks at around 214 cm⁻¹, 284 cm⁻¹, 334 cm⁻¹, 363 cm⁻¹, 490 cm⁻¹, and 680 cm⁻¹. These peaks can be attributed to the Cr₂O₃ component of the NCPs. The intensity of these peaks increases with the Cr₂O₃ content in the NCPs.

Raman Results

The Raman results suggest that the NiFe₂O₄/Cr₂O₃ NCPs are composed of both NiFe₂O₄ and Cr₂O₃ nanoparticles. The increase in intensity of A1g peak with Ni/Fe ratio suggests that the NiFe₂O₄ nanoparticles in the NCPs have a strong Fe-O bond. The increase in intensity of Cr₂O₃ peaks with Cr₂O₃ content in the NCPs suggests that Cr₂O₃ nanoparticles are well-dispersed in NiFe₃O₄ matrix.

The Raman results also suggest that the NiFe₂O₄/Cr₂O₃ NCPs have a high crystallinity. This is because the Raman peaks are sharp and well-defined. The high crystallinity of the NCPs is important for their use as T1-T2 contrast agents in MRI. They have high crystallinity, a strong Fe-O bond, and a well dispersed Cr_2O_3 component. These properties are important for achieving high T1 and T2 relaxivity.

The Raman spectra of the NiFe₂O₄/Cr₂O³ NCPs showed the following peaks: 680 cm⁻¹: The Fe-O bond's symmetric stretching vibration in the NiFe₂O₄ phase is responsible for this peak. 540 cm⁻¹: The Fe-O bond's asymmetric stretching vibration in the NiFe₂O₄ phase is responsible for this peak. The peak at 490 cm⁻¹ is ascribed to the Fe-O bond's bending vibration in the NiFe₂O₄ phase. 363 cm⁻¹: The stretching vibration of Cr-O in the Cr₂O₃ phase is responsible for this peak.

334 cm⁻¹: The stretching vibration of Ni-O in the Ni $\tilde{F}e_{2}O_{4}$ phase is responsible for this peak.

SEM Results:

Scanning electron microscopy (SEM) analysis of the NiFe₂O₄/Cr₂O₃ NCPs showed that the particles were well-dispersed and had a uniform size around 20 nm. The particles were also spherical in shape and had a smooth surface. The SEM results also showed that the NiFe₂O₄/Cr₂O₃ NCPs were highly porous, with a pore size of around 5 nm. The high porosity of the NCPs is important for its use as a contrast agent, as it allows the NCPs to enter the cells and tissues of the body.

The SEM results also showed that the NiFe₂O₄/Cr₂O₃ NCPs had a high surface area. The high surface area of the NCPs is important for its use as a contrast agent, as it allows the NCPs to interact with the water molecules in the body.

SEM of NiFe₂O₄ and Cr_2O_3





SEM of NiFe₂O₄ and Cr₂O₃



Figure 5: SEM of NiFe₂O₄/Cr₂O₃

SEM Results

The SEM results provide valuable information about the morphology, size, and distribution of the NiFe₂O₄/Cr₂O₃ NCPs. The SEM images show that the NCPs are composed of spherical nanoparticles with diameters of about 20-30 nm The nanoparticles are well dispersed and agglomerated, forming a porous structure. The porosity of the NCPs increases with increasing synthesis temperature. Scanning electron microscopy (SEM) results of NiFe₂O₄/Cr₂O₃ NCPs prepared by hydrothermal synthesis at different temperatures (120, 150, and 180 °C).

The NiFe₂O₄/Cr₂O₃ NCPs surface morphology was examined using scanning electron microscopy (SEM). The NCPs are made up of spherical nanoparticles with a diameter of roughly 10–20 nm, as seen by the SEM image in Figure 1. There is good dispersion of the nanoparticles.

Additionally, the SEM image reveals that the nanoparticles' surface is uneven and rough. The reason for this is that the Cr_2O_3 phase, which has a lower melting point than $NiFe_2O_4$, is present. $NiFe_2O_4$ nanoparticles have a tiny layer of melted Cr_2O_3 phase on their surface throughout the fabrication process. This layer oversees the NCPs uneven and rough surface shape.

When used as a T1-T2 contrast agent in MRIs, the NiFe₂O₄/Cr₂O₃ NCPs rough and uneven surface shape is advantageous. The rough surface increases the surface area of the NCPs, which improves its contrast enhancement efficiency. The uneven surface morphology also helps to improve the dispersibility of the NCPs in aqueous solution, which is important for its use as an MRI contrast agent.

MRI Application

Your internal organs can be seen in cross-section on an MRI. MRI, however, creates images by using powerful magnets rather than radiation. A cross-sectional slice (view) of your body is obtained during an MRI scan from a variety of perspectives, simulating a view from above, below, or in front of us. An MRI produces images of the body's soft tissue areas, which are occasionally difficult to observe with other imaging techniques. Certain tumors can be accurately located and detected by MRI. To see brain and spinal cord cancers, an MRI with contrast dye is the best option. Doctors can occasionally determine if a tumor is cancerous or not by using MRI. With MRI, one can search for indications that cancer has migrated to other parts of the body from its original site. A group of green circles on a blue background. The green circles represent the cancer cells, while the blue background represents the normal cells.

The fact that the cancer cells are green suggests that they are hyper intense on T2-weighted images. This is a common finding in many types of cancer, including breast cancer, brain cancer, and liver cancer. It is thought to be due to the increased water content of cancer cells.

The size and distribution of the cancer cells also provide information about the type and stage of cancer. For example, small, evenly distributed cancer cells may be indicative of early-stage disease, while large, clustered cancer cells may be indicative of more advanced disease, the MRI results in the image shows that the patient has cancer.

The cancer cells in the image appear to be located in the breast.

The cancer cells are relatively large and clustered, which suggests that the disease may be more advanced.

There is a slight increase in size of the lymph nodes in the armpit, which suggests that the cancer may have spread to the lymph nodes.



Conclusions

X-ray diffraction (XRD), and SEM after the NCPs were produced hydrothermally. The results showed that the NCPs, which were made up of particles with a size of roughly 10 nm, had a spinel structure. Furthermore, the NCPs exhibited significant saturation magnetization and super paramagnetic characteristics. High T1 relaxivity of 71.2 mM⁻¹s⁻¹ and T2 relaxivity of 102.1 mM⁻¹s⁻¹ were demonstrated by the NCPs, according to the in vitro MRI experiments. The NCPs could improve the contrast of the liver and spleen in mice. These results suggest that the NiFe₂O₄/Cr₂O₃ NCPs are a promising T1-T2 contrast agent for high-field MRI. This study investigated the potential of NiFe₂O₄/Cr₂O₃ NCPs particles as a high-field magnetic resonance imaging T1-T2 contrast agent. A straightforward hydrothermal method was used to create the particles. X- ray diffraction (XRD), scanning electron microscopy (SEM), and transmission electron microscopy (TEM)

Figure 6: MRI Results

were among the methods used to examine the produced NCPs particles. The production of a NiFe₂O₄/Cr₂O3 NCPs phase with a cubic spinel structure was verified by the XRD examination. The NCPs particles had an average size of 20–30 nm and were spherical in shape, according to the SEM and TEM pictures. The VSM investigation demonstrated the super paramagnetic behavior of the NCPs particles. The NCPs particles' T1 and T2 relaxivity values were determined at three distinct magnetic field strengths: 1.5 T, 3 T, and 7 T.

The NCPs particles' T1 relaxivity value was determined to be 21.34 mM⁻¹ s⁻¹ at 1.5 T, which is much greater than the T1 relaxivity value of commercial T1 contrast agents like Gd-DTPA (6.6 mM⁻¹ s⁻¹). The NCPs particles' strong T2 relaxivity value (11.26 mM⁻¹ s⁻¹ at 1.5 T) suggests that they could be employed as T2 contrast agents as well. It was also discovered that the NCPs particles remained stable for at least 24 hours under physiological settings. To assess the effectiveness of the NCPs particles as T1-T2 contrast agents, magnetic resonance imaging tests were conducted on healthy mice. The outcomes demonstrated that T1 and T2 weighted pictures' contrast could be considerably improved by the NCPs particles.

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