Journal of Proteomics 181 (2018) 170–189

Contents lists available at ScienceDirect

Journal of Proteomics

journal homepage: www.elsevier.com/locate/jprot

Novel functionalized nanomaterials for the effective enrichment of proteins and peptides with post-translational modifications

Cristina Núñez[a,*], Maria del Pilar Chantada-Vázquez[a], Susana B. Bravo[b], Sergio Vázquez-Estévez[c]

[a] Research Unit, Hospital Universitario Lucus Augusti (HULA), Servizo Galego de Saúde (SERGAS), 27002 Lugo, Spain
[b] Proteomic Unit, Instituto de Investigaciones Sanitarias-IDIS, Complejo Hospitalario Universitario de Santiago de Compostela (CHUS), 15706 Santiago de Compostela, Spain
[c] Oncology Division, Hospital Universitario Lucus Augusti (HULA), Servizo Galego de Saúde (SERGAS), 27002 Lugo, Spain

ARTICLE INFO

Keywords:
Sample pretreatment
enrichment
nanomaterial
low-abundance proteins/peptides
phosphoproteins/phosphopetides
glycoproteins/glycopeptides

ABSTRACT

Low abundance proteins/peptides usually suffer strong interference with highly abundant proteins/peptides as well as other contaminants, resulting in low ionization efficiency in MS analysis. Hence, the enrichment and separation of proteins/peptides from complex mixtures are of great value to their successful identification.

In this review we present an overview of the application of different nanocomposites for the specific enrichment of peptides/proteins with post-translational modifications (PTMs), such as phosphorylation and glycosylation. Furthermore, examples of the selective enrichment of cysteine-containing peptides, histidine-tagged proteins and the isolation of N-terminal peptides will be analyzed.

1. Introduction

Sample preparation is a fundamental step in most analytical procedures, particularly for the analysis of complex samples (biological and environmental) [1,2].

Many endogenous low abundance proteins/peptides, suffer strong interference with highly abundant proteins/peptides as well as other contaminants, resulting in low ionization efficiency in mass spectrometry (MS) analysis [3]. To their successful identification, the separation and enrichment of proteins/peptides from complex mixtures are of

Abbreviations: AAPBA, poly 3-acrylaminophenylboronic acid; AEX, anion-exchange chromatography; AFP, α-fetoprotein; AgNPs, silver nanoparticles; AGP, alpha-1-acid glycoprotein; Ag_2Se NPs, silver selenide nanoparticles; APBA, aminophenylboronic acid; AP-MS, affinity purification mass spectrometry; AuNPs, gold nanoparticles; BAAC, boronic acid affinity chromatography; BASA, boronate-affinity sandwich assay; BSA, bovine serum albumin; CM-CS, carboxymethyl chitosan; CMPEI, carboxymethylated branched polyethylenimine; CNTs, carbon nanotubes; COF, covalent organic frameworks; Co_3O_4, cobalt oxide nanoparticles; Con A, concanavalin A; CS, chitosan; CTA, cetyltrimethylammonium; Cys, cysteine; Cys-PAT, cysteine-specific phosphonate adaptable tag; CZE, capillary zone electrophoresis; DA, dopamine; dBA, dendrimeric boronic acid; dND, detonation nanodiamond; DPP, distillation-precipitation polymerization; EDTA, ethylenediamine tetraacetic acid; EGF, epidermal growth factor; ESI-MS, electrospray ionization mass spectrometry; f, flowerlike; FASP, filter aided sample preparation; GCB, graphitized carbon black; G/GO, Graphene/Graphene oxide; GFP, green fluorescent protein; GMA, glycidyl methacrylate; GPI, glycosylphosphatidylinositol; GSH, glutathione; HA, hyaluronate; Hb, hemoglobin; HCR, hydrazide chemical reaction; HILIC, hydrophilic interaction liquid chromatography; HOMMS, hierarchically ordered macro/mesoporous silica; HRMC, human renal mesangial cells; HRP, horseradish peroxidase; HSA, human serum albumin; HYTANE, hydrophobic tagging-assisted N-termini enrichment; IDA, iminodiacetic acid; IEC, ion exchange chromatography; IgG, immunoglobulin G; IMAC, immobilized metal ion affinity chromatography; IMER, immobilized enzymatic reactor; LAC, lectin-based affinity chromatography; LacNAc, *N*-acetyllactosamine; LbL, layer-by-layer; LDH, layered double hydroxide; MAA, methacrylic acid; magG, magnetic graphene; MALDI-TOF, matrix-assisted laser desorption/ionization-time-of-flight; MBA, poly(*N*,*N*′-methylenebis(acrylamide); MBs, magnetic beads; MCNC, magnetic colloid nanocrystal cluster; MCNTs, magnetic carbon nanotubes; MGMSs, magnetic graphene/mesoporous silica; MIP, molecularly imprinted polymer; MMA, methyl methacrylate; mNOF, magnetic nanoparticles of ferrites; MNPs, magnetic nanoparticles; MOAC, metal oxide affinity chromatography; MOF, metal organic frameworks; MPB, mercaptophenylboronic acid; MS, mass spectrometry; MUA, 11-mercaptoundecanoic acid; nLC, nano-liquid chromatography; NO, nitric oxide; NPs, nanoparticles; NTA, nitrilotriacetic acid; ODT, octadecanethiol; PAA, polyacrylic acid; PAH, protonated poly(allylamine); PAMAM, poly(amidoamine); PDA, polydopamine; PDCMAA, poly[(*N*,*N*-dicarboxymethyl)allylamine]; PdNPs, palladium nanoparticles; PEG, poly(ethylene glycol); PEGM/PEGMA, poly(ethylene glycol methacrylate); PEGMP, poly(ethylene glycol methacrylate phosphate); PEI, polyethylenimine; PGMA, polyglycidyl methacrylate; PHEMA, poly(2-hydroxyethylmethacrylate); PMAA, poly(methylacrylic acid); P(MBA), poly(*N*,*N*′-methylenebis(acrylamide); PMS, porous magnetic silica; PMSA, poly(2-(methacryloyloxy)ethyl) dimethyl-(3-sulfopropyl) ammonium hydroxide; PolyMAC, polymer-based metal ion affinity capture; PP, precipitation polymerization; PPPs, phosvitin phosphopeptides; PSV, poly (styrene-co-4-vinylbenzene-boronic acid); PTM, post-translational modification; PtNPs, platinum nanoparticles; pTyr, tyrosine phosphorylation; PVPA, poly(vinylphosphonic acid); SALDI, surface-assisted laser desorption/ionization; SCX, strong cation exchange; SERS, surface-enhanced Raman scattering; SI-ATRP, surface-initiated atom transfer radical polymerization; SiBs, silica bubbles; SILProNAQ, stable-isotope protein *N*-terminal acetylation quantification; SPE, solid-phase extraction; SPEG, solid-phase extraction of *N*-linked glycopeptides; TFM, tresyl-functionalized microspheres; THPMP, 3-(trihydroxysilyl)propylmethylphosphonate; TiNb, titanoniobate; TMPP, (*N*-Succinimidyloxycarbonylmethyl)tris(2,4,6-trimethoxyphenyl)phosphonium bromide; TMPTMA, trimethylolpropane trimethacrylate; TRF, transferrin; UHPLC, ultra-high performance liquid chromatography; VPBA, 4-vinylphenylboronic acid; ZIC, zwitterionic

* Corresponding author.
E-mail address: cristina.nunez.gonzalez@sergas.es (C. Núñez).

https://doi.org/10.1016/j.jprot.2018.04.017
Received 11 December 2017; Received in revised form 2 April 2018; Accepted 9 April 2018
Available online 17 April 2018
1874-3919/

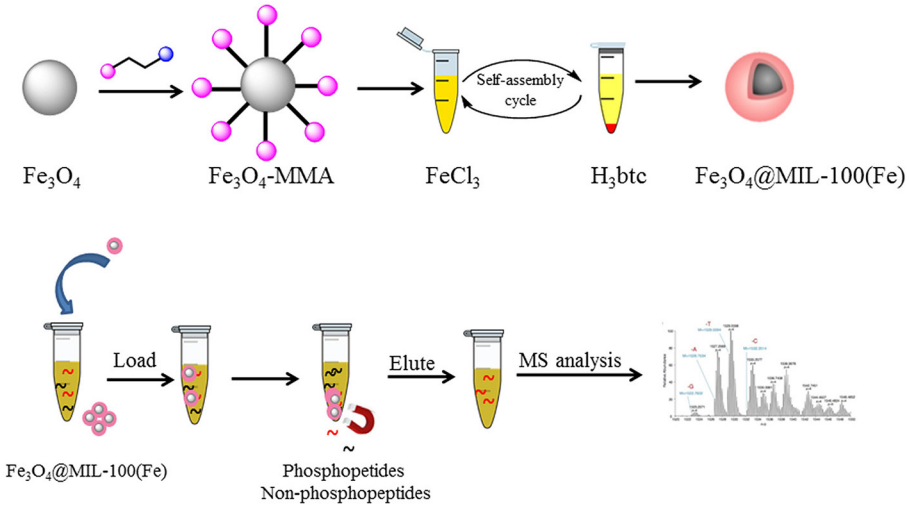

Fig. 1. (a) Schematic illustration of the synthetic procedure for the preparation of Fe_3O_4@MIL-100 (Fe) nanoparticles. (b) The typical process for selective enrichment of phosphorylated peptides using Fe_3O_4@MIL-100 (Fe) nanoparticles and magnetic separation. Adapted with permission from Ref. [43]. ACS Appl. Mater. Interfaces 2015, 7, 16338–16347

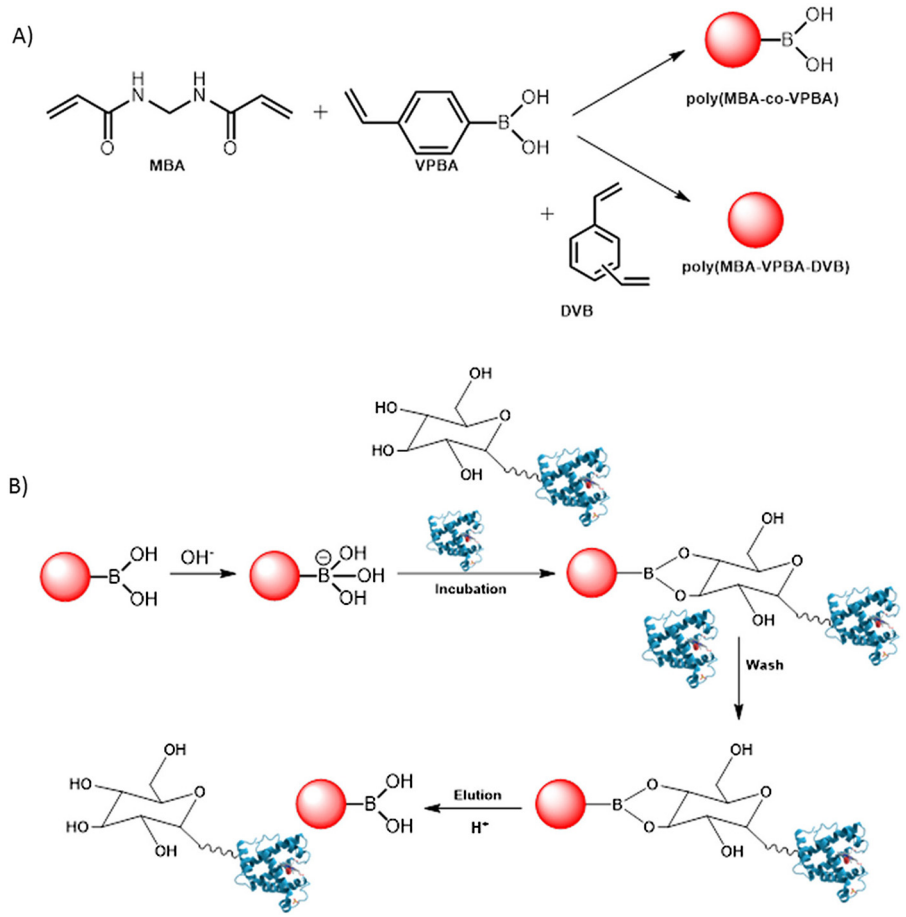

Fig. 2. (a) Synthesis of submicrometer P(MBA-*co*-VPBA) and P(MBA-*co*-VPBA-*co*-DVB) particles by a one-pot precipitation polymerization (PP) strategy. (b) Applications in the selective recognition of glycoproteins. Adapted with permission from Ref. [104]. ACS Appl. Mater. Interfaces 2014, 6, 2059–2066

great importance [4]. Therefore, rapid, convenient, gentle and efficient sample preparation methods are necessary for biological analysis [1] (Figs. 1–3).

The emergence of nanomaterials opened new horizons for the fast, efficient and convenient separation and enrichment of biological macromolecules of the proteome.

In this way, the enrichment of peptides and proteins from complex biological matrices using different nanomaterials before MS analysis were developed, without any further washing or separation procedures [5,6]. As examples, functionalized silver selenide nanoparticles (Ag_2Se NPs) with octadecanethiol (ODT) and 11-mercaptoundecanoic acid (MUA) [5], cobalt oxide nanoparticles modified with cetyltrimethylammonium (Co_3O_4/CTA^+ NPs) [7], palladium nanoparticles (PdNPs) with octadecanethiol (ODT) [8] and platinum nanoparticles (PtNPs) [9] were employed as effective extracting probes of peptides and proteins from a variety of real-world biological samples (urine, plasma, serum, insulin, milk,).

Magnetic nanomaterials and phases have also attracted considerable