rgan transplantation is the definitive treatment that can be used in patients with end-stage kidney damage. However, antibodies generated by the recipient against human leukocyte antigens (HLA) of donor are the major risk factor, especially for antibody-mediated acute rejection. Even if the targets of the humoral immune response are mainly
polymorphic HLA antigens, the investigations have shown that antibodies produced against non-HLA antigens also have effect on antibody-mediated rejection. This result was achieved by determining the presence of increased antibody-mediated rejection in the kidney transplant resulting from HLA-identical siblings. The detection of antibody-mediated rejection in the absence of donor-specific HLA antibodies has accelerated the research on antibodies developed against non-HLA antigens after cardiac, liver and renal transplantations. These antibodies can be produced against non-polymorphic or non-allelic proteins. Antibody development against non-polymorphic targets is due to inflammation, immunological response to graft, or proteins that spread to the immune system during graft damage. Transplanted tissue/organ (graft) microenvironment or rejection can destroy humoral tolerance to autoantigens.3

The first non-HLA antibodies developed against donor antigens were identified in 1995.4 Terasaki et al. examined the immunologic and non-immunological factors involved in graft damage in HLA-matched and HLA-mismatched renal transplants, and emphasized the importance of clinical study and identification of non-HLA antibodies.5 Following the first studies Collagen V (Col-V), Angiotensin type 1 receptor (AT1R), K-alpha 1 tubulin (KA1T), endothelin type A receptor (ETAR), bioactive C terminal fragment (LG3) of perlecan, MHC class I chain related protein A (MICA) and B (MICB) are determined as antigenic targets of non-HLA antibodies.6 Non-HLA antibodies raised against these targets are usually autoantibodies and alloantibodies.7

Non-HLA antibodies can play role in acute and chronic damage both as a complement fixing and non-HLA antibodies.8 In two preliminary studies, the independent data was used and it was detected that graft survival was reduced when lymphocytotoxic antibodies were existed before kidney transplantation that is performed between HLA-matched siblings. As a consequence, the importance of non-HLA immunity is underlined in chronic rejection.9 Brasile et al. were detected anti-endothelial antibodies (AECA) in a patient prior to transplantation who was transplanted from his mother who had hyperacute rejection after transplantation. This patient was later transplanted from cadaver and had a hyperacute rejection again. Against both donors, the AECA was determined in the pre-transplant serum of the recipient. This suggests that these antibodies are important in the pathogenesis of antibody mediated rejection (AMR).10

The aim of this review is to review the target antigens, therapeutic strategies and detection methods of non-HLA antibodies.

ANGIOTENSIN TYPE I RECEPTOR (AT1R)
The angiotensin type 1 receptor is a G protein-related receptor which is responsible for the regulation of the blood pressure and water-salt balance. Overexpression of AT1R causes hypertension, vasoconstriction and vascular smooth muscle migration.9 AT1R antibodies can bind to the AT1R molecules of the other organs of the recipient in addition to graft. This binding activates various cell signalling pathways as ERK signalling.11 Antibodies against AT1R have been described for the first time in preeclamptic pregnancies.9 In another study, these antibodies were identified as graft failure and acute rejection risk factors in renal transplantation.12 It was reported that these antibodies can cause cell proliferation and vascular damage of kidney, increased levels of AT1R antibodies were detected in steroid refractory vascular rejection.9,13 Banaisk et al evaluated the effect of non-HLA antibodies on kidney allograft by testing At1R antibodies of 65 renal transplanted patients. The patient’s CDC-XM results were detected negative.14 It was reported that high-level AT1R antibodies may be related to enhanced graft loss. In this study Lee et al tested 12 renal transplanted patients who had no donor specific antibodies.13 Dragun et al. have shown antibodies binding to AT1R can mimic the behaviour of angiotensin II and induce endothelial and smooth muscle cell degeneration.15

Rejection is not seen in all renal recipients with AT1R antibody. Therefore it was thought that rejection can be influenced by additional cofactors
like environmental conditions. By detecting pre-transplant AT1R antibodies, the risk for AT1R related AMR can be eliminated.

**COLLAGEN AND K-ALPHA 1 TUBULIN (KAIT) ANTIBODIES**

Collagen is a fibrous protein found in multicellular animals. They are the basic components of the skin and bones. It is secreted in high amounts in connective tissue cells and in very small amounts in other cell types. Approximately 40 collagen types have been described. Collagen V is found in the epithelium of the trachea. After an injury of the lung, antigenic fragments of the collagen V releases and thus become a target for the T lymphocytes. After autoantibody production the transplant can be rejected. Collagen IV is mainly found on glomerular extracellular matrix. Angaswamy et al. showed the interaction between the transplant glomerulopathy and collagen IV and fibronectin antibodies. Collagen antibodies have also been detected in cardiac transplant recipients. The development of collagen V antibodies in AMR patients and the correlation between them and DSA were noted.

KAIT is a cytoskeletal intermediate filament protein and is also expressed in respiratory epithelial cells. It was first discovered as a result of inducing the humoral response in lung transplants. Hachem et al detected KAIT and collagen V antibodies in 108 lung transplanted patients by ELISA method. According to their results, while 89% had antibodies to both K-α 1 tubulin and collagen V, 10% had antibodies only to K-α 1 tubulin, and 1% had antibodies only to collagen V. These antibodies can be a risk for bronchiolitis obliterans syndrome (BOS) and initiates the chronic allograft rejection process. It was also showed that a successful antibody depletion can decrease this risk. Golocheikine et al. worked with 22 lung transplanted patients and analyzed the serum samples for the presence of collagen V and KAIT antibodies. The prevalence of DSA was detected more in non-HLA antibody positive group than negative group. Their findings also supported the results of the other studies in which KAIT antibodies can increase the BOS. Immunization against major histocompatibility complex (MHC) class I antigens in pulmonary transplanted mice models has been shown to induce K-alpha1 tubulin and anti-collagen antibody responses to collagen. The attachment of the pitched tubular epithelium of these antibodies results in an increase in the activation of the cell cycle signal, and fibroproliferation. Additionally the expression of fibrogenic growth factors are also increase and all these events can cause BOS.

**ANTI-LG3 ANTIBODIES**

Perlecan is one of the largest proteoglycans which consists of about 500 kDa core protein and each side chain of 65 kDa. The core protein is composed of many structural regions and provides biofunctional diversity of perlecan. Proteoglycans are particularly involved in morphogenesis and tissue remodelling processes. It is one of the major components on the surfaces of vascular membranes. LG-3 is the C-terminal fragment of the perlecan. Pilon et al. was showed the increased circulatory and urinary LG3 levels in mice with renal dysfunction, acute rejection and chronic vascular injury. Riesco et al studied with 11 hypersensitized kidney transplantation patients and LG3 antibodies were detected in 52% of them. 4 of the 11 patients were presented AMR and LG3 antibodies were detected. They evaluated that detection of the non-HLA antibodies can decrease the risk of humoral rejection. Cardinal et al. compared acute vascular injury and acute tubule interstitial rejection. According to their results increasing levels of anti-LG3 titers were associated with acute vascular rejection. Their data showed that anti-LG3 antibodies are the elevators of immune-mediated vascular injury. However Padet et al. observed no association between the LG3 antibody levels and transplantation outcomes. Therefore further studies needed to evaluate LG3 antibody levels and transplantation outcomes which includes higher number of samples.
MIC ANTIBODIES

MHC class I related chain A (MICA) and MHC class I related chain B (MICB) are important non-HLA antibody target molecules. The MICA and MICB genes were localized to the HLA-B locus and encodes 62-kDa cell surface proteins. They have similar homology to HLA class I molecules. Many cell types, including endothelial cells and monocytes, express MICA (except lymphocytes). MICA antibodies have been identified in acute renal and cardiac allograft rejections. In particular, MICA expression is induced in T lymphocytes by cytokines such as IL-2, IL-4 and IL-15. Li et al. noted that a cytokine storm occurred during the rejection challenge in the inflamed graft and MICA expression was induced on the surface of the infiltrating lymphocytes. This group determined that MICA antibody levels were much higher in humoral rejections than in cellular rejections. Mizutani et al. reported increased levels of MICA and MICB antibodies in serum samples from patients with renal allograft rejection. They were produced in patients who had rejection episode more than patients with stable grafts function. Terasaki et al reported a close association between MICA antibodies and chronic renal rejection. There are studies on the importance of these antibodies in heart transplants.

As shown in above, studies mainly focused on MICA antibodies. This could be because of unknown mechanism of MICB antibodies and MICB expression and effect on transplantation outcomes. Further studies needed to highlight the role of MICB antibody in transplantation.

ANTI-VIMENTIN, ANTI-MYOSIN ANTIBODIES

Vimentin is an intermediate filament protein found in mesenchymal originated cells. Like other intermediate filament proteins, vimentin also plays a role in the stabilization of the structure of the cytoplasm. It has been determined that mouse models that have no vimentin expression had a normal phenotype, however in some special cases the absence of vimentin causes phenotypic abnormalities. This suggests that vimentin has an important function in dynamic cellular processes.

It is expressed in the cytosol of mature leukocytes, in fibroblasts, on the surface of apoptotic T cells and neutrophils, and in endothelial cells. Autoantibodies against vimentin are produced in autoimmune diseases such as lupus and rheumatoid arthritis. However in solid organ transplantation vimentin antibodies has been also detected. Vimentin is not expressed by adult cardiomyocytes and healthy kidney tubular cells. However during rejection some tubular epithelial cells can express vimentin.

These antibodies were first identified in 2001 as anti-vimentin antibodies of the IgM type in heart transplant patients. Vimentin is expressed in high levels in intima and coronary arteries. High titres of anti-vimentin antibodies are observed in cardiac transplant recipients with chronic arterial vasculopathy. Whether this relationship is independent of HLA sensitization is unclear.

Lopez-Soler et al showed the association between anti-vimentin antibodies ans interstitial fibrosis-tubular atrophy (IFTA) in 97 renal transplanted patients by using Luminex method. They detected that increasing levels of vimentin antibodies (>15 ug/ml) can be a risk of elevated levels of IFTA and graft loss. On the other hand, Gunasekaran et al studied with 24 patients who had biopsy proven transplant glomerulopathy after kidney transplantation. They observed increased levels of anti-vimentin antibodies of IgG isotypes in TG patients, while in stable kidney transplanted patients anti-vimentin IgM isotype was detected. Therefore it can be evaluated that the isotype switching of anti-vimentin antibodies can affect the transplantation outcome.

Carter et al. investigated the presence of anti-vimentin antibodies in 51 kidney transplanted who had graft loss. Interestingly they’ve noticed that the patients who was HLA-DQ2 positive, form more vimentin antibodies than negatives (p=<0.001). Also they investigated the association between vimentin antibodies and cytokine production and they found that while in stable conditions vimentin can regulate the immune response, vimentin can activate Th-2 immunity if there is a condition that activates immune response.
Myosin is an intracellular protein which has a coiled coil alpha-helix conformation, located in atrial myocytes, ventricular myocytes and skeletal muscle fibers. The association of anti-myosin antibodies and several heart diseases have been described. O’Donohoe et al. described the anti-myosin antibodies in 43 patients with myocardial infarction. They’ve noticed that anti-myosin antibodies are formed in patients following myocardial infarction and IgG levels persist beyond 6 months. Studies have shown that T cells of the recipient recognizes cardiac myosin proteins and induces cardiac allograft rejections in the absence of alloimmune response to MHC class II molecules. It has been determined that the life span of anti-myosin antibodies seen before the onset of the disease is less than 2 years in heart transplanted patients.

MINOR TISSUE COMPATIBILITY ANTIBODIES (MIHA)

Genes that are not associated with MHC and cause a slower rejection are called minor tissue compatibility genes. The first hypothesis on the relationship between the results of the MiHA in bone marrow transplants was suggested by a female patient who had been transferred from his brother. Peripheral bloodstream cytotoxic T cells were isolated, which were found to be counteracted by antigens presented in HL A-unrelated donor cells.

MiHAs are polymorphic peptides of 9-12 amino acids. MiHAs that bind to the antigen binding site of HLA-class I or II molecules are recognized by T lymphocytes. Thus, it has been determined that MiHAs are specific for HLA antigens. Differences between MiHAs are the result of amino acid polymorphisms, gene deletions or many intracellular mechanisms. The MiHA diversity recognized by the TCR can result from single or multiple amino acids.

MiHAs expressed by normal recipient tissues become the target of donor T cells. This immunological response causes graft-versus-host-disease (GVHD) and post-transplant mortality. Recent studies have shown that MiHAs are expressed in hematopoietic tumor cells. When donor T cells target MiHAs expressed in leukemia cells, autoimmunity causes graft versus leukemia (GVL) and after transplantation malign cells can be killed.

Minor HLAs are well-defined in HLA-identic stem cell transplantations. However, the effect is not completely known in solid organ transplantations.

DETECTION METHODS OF NON-HLA ANTIBODIES

After the description of the first lymphocytotoxicity assay by Patel and Terasaki in 1969, high throughput methods were developed to increase sensitivity and specificity. The sensitivity of these methods varies and can affect the interpretation of the results. The clinical consequences of sensitization to non-HLA antibodies cannot be determined well because non-HLA targets cannot be identified sufficiently. To increase the studies on non-HLA antibodies, screening and identification methods should be developed. It was shown that antigens expressed mainly on endothelial and epithelial cells are the primary target of humoral responses in organ transplantation. Insufficient standardized protocols limit the crossmatch tests in which endothelial cells are used. Different assays have been used to detect and identify anti-endothelial cell antibodies as complement dependent crossmatch, flow cytometry and immunofluorescence. These methods had different sensitivity, specificity and can detect distinct immunoglobulin types. As a source of donor antigens endothelial cells are difficult to isolate. Therefore a new technique called XM-ONE developed that depends on the isolation of the endothelial cell precursors from peripheral blood. In the same assay the antibodies against T and B lymphocytes, and endothelial cells can be tested.

IgG from patient sera can be used for the identification of AECA by immunoblotting. Otherwise by using immunoblotting, there are several studies that identify non-HLA targets as vimentin, AT1R, tubulin, myosin, collagen.
Carter et al. tested vimentin antibodies in 44% of the patients that had graft failure by flow cytometry assay in which recombinant vimentin was bound to polystyrene microspheres. Fchied et al. developed a bead based immunoassay using Luminex technology. The data presented in this study demonstrates by using this method and performing epitope mapping antibodies can be detected in different disease conditions. More investigations should be done for the clinical validation of the assay. Riesco et al were assessed anti-MICA and anti-perlecan antibodies by Luminex method in serum samples while AT1R antibodies were analysed by ELIS since it was not included in Luminex assay.57

Dragun et al. used a sandwich ELISA for detection of AT1R-Abs in serum to detect antibody mediated rejection. O'Donohoe was also used ELISA to detect anti-myosin antibodies in patients with myocardial infarctus. Lemy and Cox, tested MICA specificity by using LUMINEX LSA-MIC assay. They evaluated that immunosuppressive therapy could affect the MICA antibody levels and the harmful effect. Therefore it has been seen obviously that immunosuppressive treatment could have an impact on the test results.

THERAPEUTIC STRATEGIES

Standardized therapy for the treatment of the non-HLA antibody related rejections may vary and in general specific to the clinical protocols. The aim of the therapy is removing antibodies and decreasing the level in circulation. However, the results of the therapies are not certain. Data is limited to case reports and randomized therapies were trying to investigate for a longer patient survival and to prevent graft failure. Various therapies were reported for the treatment of AT1R mediated AMR. The combination of AT1R antagonists, plasmapheresis, intravenous immunoglobulin (IVIG) was reported in several studies. Jobert et al was used corticosteroids, antitimocyte globulins, plasmapheresis and oral candesartan and have successful results on AT1R antibodies. Bortezomib which is a proteasome inhibitor and plays an important role on apoptosis of plasma cells was found effective on AT1R antibodies. However it was reported that it has short-term effect. Therefore it is mainly effective on early-onset AMR than late-onset AMR. In another study, plasmapheresis, IVIG and rituximab was used to anti-MICA antibody treatment in a renal transplant patient and they observed three fold decrease of MICA mean fluorescence intense (MFI) levels. Scornik et al. estimated that de novo formed AT1R antibodies in patients who received AT1R blockers or ACE inhibitors with combination of tacrolimus, Mycophenolate mofetil (MMF) and steroids was detected not to develop features of AT1R antibody related pathology. MMF was also found effective on anti-vimentin antibodies in a study which includes 86 patients. When they compared the MMF was used instead of azathioprine, less antibody levels were detected by using MMF. More studies on targeted therapies for non-HLA antibodies in different solid organ transplantations can lead to a standardized treatment protocol.

CONCLUSION

Antibodies against HLA antigens are known to cause many problems in organ transplants, such as acute and chronic rejections resulting in the loss of the organ. There are also many studies on treatment strategies applied to prevent these problems. However, non-HLA antibodies have begun to attract interest as a result of observation of organ rejections in patients who have negative cross-match test results. It has been determined that non-HLA antibodies also cause both acute and chronic rejections and may have different effects depending on the organ they target. The response of non-HLA antibodies to treatment strategies applied to transplant patients has not been fully determined. The studies are continued to identify the pathogenicity and immunological mechanisms of non-HLA antibodies with modern genomic and proteomic platforms used in the identification of antibody repertoires. It is expected that the results of these studies will contribute to the development of new treatment strategies and to the extension of graft survival after transplantation.
**Source of Finance**

*During this study, no financial or spiritual support was received neither from any pharmaceutical company that has a direct connection with the research subject, nor from a company that provides or produces medical instruments and materials which may negatively affect the evaluation process of this study.*

**Conflict of Interest**

*No conflicts of interest between the authors and / or family members of the scientific and medical committee members or members of the potential conflicts of interest, counseling, expertise, working conditions, share holding and similar situations in any firm.*

**Authorship Contributions**

*Idea/Concept: Mustafa Soyöz, Tülay Kılıçaslan Ayna, Ibrahim Pirim; Design: Mustafa Soyöz, Tülay Kılıçaslan Ayna; Control/Supervision: Mustafa Soyöz, Tülay Kılıçaslan Ayna; Data Collection and/or Processing: Barcu Çerçi, Mustafa Soyöz; Analysis and/or Interpretation: Barcu Çerçi, Mustafa Soyöz; Literature Review: Barcu Çerçi; Writing the Article: Barcu Çerçi, Mustafa Soyöz; Critical Review: Mustafa Soyöz, Tülay Kılıçaslan Ayna; References and Funding: Ibrahim Pirim.*

**Materials:** Mustafa Soyöz, Tülay Kılıçaslan Ayna.

---

**REFERENCES**


