

Supporting information

Nanostructured manganese dioxide for anticancer applications: preparation, diagnosis, and therapy

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Table 1 Nanostructured MnO₂ for anticancer applications.

MnO ₂ type	Composition	Synthetic method	Size (nm)	Enhance mode	PDT Diagnostic mode	Loading drug	Tumor type (cell)	Advantage	Reference
Nanoparticle	HCaM-PB	Redox	192.1	–	MRI/PA/FL	HCPT	Huh-7	Microenvironment- responsive DDS	[241], 2020
Nanoparticle	Ce6-GA@MnO ₂ -HA-PEG	Redox	200	Synergistically	MRI/ FL	Ce6	HeLa	Self-boosting combined phototherapy	[137], 2020
Nanoparticle	mMnO ₂	Redox	150.9	–	MRI	AO	H1299	Enhance Radiotherapy	[78], 2020
Nanoparticle	Lipo-OGzyme-AIE	Bio-mineralization	122.5	Generate O ₂	FL	AIE	4T1	Multi-modal imaging and improve PDT	[104], 2020
Nanoparticle	MPPF	Bio-mineralization	–	–	FL	DOX	SMMC-7721	Chemo/chemodynamic co-therapy	[31], 2020
Nanoparticle	RGD-BMnNPs	Bio-mineralization	68	–	MRI/ FL	VEGFA-siRNA-Cy5	U87MG	Tumor microenvironment modulation and enhance theranostics	[30], 2020
Nanoparticle	BSA-Ce6@IrO ₂ /MnO ₂	Bio-mineralization	42 ± 3	Generate O ₂	MRI/CT/PA/thermal	Ce6	MDA-MB-231/PC3/4T1	Multimodal imaging-guided combination therapy	[93], 2020
Nanoparticle	BSA@AuNCs-MnO ₂	Redox	–	–	FL	–	HeLa	FL of intracellular GSH	[25], 2020
Nanoparticle	TarA@bM	Bio-mineralization	60	Generate O ₂	MRI/FL	δ-ALA	4T1	Imaging-guided PDT	[40], 2019
Nanoparticle	rMGB	Redox	85	Generate O ₂	FL	BSA-Ce6	4T1	Against hypoxic for PDT	[38], 2019
Nanoparticle	HMME@mMnO ₂ -Apt	Redox	200	Reduce GSH	FL	HMME	MCF-7	ROS regulator for photodynamic therapy	[131], 2019
Nanoparticle	M-Abx	Redox	140	–	FL	Abx	4T1	Oxygen-rich chemotherapy	[68], 2019
Nanoparticle	BSA-Bi ₂ S ₃ -MnO ₂	Bio-mineralization	50	–	MRI/CT/PA	–	U14	Imaging-guided enhanced tumor therapy	[97], 2019
Nanoparticle	PEGylated HCMR	Template	–	–	FL/thermal	Rapa	MDA-MB-231/MCF7/MGC803	Efficient tumor ablation	[79], 2019
Nanoparticle	HA-MnO ₂	Redox	83	–	MRI	–	HUVECs/C6	MRI and modulation of hypoxia	[82], 2019
Nanoparticle	NMOFs@BSA/SDs@MnO ₂	Bio-mineralization	122	Generate O ₂	MRI	Porphyrin	4T1	MRI and enhance PDT	[99], 2019
Nanoparticle	PPIX-Lipo-MnO ₂	Redox	752.9 ± 50.7	Generate O ₂	FL	PPIX	MCF-7	Enhance PDT by improving hypoxia	[142], 2019
Nanoparticle	R-MnO ₂ -FBP	Redox	30	Generate O ₂	MRI/FL	RhB	HeLa	O ₂ self-supply and PDT	[177], 2019
Nanoparticle	MnO ₂ -mSiO ₂ @Au-HA	Redox	166.7	–	MSOT/CT/	–	4T1	Oxygen self-supply radiotherapy	[29], 2019
Nanoparticle	MnO ₂ NP-CD	Redox	3.6	–	FL	–	SMMC-7721	FL for cancer recognition	[107], 2019
Nanoparticle	BSA-MnO ₂ /Ce6@ZIF-8	Redox	227	Generate O ₂	MRI/FL	Ce6	HeLa	Photosensitizer delivery system	[133], 2019

Table 1 (Continued)

MnO ₂ type	Composition	Synthetic method	Size (nm)	Enhance PDT mode	Diagnostic mode	Loading drug	Tumor type (cell)	Advantage	Reference
Nanoparticle	¹³¹ I-rGO-MnO ₂ -PEG	Redox	–	–	MRI	¹³¹ I	4T1	Overcome hypoxia for radioisotope therapy[71], 2018	
Nanoparticle	PMHNS	Bio-mineralization	7.0-60.9	–	MRI/	–	HeLa/MCF-7/ 4T1	Integration of polymerization and	[101], 2018
Nanoparticle	BSA-Ce6-Si-MnO ₂	Bio-mineralization	15	Generate O ₂	MRI/FL	Ce6	HeLa/HepG-2	FL imaging-guided PDT	[81],2018
Nanoparticle	HSA-MnO ₂ -Ce6	Redox	118.6±8.1	Generate O ₂	NIR/MRI/FL	Ce6	MB-49	O ₂ -generating MnO ₂ for enhanced PDT	[100], 2018
Nanoparticle	p-MoS ₂ /n-rGO-MnO ₂ -PEG	Redox	170	Generate O ₂	FL	–	HeLa	Enhance PDT	[178], 2018
Nanoparticle	AS1411/Ce6-LPMSNs-MnO ₂	Redox	179	Generate O ₂	MRI	Ce6	HeLa	PDT and MRI	[140], 2018
Nanoparticle	F127-MnO ₂ -ZIF-8@ DOX/C ₃ N ₄	Redox	78.5	Generate O ₂	FL	DOX	4T1	Chemo-photodynamic therapy	[129], 2018
Nanoparticle	ACF@MnO ₂	Redox	30	–	MRI	–	CT26	Enhance radiation therapy	[85], 2018
Nanoparticle	PEG-CuS-Au-MnO ₂	Redox	162	–	CT/MRI	CST	HepG2	Imaging-guided chemo-PTT	[208], 2018
Nanoparticle	PMAA _{BACy} /DOX/MnO ₂ -2/PEG	Bio-mineralization	124	–	MRI	DOX	HeLa	Low premature release and MRI	[108], 2018
Nanoparticle	BSA-MnO ₂ -DOX	Redox	165.5 ± 3.0	–	MRI/FL	DOX	MCF-7/ADR	Drug vehicle and MRI contrast agent	[194], 2017
Nanoparticle	BSA-MnO ₂	Redox	8.7	–	MRI	PTX/ICG	4T1	A smart nanoprobes	[138], 2017
Nanoparticle	BSA-Au-MnO ₂	Bio-mineralization	60	–	FL	–	4T1	Enhance radiotherapy	[98], 2017
Nanoparticle	BM@NCP(DSP)-PEG	Bio-mineralization	160	–	MRI/FL	DSP	4T1	Redox/pH/H ₂ O ₂ -responsive nanoplatform	[225], 2017
Nanoparticle	¹³¹ I-HSA-MnO ₂	Bio-mineralization	40	–	FL/ PA	–	4T1	Enhanced radioisotope therapy	[226], 2017
Nanoparticle	Ce6@MnO ₂ -PEG	Redox	100	Generate O ₂	MRI/FL	Ce6	4T1	Modulation of hypoxia to enhance PDT	[174], 2016
Nanoparticle	HSA-MnO ₂ -Ce6&Pt	Bio-mineralization	50	Generate O ₂	FL	Ce6/cis-Pt	4T1	Modulate hypoxia for combination therapy	[103], 2016
Nanoparticle	Man-HA-MnO ₂	Redox	203 ± 4.6	–	MRI	DOX	4T1	Alleviate hypoxia	[27], 2016
Nanoparticle	A-MnO ₂	Redox	50	–	FL	–	EMT6	Modulate microenvironment	[37], 2014
Nanosheet	MNS-GOx	Biomimetic method	~ 70	–	NIR/PA/FL	GOx	A375	Enhanced cancer starvation therapy	[189], 2020
Nanosheet	PEG-MnO ₂ -OPN siRNA	Redox	–	–	MRI	siRNA	786-O	Molecular imaging and DDS	[230], 2020
Nanosheet	MnO ₂	Hydrothermal	200	–	MRI/FL/ PAI	–	HeLa	Vacancy-driven photothermal therapy	[41], 2019
Nanosheet	MPPa-DP	Redox	212.5	Generate O ₂	FL	PPa-DP	4T1	Retard O ₂ consumption for oxygenated	[65], 2019
Nanosheet	WSSe/MnO ₂ -INH-TPP@CM	Redox	200	–	MRI/CT	TPP/INH	MCF-7	Synergistic anticancer treatment	[124], 2019

Table 1 (Continued)

MnO ₂ type	Composition	Synthetic method	Size (nm)	Enhance PDT mode	Diagnostic mode	Loading drug	Tumor type (cell)	Advantage	Reference
Nanosheet	PTX-MnO ₂ /FCN	Redox	189	–	FL	PTX	MDA-MB-231	Bioimaging and smart DDS	[212], 2019
Nanosheet	P-AgNCs-MnO ₂	Redox	–	Generate O ₂	Zn ²⁺ /FL/ MRI	Porphyrin	MCF-7	Zn ²⁺ /FL/MRI guided PDT	[221], 2019
Nanosheet	MnO ₂ -PEG-cRGD	Redox	271 ± 26.7	Generate O ₂	FL	Ce6	PC3	Synergistic photothermal/ PDT	[151], 2019
Nanosheet	CM-MMNPs	Redox	160	Generate O ₂	FL	–	HeLa/HepG2	O ₂ -evolving photodynamic therapy	[136], 2019
Nanosheet	MnO ₂ /ZnCOF@Au&BSA	Redox	–	–	FL	–	HepG2	Imaging and photothermal therapy	[148], 2019
Nanosheet	FA-CM	Redox	130	–	FL	DOX/PTX	HepG2/PC3/ SMMC7721	Nanocarrier for cancer therapy	[152], 2019
Nanosheet	MnO ₂ -Pt@Au ₂₅	Redox	–	Synergistically	MRI/FL	Au ₂₅ /Pt(IV)	HeLa	Promot PDT and chemotherapy	[171], 2019
Nanosheet	MnO ₂ @AS1411T ₃₃ /TMPipEOPP	Redox	230	Synergistically	FL	G-quadruplex/ TMPipEOPP	HeLa	A Photosensitizer for promoting absorption redshift and PDT	[180], 2019
Nanosheet	QD@SiO ₂ -MnO ₂	Redox	222.5 ± 43.6	–	FL	–	RAW264.7	Biocompatible fluorescent nanoprobe	[201], 2019
Nanosheet	MnO ₂	Redox	–	–	FL	DNAzyme	HeLa	High sensitivity nanoprobe	[144], 2019
Nanosheet	IR780-sMnO ₂ -PCM	Redox	140	Generate O ₂	FL/PA	IR780	HeLa/A2780/ HCCLM3	Hypoxia modulation and enhanced PTT	[128], 2019
Nanosheet	MPDA-WS ₂ @MnO ₂	Redox	~235.4	–	CT/MSOT/MRI	WS ₂	4T1	Thermoradiotherapy of hypoxic cancer	[132], 2019
Nanosheet	MnO ₂	Redox	200-700	–	–	–	–	Dual-signal responsive optical sensor	[211], 2019
Nanosheet	iOCOM	Redox	–	–	MRI/FL	–	KB	Image-guided photothermal therapy	[208], 2019
Nanosheet	M-NS	Bio-mineralization	105.4 ± 11.7	–	Thermographic/ PET/PA	–	U87MG	Synergistic catalysis- enhanced phototheranostics	[210], 2019
Nanosheet	MnO ₂	–	40-150	–	FL	Ce6	TNBC/HeLa/ MCF-7	2D glycoclusters for the targeted delivery	[219], 2019
Nanosheet	Ru(BPY) ₃ @MnO ₂	Redox	50	–	MRI/FL	–	HeLa	MRI nanoprobe	[198], 2018
Nanosheet	WCNO-MnO ₂	Redox	–	–	FL	–	4T1	Multichannel fluorescent nanoprobe	[202], 2018
Nanosheet	MnO ₂ /PTX-loaded C-FNP	Redox	250	–	FL	PTX	HeLa/ MDA- MB-231	Tumor-targeted drug delivery	[42], 2018

Table 1 (Continued)

MnO ₂ type	Composition	Synthetic method	Size (nm)	Enhance PDT mode	Diagnostic mode	Loading drug	Tumor type (cell)	Advantage	Reference
Nanosheet	GQD@MnO ₂	Redox	–	Reduce GSH	FL	GQDs	HeLa	Imaging and enhance PDT	[56], 2018
Nanosheet	MnO ₂ -SP	Exfoliation	255.0	–	MRI	–	4T1	Ultrathin MnO ₂ nanosheets for PTT	[235], 2018
Nanosheet	MnO ₂	Redox	50-160	–	MRI/FL	ssDNA	CEM/Ramos	Dual-modal amplification detection system	[213], 2018
Nanosheet	HMSNs@MnO ₂ (DOX)/apt	Redox	248 ± 15	–	MRI/FL	DOX	HeLa	Drug release and enhance MRI	[74], 2018
Nanosheet	MnO ₂ /Cu ₂ -xS	Redox	49.2	Generate O ₂		siRNA	A549	Photothermal/photodynamic therapy	[228], 2018
Nanosheet	UCNPs@MnO ₂	Redox	–	–	Photo-thermal imaging/FI/MR	DOX	CEM/HeLa/Ramos	Activatable FL imaging and MRI	[203], 2018
Nanosheet	Au NCs-MnO ₂	Bio-mineralization	50-100	–	MRI/FL	–	4T1/HeLa	Fluorometric/magnetic bimodal sensing	[210], 2018
Nanosheet	UCNPs@mSiO ₂ (DOX)-MnO ₂	Redox	–	–	MRI/FL	DOX	HeLas	Double-model guidedchemotherapy	[216], 2018
Nanosheet	CDs/MnO ₂ -PEG	Redox	180	Generate O ₂	MRI	CDs	HeLa	Imaging-guided PDT	[73], 2018
Nanosheet	Co-P@mSiO ₂ @DOX-MnO ₂	Redox	286.6	–	MRI	DOX	4T1	Synergistic therapy	[193], 2017
Nanosheet	SPN-Ms	Redox	40-76	Generate O ₂	FL	–	4T1	Oxygenic nanoparticles for PDT	[176], 2017
Nanosheet	MCAD	Redox	223	–	MRI/FL	DOX	4T1/RAW264.7	Bifunctional nanomodulator	[218], 2017
Nanosheet	UCNPs@TiO ₂ @MnO ₂	Redox	–	Generate O ₂	MRI/FL/CT	–	4T1	O ₂ self-supplementing for PDT	[175], 2017
Nanosheet	MnO ₂ /DVDMS	Redox	91.2	Synergistically	MRI/FL/PA	DVDMS	MCF-7	Nanotheranostic generator for PTT	[181], 2017
Nanosheet	MnO ₂ nanozyme	Redox	100-250	–	FL	DNAzyme	MCF-7/HeLa	Catalytic DNA circuit generator	[209], 2017
Nanosheet	MSU/MnO ₂ -CR	Redox	–	–	–	CR dye	–	Drug carrier for controlled release	[215],2014
Nanoshell	TAT-Pd@Au@Ce6/ PAH/H-MnO ₂	Template	–	Generate O ₂	FL	Ce6	MCF-7/A549	Photothermal and hypoxia-relieved PDT	[120], 2020
Nanoshell	Ce6/iPMC-MnO ₂	Redox	–	Generate O ₂	MRI/PAI	Ce6	4 T1	Multimodal diagnosis and treatment	[69], 2020
Nanoshell	PLTM-HMnO ₂ @Bu	Template	187	–	MRI/FL	bufalin	H22	MRI-guided chemo- chemodynamic	[122], 2020
Nanoshell	Protein@MnO ₂	Bio-mineralization	90.3 ± 6.2	–	MRI/FL	H39GFP	HCT116	Efficient vehicle for protein delivery	[109], 2020
Nanoshell	FHHPM@MnO ₂	Redox	208.8	Synergistically	MRI/CT/F	MB	4T1/Hela	Multimode imaging guided chemo-PDT	[135], 2020
Nanoshell	aMMTm	Redox	178.4	Reduce GSH	MRI/FL	Apatinib	4T1	Antiangiogenesis and PDT	[169],2019
Nanoshell	PMLR	Template	–	–	MRI	3PO/LOX	B16F10	Metabolic therapy and immunotherapy	[231], 2019
Nanoshell	CuS _{NC} @DOX@MnO ₂ -NS	Redox	89	–	MRI/FL	DOX	HepG2	Imaging-guided chemical and PTT	[207], 2019

Table 1 (Continued)

MnO ₂ type	Composition	Synthetic method	Size (nm)	Enhance PDT mode	Diagnostic mode	Loading drug	Tumor type (cell)	Advantage	Reference
Nanoshell	H-MnO ₂ -GOx-Ce6@C	Template	75	Generate O ₂	MRI/FL	Ce6	B16-F10	Photodynamic-starvation therapy	[67], 2019
Nanoshell	Lipo/HMME/ACF@MnO ₂ -AS1411	Redox	178.7±3.1	–	MRI/FL	HMME/ACF	SKOV-3	Synergistic enhance sonodynamic therapy	[85], 2018
Nanoshell	Cu _{2-x} Se@MnO ₂	Redox	60	–	MRI	–	CT26	MRI theranostic platform	[150], 2018
Nanoshell	Fe ₅ C ₂ -GOD@MnO ₂	Redox	37.8	–	MRI	–	HeLa	Nanocatalysts for enhanced ablation	[204], 2018
Nanoshell	PLGA/HMME@MnO ₂	Redox	209.8	Synergistically	MRI/FL	HMME	MCF-7	MRI and enhance PDT	[60], 2017
Nanoshell	H-MnO ₂ -PEG/C&D	Template	–	Generate O ₂	MRI/FL	Ce6/DOX	4T1	Antitumor immune responses	[121], 2017
Nanoshell	SiO ₂ -MB@MnO ₂	Redox	330	Generate O ₂	MRI	MB	HeLa	Overcoming hypoxia and MRI	[77], 2017
Nanotube	Ab ₂ -Co ₃ O ₄ @MnO ₂ -Th	Hydrothermal	400-600	–	–	AFP/antibody	–	Detection of alpha fetoprotein	[214], 2018
Nanoflower	FHCPC@MnO ₂	Redox	290	Generate O ₂	MRI/CT/FL	Ce6	HeLa	Microenvironment-responsive platform	[126], 2019
Nanoflower	MnO ₂ @PtCo	Redox	200	–	FL	PtCo nanozyme	4T1	Nanozymes to against hypoxic	[227], 2018
Honeycomb	Fol-DNAzyme/Ce6/CAT/hMnO ₂	Template	136	Synergistically	FL	Catalase/Ce6/DNAzyme	MCF-7	Gene-silencing and PDT	[118], 2017
Honeycomb	hMnO ₂ -DOX	Template	93	–	FL	DOX	HepG2	GSH-triggered drug release	[117], 2015
Nanosphere	ICG-HANP/MnO ₂	Redox	239 ± 4.2	Generate O ₂	FL/photoacoustic/ ultrasound	ICG	SCC7	Imaging guided PDT	[34], 2017
Nanowire	MnO ₂	Hydrothermal	14/700	–	FL	Cu/Ag/VB	–	Nanowires for fluorescent sensing	[190], 2019
Hydrangea	MDSP	Redox	54	Generate O ₂	Photoacoustic/ photothermal/FL	aza-BODIPY/DOX	HCT-116	Multimodal imaging and therapy	[222], 2019