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***Full title:***

**The challenge of measuring IL-33 in serum using commercial ELISA: Lessons from asthma.**

***Running title:***

**Measuring serum IL-33 in asthma**

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## **Abstract**

*Background-* Interleukin-33 (IL-33) has been subject of extensive study in the context of inflammatory disorders, particularly in asthma. Many human biological samples, including serum, have been used to determine the protein levels of IL-33, aiming to investigate its involvement in asthma. Reliable methods are required to study the association of IL-33 with disease, especially considering the complex nature of serum samples.

*Objective-* We evaluated four IL-33 ELISA kits, aiming to determine a robust and reproducible approach to quantifying IL-33 in human serum from asthma patients.

*Methods-* IL-33 levels were investigated in serum of well-defined asthma patients by the Quantikine, DuoSet (both R&D systems), ADI-900-201 (Enzo Life Sciences), and SKR038 (GenWay Biotech Inc San Diego USA) immunoassays, as well as spiking experiments were performed using recombinant IL-33 and its soluble receptor IL-1RL1-a.

*Results-* We show that 1) IL-33 is difficult to detect by ELISA in human serum, due to lack of sensitivity and specificity of currently available assays; 2) human serum interferes with IL-33 quantification, in part through IL-1RL1-a; 3) using non-serum certified kits may lead to spurious findings.

*Conclusion and Clinical Relevance-* If IL-33 is to be studied in the serum of asthma patients and other diseases, a more sensitive and specific assay method is required, which will be vital for further understanding and targeting of the IL-33/IL-1RL1 axis in human disease.

**Key words:** immunoassay, IL-33, IL-1RL1, sensitivity, specificity, interference, serum, asthma.

***To the editor:***

Accumulating evidence suggests that Interleukin-33 (IL-33) and its receptor Interleukin-1-receptor-like-1 (IL-1RL1, also called ST2) play a critical role in the pathogenesis of asthma. Multiple genetic association studies and meta-analyses have identified several independent polymorphisms in the *IL33* and *IL1RL1* regions that are associated with human asthma (reviewed in [1,2]). IL-33 is an alarmin released from damaged cells, including the lung epithelium, following allergic, viral or bacterial stimuli [1,3]. Extracellular IL-33 induces IL-1RL1 signalling, activating innate and adaptive immune cells, including innate type 2 helper cells (ILC2) and Th2 cells, resulting in increased production of type-2 cytokines IL-4, IL-5 and IL-13 [3].

IL-33 is produced as a full length (IL-33FL) 32kDa protein, which is the active form of IL-33, released upon necrosis of structural cells [1,3]. IL-33FL can be cleaved by caspases-1, -3, and -7 at D178, resulting in IL-33<sup>179-270</sup>, which is believed to result in inactivation of IL-33 during apoptosis, a non-immunogenic programmed cell death [4]. IL-33FL can also be cleaved by the (neutrophil) enzymes elastase (IL-33<sup>95-270</sup>), cathepsin G (IL-33<sup>99-270</sup>) and proteinase 3 (IL-33<sup>109-270</sup>), whilst retaining its activity [4].

When not appropriately regulated, extracellular IL-33 could contribute to chronic or exaggerated type-2 inflammation. A well-described regulatory mechanism of (extracellular) IL-33 is its capture by the soluble form of its receptor (IL-1RL1-a or sST2), thereby preventing the immunogenic activity of extracellular IL-33 [1,4]. In asthma, the IL-33/IL-1RL1 pathway seems to be dysregulated. Indeed, IL-33 levels have been reported to be increased in induced sputum, bronchial lavage fluid (BALF) and lung epithelial cells of patients with asthma compared to non-asthmatic controls [5,6]. Despite these studies, it is unknown whether serum levels of IL-33 represent a suitable biomarker for asthma or subgroups of asthma.

In the current study we set out to investigate the level of IL-33 in serum of well-characterised patients with asthma, aiming to evaluate its suitability as a biomarker for asthma phenotypes. Since this requires a robust method to quantify IL-33 in human serum, we evaluated four human IL-33 ELISA kits including three assays specifically designed for serum samples (Quantikine® by R&D systems Abingdon UK, ADI-900-201® by Enzo LifeScience Exeter UK, SKR038® by GenWay Biotech San Diego USA). We also included an assay for quantification of IL-33 in general biological samples (DuoSet® by R&D systems Abingdon UK). For IL-33 quantification we obtained serum samples from 45 asthma patients recruited from both Groningen and Nottingham (mild asthma n=25, moderate asthma n=10, severe asthma n=10, based on the GINA 2012 criteria, <http://www.ginasthma.org/>), of whom n=17 (mild asthma n=7, moderate asthma n=5, severe asthma n=5) were used across all four methods. Serum was separated from whole blood samples in serum separating tubes using centrifugation after a 20-40 minutes clotting time at room temperature. Serum was aliquoted and immediately frozen at -80°C. Transportation from the hospitals to the research facility was done on dry ice. Stocks were kept

at -80°C, while working tubes were stored at -20°C. Care was taken to keep identical freeze/thaw cycles among the comparisons.

Both studies had approval of local medical ethical committees and patients had given written informed consent. Recombinant IL-33 (from each of the kits) and IL-1RL1-a (sST2; from R&D) were used to determine specificity, sensitivity and interference of IL-1RL1 in each of the assays.

Using the three kits specifically designed for serum, the level of IL-33 was at or below the lower limit of detection (LLD) in serum from asthma patients (table 1 and figure 1, LLD being the detection limit as defined by each manufacturer). In contrast, the DuoSet showed a clear signal above the LLD in 76% of the samples, and a higher signal in ~17.5% of the serum samples. Indeed, when directly compared to the other assays, the DuoSet assay showed multiple deviating values, some of which were in a tenfold higher range (figure 1B). This discrepancy is striking, and could not easily be explained by possible confounding factors, such as asthma severity.

To evaluate specificity and sensitivity of the assays, we tested whether these were able to accurately quantify a known concentration of IL-33 when serum was present or in the presence of its soluble receptor IL-1RL1-a. This is important as IL-33 may exist in both free and IL-1RL1-a complexed forms in serum [1,4]. Both serum and recombinant IL-1RL1-a interfered significantly with the quantification of IL-33 in two of these ELISA kits (figure 1C). The Quantikine kit showed accurate detection of recombinant IL-33 irrespective of serum dilution and presence of IL-1RL1-a, indicating its technical feasibility of measuring IL-33 in serum, at least up to its LLD. These data strongly suggest that the high IL-33 measurements using the DuoSet kit in our asthma patients are unreliable, as the more sensitive and specific Quantikine kit did not measure IL-33 in any of these serum samples.

The overall lack of IL-33 detection in our serum samples suggests that IL-33 is present at very low levels in serum of these patients limiting our ability to study serum IL-33. Therefore, the activity of the IL-33/IL-1RL1 pathway might specifically be increased in severe asthma or during exacerbations, as suggested by studies correlating IL-33/IL-1RL1 levels with asthma severity [5-7], or it may indicate that serum is not the best compartment to study IL-33 levels, as IL-33 protein has previously been detected in BALF of patients with mild and moderate asthma severity [5].

Another explanation for the lack of detection of IL-33 in serum samples would be that the IL-33 present in serum has undergone posttranslational modifications that preclude its detection by the antibodies used in these kits, such as cleavage by cathepsins or elastase. Unfortunately, detailed information on the exact IL-33 epitope detected by the antibodies used in these ELISA kits is lacking to experimentally test this. As far as we are aware, no (proteomics) study has investigated the exact protein isoforms of IL-33 present in human serum, which we think are useful to enable the development of methods to detect specific IL-33 isoforms, and to improve the availability of such information.

Finally, the low levels of IL-33 detected in serum may be explained by the presence of interfering factors in serum such as IL-1RL1-a, as we find that both serum and recombinant IL-1RL1-

a (sST2) interfere with accurate quantification of IL-33 in a dose dependent manner in the GenWay and DuoSet ELISA kits. Hence, the level of IL-1RL1-a in serum should perhaps be treated as a covariate when using these kits. Nevertheless, since the maximum interfering effect of IL-1RL1-a is less than the effect of serum, at least in the DuoSet (see figure 1C), other factors may be present in serum that interfere with accurate detection of IL-33, such as serum globulins and albumins, potentially further complicating the use of these assays.

Other studies in allergic disorders have reported difficulties in detecting IL-33 in serum using ELISA; ranging from zero positive samples (n=24 allergic rhinitis patients using the Quantikine kit [8]) to detectable values in every sample, but at the lower range of the standard curve (n= 37 wheezing children using the GenWay kit [6]). Furthermore, also in a non-allergic inflammatory disorder (Sjögren), measurement of IL-33 by the currently used immunoassays was shown to be problematic [9]. Digital or multiplex immunoassays could be promising novel methods in the measurement of IL-33 [10].

In summary, we show that 1) IL-33 is difficult to detect by ELISA in human serum, due to lack of sensitivity and specificity of currently available assays 2) human serum interferes with IL-33 quantification in part through IL-1RL1-a, 3) using non serum certified kits may lead to spurious findings. We suggest that the data generated in the current study should be taken into account for prospective and retrospective studies of human serum IL-33 levels using these existing kits.

**Author contributions:** M. Ketelaar/M. Nawijn/G. Koppelman/I. Sayers designed the study. M. Ketelaar completed the experimental work and statistical analyses. D. Shaw and G. Koppelman were the collectors of clinical samples and patient information. All authors contributed to the design, interpretation of data, and revision of the article. All authors had access to the data and read and approved the final manuscript.

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**Competing interests statement:** The funders had no role in study design; the collection, analysis, and interpretation of data; the writing of the article; nor the decision to submit it for publication. Therefore, the authors declare no competing interests.

**Tables+Figure:**

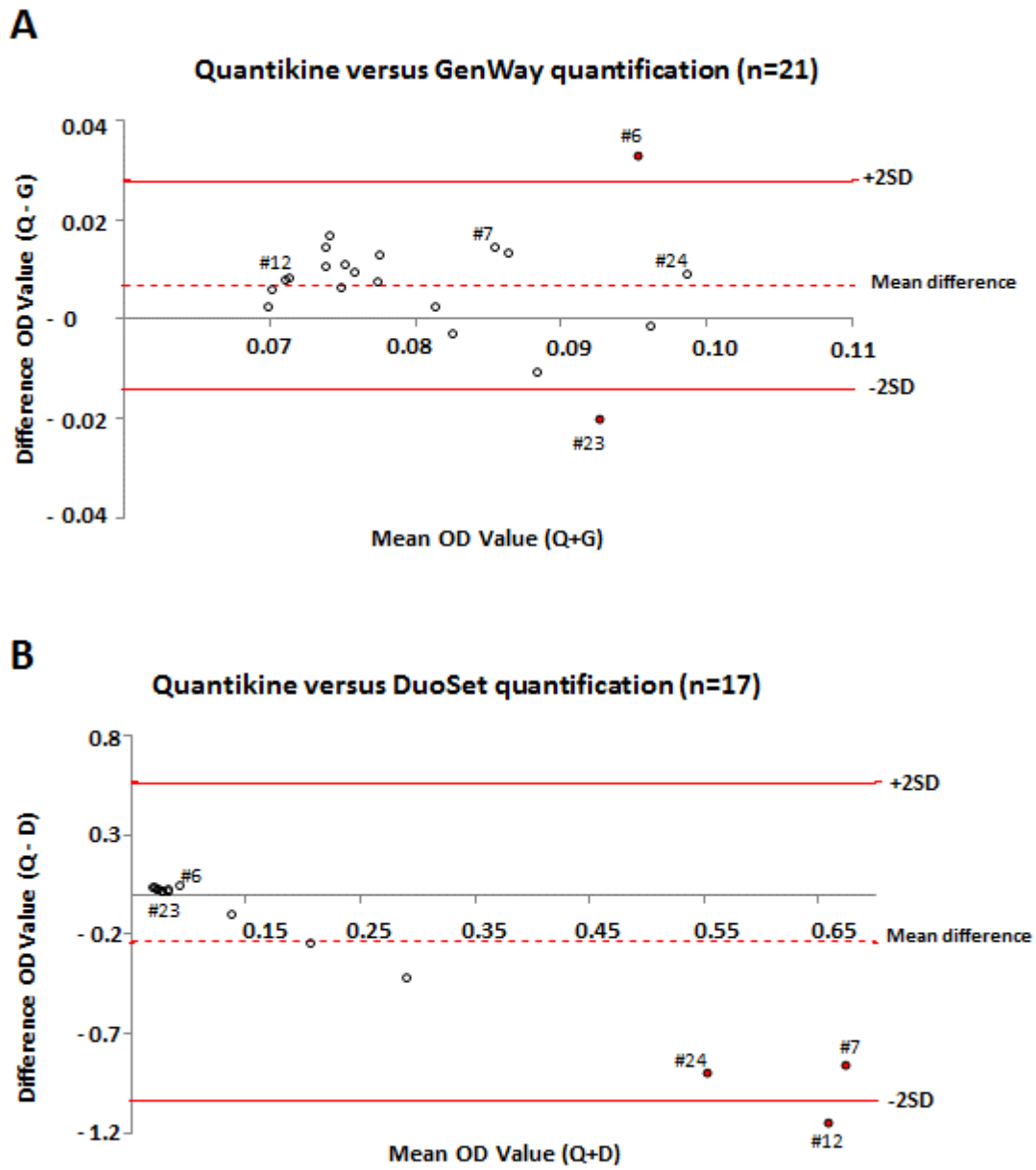
<b>Table 1. Percentage of positive signals for each IL-33 immunoassay</b>			
<i>IL-33 assay</i>	<i>N</i>	<i>% of samples above background*</i>	<i>% of samples above LLD**</i>
Quantikine	45	38	2
GenWay	22	23	0
Enzo LS	17	8	0
DuoSet	17	100	76

**Table 1 Percentage of positive signals for each IL-33 immunoassay.**

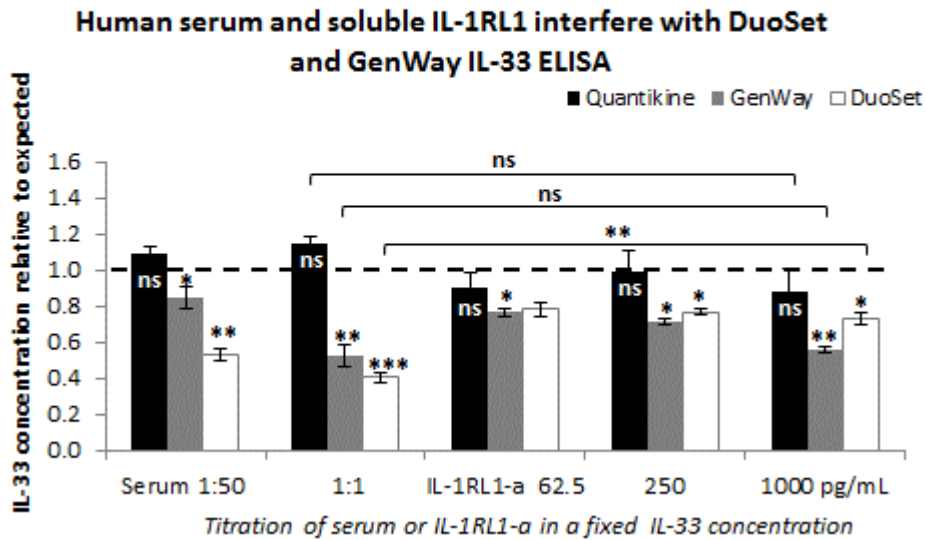
Shown are the discrepancies between the relative number of positive signals for the Quantikine, GenWay, EnzoLS and DuoSet IL-33 immunoassays, by comparing the percentage of signals above background and above the lower limit of detection of each assay. \* background based on the 95%CI of the value of the blank well of the assay, \*\* based on the 95%CI of the lower limit of detection each assay, CI= confidence interval. LLD=Lower limit of detection of each kit, as defined by the manufacturer of each assay: Quantikine (6.25pg/mL), GenWay 31.25pg/mL), Enzo LS (3.4pg/mL) and DuoSet (23.4pg/mL).



Figure 1



C



**Figure 1 Comparison of IL-33 immunoassays and identification of potential confounders.**

The upper Bland Altman Plot [fig. A] compares Optical Density (OD) values of the IL-33 immunoassays Quantikine (Q) and GenWay (G), (n=21); similar data were observed when comparing Quantikine or GenWay to the EnzoLS kit (data not shown, n=17).

The lower Bland Altman Plot [fig. B] compares the OD values of the Quantikine kit with the DuoSet (D) kit (n=17); which is representative for the comparison of the EnzoLS and GenWay assay to DuoSet (not shown, n=17). In the plots, the difference in OD value of each sample as measured by Quantikine versus GenWay (Q-G=Quantikine minus GenWay), respectively Quantikine versus DuoSet (Q-D= Quantikine minus DuoSet) is depicted on the y-axis. This is set against the average of the OD value for each sample as measured by the two compared kits (x-axis: Q+G= mean OD value of Quantikine and GenWay for each sample, Q+D= mean OD value of Quantikine and DuoSet). *Red dots indicate deviating samples (>1SD from the mean difference). Unique identifiers (#) labeling these deviating samples enable comparison between panels (A) and (B).*

In fig. C, the influence of serum or IL-1RL1-a on IL-33 detection is shown.

*X-axis:* Serum (1:50 or 1:1) or IL-1RL1-a (62.5, 250, 1000 pg/mL final concentration) was spiked into a fixed (end) concentration of recombinant IL-33, being the middle of each kits' standard curve (IL-33 concentration of 50 pg/mL, 250 pg/mL, 187.5 pg/mL for Quantikine, GenWay and DuoSet respectively).

*Y-axis:* the measured IL-33 concentration is expressed as proportion of the expected IL-33 concentration.

Groups are compared by ANOVA, using Games-Howell post-hoc testing. Results of the statistical comparison between measured IL-33 concentration and expected IL-33 concentration are indicated, as well as differences in measured IL-33 concentrations after addition of 1000 pg/mL IL-1RL1-a versus addition of 1:1 serum. Note: 1000pg/mL represents the maximum interfering effect of IL-1RL1-a, as no differences with 2000 pg/mL and 4000 pg/mL were found (p>0.3 compared to 1000 pg/ml IL-1RL1-a, not shown.)

*Values are based on duplicate readings of an N=2-3 experimental replicates.*

*\*p<0.05, \*\*p<0.01, \*\*\*p<0.001, ns= not statistically significant, dotted line (----) indicates the expected IL-33 concentration set as '1'.*

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