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ARAŞTIRMA MAKALESİ / *RESEARCH ARTICLE*

Comparison of Diagnostic Efficacy of Lancet, Multi-Head Applicator, and Specific Immunoglobulin E in Allergy Testing

Alerji Testlerinde Lanset, Çok Başlı Aplikatör ve Spesifik İmmunglobilin E'nin Tanısal Etkinliğinin Karşılaştırılması

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ABSTRACT

Objective: Allergic rhinitis and allergic asthma are common respiratory diseases in children. Skin prick tests (SPT) and allergen-specific immunoglobulin E (SpIgE) measurements play a crucial role in their diagnosis. In recent years, the use of rapid diagnostic kits has increased. This study aimed to investigate the diagnostic performance of multi-headed applicator and allergen SpIgE compared to the gold standard lanset.

Materials and Methods: Skin prick tests were conducted on the same patients using both a multi-headed applicator and lancet with the same allergen solutions. Additionally, allergen SpIgE levels were measured for each patient. The diagnostic performances of multi-headed applicator and allergen SpIgE were statistically compared to those of lancet.

Results: A total of 2100 SPTs were performed on 105 patients, from whom allergen SpIgE levels were also obtained. Allergen sensitivities were detected in order of prevalence as house dust mites, pollens, and molds. Sensitization rates were found to be 73.3% for multi-headed applicators, 82.9% for lanset, and 81% for SpIgE. The diagnostic sensitivity of the multi-headed applicator ranged from 0% to 52%, and its correlations with lanset were weak.

Conclusion: Rapid-result tests aimed at allergen sensitivity assessment showed limited effectiveness. The use of accurate and reliable diagnostic methods such as lancet-based SPT and SpIgE measurements is crucial. This study holds the distinction of being the first to evaluate different SPT methods using allergen solutions, providing important insights for accurate diagnosis and treatment of allergic diseases.

Keywords: skin tests, sensitivity and specificity, equipment and supplies, children, allergy

ÖZ

Amaç: Alerjik rinit ve alerjik astım, çocuklarda sık görülen solunum hastalıklarıdır. Bu hastalıkların tanısında, deri prik testleri (DPT) ve alerjen spesifik immunglobulin E (SpIgE) ölçümleri önemli bir rol oynamaktadır. Son yıllarda hızlı tanı kitlerinin kullanımı artmıştır. Bu çalışmanın amacı çok başlı aplikatör ve alerjen SpIgE'lerin tanısal performanslarını altın standart kabul edilen lanset DPT göre etkinlikleri araştırıldı.

Gereç ve Yöntem: Çok başlı aplikatör, lanset ile aynı alerjen solüsyonları kullanılarak aynı hastalara deri prik testleri yapıldı. Ayrıca, her hastadan alerjen SpIgE düzeyleri ölçüldü. Lanset ile yapılan DPT'lere göre çok başlı aplikatör ve alerjen SpIgE'lerin tanısal performansları istatistiksel olarak incelendi.

Bulgular: Toplamda alerjen SpIgE'leri de alınan 105 hasta üzerinde 2100 DPT yapıldı. Hastalarda sıklık sırasına göre ev tozu akarı, polenler ve küf alerjen duyarlılığı saptandı. Çok başlı aplikatör ile yapılan DPT %73.3, lanset ile yapılan DPT %82.9 ve SpIgE ile yapılan test %81 oranında duyarlanma tespit edildi. Çok başlı aplikatörün tanısal duyarlılık değeri %0-52 arasında ve lanset ile korelasyonları zayıf bulundu.

Sonuç: Hızlı sonuç alma amaçlı testler, alerjen duyarlılığını tespitte yeterince etkin olmamıştır. Lanset ile yapılan DPT ve SpIgE ölçümleri gibi doğru ve güvenilir tanı yöntemlerinin kullanılması önemlidir. Bu çalışma, alerjen duyarlılığı tespitinde alerjen solüsyonları da kullanılarak yapılan farklı DPT yöntemlerinin değerlendirildiği ilk çalışma olma özelliği taşımaktadır ve alerjik hastalıkların tanı ve tedavisinde doğru yönlendirmeler yapmak adına önemli bilgiler sunmaktadır.

Anahtar Kelimeler: deri testleri, duyarlılık ve özgüllük, ekipman ve malzemeler, çocuklar, alerji

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INTRODUCTION

Allergic rhinitis (AR) and asthma are chronic respiratory diseases commonly observed in children, significantly affecting their quality of life.[1] In the diagnosis of these diseases, skin prick tests (SPT) are used to assess allergen-specific immunoglobulin E (spIgE) levels and measurements of allergen-spIgE) play a significant role. [2] Skin prick tests are reliable and sensitive methods commonly used to detect IgE responses to various allergens.[3] In recent years, various techniques and methods have been developed in skin prick tests to obtain rapid results.[4] Especially in developing countries with limited healthcare access like our country, there is a trend towards directing the use of rapid and practical diagnostic techniques instead of the gold standard methods[5] accepted by health authorities, aiming to expedite diagnostic processes and enhance access to public resources. However, this approach can lead to challenges in accurate diagnosis and result in confusing outcomes.

This research article was conducted to assess the reliability of different skin prick test (SPT) methods and allergen-specific IgE measurements in children with allergic rhinitis and asthma. Particularly, for the evaluation of allergenic sensitization, a comparison will be made among the commonly used multi-headed applicator SPTs, lancet-based SPTs, and specific IgE tests, which are widely employed in public hospitals in our country. This comparison aims to assess each testing method's diagnostic accuracy, sensitivity, and specificity. Previous research has demonstrated the effectiveness of SPTs in evaluating specific IgE responses to allergens. [6] However, further research is needed to investigate the outcomes of different methods used in SPTs.

In this study, we aimed to determine which method exhibits better diagnostic performance by comparing skin prick tests and spIgE results conducted through different approaches in children with allergic rhinitis and asthma.

More accurate and reliable diagnostic methods can aid in directing patients toward appropriate treatments promptly and accurately. Furthermore, they can contribute to optimizing treatment options, preventing unnecessary time and financial losses, and adopting a more effective approach to managing allergic diseases. This study will present the details of the investigation focused on comparing the results of skin prick tests in children with allergic rhinitis and asthma, and the findings will be discussed.

MATERIALS AND METHODS

A total of 105 participants voluntarily enrolled in the study, who were diagnosed with allergic rhinitis or asthma. The patients were randomly selected based on their order of presentation at the clinic. Demographic and clinical characteristics including age, gender, allergens causing symptoms according to clinical history, and other relevant factors were recorded for all participants.

Skin Prick Tests

SPTs were conducted on all participants using allergen solutions (ALK-Abello Pharm allergen extracts) known as common triggers for allergic rhinitis and asthma. A multi-headed SPT applicator with 10 distinct chambers (positive control, negative control, *Dermatophagoides Pteronyssinus* (DP), *Dermatophagoides Farinea* (DF), mixture of mold allergens, mixture of weed pollen, mixture of grass pollen, mixture of tree pollen, cockroach, cat, and dog) was employed. Additionally, SPTs were performed using a lancet (ALK®, Horsholm, Denmark) with the same solutions (**Figure 1**). A total of 2100 SPTs (105 patients × 10 tests for each arm × 2 arms) were administered, with 10 SPTs conducted on each arm of the 105 patients. During the tests conducted with a lancet and a multi-headed applicator (Aller-tech rapid allergy test applicator), adherence to the manufacturer's recommended guidelines for application was ensured. The SPTs were conducted on the inner surface of the arm in a standardized area. Each volunteer participant received SPTs on the inner surface of one arm using the multi-headed applicator and on the other arm using the lancet, both with the same allergen solutions. In the multi-headed applicator SPTs, a single allergen was applied to each chamber of the applicator. For the lancet SPTs, a separate lancet was used for each allergen using the same solutions. The SPTs were administered by the same experienced healthcare professional. One minute after the SPTs were performed, the droplets were dried without allowing them to mix. Following the SPTs, independent technicians measured and recorded skin reactions for swelling and wheel size. After 15 minutes, the longest diameter of the wheel was measured, and then the perpendicular diameter was measured and divided by two to determine the wheel diameter. Due to inadequate cockroach solution, enough data related to cockroach allergy could not be collected.

Allergen-specific IgE Measurement

Additionally, blood samples were collected from each participant on the same day. The blood samples were analyzed using the immunoCAP method, commonly employed in laboratory tests, to assess allergen-specific IgE levels.

Data Analysis

The data were analyzed using IBM SPSS Statistics 22.0 (IBM Corp., Armonk, New York, USA) statistical software package. Descriptive statistics were presented as unit count (n), percentage (%), mean ± standard deviation ($\bar{x}$±SD), median values, and minimum-maximum values. SPT results were compared between the multi-headed applicator and lancet-based tests. Furthermore, comparisons were made with allergen SpIgE results. These comparisons were conducted based on performance criteria such as sensitivity, specificity, and positive/negative predictive values.

Correlation analyses were performed between the applicator and SpIgE results compared to lancet-based SPT results. The normality distribution of variables was assessed using the

Kolmogorov-Smirnov test. For variables showing a normal distribution, Pearson correlation analysis was applied, while for non-normally distributed variables, Spearman correlation analysis was utilized to assess correlations.

Ethical Approval:

This research was conducted with the approval of the Istanbul Başakşehir Çam ve Sakura City Hospital Clinical Research Ethics Committee (Date: 22 February 2023 Decision no: 2023-72). Informed consent was obtained from all patients and their parents, and their privacy rights were respected.

RESULTS

Among the 105 patients evaluated for allergen sensitivity, with a total of 2100 SPTs conducted - one arm using a multi-headed applicator and the other arm using a lancet - and allergen-specific IgE levels measured, 67 (63.8%) were male. The median age was 96 months (range: 24-204), of which 63 (60%) had AR, 18 (17.1%) had allergic asthma with comorbid AR, and 24 (22.9%) had isolated allergic asthma. Additionally, 9 (8.5%) patients presented with atopic dermatitis alongside respiratory allergic diseases. Regarding specific allergen sensitivities, 49 (46.7%) cases exhibited reactivity to house dust mites and pollens, 40 (38.1%) to house dust mites, 13 (12.4%) to pollens, and 3 (2.9%) to molds and animal epithelial allergens.

In the SPT administered with a multi-headed applicator, sensitization to at least one allergen was observed in 77 cases (73.3%), whereas in the lancet group, this was noted in 87 cases (82.9%), and through specific IgE testing, 85 cases (81%) showed positive reactions.

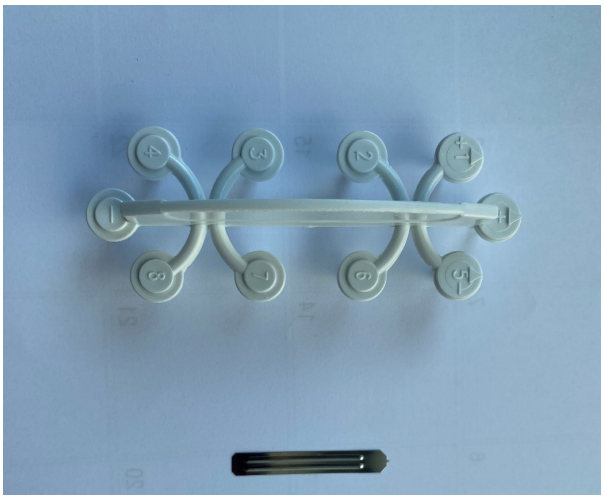

Figure 1: Example of multi-headed applicator and lancet used for tests

Table 1: Diagnostic values for multi-headed applicator and allergen-specific IgE compared to lancet SPT

Lanset (+) N:105		Positivity	Sensitivity	Specificity	NPV	PPV	Accuracy
***D. Pteronyssinus* n:75(71.4%)**	APK	46(43.8%)	39(52%)	23(76.7%)	23(39%)	39(84.8%)	59%
	SpIgE (n:99)	71(71.7%)	65(94.2%)	24(80%)	24(85.7%)	65(91.5%)	90%
***D. Farinea* n:75(71.4%)**	APK	34(32.4%)	29(38.7%)	25(83.3%)	25(35.2%)	25(85.3%)	51.4%
	SpIgE (n:99)	71(71.7%)	65(92.9%)	23(79.3%)	23(82.1%)	65(91.5%)	88.9%
Mix mold n:17(16.2%)	APK	12(11.4%)	3(17.6%)	79(89.8%)	79(84.9%)	3(25%)	78%
	SpIgE (n:95)	5(4.8%)	4(25%)	78(98.7%)	78(86.7%)	4(80%)	86.3%
Grass pollens n:43(41%)	APK	26(24.8)	18(41.9%)	54(58.1%)	54(68.4%)	18(69.2%)	78.1%
	SpIgE (n:101)	26(25.7%)	24(60%)	59(96.7%)	59(78.7%)	24(92.3%)	82.2%
Weeds pollen n:14(13.3%)	APK	8(7.6%)	0(0%)	83(91.2%)	83(85.6%)	0(0%)	79%
	SpIgE (n:97)	11(11.3%)	4(33.3%)	78(91.8%)	78(90.7%)	4(36.4%)	84.5%
Trees pollen n:17(16.22%)	APK	9(8.6%)	2(11.8%)	81(92%)	81(84.4%)	2(22.2%)	79%
	SpIgE (n:21)	4(3.8%)	2(33.3)	13(86.7)	13(76.5%)	2(50%)	71.4%
Cat allergens n:31(29.5%)	APK	16(15.2%)	10(32.3%)	68(91.9%)	68(76.4%)	10(62.5%)	74.3%
	SpIgE (n:65)	22(33.8%)	16(84.2%)	40(87%)	40(93%)	16(72.7%	86.2%
Dog allergens n:9(8.6%)	APK	11(10.5%)	2(22.2%)	87(90.6%)	87(92.6%)	2(18.2%)	84.7%
	SpIgE (n:63)	1(1.6%)	0(0%)	58(98.3%)	58(93.5%)	0(0%)	92%

APK: Skin prick test with multi-headed applicator; SpIgE: allergen-specific immunoglobulin E; NPV: negative predictive value; PPV: positive predictive value

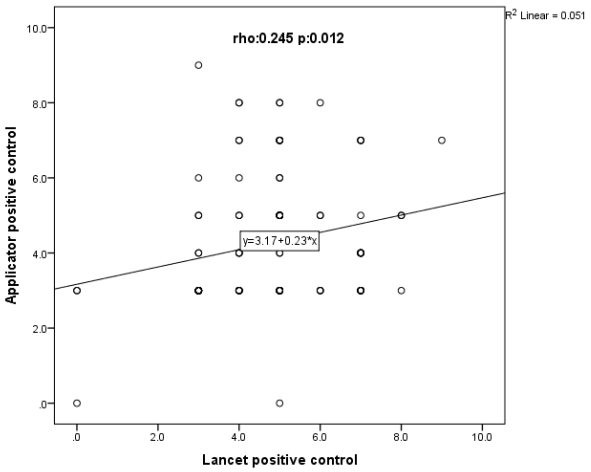

Figure 2: Correlation graph of positive control (histamine) between lancet and multi-headed applicator

In SPTs conducted with the applicator, false negative results for at least one allergen that was clinically compatible (despite positive results in the lancet-based SPTs and/or spIgE) were observed in 80 cases (76.4%). In 23 cases (21.9%), false positive results for at least one allergen, which were clinically incompatible and negative in other tests, were detected in the SPTs conducted with the applicator. False-negative results were observed in 23 cases (20.5%) in SpIgE measurements. Diagnostic values of the multi-headed applicator and inhaled allergen-specific IgE, based on the lancet-based SPT, are presented in Table 1.

In the SPTs conducted with the applicator and lancet, a weak positive correlation was observed between wheal diameters in the positive control test with histamine (rho: 0.245, p: 0.012) (Figure 2).

In the case of *DP* a weak correlation was observed between the wheal diameter of SPTconducted with a lancet and the wheal

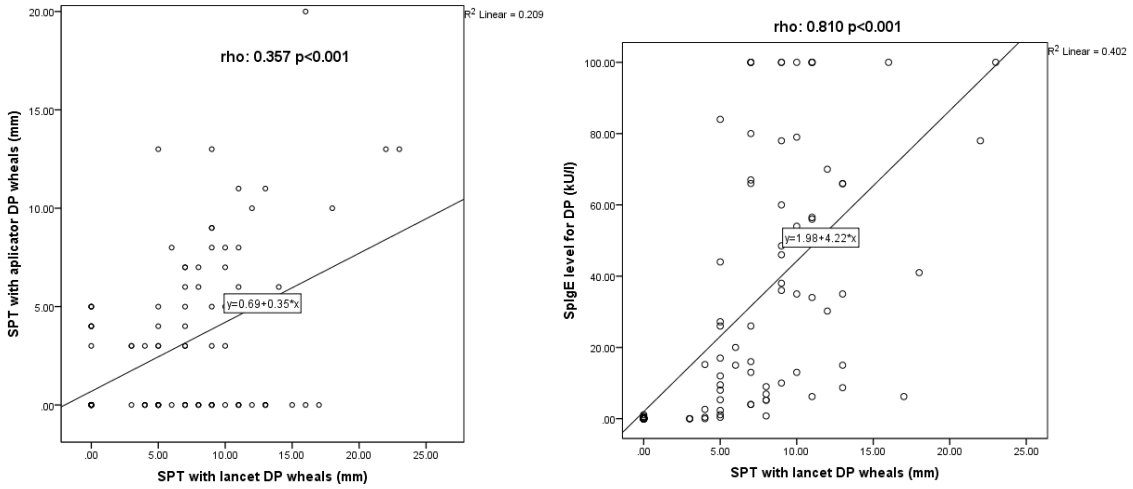

Figure 3: Correlation plots of wheal size from Multi-headed Applicator SPT and spIgE Level for Dermatophagoides pteronyssinus (DP) based on the result of Lancet SPT

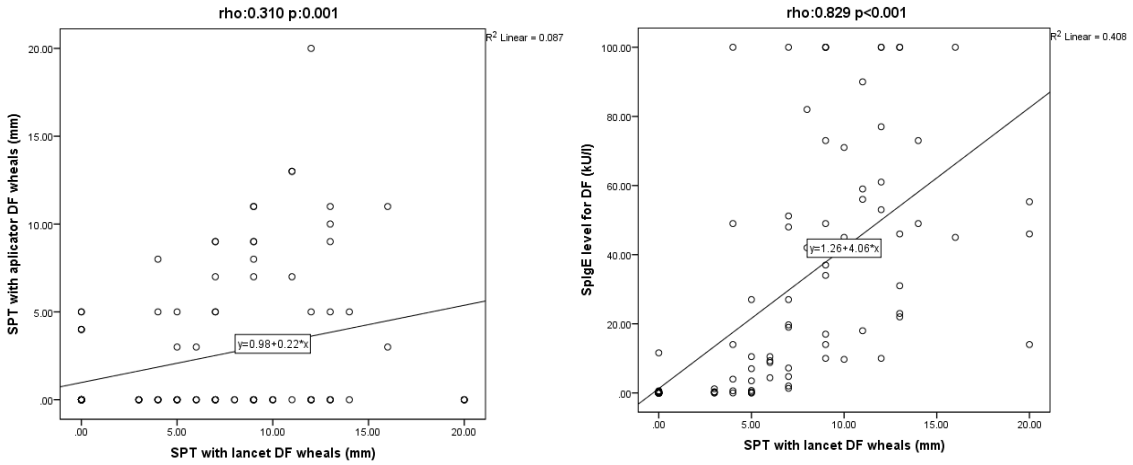

Figure 4: Correlation plots of wheal size from Multi-headed Applicator SPT and spIgE Level for Dermatophagoides farinea (DF) based on the result of Lancet SPT

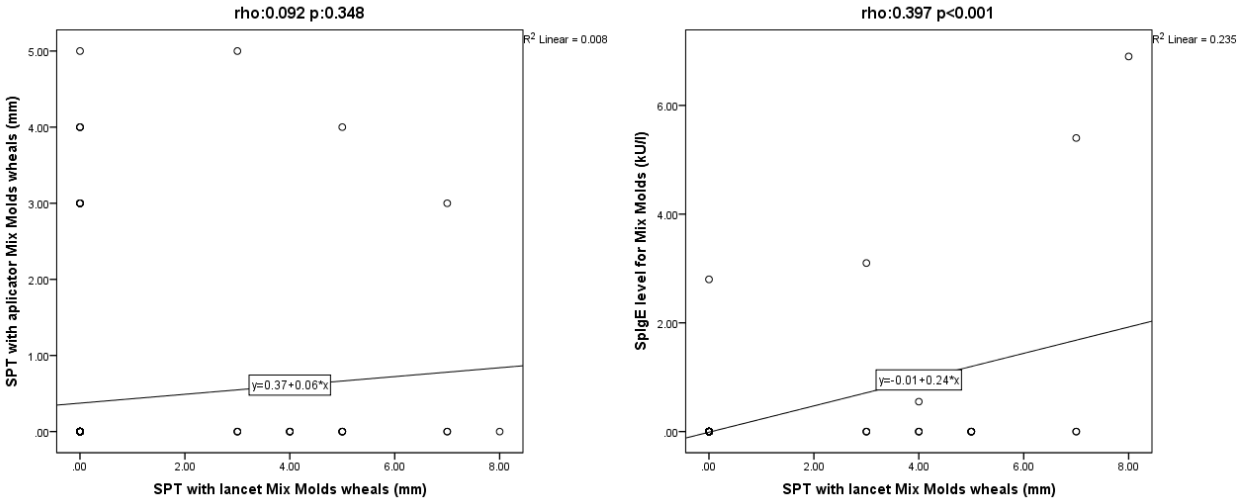

Figure 5: Correlation plots of wheal size from Multi-headed Applicator SPT and spIgE Level for Mix molds based on the result of Lancet SPT

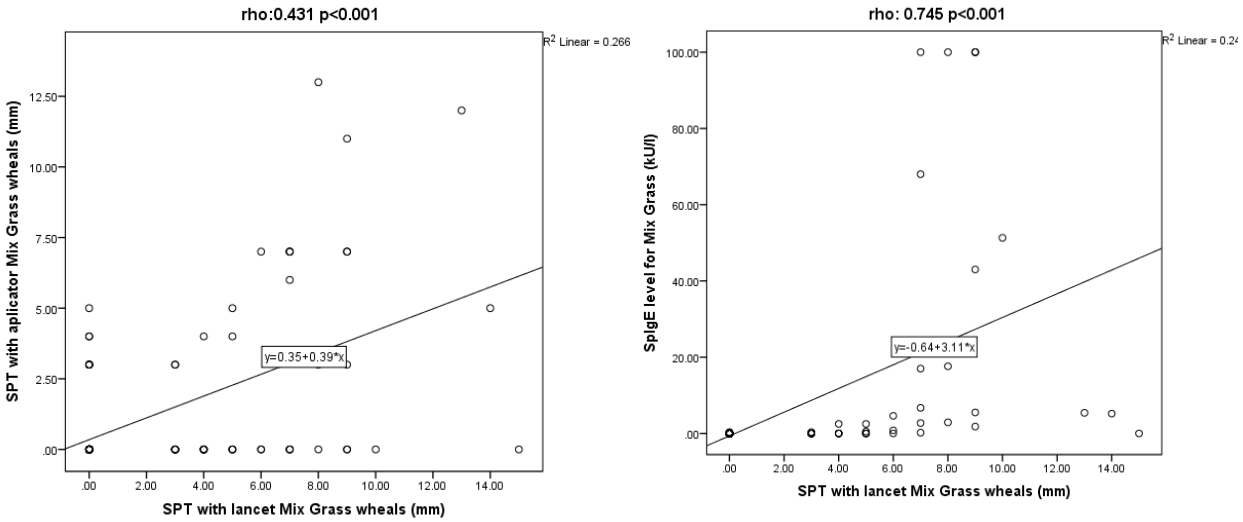

Figure 6: Correlation plots of wheal Size from Multi-headed Applicator SPT and SpIgE Level for Grass pollens based on the result of Lancet SPT

diameter of SPT conducted with an applicator (rho: 0.357, p < 0.001). However, a strong relationship was established between DP-specific IgE levels and the wheal diameter of SPT conducted with a lancet (rho: 0.810, p < 0.001) (Figure 3).

Regarding DF, a weak correlation was found between lancet-based SPT wheal diameter and applicator-based SPT wheal diameter (rho: 0.310, p: 0.001). Conversely, a strong correlation was observed between DF-specific IgE levels and lancet-based DF SPT wheal diameter (rho: 0.839, p < 0.001) (Figure 4).

For the mold mixture, there was no significant correlation between lancet-based SPT wheal diameter and applicator-based SPT wheal diameter (rho: 0.092, p: 0.348). However, a weak correlation was found between mold mixture-specific IgE levels and lancet-based mold mixture SPT wheal diameter (rho: 0.397, p < 0.001) (Figure 5).

There is a moderate correlation between lancet-based and applicator-based SPT wheal diameters for the grass mixture (rho: 0.431, p < 0.001). Additionally, a strong correlation exists between grass mixture-specific IgE levels and lancet-based SPT wheal diameter (rho: 0.745, p < 0.001) (Figure 6).

No correlation between lancet and applicator SPT wheal diameters for weeds mixture (rho: -0.112, p: 0.254), but a weak correlation exists between weeds mixture SpIgE levels and lancet SPT wheal diameter (rho: 0.239, There p: 0.018) (Figure 7).

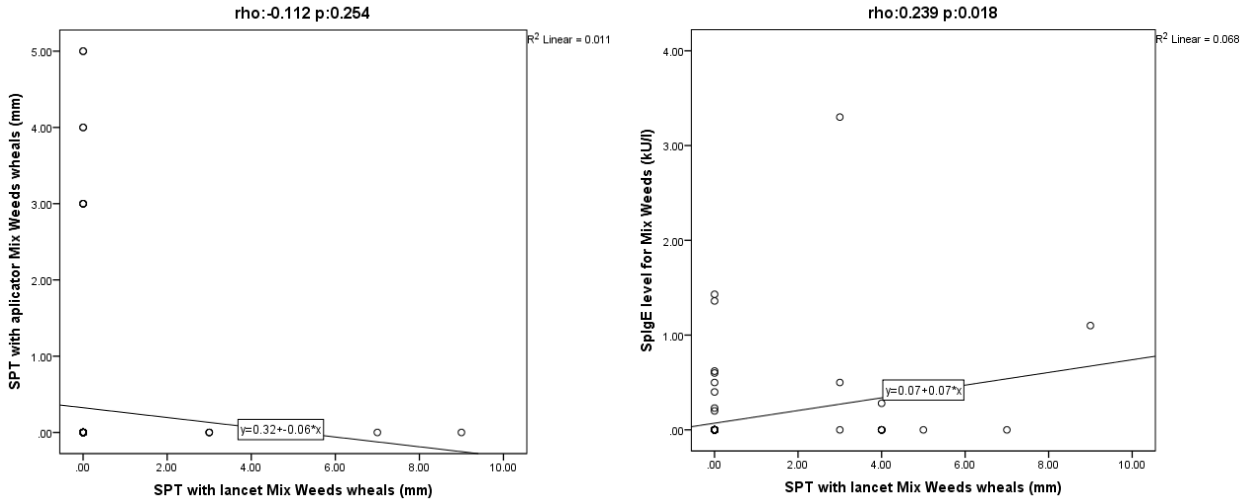

Figure 7: Correlation plots of wheal size from Multi-headed Applicator SPT and spIgE Level for Weeds pollens based on the result of Lancet SPT

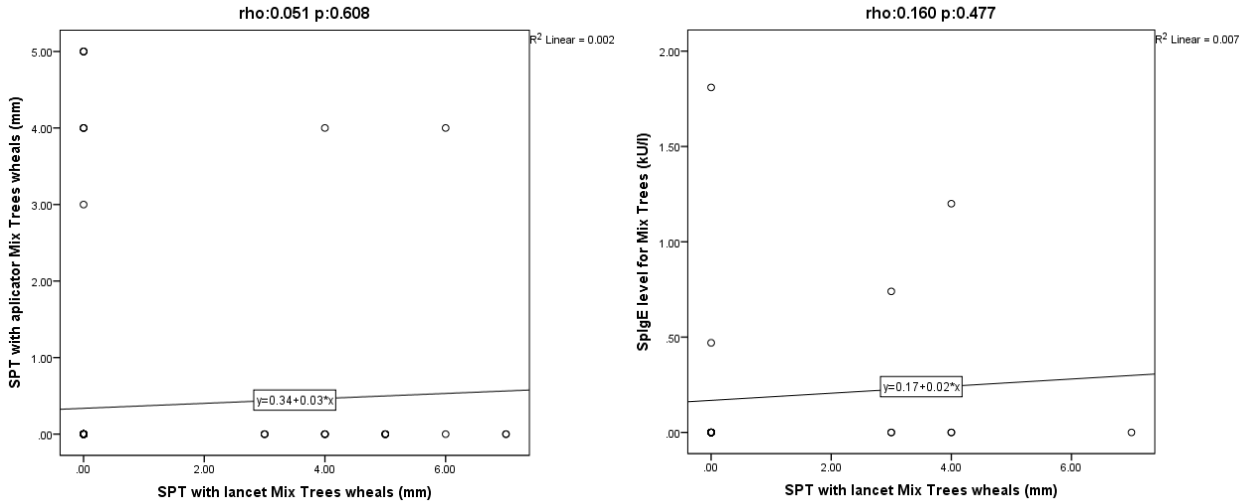

Figure 8: Correlation plots of wheal size from Multi-headed Applicator SPT and spIgE Level for Trees pollens based on the result of Lancet SPT

No correlation between the lancet and applicator SPT wheal diameters for trees mixture (rho: 0.051, p: 0.608) and tree mixture-spIgE levels and lancet SPT wheal diameter (rho: 0.160, p: 0.407) (Figure 8).

Weak correlation between the lancet and applicator SPT wheal diameters for cat allergens (rho: 0.281, p: 0.004) and, a strong correlation between cat allergens lancet SPT wheal diameter and spIgE levels (rho: 0.809, p < 0.001) (Figure 9).

No correlation was found between the lancet and applicator SPT wheal diameters for the dog allergen mixture (rho: 0.149, p: 0.130), no correlation between dog allergen mixture lancet SPT wheal diameter and spIgE levels (rho: -0.46, p: 0.718) (Figure 10).

DISCUSSION

In this study, different SPT methods and allergen spIgE results were evaluated for allergen sensitivity in children with allergic rhinitis and asthma. Sensitization to house dust mites, pollens, and molds was observed in most patients. Through SPTs with the multi-headed applicator, lancet, and SpIgE measurements, sensitization to at least one allergen was observed in 73.3%, 82.9%, and 81% of cases, respectively. The applicator skin prick test yielded 76.4% false negatives and 21.9% false positives, while the spIgE measurement resulted in 20.5% false negatives.

Applicator and lancet SPTs showed weak correlations with histamine-positive control wheel sizes. Strong correlations were observed between lancet SPTs and spIgE levels for DP, DF, and cat allergens. Mold mixture spIgE displayed a weak correlation, while grass mixture exhibited a good correlation, and weeds mixture indicated a weak correlation. No correlations were

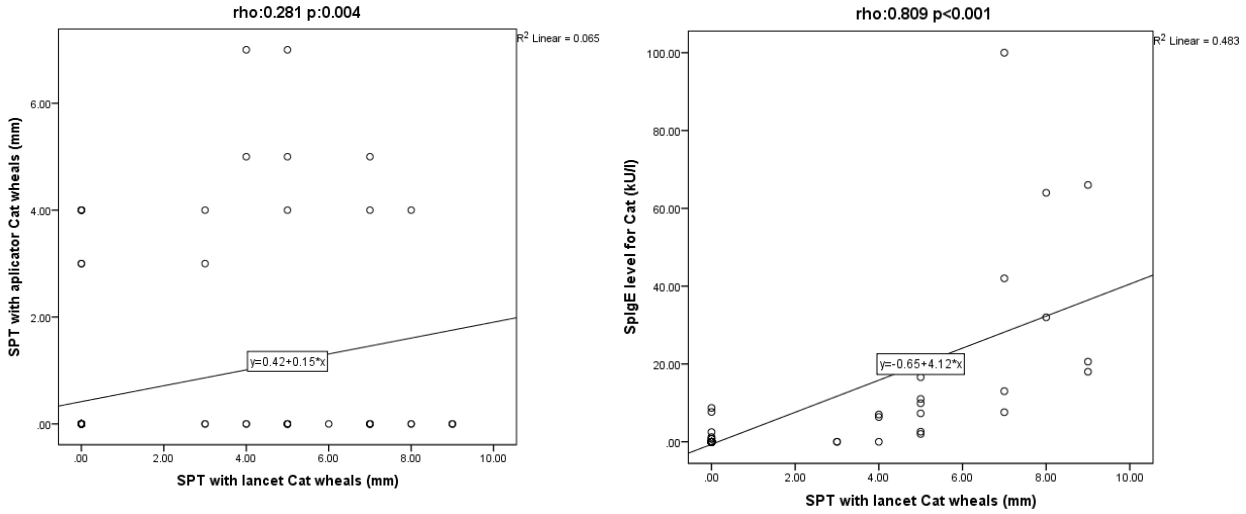

Figure 9: Correlation plots of wheal size from Multi-headed Applicator SPT and spIgE Level for Cat allergens based on the result of Lancet SPT

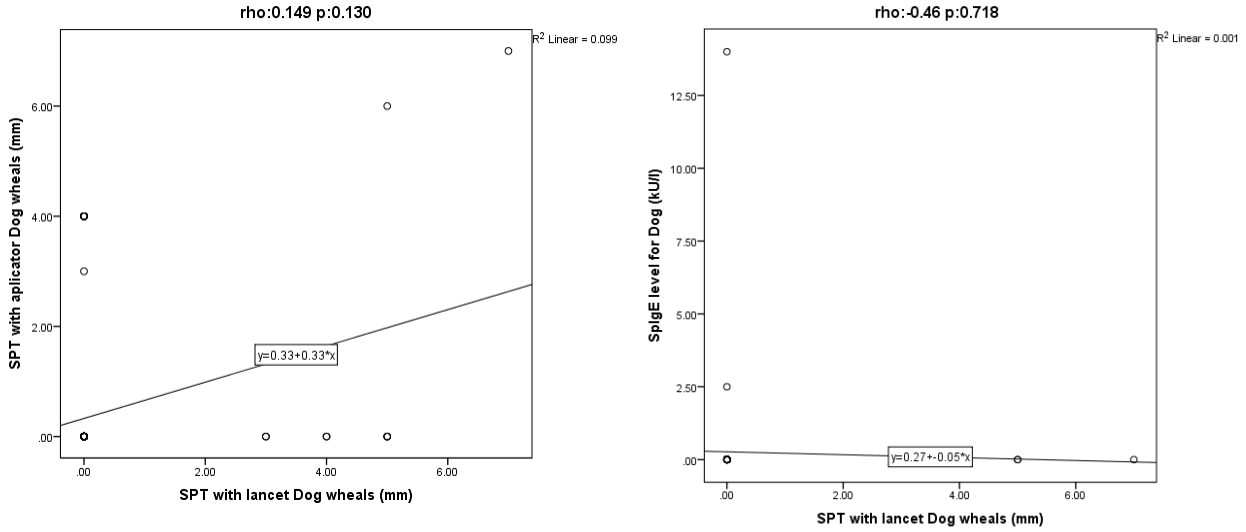

Figure 10: Correlation plots of wheal size from Multi-headed Applicator SPT and spIgE Level for Dog allergens based on the result of Lancet SPT

identified between dog and tree spIgE and lancet SPT wheel sizes. In applicator SPTs, weak correlations were found with house dust mites, grass, and cats, while other allergens showed no significant correlations. Applicator SPTs demonstrated notably low sensitivity, specificity, negative predictive values, positive predictive values, and accuracy.

In the literature, various devices including single-use needles and lancets have been compared, and it has been determined that the best results are obtained with a 23-gauge needle or a metal lancet. The single-use applicator (Stallerpoint®) that we used for testing exhibited a sensitivity of 20% with a single puncture and a sensitivity of 57% after a 90-degree rotation following the puncture. [7] In another study, different puncture and rotation techniques were compared using histamine and saline without using allergen solutions, resulting in a sensitivity of 100%. However, the limited number of cases, the absence of real allergen solutions, and the inclusion of non-atopic patients are noteworthy aspects of this study.[4]

In our hospital's multi-headed applicator, only puncturing is possible. In studies conducted using multi-headed devices, it has been observed that the false negative rate with histamine and saline is higher compared to single lancets or similar devices, and their sensitivities have decreased up to 51%. [8,9] In our study, the sensitivity ranged from 0% to 52% for all allergens with the multi-headed applicator.

Clinicians need to be well-informed about each SPT test device, follow the recommended usage guidelines, and interpret the test results accurately.[10] False negative results in patients with

a history of severe asthma or anaphylaxis can lead to life-threatening consequences.[11]

Similar studies in the literature have evaluated different SPT test devices by assessing their performance with positive controls (histamine) and negative controls (usually saline), as well as pain levels.[4,7–15]

We could not find an English-language published study that utilized actual allergen solutions. To the best of our knowledge, our study appears to be the first one that compares the diagnostic performances of allergen solution-based lancet SPT, multi-headed applicator SPT, and allergen spIgE measurements.

CONCLUSIONS

Skin prick tests conducted with lancets and spIgE measurements are effective methods for evaluating sensitization to allergens. However, newly developed rapid-result testing methods have not shown successful results in accurately detecting allergen sensitivities in patients. Further research is necessary to improve consistency and minimize false results among current skin prick test methods. Additionally, developing more accurate diagnostic and treatment approaches for allergic diseases is vital for effective patient management.

Ethics Committee Approval: This study was approved by the ethics committee of the Istanbul Başakşehir Çam ve Sakura City Hospital Clinical Research Ethics Committee (Date: 22 February 2023 Decision no: 2023-72).

Informed Consent: Written consent was obtained from the participants.

Peer Review: Externally peer-reviewed.

Author Contributions: Conception/Design of Study- S.A., Ç.A.; Data Acquisition- S.A.; Data Analysis/Interpretation- A.A.; Drafting Manuscript- S.A., Ç.A.; Critical Revision of Manuscript- S.A., Ç.A.; Final Approval and Accountability- S.A., Ç.A.

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REFERENCES

1. Matricardi PM. What is allergy, Global Atlas of Allergy [Internet]. Ring J, Akdis CA, Agache I, editors. European Academy of Allergy and Clinical Immunology. 2014. 112–114 p. Available from: www-eaaci.org
2. Scala E, Villalta D, Meneguzzi G, Brusca I, Cecchi L. Comparison of the Performance of Skin Prick and ISAC Tests in the Diagnosis of Allergy. Eur Ann Allergy Clin Immunol [Internet]. 2020 Nov;52(06):258. Available from: http://www.eurannallergyimm.com/cont/journals-articles/872/volume-comparison-performance-skin-prick-isac.asp
3. Bousquet J, Heinzerling L, Bachert C, Papadopoulos NG, Bousquet PJ, Burney PG, et al. Practical guide to skin prick tests in allergy to aeroallergens. Allergy [Internet]. 2012 Jan [cited 2022 Nov 23];67(1):18–24. Available from: https://onlinelibrary.wiley.com/doi/10.1111/j.1398-9995.2011.02728.x
4. Kahveci M, Karabulut E, Soyer O, Sahiner UM, Buyuktiryaki B, Sekerel BE. Fine-tuning the use of a skin prick test device. World Allergy Organ J [Internet]. 2020 May 1 [cited 2022 Nov 23];13(5):100122. Available from: https://linkinghub.elsevier.com/retrieve/pii/S1939455120300259
5. Heinzerling L, Mari A, Bergmann K, Bresciani M, Burbach G, Darsow U, et al. The skin prick test – European standards. Clin Transl Allergy [Internet]. 2013 Jan;3(1):3. Available from: https://onlinelibrary.wiley.com/doi/10.1186/2045-7022-3-3
6. Eckl-dorna J, Villazala-merino S, Linhart B, Karaulov A V, Zhernov Y, Khaitov M, et al. Allergen-Specific Antibodies Regulate Secondary Allergen-Specific Immune Responses. 2019;9(January):1–15.
7. Masse MS, Granger Vallée A, Chiriac A, Dhivert-Donnadieu H, Bousquet-Rouanet L, Bousquet PJ, et al. Comparison of five techniques of skin prick tests used routinely in Europe. Allergy [Internet]. 2011 Nov 1 [cited 2023 Jul 27];66(11):1415–9. Available from: https://onlinelibrary.wiley.com/doi/full/10.1111/j.1398-9995.2011.02679.x
8. Nelson HS, Kolehmainen C, Lahr J, Murphy J, Buchmeier A. A comparison of multiheaded devices for allergy skin testing. J Allergy Clin Immunol [Internet]. 2004 Jun 1 [cited 2022 Nov 23];113(6):1218–9. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0091674904006062
9. Yoon IK, Martin BL, Carr WW. A comparison of two single-headed and two multi-headed allergen skin test devices. Allergy asthma Proc [Internet]. 2006 Nov [cited 2023 Jul 27];27(6):473–8. Available from: https://pubmed.ncbi.nlm.nih.gov/17176781/
10. Carr WW, Martin B, Howard RS, Cox L, Borish L, the Immunotherapy Committee of th. Comparison of test devices for skin prick testing. J Allergy Clin Immunol [Internet]. 2005 Aug [cited 2023 Jul 29];116(2):341–6. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0091674905006135
11. Tversky JR, Chelladurai Y, McGready J, Hamilton RG. Performance and Pain Tolerability of Current Diagnostic Allergy Skin Prick Test Devices. J Allergy Clin Immunol Pract [Internet]. 2015 Nov [cited 2023 Jul 29];3(6):888–93. Available from: http://dx.doi.org/10.1016/j.jaip.2015.07.022

12. Werther RL, Choo S, Lee KJ, Poole D, Allen KJ, Tang MLK. Variability in skin prick test results performed by multiple operators depends on the device used. World Allergy Organ J [Internet]. 2012 Jan 1 [cited 2023 May 20];5(12):200–4. Available from: http://www.worldallergyorganizationjournal.org/article/S1939455119304016/fulltext
13. Morales-Palacios M de la P, Núñez-Córdoba JM, Tejero E, Matellanes Ó, Quan PL, Carvallo Á, et al. Reliability of a novel electro-medical device for wheal size measurement in allergy skin testing: An exploratory clinical trial. Allergy [Internet]. 2023 Jan 1 [cited 2023 Aug 10];78(1):299. Available from: /pmc/articles/PMC10087902/
14. Gorris S, Uyttebroek S, Backaert W, Jorissen M, Schrijvers R, Thompson MJ, et al. Reduced intra-subject variability of an automated skin prick test device compared to a manual test. Allergy Eur J Allergy Clin Immunol. 2023;78(5):1366–8.
15. Chiaranairungroj M, Chatchatee P, Srituravanich W. The effect of applied force and device design on skin prick test performance. Ann Allergy, Asthma Immunol [Internet]. 2023;130(3):312–6. Available from: https://doi.org/10.1016/j.anai.2022.11.014