

Chapter 3

Evaluation of two new high-sensitivity C-reactive protein methods

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Abstract

Background

The implementation of a high-sensitivity C-reactive protein (hs-CRP) assay as a routine laboratory parameter may be necessary. It would be most practical to use one CRP method giving reliable results for the whole concentration range. We report here the evaluation of two new hs-CRP methods, which cover both the low and the high concentration ranges.

Methods

The BN ProSpec hs-CRP (Dade Behring) and Synchron LX20 PRO hs-CRP methods were compared with the existing hs-CRP IMMAGE method (taken as a reference) and, for the high concentration range, also with the routine Synchron LX20 CRP method (all from Beckman). Agreement among methods was examined in 521 samples. Reference values were estimated in 291 blood donors. Additionally, the influence of sample turbidity, a major problem of the present Synchron LX20 CRP method, was evaluated.

Results

Measurements of CRP by the BN ProSpec were linear down to 0.2 mg/L, whereas the linearity of Synchron LX20 PRO showed some systematic discrepancies. Over the whole measured range (0.2–250 mg/L), precision (coefficient of variation, CV) was $\leq 3.7\%$ for the BN ProSpec and $\leq 6.1\%$ for LX20 PRO. The Synchron LX20 PRO hs-CRP method was found to be superior to the current routine Synchron LX20 CRP method with regard to precision in the low concentration range and the influence of sample turbidity. Both in the low concentration range and especially in the high concentration range, large discrepancies between methods were observed.

Conclusion

Although acceptable performance was found for the Synchron LX20 PRO hs-CRP method, overall the performance of the BN ProSpec hs-CRP method was superior. However, standardization among assays needs further improvement in both the low and the high concentration ranges.

Introduction

C-reactive protein (CRP), an acute-phase protein, is a valuable laboratory parameter in the clinical evaluation of inflammatory disease. Although CRP is a classical acute-phase reactant, in the absence of infection or trauma its concentration is biologically stable over a long period of time¹. CRP has been introduced as a strong independent predictor of future coronary events in apparently healthy subjects as demonstrated in several clinical studies¹⁻³. Recently, a cardiovascular risk assessment algorithm has been proposed, using high-sensitivity CRP (hs-CRP) in the concentration range 0.7–3.9 mg/L as determined with a nephelometric immunoassay (BN II, from Dade Behring)¹. Although in some studies the limited clinical utility has been discussed⁴, there is still a need for more sensitive assays. Furthermore, implementation of hs-CRP as a routine laboratory parameter is to be expected.

In most clinical laboratories CRP measurements are performed by immunoturbidimetry on a routine clinical chemistry analyzer, with detection limits for CRP of about 2–5 mg/L. These methods are primarily suitable for detection of active inflammation. For studies on CRP as a risk factor for coronary artery disease, a hs-CRP method with a detection limit of about 0.2 mg/L is required⁵. A variety of methods have now been introduced for measuring hs-CRP and their analytical performance has been evaluated and compared⁵⁻⁷. These studies were mainly focused on comparing different methods in the low concentration range of 0–10 mg/L, taking BNII from Dade Behring as the reference method. It was apparent that standardization between the assays still needs improvement in the low range⁵⁻⁸. However, large discrepancies between different hs-CRP methods were also observed in the high concentration range (above 100 mg/L)⁹. The aim of the present study was to evaluate two new hs-CRP methods (Synchron LX20 PRO and BN ProSpec) and compare them to the existing hs-CRP IMMAGE method and also (in the higher range) to our routine Synchron LX20 CRP method. For the laboratory it is most practical to use one CRP method for both the low and the high concentration ranges. Therefore, to find out whether the hs-CRP methods can be used for both risk stratification and detection and monitoring of inflammation, their evaluation was performed over the whole measuring range.

In addition, the influence of sample turbidity, a known major problem of the routine Synchron LX20 method, was examined.

Materials and methods

Samples

Samples for method comparisons were collected from 521 persons either for whom CRP was requested for routine analysis or from a donor population (42 samples). Furthermore, venous blood samples were separately collected from 291 ostensibly healthy blood donors, (177 men and 114 women), who were selected according to the selection criteria of the Sanguin Blood Bank in Maastricht. The medical ethical committee of the hospital approved the procedure that was followed. Serum was

directly separated from the red cells after centrifugation and stored at -80°C until analysis¹⁰.

Methods

The hs-CRP assay on the BN ProSpec from Dade Behring is based on particle-enhanced immunonephelometry (N Hs CRP, cat no OQIY G13; supplement reagent OUMU15; Dade Behring, Liederbach, Germany).

The IMAGE hs-CRP (trade name: IMAGE[®] CRPH) and the LX20 hs-CRP (trade name Synchron LX[®]20 PRO) are both turbidimetric methods based on the peak rate principle⁵, measured by a near-infrared particle immunoassay, with a laser diode at 940 nm (cat no. 474630 and 378020; Beckman Coulter, Fullerton CA, USA).

CRP was measured on a routine clinical chemistry analyzer, the Synchron LX20 (trade name Synchron LX[®]20, cat no 465131; Beckman Coulter, Fullerton CA, USA): the method is based on immunoturbidimetry.

All the methods were calibrated to CRM 470/RPPHS. According to the manufacturers, the CRP target for CRM 470 is 39.2 mg/L, which was recovered by all instruments within 5% of that target. Table 3.1 presents the assay characteristics of the different methods used.

Table 3.1. Assay characteristics of the methods used.

Analyzer	Method	Dilution (mg/L)	Assay range (mg/L)	Manufacturer's claimed	
				Measuring range (mg/L)	Detection limit (mg/L)
IMAGE	hs-CRP	neat	0.20 – 60	0.20 – 1440	0.20
		1:6	1.2 – 360		
		1:24	4.8 – 1440		
BN ProSpec	hs-CRP	1:20	0.18 – 11	0.20 – 380	0.18
		1:100	0.88 – 55		
		1:400	3.5 – 220		
		1:2000	17.5 – 1150		
SynchronLX20 PRO	hs-CRP	neat	0.2 – 80	0.20 – 380	0.20
		ORDAC ^a	60 – 380		
Synchron LX20	CRP	neat	5 – 200	5.0 – 488	5.0
		ORDAC ^a	150 – 488		

^a ORDAC, over range detection and correction; the LX20 uses a smaller sample size for analysis of such samples. hs-CRP, high-sensitivity C-reactive protein.

The serum index measured on the Synchron LX20 was used to indicate the sample condition in terms of lipemia. A lipemic index above 1 was used to indicate turbidity. Sample turbidity was also assessed by macroscopic examination and by measuring triglycerides. Samples with triglyceride concentration above 3 mmol/L were classified as turbid samples.

Samples for precision studies were prepared from 11 serum pools in the concentration range from 0.2 – 250 mg/L, as determined on the BN ProSpec, taking into account cardiovascular risk assessment algorithm cut-off points³. Within-run precision was obtained by measuring one sample 20 times within a single run. Between-run precision

was obtained by measuring each concentration on 20 consecutive days, based on a single calibration (one lot number). Since the method agreement experiment was performed on the basis of one lot number (four calibrations), no lot-to-lot stability investigations during the between-run precision experiment were performed.

Statistics

Agreement between methods was assessed visually by the method of Bland and Altman^{11,12} and by Deming regression analysis¹³. For evaluation of blood donor samples, the 0.95 non-parametric inter-percentile interval was calculated¹⁴. Gender differences in samples from blood donors were assessed by the Mann-Whitney U test. Median serum versus plasma comparisons was assessed by Wilcoxon matched pairs signed-ranks test.

Results

Precision and linearity studies

Precision data for BN ProSpec and LX20 PRO are presented in Table 3.2. The mean value of the lowest pool (0.25 mg/L) as measured on the BN ProSpec was below the detection limit of the LX20 PRO and therefore these data cannot be reported. In the hs-CRP concentration range 0.7 to 3.9 mg/L, which has been proposed for cardiovascular risk assessment, between-run coefficients of variation (CVs) ranged from 1.1 to 3.3% for the BN ProSpec and from 2.5% to 5.4% for LX20 PRO. Precision of BN ProSpec was better ($CV \leq 3.7\%$) than that of the LX20 PRO ($CV \leq 6.1\%$) over the measured range (0.2 – 250 mg/L, as measured on the BN ProSpec).

Linearity results are presented as percentage deviation from expected values (Figure 3.1). Expected values were calculated from two initial pools containing 60 and 310 mg/L CRP. No systematic deviation from expected values for the BN ProSpec could be detected over the whole tested range. However, for LX20 PRO, the linearity of the method was less good (below 10 mg/L). Deviation from expected values changed from positive (0 – 10 mg/L) to negative (above 10 mg/L) values. No specific discrepancies in linearity were observed at concentrations for which automatic dilution is performed (Table 3.1).

Influence of sample turbidity on the CRP and hs-CRP methods on the LX20

To evaluate whether the hs-CRP LX20 PRO method is less sensitive to sample turbidity than the present LX20 CRP method, lipemic index, triglycerides and sample turbidity assessed by macroscopic examination were determined in all samples. Both methods were compared to the hs-CRP IMMAGE method (Figure 3.2). Below 20 mg/L ($n = 270$), 12 (4.4%), 29 (10.7%) and 100 (37%) samples were classified as turbid by means of lipemic index, triglycerides and macroscopic examination, respectively. Therefore, assessment of sample turbidity by means of macroscopic examination

appeared to be more sensitive than the use of either lipemic index or measurement of triglycerides.

Because a good relation was found between LX20 PRO and IMMAGE, LX20 PRO appears insensitive to sample turbidity, whereas on the LX20 a reliable CRP analysis seems possible only for clear serum samples.

Table 3.2 Summary of precision data.

Pool	Synchron LX20 PRO			BN ProSpec		
	Mean hs-CRP concentration (mg/L)	CV _B ^a (%)	CV _w ^b (%)	Mean hs-CRP concentration (mg/L)	CV _B (%)	CV _w (%)
0	- ^c	-	-	0.25	3.1	3.7
1	0.36	4.5	6.1	0.40	3.3	3.5
2	0.77	5.4	4.8	0.64	2.5	2.7
3	1.65	3.8	3.4	1.30	1.5	1.5
4	2.67	3.1	1.8	2.18	1.1	0.6
5	4.35	2.5	1.6	3.86	1.4	0.9
6	7.06	5.5	1.7	6.74	1.6	1.0
7	14.7	2.1	2.1	15.0	1.6	1.0
8	51.4	2.1	2.0	45.1	1.4	1.0
9	162	2.5	2.9	133	2.3	0.8
10	318	3.1	2.0	246	1.4	1.0

^{a, b} The concentration of high-sensitivity C-reactive protein (hs-CRP) are based on between-run results.

^a CV_B, between-run coefficient of variation (n = 20).

^b CV_w, within-run coefficient of variation (n = 20).

^c -, below detection limit.

Agreement between methods

Bland-Altman plots are presented in Figure 3.3, and the statistics are summarized in Table 3.3. The percentage plots¹⁵ were used, as the method differences appeared correlated with their mean values. Large discrepancies were observed both in the low and high concentration ranges.

For the BN ProSpec method, the observed bias was negative across the whole concentration range. However, in the low concentration range average bias was approximately 2.5 times higher than in the high concentration range (-19.3% versus -7.1%). As can be seen from percentage plots for the range 0 – 10 mg/L, a change in the slope occurs at 1.6 mg/L. Thus bias and limits of agreement were calculated for the range 1.6 to 10 mg/L (Table 3.3). Very broad limits of agreement were found, indicating poor agreement (-40 to 1.8%). Because of the proposed cardiovascular assessment algorithm, a separate Deming regression analysis was performed for concentrations below 1.6 mg/L. Deming comparison (0 – 1.6 mg/L range) of the BN ProSpec and IMMAGE methods gave a mean (standard deviation, SD) slope of 1.37 (0.22), an intercept of -0.09 (0.11) and an S_{y|x} of 0.06 (r = 0.979).

For LX20 PRO method, in the range from 0 – 10 mg/L, the observed bias was negative (-12.6%), whereas above 10 mg/L the observed bias was positive (8.9%). Again, very broad limits of agreement (-30 to 5%) were observed in the low concentration range.

Above 10 mg/L, the bias for LX20 PRO *versus* IMMAGE was higher and positive (8.9%) compared with BN ProSpec *versus* IMMAGE (-7.1%). Overall, the plots in Figure 3.3 suggest better agreement with the BN ProSpec. Moreover, above 100 mg/L there were 23% BN ProSpec samples, compared with 38% LX20 PRO samples having absolute differences with the reference method of more than 30 mg/L.

Comparison of the hs-CRP methods with our routinely used CRP method (Synchron LX[®]20) above 15 mg/L, resulted in a good agreement only with BN ProSpec: less good agreement was found with both IMMAGE and LX20 PRO (data not shown).

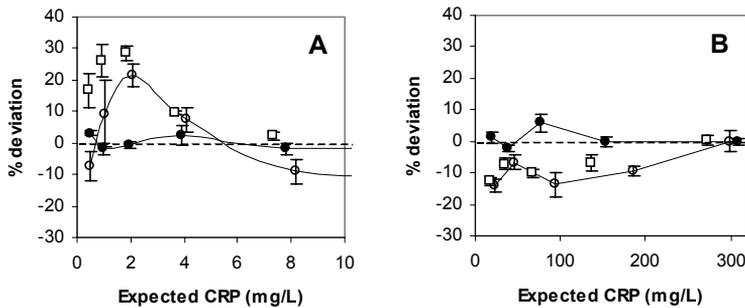


Figure 3.1. Linearity of the evaluated high sensitivity C-reactive protein (hs-CRP) methods for the CRP range 0 - 10 mg/L (A) and 10 - 300 mg/L (B).

Linearity is presented as the average percentage deviation together with standard deviation: $\text{deviation (\%)} = [(\text{measured} - \text{expected})/\text{expected}] \times 100$. Open circles indicate LX20 PRO results, closed circles the BN ProSpec hs-CRP results and square open symbols the hs-CRP IMMAGE results. The linearity data for the hs-CRP IMMAGE method were published previously⁹.

Evaluation of blood donor samples

The hs-CRP concentrations of 291 serum samples collected from apparently healthy adult blood donors were measured on the LX20 PRO and the BN ProSpec. A frequency histogram with percentile values is shown in Figure 3.4. On the LX20 PRO, the median CRP concentration was 1.81 mg/L with a 0.95 inter-percentile interval of 0.26 – 12.72 mg/L, whereas for the BN ProSpec a median CRP concentration of 1.35 mg/L and a 0.95 inter-percentile interval of 0.26 – 12.51 mg/L were found. No significant gender differences were found ($p < 0.053$ for LX20 PRO, $p < 0.132$ for BN ProSpec). In Figure 3.4 percentile values are reported for samples with CRP concentration < 10 mg/L (3.4% of cases omitted). The inter-percentile intervals found were 0.26 – 7.42 mg/L for LX20 PRO and 0.26 – 7.24 mg/L for BN ProSpec.

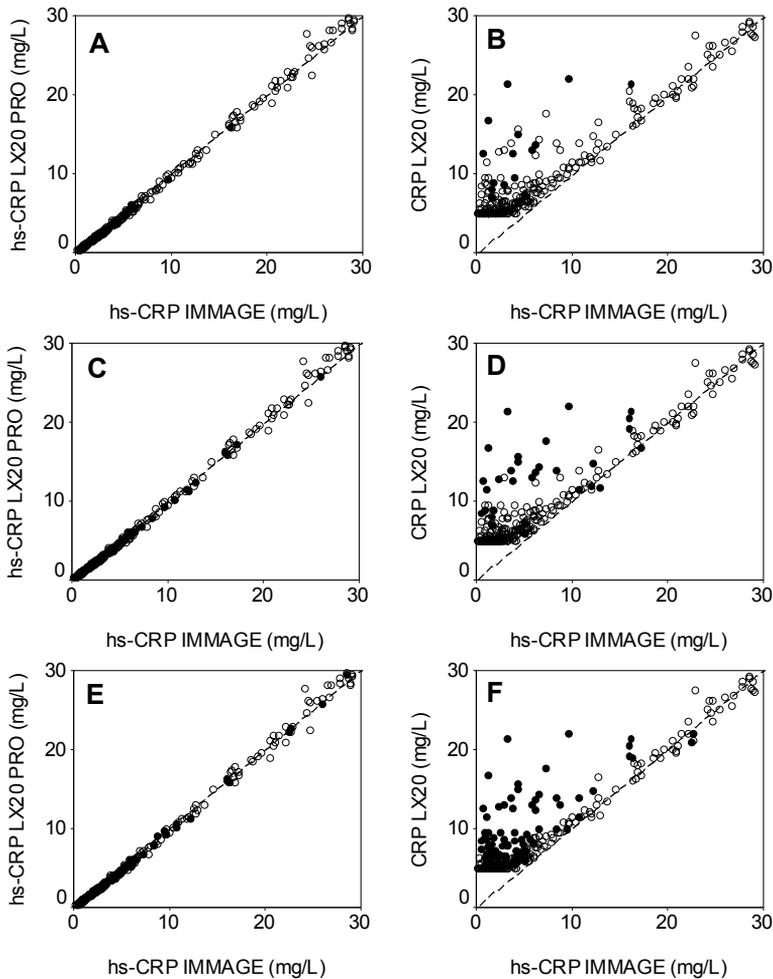


Figure 3.2. Influence of sample turbidity on C-reactive protein (CRP) and high sensitivity CRP (hs-CRP) measurements using the LX20 and LX20 PRO, respectively.

Samples with a lipemic index < 1 (A, B), triglycerides concentrations < 3 mmol/L (C, D) or turbidity assessed by macroscopic examination (E, F) are indicated by closed circles. The dashed line indicates unity.

Serum versus plasma comparison

To compare sample types, serum, heparin- and EDTA-plasma hs-CRP concentrations for 25 patients were compared for the two new methods. Only slight differences were seen between serum and plasma samples. For BN ProSpec, mean (SD) recoveries in heparin- and EDTA-plasma were 98.3 (3.4)% ($p < 0.02$) and 99.9 (10.5)% ($p < 0.18$), respectively, 100.4 (5.0)% ($p < 0.90$) and 108.5 (10.4)% ($p < 0.04$), respectively, for the hs-CRP LX20 PRO.

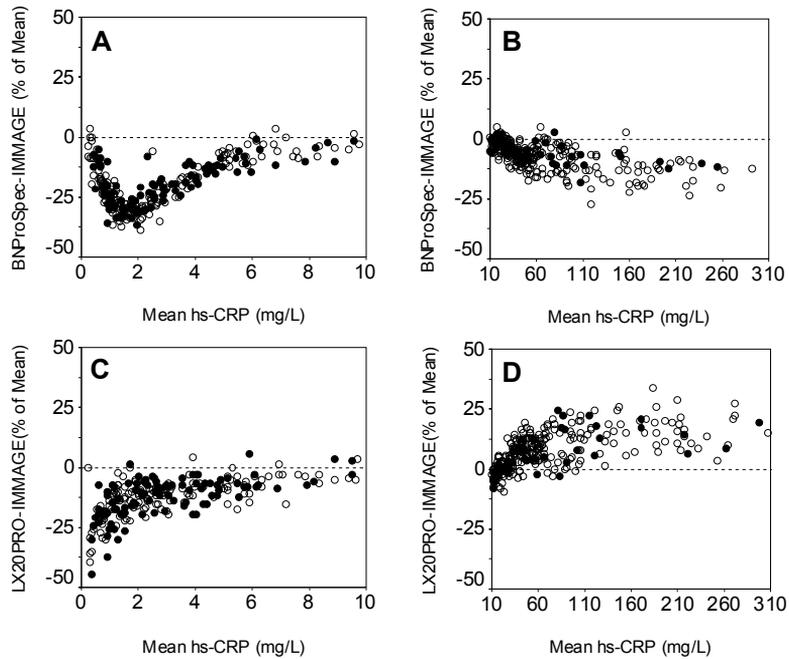


Figure 3.3. Method comparison in 521 patient samples by means of Bland-Altman analysis for the high-sensitivity C-reactive protein (hs-CRP) concentration ranges 0 – 10 mg/L (A, C) and 10 – 300 mg/L (B,D).

The *dashed lines* indicate zero difference between the methods. Closed symbols indicate samples showing turbidity assessed by macroscopic examination, open symbols indicate completely clear samples.

Table 3.3. Comparison of the LX20 PRO and BN ProSpec methods with the IMMAGE method.

	0 – 10 mg/L		10 – 350 mg/L	
	LX20 PRO (y) versus IMMAGE (x)	BN ProSpec (y) versus IMMAGE (x) ^a	LX20 PRO (y) versus IMMAGE (x)	BN ProSpec (y) versus IMMAGE (x)
<i>Deming regression analysis</i>				
Slope±SD	1.15 ± 0.17	0.96 ± 0.11	1.16 ± 0.12	1.11 ± 0.08
Intercept±SD	-0.10 ± 0.17	0.73 ± 0.03	-2.75 ± 3.42	-1.52 ± 2.49
r	0.995	0.996	0.995	0.997
S _{y x}	0.23	0.19	7.59	5.10
<i>Bland-Altman analysis</i>				
Bias (in %)	-12.6	-19.3	8.9	-7.1
Limits of agreements (in %)	-30 to 5	-40 to 1.8	-7.4 to 2.4	-18 to 4
Wilcoxon's test (z, p)	-12.6 p < 0.0001	-13.0 p < 0.0001	-13.7 p < 0.0001	-11.0 p < 0.0001

^a Deming regression and Bland-Altman analysis were performed on data for 1.6 – 10 mg/L (results for 0 – 1.6 mg/L are presented in the text). SD, standard deviation.

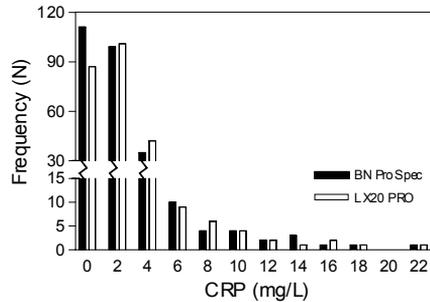


Figure 3.4. Evaluation of blood donor samples.

C-reactive protein (CRP) values were quantified in 291 blood donors (177 men and 114 women) of median age 49 years. Percentile values are based on samples with CRP concentrations of less than 10 mg/L. 2.5th, 25th, 50th, 75th and 97.5th percentile values for the BN ProSpec were 0.26, 0.67, 1.35, 2.64 and 7.24 respectively, and for the LX20 PRO they were 0.26, 0.77, 1.81, 3.12 and 7.42 respectively.

Discussion

Agreement among the methods

Two distinct populations of data could be identified from the Bland-Altman plots (*i.e.* those below and above 10 mg/L). Regression analysis and bias estimates were therefore performed separately for these two measuring ranges. In the percentage plots, mean bias (mean of relative differences) appeared to be larger in the low concentration range (-12.6% LX20 PRO, -19.3% BN ProSpec) than in the higher concentration range (8.9% LX20 PRO, -7.1% BN ProSpec) when comparing the methods to the hs-CRP IMMAGE method. Moreover, in the low concentration range BN ProSpec (nephelometric assay) showed a non-linear relationship with the IMMAGE (turbidimetric assay), with a slope change at around 1.6 mg/L, probably caused by lack of linearity of the LX20 PRO (see Figure 2.1). Hamwi et al. noticed similar disagreement when comparing four turbidimetric assays to the BN II method⁷.

However, in the higher range, regardless of the lower percentage bias, the differences found are clinically significant. Above 100 mg/L as measured by the hs-CRP IMMAGE method, there were 23% of BN ProSpec samples and 38% of LX20 PRO samples for which the absolute differences with the reference method was >30 mg/L. These results suggest that, above 100 mg/L there is better agreement between the BN ProSpec and the IMMAGE methods compared with that between the LX20 PRO and the IMMAGE methods. The observed results are in accordance with previous studies, in which at concentrations above 100 mg/L, the same large discrepancies were observed between the compared methods^{5,9}.

Since all method agreement studies were performed using reagents of only one lot number, influence of lot-to-lot instability could *a priori* be excluded. The differences between the methods might also have been caused by improper automatic dilution, but

this does not appear to be the case (Table 3.1). Furthermore, poor linearity might also cause poor agreement. Inspection of linearity results reveals that the LX20 PRO method is not linear, whereas the BN ProSpec appears linear across the whole concentration range. To be able to follow the influence of linearity on the agreement among the methods, previously published linearity results of the IMMAGE method were presented as percentage deviation from expected values in the same graph (Figure 3.1). The same trend in deviation from linearity seen for the LX20 PRO was seen for the IMMAGE. This deviation does not appear to be dependent on precision. Although slightly higher CVs were obtained below 1 mg/L, good precision data were observed for LX20 PRO and BN ProSpec across the whole range examined. Although the performance of BN ProSpec is better with respect to precision, the hs-CRP assay precision for risk stratification of vascular disease should be less than 10% at a concentration of 0.2 mg/L⁵, which was achieved for both methods.

All methods were calibrated to CRM 470/RPPHS. However, even assays calibrated to the same reference material may yield different results. The difference may be related to suboptimal value transfer. Alternatively, inappropriate curve-fitting or matrix differences between the system specific calibrators may be responsible for the observed bias⁸. It is obvious that standardization among assays should be improved not only in the low range, but also for the whole measuring range.

From our results it is clear that agreement between methods needs further improvement. Moreover, for clinical risk stratification, concordance between assays is needed, especially at cut-off values separating risk groups⁸.

Samples from blood donors

Samples from blood donors appeared to have higher median values (1.81 mg/L on the LX20 PRO, 1.35 mg/L on BN ProSpec) than those reported by others (range 0.58 – 1.13 mg/L^{5,16}), but were similar to the findings reported previously¹⁰. Methodology-related differences cannot be excluded. Besides, a weak positive correlation between age and hs-CRP concentration has been observed^{10,16}. Since in our population the median age was 49 years, compared to 32 years reported in the earlier study, this might also contribute to the higher values found⁵. The hs-CRP values higher than 10 mg/L (3.4% of blood donors) might be due to existence of some subclinical inflammatory disease^{5,10,17}.

Influence of sample turbidity

In this study, parallel comparison of the hs-CRP LX20 PRO method and the routine CRP turbidimetric method with the IMMAGE method revealed that turbidity of samples results in considerable overestimation of CRP concentrations measured with our routine CRP LX20 method. The samples that were used were randomly taken from hospital population (mostly fasting) and from donor samples (non fasting), the latter group to obtain more samples in the low range (<10 mg/L). As a consequence, there are relatively more donor samples (non-fasting), and thus turbid samples, in the lower concentration range (16.3% lower than 10 mg/L compared with 0.8% above 10 mg/L). An effect of turbidity is of course present for the whole concentration range, but in our study this was more pronounced in the lower range caused by the sample population.

Although the reagent insert from Beckman indicates that turbidity can interfere in the test and ultracentrifugation of turbid samples is required, we showed that the influence of non-specific interferences with the Synchron LX20 CRP is greatly underestimated. This is very important, assuming that in order to allow stat analysis, CRP is still measured in many laboratories using the immunoturbidimetric Synchron LX20 method, which according to the manufacturer is reliable for clear samples with values above 5 mg/L. Besides, lipemic index, the automatic screening procedure for selection of turbid samples on the LX20, appeared inadequate.

Conclusion

Use of hs-CRP as a routine laboratory parameter appears inevitable. Therefore, for the laboratory, it would be most practical to use one CRP method giving reliable results for the whole measuring range. The BN ProSpec method appears superior to the Synchron LX20 PRO method and suitable for the whole measuring range. The Synchron LX20 PRO is to be preferred to the current Synchron LX20 CRP method, regarding precision in the low concentration range and influence of sample turbidity. However, the Synchron LX20 PRO needs some improvement with respect to linearity. Furthermore, better standardization among hs-CRP assays is still needed.

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