



# Endotyping Cellular and Humoral Immunoreactivity against Aluminum in Allergic Patients: A Retrospective Study

Celso Eduardo Olivier <sup>a\*</sup>, Daiana Guedes Pinto <sup>a</sup>,  
Ana Paula Monezzi Teixeira <sup>a</sup>,  
Jhéssica Letícia Santos Santana <sup>b</sup>,  
Raquel Acácia Pereira Gonçalves Santos <sup>a</sup>  
and Regiane Patussi Santos Lima <sup>c</sup>

<sup>a</sup> Instituto Alergoimuno de Americana, Brazil.

<sup>b</sup> Instituto de Ensino e Pesquisa do Hospital de Amor de Barretos, Brazil.

<sup>c</sup> Lavoisier laboratórios, São Paulo, Brazil.

## Authors' contributions

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

## Article Information

### Open Peer Review History:

This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here:

<https://www.sdiarticle5.com/review-history/122945>

**Original Research Article**

**Received: 09/07/2024**

**Accepted: 11/09/2024**

**Published: 14/09/2024**

## ABSTRACT

**Background:** Several publications report that aluminum is responsible for hypersensitivity reactions. There is no standardized lab exam that can endotype (determine the pathophysiology responsible for the phenotype) hypersensitivity to aluminum.

\*Corresponding author: E-mail: [celso@alergoimuno.med.br](mailto:celso@alergoimuno.med.br);

**Cite as:** Olivier, Celso Eduardo, Daiana Guedes Pinto, Ana Paula Monezzi Teixeira, Jhéssica Letícia Santos Santana, Raquel Acácia Pereira Gonçalves Santos, and Regiane Patussi Santos Lima. 2024. "Endotyping Cellular and Humoral Immunoreactivity Against Aluminum in Allergic Patients: A Retrospective Study". *Asian Journal of Immunology* 7 (1):149-58. <https://journalaji.com/index.php/AJI/article/view/139>.

**Aim:** To evaluate the potential of the Tube Titration of Precipitins (TTP) and the Leukocyte Adherence Inhibition Test (LAIT) to endotype humoral and cellular immunoreactivity against aluminum in patients clinically diagnosed with allergic contact dermatitis, intrinsic atopic dermatitis, and/or non-IgE-mediated urticaria.

**Study Design:** We retrospectively examined the medical charts of two cohorts of 100 patients each; range 6 to 87 years; diagnosed with allergic phenotypes, who were investigated with the help of TTP (first cohort) or *ex vivo* challenge tests monitored by LAIT (second cohort) against aluminum.

**Methodology:** The registered results of TTP against 1 mg/mL aluminum solution were distributed in ranges through a cascade distribution chart to outline the variability of the results inside the first cohort. The registered results of the Leukocyte Adherence Inhibition (LAI) percentage promoted by the *ex vivo* challenges with 1 mg/mL aluminum solution were distributed in ranges through a cascade distribution chart to outline the variability of results inside the second cohort.

**Results:** Most TTP results concentrated on higher dilutions. The mean was estimated at 1:301; the median was 1:256; the standard deviation was estimated at 1:204; the mode was 1:512 (appeared 46 times). The LAI ranged from 0% to 88%. The mean was 52%; the median was 49%; the standard deviation was 23.9%; the mode was 60% (appeared five times). The cascade graphs demonstrate a wide range of distribution of TTP and LAI results.

**Conclusion:** Our preliminary results support that the TTP and LAIT performed with 1 mg/mL aluminum solution may discriminate diverse humoral and cellular immunoreactivity degrees in patients suffering from allergic contact dermatitis, intrinsic atopic dermatitis, and/or non-IgE-mediated urticaria.

**Keywords:** Aluminum; endotype; hypersensitivity; leukocyte adherence inhibition; leukocyte adherence inhibition test; phenotype; precipitins; precision medicine.

## ABBREVIATIONS

LAI : Leukocyte Adherence Inhibition

LAIT : Leukocyte Adherence Inhibition Test

TTP : Tube Titration of Precipitins

## 1. INTRODUCTION

Aluminum (or aluminium) is a post-transition metal with the symbol Al, atomic number 13, and a relative atomic mass of 26.98, which has a great affinity to oxygen [1]. The American Contact Dermatitis Society elected aluminum as the "Allergen of the Year 2022" [2]. Aluminum may be present naturally in jewelry, piercings, cosmetics, tubes of toothpaste, medicines, tattoo inks, foods (at shallow levels), or due to using aluminum cooking utensils and food additives [3]. Some foods, such as potatoes, spinach, and some teas, may contain naturally higher levels of aluminum [4]. Remarkably, the mean concentration of aluminum in soy-based infant formulas is remarkably higher than in milk-based and corn-based infant formulas [5]. The sixty-seventh meeting of the Joint FAO/WHO Expert Committee on Food Additives held in Rome in 2006 established the provisional tolerable weekly aluminum intake as 1 mg/kg body weight [6]. Aluminum in its metal presentation (E 173) and aluminum salts are bactericides frequently used

as preservatives for foods and cosmetics [7]. Aluminum sulfates (E 520 to E 523) are mainly used in the food industry as thickeners and emulsifiers [8]. Aluminum-containing additives are also used for specific purposes: A) as raising agent in baking powder, such as aluminum sodium sulfate (E 521) and sodium aluminum phosphate-acidic (E 541); B) as firming agents during the processing of jellyfish and pickles such as aluminum potassium sulfate (E 522); C) as emulsifiers in processed cheese, such as sodium aluminum phosphate-basic (E 541); D) as anti-caking agents in powder mixes for beverage mixers and non-dairy creams such as sodium aluminosilicate (E 554); E) as anti-caking agents for table salt and vanilla powder such as calcium aluminum silicate (E 556); F) as carriers for pigments (titanium dioxide and iron oxides) such as the potassium aluminum silicate (E 555) and aluminum powder (E 173) in decorating sugar-coated flour confectionery candy coatings, also known as lakes [9-14].

Aseptic aluminum-containing plastic packages and cartons prevent oxidation and light damage to perishable food [15]. Elemental aluminum and its salts (such as sulfate, phosphate, hydroxide, and silicate) have a wide variety of uses, such as food additives, cooking utensils, food packaging (beverage cans and foil), water treatment,

cosmetics (sunscreens), toiletry products (antiperspirants, tubes of toothpaste and sun blockers), antacids with aluminum hydroxide, anti-diarrheic with kaolin (hydrated aluminum silicate or E 559), producing contact dermatitis, granuloma, and urticaria in sensitized people [16-19]. Pool water flocculants are made with aluminum salts and may produce occupational allergies [20]. Aluminum-containing compounds have been employed as adjuvants in vaccines to amplify antigen-specific Th2 responses [21]. There is a positive dose-response relationship between plasmatic aluminum concentrations and cognitive impairment among workers with occupational exposure to aluminum [22]. Aluminum nanoparticles are associated with memory impairment and hippocampal inflammation induced by microglial activation, following upregulation of the inflammatory cytokine IL-1 $\beta$  (interleukin-1 $\beta$ ) in mice [23]. Current lab models to study Alzheimer's disease are established through intraperitoneal injection of aluminum chloride (AlCl<sub>3</sub>) in rats or aluminum nanoparticles in mice [24,25]. Diagnosis of delayed hypersensitivity to aluminum is usually clinically made in patients with contact dermatitis with the help of cutaneous patch tests performed with aluminum salts dispersed in petrolatum [26]. However, systemic aluminum immunoreactivity has already been documented by systemic immunoassay markers, such as eosinophilia [27].

The clinical suspicion of immediate and delayed hypersensitivity against aluminum is usually confirmed through skin allergy tests and patch tests, respectively. Until now, no widespread lab exam has been able to document specific immunoreactivity against aluminum to help with clinical diagnosis.

The Leukocyte Adherence Inhibition Test (LAIT) and the Tube Titration of Precipitins (TTP) are performed in our facilities as triage tests for suspected allergens prescribed before the performance of more exhaustive *in vivo* provocation tests [28-34].

The present study hypothesizes that the LAIT and the TTP may differentiate endotypes and degrees of immunoreactivity against aluminum among patients suffering from common allergic phenotypes. To evaluate the potential of the LAIT and the TTP to discriminate humoral and cellular immunoreactivity against aluminum, we

retrospectively compiled the electronic medical charts of patients clinically diagnosed with allergic contact dermatitis, intrinsic atopic dermatitis, and/or non-IgE-mediated urticaria who were investigated with these procedures.

## 2. MATERIALS AND METHODS

### 2.1 Subjects

After receiving Institutional Review Board approval from the Instituto Alergoimuno de Americana (Brazil; 06/2024), we proceeded with the electronic chart review of 9,200 outpatients who attended our facility from January 2018 to August 2024.

The first cohort of 100 outside patients had been submitted to TTP with 1 mg/mL of aluminum solution for presenting allergic contact dermatitis, intrinsic atopic dermatitis, and/or non-IgE-mediated urticaria. This cohort counted 24 males and 76 females; mean age 38.4 years; SD 20.4 years; range 6 to 87 years; median 36.5 years; mode = 46 (appeared five times); geometric mean = 32 years.

The second cohort of 100 outside patients had been submitted to an *ex vivo* allergen challenge test with aluminum solution 1mg/mL monitored with LAIT for presenting allergic contact dermatitis, intrinsic atopic dermatitis, and/or non-IgE-mediated urticaria. This cohort counted 28 males and 72 females; mean age 40.3 years; SD 17.5 years; range 8 to 75 years; median 42 years; mode = 42 (appeared six times); geometric mean = 35.2 years.

This study did not include patients under biological and/or systemic anti-inflammatory therapy. These procedures were offered to patients with clinical suspicion of aluminum hypersensitivity who demonstrated a non-reactive or inconclusive skin test against aluminum 1 mg/mL solution [35]. The cascade graphs were mounted using the functionalities of the spreadsheet editor Microsoft Excell® software.

### 2.2 Aluminum Solution

The aluminum solution was prepared with powdered acetate aluminum diluted with distilled water at 1 mg/mL to perform the allergic skin tests, TTP, and LAIT.

### 2.3 Ex vivo Investigation: Leukocyte Adherence Inhibition Test

#### 2.3.1 Procedure for allergen ex vivo challenging

We performed the LAIT as previously described [29,30,36-45]. Shortly, each donor's fresh plasma was divided into two parts and used in paralleled ex vivo challenging tests with aluminum acetate solution 1 mg/mL and the unchallenged plasma assay. We collected the plasma with high leukocyte content (buffy coat) from the heparinized tube after one hour of sedimentation at 37 °C. Then, we distributed aliquots of 100 µL into Eppendorf tubes kept under agitation for 30 minutes (200 rpm at 37 °C) with aluminum solution (10µL of a solution with 1mg/mL) or without aluminum solution (when used as control).

#### 2.3.2 Procedure for adherence assay

After incubation, the plasma was allocated into a standard Neubauer hemocytometer counting chamber with a plain, non-metallic glass surface and left to stand for 2 hours at 37 °C in the humidified atmosphere of the covered water bath to allow leukocytes to adhere to the glass. Next, we counted the leukocytes, removed the coverslip, and washed the chamber by immersion in a beaker with PBS at 37 °C. Then, we added a drop of PBS to the hemocytometer's chamber and allocated a clean coverslip over it. The remaining cells were counted in the same squares as previously examined.

#### 2.3.3 Procedure for calculation

The percentage of Leukocyte Adherence (LA) of each assay was estimated as: (the number of leukocytes observed on the hemocytometry chamber after washing divided by the number of leukocytes observed on the hemocytometry chamber before washing) and multiplied by 100 (%). The Leukocyte Adherence Ratio (LAR) was estimated based on the ratio between the LA from the antigen-specific challenged plasma and the LA from the unchallenged control plasma:  $LAR = LA \text{ of the challenged sample} / LA \text{ of unchallenged control plasma} \times 100$  (%). To further calculate the Leukocyte Adherence Inhibition (LAI), we subtracted the LAR from 100 (%). We employed the LAI results for the cascade distribution chart and the statistics calculations, both performed with the help of the Microsoft Excel® statistical package.

### 2.3.4 In vitro Investigation: Tube Titration of Precipitins (TTP)

As previously reported, the semi-quantitative TTP against the aluminum solution was performed in a transparent vitreous tube [46]. Shortly, the patient's blood was collected in a clot-activator collecting tube. After separation, the serum was centrifugated at 2,000 rpm for 10 minutes. The allergen extracts were allocated in sets of eleven glass tubes at progressive duplicated serum dilutions. The progressive dilutions were combined with the 15 µL of the antigen (1 mg/mL) with 250 µL of the patient's serum, progressively diluted into physiological saline solution (NaCl 0,9%) in the dilution ratios of 1:1; 1:2; 1:4; 1:8; 1:16; 1:32; 1:64; 1:128; 1:256; and 1:512. One tube was a blank control done with the water and serum to observe occasional spontaneous precipitation (Sia Test). After 24 hours, the tubes were examined, and the titers (the highest dilution factor that yields a positive reading) were recorded [47].

## 3. RESULTS

As a retrospective survey, there was no research protocol; therefore, we report the incidental immune investigation as registered in the digital medical charts.

The cascade distribution graph showed a wide distribution range of TTP results. There was one negative result. Most positive results concentrated on the higher dilutions (Fig. 1). The mean was estimated at 1:301; the median was 1:256; the standard deviation was estimated at 1:204; the mode was 1:512 (appeared 46 times). All Sia tests were negative.

The LAI ranged from 0% to 88%. The mean was 52%; the median was 49%; the standard deviation was 23.9%; the mode was 60% (appeared five times). The cascade distribution graph demonstrates a wide range of distribution of LAI results (Fig. 2). Three patients ignored the presence of the allergen on the plasma and presented no inhibition of leukocyte adherence (LAI = 0%) after contact with the aluminum solution. Some patients showed low or moderate immunoreactivity during the ex vivo challenge test, while most displayed strong immunoreactivity, suggesting aluminum's participation in the hypersensitivity condition.

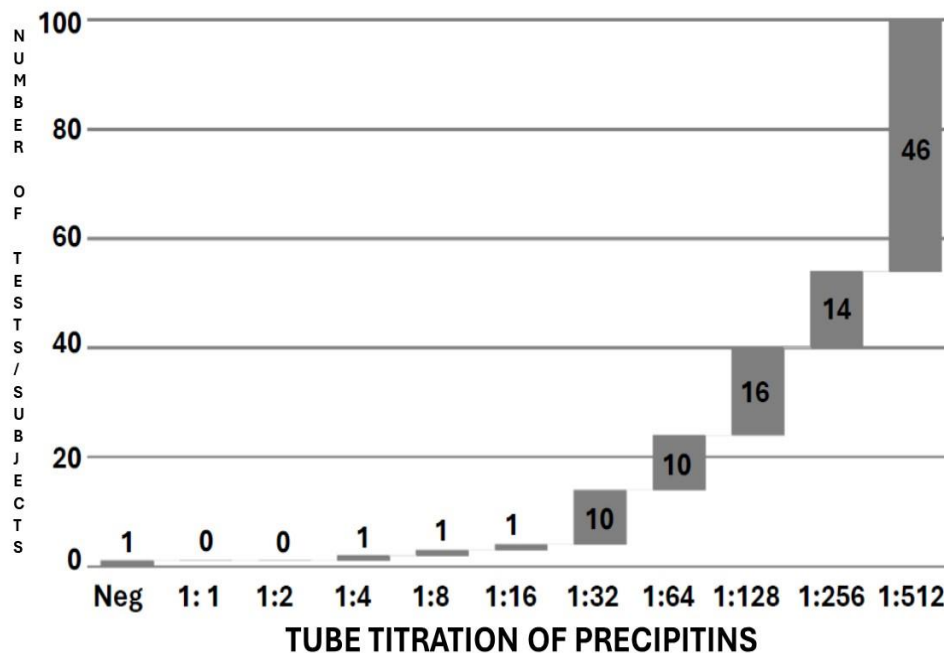
## 4. DISCUSSION

Aluminum was one of the first inorganic adjuvants envisaged to boost the immune

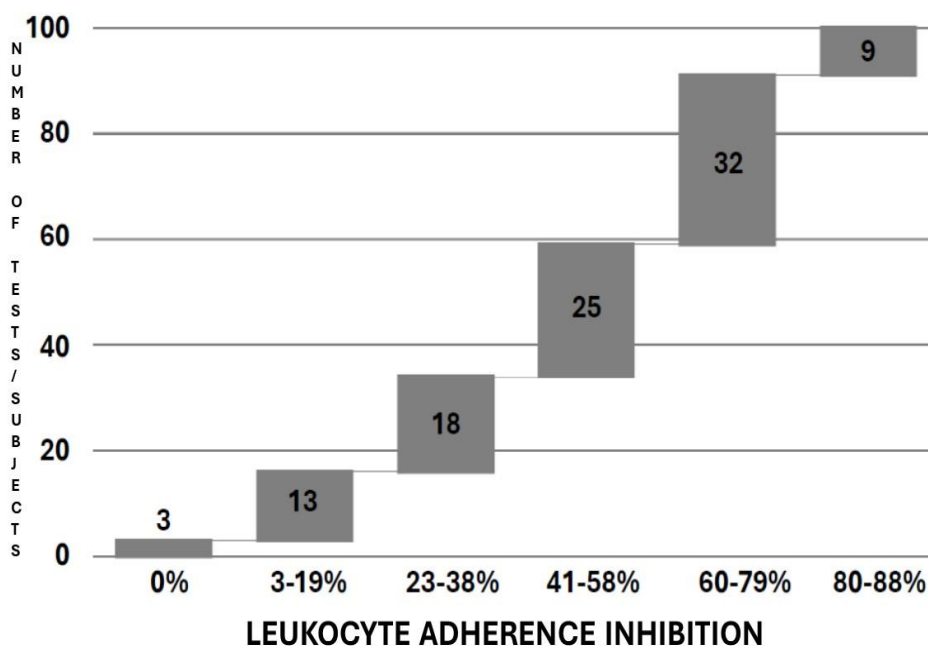
response of infectious vaccines and subcutaneous allergen immunotherapies [48]. The first description of using aluminum salts to boost immune response was published in 1924 when used as an adjuvant to tetanus and diphtheria toxoids [49]. Further (1938), aluminum salts were presumed as adjuvants to subcutaneous allergen immunotherapies for their depot effect, increasing the permanence of the immunotherapeutic agent on the site of the injection, allowing more time for the innate immune system to process the antigens (adsorptive adjuvant) [50]. Later (1985), it was established that the presence of aluminum salts increased the uptake of allergens by antigen-presenting cells, stimulating antigen-induced T-cell proliferation [51]. Aluminum-containing adjuvants also activate innate immune response by stimulating dendritic cells, inducing CD4<sup>+</sup> T cell differentiation [52]. Aluminum acts as a vaccine adjuvant by producing cellular necrosis that releases inflammatory cytokines (such as IL-33), stimulating innate and adaptive immunity [53]. It is a corollary to think that ingestion, contact, and parenteral administration of this metal may produce residual asymptomatic or even symptomatic conditions in a society "drowned" in aluminum through food additives, cosmetic preservatives, medicines, vaccine

adjuvants, and others [54]. Aluminum hypersensitivity might represent just the iceberg's tip of an organism saturated by its effects, alerting the patient's conscious mind to avoid contact and ingestion.

Personalized medicine is an approach dedicated to diagnosing the endotypes responsible for disease phenotypes. [55]. While phenotypes are defined by the visible clinical manifestations of the conditions (some of these induced by multiple underlying mechanisms), an endotype is a subtype of a given phenotype defined by its pathophysiological mechanism [56]. The classical four hypersensitivity mechanisms described by Gell and Coombs in the sixties are now amplified to seven types with several subtypes, implying an increased responsibility of the clinical caretakers to investigate the mechanisms responsible for the disease phenotypes in order to recommend better strategies to avoid the allergens and to prescribe tailored treatments for these infirmities [57,58]. Endotyping the hypersensitivity mechanisms may also help distinguish superimposable phenotypes presenting similar symptoms that may hamper establishing a precise diagnosis [59]. To detect immune responses against aluminum, we spreadsheet a retrospective compilation of data



**Fig. 1. Cascade distribution chart of the Tube Titration of Precipitins (TTP on the x-axis) resulting from the aluminum solution against the serum of a cohort of 100 tests/subjects (y-axis)**



**Fig. 2. Cascade distribution chart of the range groups of Leukocyte Adherence Inhibition (LAI) results (x-axis %) of *ex vivo* aluminum solution monitored by the Leukocyte Adherence Inhibition Test (LAIT), according to the respective number of outcomes over a cohort with 100 tests/subjects (y-axis)**

produced at our facilities by TTP and TIAL, exploring humoral and cellular immunoreactivities against aluminum. TTP and LAIT are complementary triage tests used at our facilities to select worthwhile antigens to proceed with more laborious *in vivo* provocation tests when the specific IgE is undetectable and skin tests are inconclusive or unfeasible due to the patient's skin conditions.

These assays do not identify the exact immune mechanisms responsible for the clinical condition. Instead, they provide clues about sensitization and immunoreactivity distributed into an extensive spectral range between immune tolerance and symptomatic hypersensitivity. TTP and LAIT must be interpreted as triage immune markers of the humoral and cellular responses after contact with a specific antigen, configuring themselves as techniques to quantify an exposome measurement, as proposed by the exposome-wide association study [60].

This preliminary retrospective survey demonstrated extensive results from the TTP and the *ex vivo* challenge test monitored by LAIT against aluminum in two cohorts of patients with

various allergic symptoms. None of our patients presented an exclusive reaction to aluminum. Every patient was simultaneously tested with several chemical and biological allergens, demonstrating positive results for some of them. Our results suggest that reactive allergic patients may impair their symptoms by an additional immunoreactivity against environmental or ingested aluminum.

## 5. CONCLUSION

Our preliminary results show that the TTP and LAIT may differentiate diverse degrees of immunoreactivity against aluminum in patients clinically diagnosed with non-IgE-mediated cutaneous allergies. This methodology can provide a socioeconomic impact since the methodologies to perform TTP and LAIT are inexpensive and can be performed in a single lab attached to the facilities with minimum laboratory equipment. However, the propaedeutic meaning of these results and the possibility of interferents must be better established [61]. More studies focused on the quality-by-design approach with prospective larger double-blind cohorts need to evaluate the potential contribution of TTP and LAIT for endotyping immunoreactivity of patients

suspected of symptomatic hypersensitivity against aluminum and other similar food processing additives [62,63].

## 6. LIMITATIONS

This study is a retrospective analysis of data collected over six years. There was no protocol research, and the subject's data were limited to the essentials available on our electronic sheets. Therefore, we could not establish a cross-comparison between positive and negative controls to validate the results. The number of subjects is appropriate for a preliminary study; however, future studies must be more comprehensive. The lack of a research protocol implies the possibility of a bias produced by the physician's point of view who indicated the exam (CEO) based on a clinical suspicion led purely by the anamnesis, physical examination, routine lab exams, and allergic skin tests. The study lost many of these patients to follow-up, so assuring the relationship between the immunoassays' results and the patient's clinical outcome is impossible.

## DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

## ETHICAL APPROVALS

The authors have collected and preserved written ethical approval per international standards.

## ACKNOWLEDGEMENTS

The Instituto Alergoimuno de Americana funded this work. We want to thank laboratory technician Alessandra Vieira de Oliveira for her help with the exams.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

## REFERENCES

1. Laeter JR, Böhlke JK, Bièvre P, Hidaka H, Peiser HS, Rosman KJR, Taylor PDP. Atomic weights of the elements. Review

- 2000 (IUPAC Technical Report). Pure Appl. Chem. 2003;75(6):683-800.
2. Novack DE, Yu J, Adler BL. Aluminum: The 2022 American Contact Dermatitis Society Allergen of the Year. *Cutis*. 2022; 110(1):21-24.
3. Forte G, Petrucci F, Bocca B. Metal allergens of growing significance: epidemiology, immunotoxicology, strategies for testing and prevention. *Inflamm Allergy Drug Targets*. 2008;7(3): 145-62.
4. Chemical-Hazard-Evaluation Aluminum in Foods. Risk Assessment Studies, No. 35. Centre for Food Safety, Food and Environmental Hygiene Department,. Available:[https://www.cfs.gov.hk/english/pr ogramme/programme\\_rafs/programme\\_raf s\\_fa\\_01\\_06\\_ra35.html](https://www.cfs.gov.hk/english/pr ogramme/programme_rafs/programme_raf s_fa_01_06_ra35.html).
5. Elaridi J, Dimassi H, Estephan M, Hassan HF. Determination of Aluminum, Chromium, and Barium Concentrations in Infant Formula Marketed in Lebanon. *J Food Prot*. 2020;83(10):1738-1744.
6. Joint-FAO/WHO-Expert-Committee Evaluation of certain food additives and contaminants. Sixty-seventh report of the Joint FAO/WHO Expert Committee on Food Additives; 0512-3054 (Print) 0512-3054; Geneve, 2007;44.
7. Kakita K, Kishida M. Isolation of Aluminum-Tolerant and -Absorbing Yeast. *Biocontrol Sci*. 2020;25(4):231-234.
8. Younes M, Aggett P, Aguilar F, Crebelli R, Dusemund B, Filipič M, et al. Re-evaluation of aluminium sulphates (E 520-523) and sodium aluminium phosphate (E 541) as food additives. *EFSA journal*. Eur Food Safety Authority. 2018;16(7):e05372.
9. Saiyed SM, Yokel RA. Aluminium content of some foods and food products in the USA, with aluminium food additives. *Food Addit Contam*. 2005;22(3):234-44.
10. Li JR, Hsieh YH. Traditional Chinese food technology and cuisine. *Asia Pacific J Clin Nutrition*. 2004;13(2):147-55.
11. Smith J. Food Additive User's Handbook. Blackie and Son Ltd: New York; 1991.
12. Younes M, Aquilina G, Castle L, Engel KH, Fowler P, Frutos-Fernandez MJ, et al. Re-evaluation of sodium aluminium silicate (E 554) and potassium aluminium silicate (E 555) as food additives. *EFSA journal*. Eur Food Safety Authority. 2020;18(6): e06152.
13. National Center for Biotechnology Information. PubChem Compound

- Summary for CID 21881395, A. c. s. R. A.; 2024.  
Available:<https://pubchem.ncbi.nlm.nih.gov/compound/Aluminum-calcium-silicate>.  
PubChem Compound Summary for CID 21881395, Aluminum calcium silicate; 2024.  
Available:<https://pubchem.ncbi.nlm.nih.gov/compound/Aluminum-calcium-silicate>.
14. European-Commission-Regulation (EC) No 1333/2008 of the European Parliament and of the Council of 16 December 2008 on food additives.  
Available:<https://eur-lex.europa.eu/eli/reg/2008/1333/oj>
  15. Dang KDN, Ngo QN, Le PK, Chiang KY, Lan-Thao-Ngo TN. Recovery of aluminum from plastic packages containing aluminum by gasification. *Waste Manag.* 2024;178:385-394.
  16. Bruze M, Netterlid E, Siemund I. Aluminum-Allergen of the Year 2022. *Dermatitis: contact, atopic, occupational, drug.* 2022;33(1):10-15.
  17. Badaoui A. Allergic contact dermatitis to aluminium in a sunscreen. *Contact Dermatitis.* 2023;89(4):305-307.
  18. Gordon SC, Bartenstein DW, Tajmir SH, Song JS, Hawryluk EB. Delayed-type hypersensitivity to vaccine aluminum adjuvant causing subcutaneous leg mass and urticaria in a child. *Pediatr Dermatol.* 2018;35(2):234-236.
  19. World Health Organization. Aluminium in drinking-water: background document for development of WHO Guidelines for drinking-water quality.  
Available:<https://iris.who.int/handle/10665/75362>.
  20. Stenveld H. Allergic to pool water. *Safety and health at work.* 2012;3(2):101-3.
  21. Brewer JM, Conacher M, Hunter CA, Mohrs M, Brombacher F, Alexander J. Aluminium hydroxide adjuvant initiates strong antigen-specific Th2 responses in the absence of IL-4- or IL-13-mediated signaling. *J Immunol.* 1999;163(12):6448-54.
  22. Wang S, Xue Y, Zhang J, Meng H, Zhang J, Li X, et al. Interaction between aluminum exposure and ApoE $\epsilon$ 4 gene on cognitive function of in-service workers. *Chemosphere.* 2023;323:138282.
  23. Izadi S, Abdolrezaei M, Soukhaklari R, Moosavi M. Memory impairment induced by aluminum nanoparticles is associated with hippocampal IL-1 and IBA-1 upregulation in mice. *Neur Res.* 2024; 46(3):284-290.
  24. Wang Y, Gong Q, Pan H, Wang X, Yan C. Gardenia jasminoides J. Ellis extract attenuates memory impairment in rats with Alzheimer's disease by suppressing NLRP3 inflammasome. *Brain Res.* 2024; 1824:148687.
  25. Izadi S, Rezaei A, Esmaili Z, Soukhaklari R, Moosavi M. Agmatine prevents the memory impairment and the dysfunction of hippocampal GSK-3 $\beta$  and ERK signaling induced by aluminum nanoparticle in mice. *Behavioural Pharmacol.* 2023;34(5):299-305.
  26. Siemund I, Dahlin J, Hindsén M, Zimerson E, Antelmi A, Hamnerius N, et al. Contact Allergy to Two Aluminum Salts in Consecutively Patch-Tested Dermatitis Patients. *Dermatitis: contact, atopic, occupational, drug.* 2022;33(1):31-35.
  27. Terhune TD, Deth RC. Aluminum Adjuvant-Containing Vaccines in the Context of the Hygiene Hypothesis: A Risk Factor for Eosinophilia and Allergy in a Genetically Susceptible Subpopulation? *Int J Environ Res Public Health.* 2018; 15(5):901.
  28. Kuratsuji T. Studies on leukocyte adherence inhibition test. Part II. Clinical applications of LAI test to detect delayed type hypersensitivity in infants and children. *Keio J Med.* 1981;30(2):65-9.
  29. Olivier CE, Pinto DG, Teixeira APM, Santana JLS, Santos RAPGS, Lima RPS, et al. Evaluating Non-IgE-mediated Allergens' Immunoreactivity in Patients with "Intrinsic" Persistent Rhinitis with Help of the Leukocyte Adherence Inhibition Test. *Eur J Med Health Sci.* 2023;5(1):17-22.
  30. Olivier CE, Pinto DG, Teixeira APM, Santana JLS, Santos RAPGS, Lima RPS, et al. Evaluating Non-IgE-Mediated Allergens' Immunoreactivity in Patients Formerly Classified as "Intrinsic" Asthmatics with Help of the Leukocyte Adherence Inhibition Test. *Eur J Clin Med.* 2023;4(2):1-7.
  31. Olivier CE, Pinto DG, Teixeira APM, Santana JLS, Santos RAPGS, Lima RPS, et al. Contribution of the Leukocyte Adherence Inhibition Test to the Diagnosis of Innate Non-IgE-mediated Immunoreactivity against *Alternaria alternata*. *Asian J Immunol.* 2023;6(1):243-251.



32. Olivier CE, Pinto DG, Teixeira APM, Santana JLS, Santos RAPGS, Lima RPS. Contribution of the Leukocyte Adherence Inhibition Test to the Diagnosis of Innate Non-IgE-mediated Immunoreactivity against *Saccharomyces cerevisiae*. *Asian J Immunol.* 2023;6(1):234-241.
33. Olivier CE, Pinto DG, Teixeira APM, Santana JLS, Santos RAPGS, Lima RPS, et al. Contribution of the Leukocyte Adherence Inhibition Test to the Diagnosis of Non-IgE-mediated Immunoreactivity against *Candida albicans* in Patients with Atopic Dermatitis. *Asian J Immunol.* 2023; 6(1):268-276.
34. Olivier CE, Pinto DG, Teixeira APM, Santana JLS, Santos RAPGS, Lima RPS, et al. Contribution of the Leukocyte Adherence Inhibition Test in Diagnosing Non-IgE-Mediated Immunoreactivity against *Aspergillus fumigatus* in Patients with Allergic Rhinitis and Asthma. *Asian J Immunol.* 2024;7(1):12-20.
35. Olivier CE, Argentão DGP, Santos RAPG, Silva MD, Lima RPS, Zollner RL. Skin scrape test: an inexpensive and painless skin test for recognition of immediate hypersensitivity in children and adults. *The Open Allergy Journal.* 2013; 6:9-17.
36. Olivier CE, Lima RPS, Pinto DG, Santos RAPG, Silva GKM, Lorena SLS, et al. In search of a tolerance-induction strategy for cow's milk allergies: significant reduction of beta-lactoglobulin allergenicity via transglutaminase/cysteine polymerization. *Clinics.* 2012;67(10):1171-1179.
37. Olivier CE, Santos RAPG, Lima RPS, Argentão DGP, Silva GKM, Silva MD. A Novel Utility for an Old Method: The Leukocyte Adherence Inhibition Test Is an Easy Way to Detect the Immunoreactive Interference of the Collection Tube Anticoagulant on Cellular Immunoassays. *J Cell Adhesion*; 2014. Article ID 860427 Available:<http://dx.doi.org/10.1155/2014/860427>:1-6.
38. Olivier CE, Pinto DG, Lima RPS, Silva MD, Santos RAPG, Teixeira APM, et al. Assessment of Immunoreactivity against Therapeutic Options Employing the Leukocyte Adherence Inhibition Test as a Tool for Precision Medicine. *Eur J Clin Med.* 2021;2(3):40-45.
39. Olivier CE, Pinto DG, Santos RAPG, Lima RPS. Dextran's interference over the Leukocyte Adherence Inhibition Test. *Academia Letter.* 2021; article number 3792.
40. Olivier CE, Pinto DG, Teixeira APM, Santana JLS, Santos RAPGS, Lima RPS. Immunoreactivity against *Dermatophagoides pteronyssinus* assessed by the Leukocyte Adherence Inhibition Test in patients with Intrinsic Atopic Dermatitis and correlated "Intrinsic" Non-IgE-mediated allergic conditions. *Eur J Clin Med.* 2021;2(6):45-50.
41. Olivier CE, Pinto DG, Teixeira APM, Santana JLS, Santos RAPGS, Lima RPS. Contribution of the Leukocyte Adherence Inhibition Test to the Evaluation of Cellular Immunoreactivity against Latex Extracts for Non-IgE-Mediated Latex-Fruit-Pollen Syndrome in Allergic Candidates to Exclusion Diets and Allergic Desensitization. *Eur J Clin Med.* 2022; 3(1):11-17.
42. Olivier CE, Pinto DG, Teixeira APM, Santana JLS, Santos RAPGS, Lima RPS. Contribution of the Leukocyte Adherence Inhibition Test for the evaluation of immunoreactivity against gluten extracts in non-IgE-mediated / non-autoimmune Gluten-Related Disorders. *Eur J Clin Med.* 2022;3(2):1-7.
43. Olivier CE, Pinto DG, Teixeira APM, Santana JLS, Santos RAPGS, Lima RPS. Leukocyte Adherence Inhibition Test to the Assessment of Immunoreactivity Against Cow's Milk Proteins in Non-IgE-Mediated Gastrointestinal Food Allergy. *Eur J Clin Med.* 2022;3(2):38-43.
44. Olivier CE, Pinto DG, Teixeira APM, Santana JLS, Santos RAPGS, Lima RPS. Contribution of the Leukocyte Adherence Inhibition Test to the Diagnosis of Immunoreactivity against Cobalt. *Asian J Immunol.* 2023;6(1):174-184.
45. Olivier CE, Pinto DG, Teixeira APM, Santana JLS, Santos RAPGS, Lima RPS. Exploring the Role of Leukocyte Adherence Inhibition Test in Assessing Non-IgE Mediated Immunoreactivity to Benzoic Acid in Allergic Patients. *Asian J Immunol.* 2024;7(1):63-70.
46. Olivier CE, Pinto DG, Teixeira APM, Santana JLS, Santos RAPGS, Lima RPS. Intrinsic Atopic Dermatitis: Titration of Precipitins in the Screening of Food Allergens for Prescription of Elimination Diets and Desensitization Strategies. *Eur J Clin Med.* 2021.2(6):1-9.

47. Williams CA, Chase MW. CHAPTER 13 - Precipitation Reactions. In Reactions of Antibodies with Soluble Antigens, Academic Press. 1971;3:1-102.
48. Olivier, CE. The use of allergoids and adjuvants in Allergen Immunotherapy. Arch Asthma Allergy Immunol. 2017;1: 40-60.
49. Glenn AT, Barr M. The precipitation of diphtheria toxoid by potash alum. J Pathol Bacteriol. 1931;34(2):131-138.
50. Sledge RF. Treatment of hay fever with alum-precipitated pollen extract. J Allergy. 1938;9(4):424.
51. Mannhalter JW, Neychev HO, Zlabinger GJ, Ahmad R, Eibl MM. Modulation of the human immune response by the non-toxic and non-pyrogenic adjuvant aluminium hydroxide: effect on antigen uptake and antigen presentation. Clin Exp Immunol. 1985;61(1):143-151.
52. Sokolovska A, Hem SL, HogenEsch H. Activation of dendritic cells and induction of CD4(+) T cell differentiation by aluminum-containing adjuvants. Vaccine. 2007; 25(23):4575-85.
53. Rose WA, Okragly AJ, Patel CN, Benschop R J. IL-33 released by alum is responsible for early cytokine production and has adjuvant properties. Sci Rep. 2015;5:13146.
54. Jutel M, Mosnaim GS, Bernstein JA, del Giacco S, Khan DA, Nadeau KC. The One Health approach for allergic diseases and asthma. Allergy. 2023;78(7):1777-1793.
55. Jutel M, Gajdanowicz P. Chapter 5 - Revised Disease Nomenclature Including Disease Endotypes. In Implementing Precision Medicine in Best Practices of Chronic Airway Diseases, Agache, I.; Hellings, P., Eds. Academic Press: 2019;27-29.
56. Kuruvilla ME, Lee FEH, Lee GB. Understanding Asthma Phenotypes, Endotypes, and Mechanisms of Disease. Clin Rev Allergy Immunol. 2019;56(2):219-233.
57. Gell PGH, Coombs RRA. Classification of Allergic Reactions Responsible for Clinical Hypersensitivity and Disease. In Clinical Aspects of Immunology, 2<sup>nd</sup> ed.; Eds. Blackwell Scientific Publications: Oxford, 1968;575-596.
58. Jutel M, Agache I, Zemelka-Wiacek M, Akdis M, Chivato T, Del Giacco S, et al. Nomenclature of allergic diseases and hypersensitivity reactions: Adapted to modern needs: An EAACI position paper. Allergy. 2023;78(11):2851-2874.
59. Davies C, Wu F, Huang EY, Takashima M, Rowan NR, Ahmed OG. Central Compartment Atopic Disease as a Pathophysiologically Distinct Subtype of Chronic Rhinosinusitis: A Scoping Review. Sinusitis. 2023;7(2):12-26.
60. Chung MK, House JS, Akhtari FS, Makris KC, Langston MA, Islam KT, et al. Decoding the exposome: data science methodologies and implications in exposome-wide association studies (ExWASs). Exposome. 2024;4(1):osae001.
61. Anouar S, Hazim R, Brahim A. Interferences in Immunological Assays: Causes, Detection, and Prevention. Asian J Immunol. 2024;7(1):71-78.
62. Chiarentin L, Gonçalves C, Augusto C, Miranda M, Cardoso C, Vitorino C. Drilling into "Quality by Design" Approach for Analytical Methods. Crit Rev Anal Chem. 2023:1-42.
63. World Medical Association Declaration of Helsinki: ethical principles for medical research involving human subjects. JAMA. 2013;310(20):2191-4.

**Disclaimer/Publisher's Note:** The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of the publisher and/or the editor(s). This publisher and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.

© Copyright (2024): Author(s). The licensee is the journal publisher. This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

*Peer-review history:*  
The peer review history for this paper can be accessed here:  
<https://www.sdiarticle5.com/review-history/122945>