Comparison of the Reliability of 17 Celiac Disease Associated Bio-Markers to Reflect Intestinal Damage
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Abstract
In view of the increasing importance of serological biomarkers for screening and diagnosing celiac disease (CD) and the lack of back-to-back comparison of their differential performance to their reliability to reflect the intestinal damage in children with CD, their performances were evaluated.

95 pediatric CD patients (mean age 8.3), 45 nonspecific abdominal pain children (AP) (mean age 7.3), 99 normal children (NC) (mean age 8.5) were tested with following ELISAs (detecting IgA, IgG or both, IgA and IgG (check): AESKULISA® Gliadin (AGA), AESKULISA® DGP (DGP), AESKULISA® TtG “New Generation” (Neo-epitope tTg complexed to gliadin=tTg-neo), tTg (for in house research purpose only), AESKULISA® mTg neo-epitope and mTg (RUO). Anti-endomysial antibodies (EMA) were checked via immunofluorescence test. Results were compared to the degree of intestinal injury, using the revised Marsh criteria. Scatter diagrams and regression analysis comparing the 17 antibodies’ activities to the degree of the intestinal damage were performed.

Most of the assays were able to discriminate patients with low and high degree of intestinal damage. Comparing the different correlations of CD associated IgA and IgG antibodies’ isotypes, the tTg-neo IgA (r²=0.6165, p<0.0001) and iTtG-neo check (r²=0.6492, p<0.0001) stood out, significantly, as the best indicators for intestinal damage in CD. EMA-IgA, iTg, DGP checks and mTg-neo IgG correlated closely to the mucosal injury.

The highest optical densities (medium 2.94 ± 1.2, p<0.0001) were measured in the iTtG-neo IgA ELISA of patients with Marsh 3c.

As a conclusion, it is suggested that iTtG-neo IgA/IgG antibodies should be used preferably to closely reflect intestinal damage during screening and diagnosing childhood CD. EMA-IgA, iTg and DGP checks and mTg-neo IgG titer followed the iTtG-neo check performance. mTg-neo IgG may present a new serological biomarker for CD.

Keywords: Celiac disease; Neo-epitope tissue transglutaminase; Tissue transglutaminase; Deamidated gliadin peptide; Antibodies; Serology; Bio-markers; Intestine; Pathology

Introduction
Celiac disease (CD) is a small intestine inflammatory autoimmune disorder in genetically susceptible individuals, triggered by digestion of prolamins contained in wheat, barley, rye and partially in oat. The accepted incidence in Western countries is 1-1.5%. The majority of patients are still under-diagnosed, but increasing awareness and improved serological performances, raise the diagnostic yield. In contrast, in high-risk populations the average risk of CD can reach 5-10% [1]. In the last decades CD frequency is increasing, joining the surge in autoimmune disease incidence and prevalence worldwide [2,3].

CD is a life-long multi-faced condition with an increased risk of complications. Hematological and gastrointestinal malignancies, osteoporosis/penia and other extraintestinal manifestations, decreased height, malnutrition and nutritional deficiencies, fertility impairment, stillbirth, dismaturity, hypercoagulability, psychosocial compromise, impairment of quality of life and-if left untreated-increased mortality and additional autoimmune conditions, to name a few [4]. The epidemiology and phenotype of CD are constantly changing, early diagnosis and subsequent adherence to a gluten-free diet is highly recommended. It has been shown that the classic intestinal clinical picture of malnutrition, chronic diarrhea and nutritional deficiencies are disappearing and extraintestinal presentations are emerging. Nowadays, we are witnessing an epidemiological shift in the disease phenotype toward a more advanced age, and increased prevalence of latent, hypsymptomatic or asymptomatic presentations [5]. All these changes make reliance on symptomatology more remote and therefore diagnosis of the disease more difficult [6]. Recent, major improvements in serological markers performance, with sensitivities and specificities above 90%, are an additional reason why serological screening of CD has achieved prime importance [1].

In the beginning of 2012 the European Society of Pediatric Gastroenterology, Hepatology and Nutrition (ESPGHAN) released a new set of guidelines for the diagnosis of CD, based on both: the significant progress in the development of specific antibody tests and the understanding of the high prevalence of specific HLA haplotypes [7]. These advances were the base of updated guidelines for CD diagnosis in asymptomatic and asymptomatic children, where, in certain circumstances, small bowel biopsy can be omitted. Contrasting, multiple adult guidelines still advocate serological screening followed by obligatory intestinal biopsies for the diagnosis.

Since only the tip of the CD iceberg is above the waterline and a much larger portion remains under water undetected, it can be

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Received: October 18, 2016; Accepted: January 24, 2017; Published: January 27, 2017


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expected that prevalence of the disease will increase continuously. Therefore, presenting symptoms will continue to change towards a-/hyposymptomatic, supporting the need for improved serological screening methods. There are multiple serological tests on the market: IgA anti-endomysial antibody (EMA), IgA and/or IgG tissue transglutaminase (tTg), IgA and/or IgG deamidated gliadin peptide (DGP), whereby IgA-tTg is the most frequently used and ESPGHAN's recommended one. Several combination tests are available too: DGP IgA+G, tTg IgA+G, Gliadin IgA+G (check), CeliCheck IgA, IgG or IgA+IgG (autoantibodies against the cross-linked complex of tTg and gliadin peptides (tTg neo-epitope) and the recently described IgG and/or IgA or IgG+IgA combined mTg neo-epitope and mTg (AESKULISA® mTg neo-epitope and mTg, RUO) [1]. Being a new serological biomarker of CD mTg neo-epitope deserves some background information. Microbial transglutaminase (mTg) is capable of cross-linking numerous molecules (including gliadin), thereby creating an mTg-gliadin neo-complex. This post-translational modification of gliadin imitates its family member (human tTg) involved in CD.

For the last 26 years, numerous studies evaluated only one serological marker in relation to intestinal pathology, mainly EMA and later on, tTg [8,9]. Fewer studies checked two antibodies, mainly IgA-tTg and IgA-EMA, the latest being in 2012-13 [10-13]. Only in two Israeli studies, 5 different antibodies' levels were correlated to the mucosal damage [14,15]. Parizade M. et al. found that high antibody concentrations were predictive of villous atrophies for IgA+IgG-tTg, IgA+IgG-DGP and IgA-EMA [14], where EMA and IgA-tTg stood out to be the best. The second multi-marker study evaluated IgA+IgG+IgA-EMA and IgA-tTg combined mTg neo-epitope and mTg (AESKULISA® mTg neo-epitope and mTg, RUO) according to the manufacturer instructions.

Antibody determination by ELISA

The following ELISAs, detecting IgA, IgG separated or combined IgA and IgG (check) were used: AESKULISA® Gliadin (AGA), tTg (tTg; RUO (for in house research use only)), AESKULISA® DGP (DGP), AESKULISA® (tTg New Generation (tTg neo-epitope), AESKULISA® mTg neo-epitope and mTg (RUO), according to the manufacturer instructions.

Antibody determination by IFA

AESKULISIDES® EMA (endomysium antibodies) were used for indirect fluorescent IgA and IgG determination of human anti-endomysium antibodies, according to the manufacturer instruction.

The endomysium is the supporting, connective structure that surrounds the smooth fibers, located in the middle third of the esophagus. A representative positive EMA is shown in Figure 1.

Statistics

Statistical analyses were performed using the Software MedCalc® (V 15.6.1). Normally distributed values were expressed as mean ± standard deviation (SD) and were compared by the Student’s t test. Correlations were assessed by the Pearson correlation test. p<0.05 was considered as significant.

Scatter diagrams and regression analysis comparing the 17 antibodies' OD activities to the degrees of the intestinal damage were correlated. Antibody results were compared to the degree of intestinal injury, using revised Marsh criteria.

Results

The performance of the different tests for the 99 pediatric CD, were compared to 45 pathological controls with AP and 99 normal control children, with similar age and sex ratio. All antibodies were detected via ELISA, except for EMA which was checked via immunofluorescence.

A general overview of the different IgA and IgG antibodies' U/ml titers is shown in Figure 2. All CD associated mean antibody's levels were above the cut-off levels. IgA isotype (Figure 2A) levels were higher than of IgG isotypes (Figure 2B), except for the DGP-IgA and mTg-neo IgA, here IgG dominated. The Ttg neo-epitope IgA test had the highest immunoreactivity (P<0.0001) and Ttg neo-epitope IgG had a higher immunoreactivity compared to single tTg-IgC. The following Figures 3-6 correlate the various ABs activities to the degree of intestinal damage, as characterized by Marsh criteria.

All assays were able to differentiate between patients of low and
high degree intestinal damage. Comparing the different correlations between CD associated IgA and IgG antibodies’ isotypes, EMA-IgA, tTg-neo IgA and tTg-neo check, stood out significantly as the best indicators of CD caused intestinal damage. The highest OD values (mean 2.94 ± 1.2, p<0.0001) were achieved using the tTg-neo IgA ELISA with Marsh 3c patients (Figure 3). The correlations, as well as their corresponding statistical significance of each AB isotype, are summarized (in increasing order) in Table 1.

Since EMA testing is performed via immunofluorescence (Figure 1), which is semi quantitative and operator-dependent, it is shown separately in Figure 6. The IgA and not the IgG isotype reflects the intestinal pathology best.

For better comparison of diagnostic reliability, Table 1 lists various ABs’ activities of 5 combined (checks) and 12 single isotypes associated with CD. Many of the antibodies had high specificity and low sensitivity. Combining the specificity and sensitivity by analyzing the AUC, tTg-neo IgA and EMA-IgA, in the single isotype, and tTg-neo check, in the combined isotype, stood out as best performers. Similarly, tTg-neo check and EMA-IgA reflect best the intestinal damage (p<0.005, Table 1). Of note, mTg-neo IgG and not the IgA isotype, had a high AUC (0.95) and reflected significantly the intestinal histology in the CD group.

Discussion

The present study explored 15 ELISA kits encompassing 5 different families of antigens (gliadin, tTg, DGP and tTg neo-epitope and mTg neo-epitope) for specific IgA, IgG, combined IgA+G reactivities and 2 immunofluorescence EMA kits. The performances of all Kits were assessed with the same blood sample, and then compared against the rigid criterion of the corresponding biopsy-demonstrated duodenal histology, further enhancing the uniformity of the study. The analysis showed that antibody levels were well correlated to the duodenal damage degree in CD children, but there was a hierarchy among the evaluated tests. The tTg neo-epitope IgA Kit occupied the first place in the IgA isotype group, DGP-IgG and tTg neo-epitope IgG shared the first place of IgG isotype Tests. The combined IgA+IgG isotypes had low correlations to intestinal histology, except for the tTg-neo check, which showed better performance than tTg-neo IgG or IgA kits. Concerning the differential performance of Kit groups, IgA Kits surpassed IgG in reflecting intestinal damage, except for the mTg-neo IgG, which showed better performance than the mTg-neo IgA kit.

Our own experience [16,18,19] and that of many others [1] favors combination tests to screen for CD. The main single antigen ELISA kit candidates are anti-tTg IgA and anti-DGP IgG, competing with the new CeliCheck combination of IgA and IgG thus omitting screening for IgA deficiency [16,18-21]. However, when reflection of intestinal pathology is concerned, singl e isotype Test are preferable, mainly the tTg-neo IgA.

The tTg-neo IgA kit uses a neo-epitope formed by complexing tTg and gliadin, the main antigens in CD. The basic idea is that tTg not only able to deamidate gliadin peptides but also to cross-link with a high catalytic rate [22-24]. In the latter case, tTg/gliadin complexes are formed, resulting in the formation of new epitopes (neo-epitopes), evidence has been shown in-vitro. More so, formation of the tTg-DGP complex was suggested to involve epitope spreading from gliadin to tTg [21]. The antibodies against neo-epitopes of the tTg-gliadin complex provide a new screening and diagnostic test in CD. Multiple studies have exhibited diagnostic sensitivities of 95% and specificities of 97% or more, when compared with those of traditional antibody assays [25,26]. The neo-tTg/DGP complex is potentially able to drive the development of newly formed epitopes derived from the cross-linkage between the enzyme and the substrate. It is foreseeable that the autoantibodies generated against the neo-epitope may represent the best means for screening populations, diagnosing high-risk groups and identify silent or latent patients. In fact, several studies have shown the superiori ty of screening for CD using the neo-tTg/DGPs complex strategy in the general population [26,27] or in high-risk groups’ subjects [16,18,19,28-30]. The present results go along this serological diagnostic strategy and add the aspect of intestinal damage reflection.

Several debates and disagreements exist in the literature concerning the cross talks between serological markers and reflection of the intestinal pathology in CD.

On the pathological aspect a concern exists that intestinal biopsy is the gold standard for diagnosis. Recently incorrect biopsy interpretation causing under diagnosis [31], lack of uniformity in the use of Marsh-Oberhuber classification [32] and unrecognized, misleading pathological features that are positively associated with more advanced stages of the disease were described [33]. More so, even the cut-off for the intraepithelial lymphocyte count, a hallmark of CD intestinal pathology, is debatable [34-35]. In the serological domain assays uniformity, lack of standardization, plethora of commercial immune fluorescent and ELISA kits with variable cut-off levels are some
Figure 2: Comparison of A. IgA and B. IgG celiac disease associated antibody activities.

Figure 3: Correlations between IgA antibody activities and intestinal injury in celiac disease.
of the problematic aspects. On top of it, being on gluten containing diet, CD associated antibodies fluctuates or disappears spontaneously in CD children [36]. Positive celiac serology coexists with normal villous morphology [37]. Normalization of serology does not predict normalization of intestinal histology [38]. A recent study from the UK national external quality assessment service center (UK NEQAS) states that not all commercial available IgA-tTg kits are reliable and that the ESPGHAN guidelines are not readily transferable to use in all centers and should not be used in the UK [39]. Interestingly, even in the most recommended autoantibodies for CD diagnosis, multiple false positive and negative exist [40].

Screening some recent reviews and guidelines, comparing reliability of the celiac specific serological markers, one sees the vast variability in their sensitivity and specificities [1,7,41-43].

The present study has several advantages:

1. Much more CD associated antibodies were evaluated in a back-to-back experimental design (12 vs. 5).
2. It is the first study to incorporate the neo-epitopes of tTg/mTg in correlation to the intestinal injury.
3. The group of AP is unique in composing pathological controls with normal intestinal biopsy.
4. It is the only study that compared 17 CD associated serological markers, encompassing IgA, IgG and check isotypes.
5. The addition of the IgA+IgG-AGA is important in reference to less recent historical data.
6. All determinations were done in the same laboratory, by the same person, under same conditions for better uniformity and comparability.
7. The antibodies’ activities were correlated to the same intestinal Marsh degree of atrophies.

Table 1: Antibodies diagnostic performances in pediatric celiac disease and their correlations between their activity and the degree of intestinal damage.

<table>
<thead>
<tr>
<th>Assay</th>
<th>sensitivity</th>
<th>specificity</th>
<th>npv</th>
<th>ppv</th>
<th>AUC</th>
<th>corr</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>tTg IgG</td>
<td>13,13</td>
<td>98,99</td>
<td>53,26</td>
<td>92,86</td>
<td>0,56</td>
<td>0,2601</td>
<td>&lt;0,0001</td>
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<tr>
<td>mTg neo IgA</td>
<td>64,65</td>
<td>98,99</td>
<td>73,68</td>
<td>98,46</td>
<td>0,82</td>
<td>0,3018</td>
<td>0,0003</td>
</tr>
<tr>
<td>Gliadin IgA</td>
<td>37,37</td>
<td>98,99</td>
<td>61,25</td>
<td>97,37</td>
<td>0,68</td>
<td>0,324</td>
<td>&lt;0,0001</td>
</tr>
<tr>
<td>DGP IgA</td>
<td>66,67</td>
<td>98,99</td>
<td>74,81</td>
<td>98,51</td>
<td>0,83</td>
<td>0,359</td>
<td>&lt;0,0001</td>
</tr>
<tr>
<td>Gliadin Check</td>
<td>57,58</td>
<td>98,99</td>
<td>70</td>
<td>98,28</td>
<td>0,78</td>
<td>0,3836</td>
<td>&lt;0,0001</td>
</tr>
<tr>
<td>tTg IgA</td>
<td>60,61</td>
<td>98,99</td>
<td>71,53</td>
<td>98,36</td>
<td>0,80</td>
<td>0,4692</td>
<td>&lt;0,0001</td>
</tr>
<tr>
<td>DGP IgG</td>
<td>70,71</td>
<td>98,99</td>
<td>77,17</td>
<td>98,59</td>
<td>0,85</td>
<td>0,4922</td>
<td>&lt;0,0001</td>
</tr>
<tr>
<td>mTg neo Check</td>
<td>90,91</td>
<td>87,88</td>
<td>90,62</td>
<td>88,24</td>
<td>0,89</td>
<td>0,5127</td>
<td>&lt;0,0001</td>
</tr>
<tr>
<td>Gliadin IgG</td>
<td>84,85</td>
<td>98,99</td>
<td>86,73</td>
<td>98,82</td>
<td>0,92</td>
<td>0,5181</td>
<td>&lt;0,0001</td>
</tr>
<tr>
<td>tTg neo IgG</td>
<td>77,78</td>
<td>98</td>
<td>81,67</td>
<td>97,47</td>
<td>0,88</td>
<td>0,5334</td>
<td>&lt;0,0001</td>
</tr>
<tr>
<td>mTg neo IgG</td>
<td>95,96</td>
<td>93,94</td>
<td>95,88</td>
<td>94,06</td>
<td>0,95</td>
<td>0,5633</td>
<td>&lt;0,0001</td>
</tr>
<tr>
<td>DGP Check</td>
<td>82,83</td>
<td>98,99</td>
<td>85,22</td>
<td>98,78</td>
<td>0,91</td>
<td>0,5902</td>
<td>&lt;0,0001</td>
</tr>
<tr>
<td>EMA IgG</td>
<td>55,7</td>
<td>99,3</td>
<td>N.D.</td>
<td>N.D.</td>
<td>0,78</td>
<td>0,5996</td>
<td>&lt;0,0001</td>
</tr>
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<td>tTg Check</td>
<td>79,8</td>
<td>98,99</td>
<td>83,05</td>
<td>98,75</td>
<td>0,89</td>
<td>0,6093</td>
<td>&lt;0,0001</td>
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<tr>
<td>tTg neo IgA</td>
<td>88,89</td>
<td>98,99</td>
<td>89,91</td>
<td>98,88</td>
<td>0,94</td>
<td>0,6165</td>
<td>&lt;0,0001</td>
</tr>
<tr>
<td>tTg neo check</td>
<td>97,98</td>
<td>98,99</td>
<td>98</td>
<td>98,98</td>
<td>0,98</td>
<td>0,6492</td>
<td>&lt;0,0001</td>
</tr>
<tr>
<td>EMA IgA</td>
<td>90,2</td>
<td>94,1</td>
<td>N.D.</td>
<td>N.D.</td>
<td>0,94</td>
<td>0,8094</td>
<td>&lt;0,0001</td>
</tr>
</tbody>
</table>

Figure 4: Correlations between IgG antibody titers and intestinal injury in celiac disease.
On the other hand, several limitations should be mentioned:

1. A multicenter study would have better represented the global clinical reality. Moreover, a multicenter-approach could have normalized the potential biases encountered in one single center.

2. Comparing extended study populations would have increased the statistical power and the conclusion’s reliability.

3. The present study represents only one aspect (intestinal pathology reflection) in the decisional algorithm of the best serological marker for CD screening and diagnosis.

For transparency, some of the data were published separately:

- tTg IgA compared to tTg-neo isotypes [24]

mTg-neo isotypes compared to other ABs (but not to DGP and EMA isotypes) [44]. Since mTg-neo ABs isotypes are the newest published CD biomarkers of the 17 presently compared, in the following, some facts will be summarized. mTg-neo ABs isotypes are not autoimmune ABs, they are directed against neo-epitopes, formed during the conformational changes happening in the formation mTg/gliadin cross-link complex [22, 44-46]. Since mTg is heavily used by the processed food industries, it is consumed daily [44,47]. mTg neo-epitopes have, most recently, been shown to be immunogenic in active CD patients [44,46]. Presently, it represents a good reflector of CD intestinal atrophy, although, not the best one. CD is an IgA mediated disease, so it is not astonishing that antibodies against tTg and tTg-neo are of IgA isotype. Interestingly, the predominant antibody against mTg-neo is of IgG isotype, reflecting the immune response against an
following advantages over the single tTg-IgA ELISAs:

- Higher sensitivity, though comparable specificity, directed against different/new epitopes compared to the tTg antibody.
- It is suitable for IgA deficient patients, since it includes IgG isotype.

In the hierarchy of the 17 bio-markers, the three autoantibodies best reflecting CD intestinal damage, tTg-neo-IgA, tTg-neo check and EMA IgA, won the competition. Therefore, it is suggested that tTg neo-epitope antibodies should be preferably used to screen, diagnose and monitor compliance in CD patients. The mTg neo-epitope IgG represent a novel serological biomarker for CD. Its significance, pathogenic role, involvement in other autoimmune diseases or in non-celiac gluten sensitivity, awaits further scientific explorations.

References

children observed from birth in a natural history study. Amer J Gastroenterol 102: 2026-2035.