

RETRACTED: Autoantibodies in renal diseases – clinical significance and recent developments in serological detection

Gianna Mastroianni-Kirsztajn¹, Nora Hornig² and Wolfgang Schlumberger^{2*}

¹ Division of Nephrology, Department of Medicine, Federal University of São Paulo, São Paulo, Brazil, ² EUROIMMUN Medizinische Labordiagnostika AG, Institute for Experimental Immunology, Lübeck, Germany

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*Correspondence:

Wolfgang Schlumberger,
EUROIMMUN Medizinische
Labordiagnostika AG, Institute for
Experimental Immunology, Seekamp
31, Lübeck 23560, Germany
w.schlumberger@euroimmun.de

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Autoimmune dysfunctions are the “bête noire” in a range of debilitating nephropathies. Autoimmune-mediated damage to the kidneys can be triggered by autoantibodies directed against specific proteins or renal structures, for example, the phospholipase A2 receptor or the glomerular basement membrane, resulting in glomerular diseases such as primary membranous nephropathy or Goodpasture’s disease. Moreover, secondary damage to the kidney can be part of the wide-reaching effects of systemic autoimmune diseases such as vasculitis or systemic lupus erythematosus (SLE) – the latter counts lupus nephritis among its most severe manifestations. Systemic autoimmune diseases are characterized by non-organ-specific autoantibodies, directed for example against neutrophil cytoplasmic antigens in systemic vasculitis and against double-stranded DNA and nucleosomes in SLE. A large variety of innovative and highly specific and sensitive autoantibody tests have been developed in the last years that are available to identify autoimmune kidney diseases at an early stage. Thus, serological *in vitro* diagnostics allow for appropriate interventional therapy in order to prevent disease progression often resulting in need of dialysis and transplantation.

Keywords: autoantibodies, renal autoimmune diseases, anti-PLA2R, anti-THSD7A, anti-nucleosomes, anti-dsDNA, ANCA, anti-PR3

Introduction

Several autoantibodies have been characterized as associated with renal diseases with some of them being possibly implicated in pathogenesis. Even if this causal relationship is not established, the detection of autoantibodies has an important role in diagnosis and follow-up of these diseases (i.e., as a marker of response during treatment).

Among the renal diseases associated with autoantibodies, glomerular diseases are particularly important. It is of note that glomerulopathies are rare, but often responsible for progression to end-stage renal disease. Therefore, adequate and early diagnosis is essential in the management of glomerular disease with influence on prognosis.

This paper will review the main aspects of four clinically relevant renal autoimmune diseases – membranous nephropathy (MN), Goodpasture’s disease, lupus nephritis (LN), and anti-neutrophil cytoplasmic autoantibodies (ANCA)-associated vasculitis (AAV). The diseases may be grouped according to their autoimmune response to either renal or ubiquitous antigens (Table 1).

TABLE 1 | Renal autoimmune diseases and associated autoantigens.

Disease	Target antigen
Immune responses against renal antigens	
Primary membranous nephropathy (pMN)	PLA2R, THSD7A
Goodpasture's disease	NC1 domain of collagen type IV
Systemic immune responses against ubiquitous antigens associated with renal inflammation	
Lupus nephritis (LN)	dsDNA, nucleosomes, C1q
ANCA-associated vasculitis (AAV)	PR3, MPO
IgA nephropathy (IgAN)	Galactose-deficient IgA1
Atypical hemolytic uremic syndrome (aHUS)	Complement factor H
Membranoproliferative glomerulonephritis (MPGN)	C3 convertase, C1q, complement factor B and H

Immune Responses Against Renal Antigens

Anti-PLA2R and Anti-THSD7A Autoantibodies in Primary Membranous Nephropathy

Membranous nephropathy, one of the most frequent glomerular diseases, is the major cause of nephrotic syndrome (1). It predominantly affects adults and the elderly. Although spontaneous remission occurs in about one-third of patients, a similar number of patients develop end-stage renal failure within 10 years.

The clinical picture and traditional laboratory tests give hints toward the diagnosis in MN. Definitive diagnosis can only be made after histological examination of kidney tissue obtained by biopsy using different microscopy techniques (light, immunofluorescence, and electron microscopy).

Nevertheless, it is important to know that there are exceptional situations in which such diagnosis is not sufficiently clear, for instance at earlier phases of the disease, or if the biopsy specimen does not include adequate tissue for all mentioned microscopy techniques, is contraindicated or not available.

Further obstacles in obtaining the correct diagnosis are due to the etiology of MN. MN can be the primary disorder (pMN) or it can be secondary to underlying systemic lupus erythematosus (SLE), hepatitis B and C infection, malignancies, use of certain medications, and several other etiologic agents. The differentiation between both forms is important but can be challenging at times. If the search of an underlying disease applying routine laboratory markers is negative, doubts can persist and complicate the management of the disease.

One of the most important discoveries in glomerular diseases in the last decade was the understanding of the possible mechanisms of disease development by the identification of the M-type phospholipase A2 receptor (PLA2R) as the target antigen of autoantibodies in idiopathic MN (2).

Anti-PLA2R autoantibodies are highly specific for pMN and are found in the serum of approx. 75% of pMN patients at time of diagnosis. In patients with secondary MN or in healthy individuals, anti-PLA2R antibodies only occur rarely. The target antigen is a type-1 transmembrane glycoprotein receptor that is expressed on the surface of podocytes. Although the exact mechanisms causing pMN are still not completely resolved, it is assumed that upon binding of circulating autoantibodies to podocyte PLA2R,

subepithelial deposits are formed *in situ*, subsequently leading to nephrotic syndrome including proteinuria after a cascade of events.

For the determination of anti-PLA2R autoantibodies, two standardized assays are available from EUROIMMUN that are highly suitable for routine diagnostic purposes: a recombinant cell-based indirect immunofluorescence test (RC-IIFT) and an enzyme-linked immunosorbent assay (ELISA). RC-IIFT uses the human cell line HEK293 overexpressing full-length human PLA2R as substrate (3). The PLA2R-positive cells are arranged in a biochip format in combination with control-transfected cells in one incubation field (mosaic) [Anti-PLA2R IIFT (IgG)]. Using this assay, anti-PLA2R antibodies were detected with maximal specificity (100%) and with a sensitivity of 77% in a cohort of 275 biopsy-proven pMN patients. In concordance with the finding that anti-PLA2R antibody concentrations decrease in patients undergoing successful immunosuppressive therapy and can reach undetectable level, a lower prevalence of 52% was found in a cohort of pMN patients that included several patients under rituximab treatment (3). For the accurate quantification of autoantibody concentrations, an ELISA based on the recombinantly produced extracellular domain of PLA2R has recently been developed [Anti-PLA2R ELISA (IgG)] (4). In a large cohort of clinically well-characterized patients, this assay revealed very high sensitivity with respect to RC-IIFT (96.5%) at a set specificity of 99.9%. The quantitative results of ELISA and RC-IIFT show a good correlation ($R^2 = 0.7491$).

Detection of anti-PLA2R antibodies is crucial to discriminate between patients with primary and secondary MN, as both forms require different diagnostic approaches and treatment strategies. Moreover, anti-PLA2R autoantibody concentrations allow the assessment of disease activity: they reflect immunological rather than clinical disease activity (proteinuria) with an increase in antibody levels preceding a rise in proteinuria and a decrease in antibody levels being followed by a fall in proteinuria. Determination of autoantibody concentrations also allows for predictions regarding clinical outcome: in a prospective multicenter study including 133 adult pMN patients with detectable anti-PLA2R antibodies (who had not received immunosuppressive therapy at study inclusion), anti-PLA2R antibody levels were identified as a risk factor for not achieving remission of proteinuria (5). In this study, immunosuppressive therapy led to a persistent reduction of anti-PLA2R antibody levels by 81% which was accompanied by proteinuria reduction of 39% within 3 months. At the time of study inclusion, anti-PLA2R antibody levels were significantly lower in patients who experienced remission of proteinuria after 12 months compared to patients with no remission.

Up to 40% of patients with pMN relapse after kidney transplantation. This risk is particularly high if anti-PLA2R autoantibodies are persistently found during the first 6 months after organ transplantation (6). Therefore, the determination of autoantibody levels may be useful to assess the necessity and intensity of immunosuppressive therapy after transplantation in order to avoid relapses.

Hence, in addition to differential diagnosis of MN, the quantification of anti-PLA2R autoantibodies by ELISA allows assessment of disease activity and severity as well as prediction of

disease outcome (remission, relapse) and risk of recurrence of MN after kidney transplantation. Moreover, it facilitates treatment decisions and monitoring of response to treatment.

Very recently, thrombospondin type-1 domain-containing 7A (THSD7A) was discovered as a second antigenic target in approx. 2.5–5% of patients with idiopathic MN (7). Importantly, these autoantibodies have exclusively been found in 8–14% of anti-PLA2R antibody-negative patients, suggesting that these patients represent a distinct disease subgroup. No reactivity against THSD7A was observed among healthy controls and among patients with other proteinuric or renal autoimmune diseases. As PLA2R, THSD7A is an N-glycosylated high molecular mass protein expressed on the podocyte membrane and shows reactivity with serum antibodies only under non-reducing conditions. Similar to anti-PLA2R antibodies, an association between anti-THSD7A antibody levels and disease activity is suggested. Further studies using THSD7A-based RC-IIFT (IgG) are currently ongoing.

Anti-Glomerular Basement Membrane Autoantibodies in Goodpasture's Disease

Goodpasture's disease is a rare organ-specific autoimmune disease that is mediated by anti-glomerular basement membrane (anti-GBM) antibodies. Kidney involvement is characterized by crescentic glomerulonephritis with linear immunofluorescence staining for IgG on the GBM. The percentage of glomerular crescents is associated with poor renal outcome. Clinically, Goodpasture's disease presents with rapidly progressive glomerulonephritis and renal failure, accompanied by pulmonary hemorrhage that may be life-threatening. Both pulmonary and renal involvement occur in 60–80% of the patients (8). Renal manifestations alone are seen in 20–40% and are referred to as anti-GBM glomerulonephritis. The etiology of Goodpasture's disease is unknown.

The diagnosis of anti-GBM disease relies on the detection of anti-GBM antibodies (IgG) in tissues or circulation in combination with the detection of glomerulonephritis and/or alveolitis. Anti-GBM antibodies are highly specific and sensitive markers of the disease. The relevant antigenic target is the non-collagenous domain 1 (NC1) of the $\alpha 3$ chain of type IV collagen within the GBM or the alveolar basal membrane. Distribution of this molecule in the human body is limited to specific organs, such as kidneys and lungs, thereby explaining the main manifestations of the syndrome (9).

Anti-glomerular basement membrane antibodies are by definition present in all patients with Goodpasture's disease. They can be detected either by indirect immunofluorescence tests (IIFT) using cryo-sections of primate kidney or by monospecific immunoassays based on the purified NC1 domain (e.g., ELISA, line assays, microdots in IIFT). Twenty to thirty-five percent of patients with anti-GBM antibodies also have ANCA, mostly with specificity for myeloperoxidase (MPO). Since Goodpasture's disease and AAV may have the same clinical presentation, it is recommended that anti-GBM and ANCA should be analyzed in parallel in patients with renal disease (9) (Figure 1).

Anti-glomerular basement membrane antibodies have shown to be crucial for early diagnosis of the disease. Clinical progression

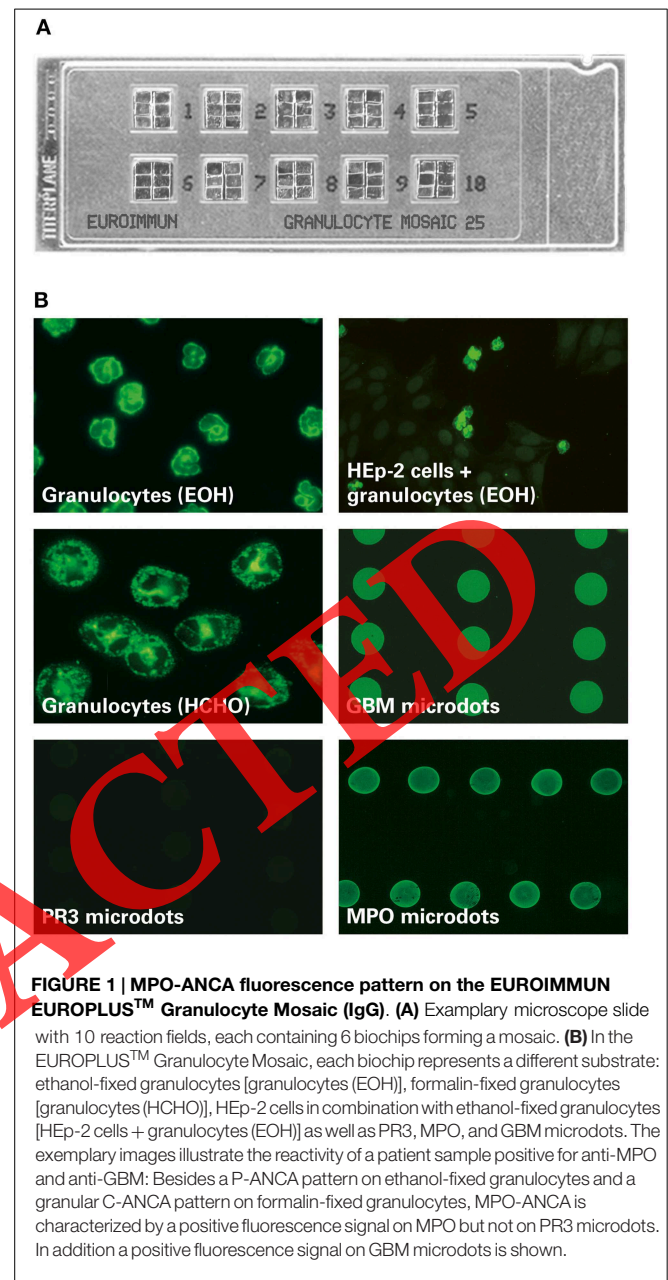


FIGURE 1 | MPO-ANCA fluorescence pattern on the EUROIMMUN EUROPLUS™ Granulocyte Mosaic (IgG). (A) Exemplary microscope slide with 10 reaction fields, each containing 6 biochips forming a mosaic. (B) In the EUROPLUS™ Granulocyte Mosaic, each biochip represents a different substrate: ethanol-fixed granulocytes [granulocytes (EOH)], formalin-fixed granulocytes [granulocytes (HCHO)], HEp-2 cells in combination with ethanol-fixed granulocytes [HEp-2 cells + granulocytes (EOH)] as well as PR3, MPO, and GBM microdots. The exemplary images illustrate the reactivity of a patient sample positive for anti-MPO and anti-GBM: Besides a P-ANCA pattern on ethanol-fixed granulocytes and a granular C-ANCA pattern on formalin-fixed granulocytes, MPO-ANCA is characterized by a positive fluorescence signal on MPO but not on PR3 microdots. In addition a positive fluorescence signal on GBM microdots is shown.

of the disease correlates with antibody concentrations, with high concentrations of circulating anti-GBM antibodies indicating an unfavorable prognosis.

Systemic Autoimmunity Against Ubiquitous Antigens in Association with Renal Inflammation

Anti-dsDNA and Anti-Nucleosome Autoantibodies in Lupus Nephritis

Lupus nephritis is one of the most frequent and severe manifestations of SLE, contributing to end-stage renal disease and different extrarenal complications. It can present as nephritic and/or

nephrotic syndrome with different combinations of proteinuria, hematuria, impaired renal function, edema, abnormal lipid profile, and hypertension. Renal biopsy is an important measure in disease management, allowing the identification of six histological classes of glomerulonephritis which have an impact on therapeutic decisions.

Systemic lupus erythematosus and LN are characterized by the presence of several autoantibodies directed against components of the cell nucleus and the cytoplasm as well as against other autoantigens. Diagnosis is based on 11 criteria according to the American College of Rheumatology, including immunological parameters.

Anti-nucleosome antibodies (ANuA) represent the first serological marker described in SLE. The term “nucleosome” defines a highly organized functional subunit of chromatin which consists of approximately two turns of dsDNA wrapped tightly around an octamer of histones (two molecules of each H2A, H2B, H3, and H4). Neighboring nucleosomes are joined by linker DNA, which is associated with histone H1 located outside the nucleosome core. Nucleosome-specific antibodies are able to bind to the intact nucleosome, but not its individual components (dsDNA and histones).

Although the prevalence of ANuA in sera from SLE patients is high, the diagnostic use of this parameter has been limited for a long time, since sera from patients with progressive systemic sclerosis (PSS) demonstrated significant positive reactions (10–68%) with conventional ANuA test systems (first generation). These false positive reactions were eliminated in the second generation EUROIMMUN Anti-Nucleosome ELISA (IgG) (10); here, the antigen is based on an innovative purification protocol using sucrose density gradient centrifugation under carefully optimized NaCl conditions. This procedure results in highly purified mononucleosomes which are free from contaminating histone H1, non-histone proteins such as Scl-70, and chromatin DNA fragments. Using the second generation Anti-Nucleosome ELISA, specificity was 100% with respect to healthy blood donors and PSS patients. In contrast, in first generation Anti-Nucleosome ELISA, 52% of sera from PSS patients cross-reacted with Scl-70 due to impurities of the nucleosome preparation. Sensitivity was similar in both assays.

Anti-nucleosome antibodies have been shown to be a prognostic indicator for SLE with renal involvement: the prevalence of ANuA was particularly high in severe cases of LN requiring transplantation (79%), compared to less severe cases (18%) and SLE without nephritis (9%) (11).

Anti-dsDNA antibodies are found in 60–90% of SLE patients and represent the most established marker for the disease. In order to improve the diagnostic performance of anti-dsDNA ELISA in comparison to established test systems, an optimized test referred to as Anti-dsDNA-NcX ELISA (IgG) was developed by EUROIMMUN (12): this ELISA is based on a novel coating technology and applies the highly purified mononucleosomes used in the second generation Anti-Nucleosome ELISA as linker substance for the immobilization of dsDNA. The specific configuration of the Anti-dsDNA-NcX ELISA minimizes false positive reactions that typically occur when using conventional coating

materials such as poly-L-lysine and protamine sulfate. Moreover, it ensures precise and authentic presentation of major epitopes thus leading to superior diagnostic accuracy. At a comparable specificity of 98.2% (based on ROC analysis), the sensitivity of the Anti-dsDNA-NcX ELISA (IgG) (66.7%) highly exceeds that of Farr-RIA (55.6%), Anti-Nucleosome ELISA (IgG) (55.6%), and conventional Anti-dsDNA ELISA (IgG) (41.5%), as well as that of IIFT using *Crithidia luciliae* (IgG) (28%). Comparison of the diagnostic concordance of Anti-dsDNA-NcX ELISA, Farr-RIA, and *C. luciliae*-based IIFT reveals that there is a considerable number of serum samples which are solely positive in one of the three methods with the ELISA detecting the highest number.

Hence, the non-radioactive Anti-dsDNA-NcX ELISA is superior to Farr-RIA and *C. luciliae*-based IIFT in diagnosing SLE. However, both classical methods continue to be important for the identification of the few SLE patients who present with negative Anti-dsDNA-NcX ELISA results.

Anti-dsDNA-NcX ELISA is also suitable for monitoring disease activity in SLE patients: in a longitudinal analysis of 20 patients over a period of 10 months, changes in Anti-dsDNA-NcX ELISA results correlated significantly with changes in disease activity over time (assessed by mSLEDAI 2000 score), while neither Anti-dsDNA ELISA nor Farr-RIA did reflect these changes (12). Moreover, Anti-dsDNA-NcX ELISA might be suitable for monitoring the course of the disease in response to treatment: preliminary results from a longitudinal monitoring of individual LN patients under therapy show a high correlation between Anti-dsDNA-NcX concentrations and disease activity (assessed by BILAG-2004 score).

Anti-Neutrophil Cytoplasmic Antibodies in Renal Vasculitis

Vasculitis associated with ANCA comprises a group of multi-systemic diseases that affect small-to-medium-sized vessels, resulting in a wide spectrum of organ involvement including the kidneys and the lung. In the kidney, ANCA are predominantly responsible for rapidly progressive glomerulonephritis which is histologically characterized by a pauci-immune deposition pattern in immunofluorescence of renal biopsy-derived tissue and the presence of crescents in light microscopy. Renal failure is a common and severe complication in this disease, particularly in the elderly population.

Autoimmune vasculitis is characterized by ANCA. Unfortunately, diagnosis based on clinical manifestations is complicated because of varying and frequently non-specific initial symptoms. Therefore, the serological determination of ANCA is an essential tool for identifying and differentiating AAV, consequently contributing to treatment and follow-up.

A number of different methods are used to detect ANCA. The standard technique for screening of ANCA is IIFT using ethanol-fixed granulocytes. Two main staining patterns can be differentiated: a cytoplasmic (C-ANCA) and a perinuclear (P-ANCA) pattern. The C-ANCA pattern is mainly induced by antibodies directed against proteinase 3 (PR3), which are typically found in

granulomatosis with polyangiitis (GPA) but also in other AAVs. The P-ANCA pattern mainly results from antibodies against MPO which are associated with various AAVs, particularly microscopic polyangiitis (MPA), eosinophilic granulomatosis with polyangiitis (EGPA), and pauci-immune crescentic glomerulonephritis.

According to an international consensus statement, ANCA testing should include screening with IIFT and confirmation in MPO- and PR3-ANCA-specific assays (13). As a multiplexing approach, the EUROIMMUN EUROPLUS™ Granulocyte Mosaic (IgG) system combines the conventional cell substrates and single microdots of purified PR3 and MPO as biochips in one incubation field of a microscope slide (**Figure 1**) (14). Besides the simultaneous observation of ANCA IIFT patterns on ethanol- and formalin-fixed granulocytes, the test system allows for exclusion of ANA interference due to the combined HEP-2/ethanol-fixed granulocyte substrate as well as for the monospecific determination of MPO- and PR3-reactivity. This combination greatly facilitates the interpretation of the ANCA IIFT patterns and has shown a high concordance with a reference multi-testing algorithm [based on the combination of IIFT with ethanol-fixed granulocytes (IgG) as well as direct and capture ELISAs for both MPO- and PR3-ANCA (IgG)] (14).

Additionally, the EUROPLUS™ Granulocyte Mosaic can be supplemented with microdots of GBM antigen in order to analyze for potential anti-GBM antibodies (see Glomerular Basement Membrane Autoantibodies in Goodpasture's Disease).

A further major advance in ANCA testing is the recent development of an ELISA based on a novel PR3 diagnostic antigen, which consists of a mixture of human native (hn) PR3 and human cell-expressed recombinant (hr) designer PR3, exhibiting modified N- and C-terminal signal sequences as well as an inactivated

enzymatic core (15). At a defined specificity of 99%, sensitivity of the EUROIMMUN Anti-PR3-hn-hr ELISA (IgG) is significantly higher (95%) than sensitivity of other ELISA based only on native antigen [Anti-PR3-hn ELISA (IgG): 80%, Anti-PR3 Capture ELISA (IgG): 77%]. In addition to its excellent diagnostic performance, the ELISA also allows for a good predictability of clinical relapses in patients with PR3-AAV.

Concluding Remarks

Autoantibodies can be found in several forms of nephropathies. They can either be directed against kidney-specific autoantigens or against ubiquitous antigens as in systemic autoimmune diseases with renal manifestations. Recent developments in autoantibody diagnostics in nephrology include the identification of PLA2R and THSD7A as antigenic targets in pMN, as well as considerable improvements in sensitivity, specificity, and convenience of test systems for anti-dsDNA, ANuA-ANCA, and anti-GBM. These advances have boosted the ease, reliability, and relevance of autoantibody testing, aiding the diagnosis of autoimmune nephropathies, especially in early stages. This is crucial for the decision on interventional therapy, e.g. with immunosuppressants, which can help to delay the serious and irreversible damage that occurs with disease progression. This, in turn, may circumvent the need for intensive and distressing end-stage procedures such as dialysis and transplantation – a boon for patients to the benefit of healthcare system.

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declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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