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## Development of a biosensor immunoassay for the quantification of $\alpha_{S1}$ -casein in milk

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An immunoassay to quantify  $\alpha_{S1}$ -casein ( $\alpha_{S1}$ -CN) in milk using an optical biosensor, based on surface plasmon resonance (SPR) measurement, has been developed. The assay consists of a two-step sandwich strategy, with two anti- $\alpha_{S1}$ -CN antibodies directed against each extremity of the molecule. This strategy permits only intact  $\alpha_{S1}$ -CN to be quantified and not its degradation products. The calibration curve was obtained using a reference milk powder with a known  $\alpha_{S1}$ -CN concentration. Analysis time per sample was less than ten minutes. The antibody-coated surface could be used for more than 150 determinations. Detection limit was established at 0.87  $\mu\text{g/ml}$  and the intra- and inter-assay variation coefficients were 2.86 and 5.31%, respectively. The method was applied to raw milk to quantify intact  $\alpha_{S1}$ -CN, with no pre-treatment of the sample. An initial analysis of 48 milk samples permitted  $\alpha_{S1}$ -CN concentrations ranging from 8.8 to 12.06  $\text{mg/ml}$  to be obtained.

**Keywords:**  $\alpha_{S1}$ -casein, biosensor, immunoassay, milk, quantification.

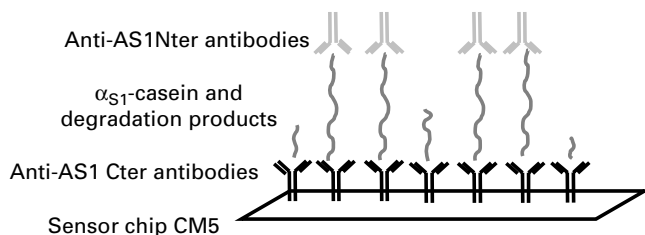
Cow milk contains around 33 g proteins/l. Milk proteins are divided into two principal families, whey proteins (WP; 20% of milk proteins) and caseins (CN; 80% of milk proteins). WP include  $\beta$ -lactoglobulin ( $\beta$ -lg),  $\alpha$ -lactalbumin ( $\alpha$ -la), serum albumin (BSA) and immunoglobulins (Igs). CN are represented by four major proteins named  $\alpha_{S1}$ -,  $\alpha_{S2}$ -,  $\beta$ - and  $\kappa$ -CN, respectively. The relative concentration of these four CN in milk can vary according to different factors, such as the breed (Storry et al. 1983), the lactation stage of the cow (Barry & Donnelly, 1980) and the feeding (Sutton, 1989). These variations can affect the coagulation properties of milk (Okigbo et al. 1985), the cheese yield (Montagne et al. 1995) and the general quality of cheese. Furthermore, indigenous milk enzymes can hydrolyse CN, leading to the formation of degradation products that, for the most part, are soluble. Among the different types of proteins present in milk, only intact CN will constitute the cheese matrix, WP and degradation products being mainly eliminated with the whey during draining. Therefore, the quality of milk will depend not only on the relative proportion of the four CN, but also on the state of hydrolysis of these CN. Thus, the determination of intact CN con-

centration seems to be important in obtaining an accurate estimation of the quality of milk used for cheesemaking.

Several biochemical methods have been developed to quantify the four major CN in milk, such as gel electrophoresis (Ng-Kwai-Hang & Kroeker, 1984; Collin et al. 1987; Deshmukh et al. 1989), Fast Protein (FPLC) (Andrews et al. 1985; Guillou et al. 1987; Collin et al. 1991) and High Performance Liquid Chromatography (HPLC) (Visser et al. 1991; Bobe et al. 1998; Mas et al. 1999; Bordin et al. 2001) and capillary electrophoresis (De Jong et al. 1993; Vallejo-Cordoba, 1997). But none of these methods gave an optimum separation of all the major milk proteins. In particular, separation between  $\alpha_{S1}$ - and  $\alpha_{S2}$ -CN by FPLC, and  $\alpha_{S2}$ - and  $\kappa$ -CN by HPLC, were not always achieved (Leonil et al. 1995; Bobe et al. 1998). Moreover, these techniques required sample preparation before analysis, increasing the assay time. Finally, a microparticle-enhanced nephelometric immunoassay has been developed to quantify  $\alpha_{S1}$ -,  $\beta$ - and  $\kappa$ -CN (Collard-Bovy et al. 1991; El-Bari et al. 1991) and applied to milk and dairy products (Humbert et al. 1991). This technique used polyclonal antibodies directed against the whole CN, rendering impossible the discrimination between intact CN and their degradation products.

Biosensor systems, using the detection principle of surface plasmon resonance (SPR) (Jonsson et al. 1991), are a

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**Fig. 1.** Strategy developed for the quantification of  $\alpha_{S1}$ -CN using a sandwich assay.  $\alpha_{S1}$ -CN is taken between two antibodies specific of its N- and C-terminal extremities, allowing the detection of only the intact molecule.

recent addition to research and a new analytical tool. The biosensors enable study of all types of interactions between two molecules (protein–protein, enzyme–substrate, antigen–antibody, etc). Among the optical biosensors commercially available, the Biacore system (Biacore International SA, Uppsala, Sweden) is one of the most commonly used. Indeed, it has already been applied in the detection of enterotoxins (Rasooly & Rasooly, 1999; Rasooly, 2001; Homola et al. 2002), drug residues (Sternesjo et al. 1995; Baxter et al. 2001; Gaudin & Maris, 2001; Haasnoot & Verheijen, 2001; Ferguson et al. 2002) or vitamins (Caselunghe & Lindeberg, 2000; Indyk et al. 2000), in milk and dairy products. Several analysis kits are now commercialised to quantify contaminants or vitamins in food products.

$\alpha_{S1}$ -CN, the most abundant CN, accounts for 35–45% of the CN content in milk. In fresh raw milk, the  $\alpha_{S1}$ -CN may be hydrolysed by indigenous milk enzymes, plasmin and cathepsin-D (Eigel, 1977; Kaminogawa et al. 1980).  $\alpha_{S1}$ -CN plays a role in milk coagulation, in curd firmness (Grandison et al. 1985; Remeuf et al. 1989) and has an important structural role by contributing to the integrity of the cheese matrix (Lawrence et al. 1987).

The objective of the present study was to develop a method that specifically quantifies intact  $\alpha_{S1}$ -CN only and not its degradation products. Therefore, the strategy used was a sandwich immunoassay, taking the protein to be quantified between two antibodies directed against the N- and C-terminals (Fig. 1). This method was developed and validated on milk.

## Materials and Methods

### Reagents

Unless otherwise stated, chemicals of analytical grade were purchased from VWR (VWR International, Fontenay-sous-Bois, France).

Sensor chip carboxymethyl 5 (CM5) (research grade), Rabbit anti-mouse Fc  $\gamma$  Igs (RAM), HEPES buffer saline (HBS-EP) pH 7.4 (10 mM-4-(2-hydroxyethyl)-piperazine-1-ethanesulfonic acid, 150 mM-NaCl, 3.4 mM-EDTA, 0.005%

Surfactant P20), Acetate pH 4.5 (10 mM-sodium acetate pH 4.5), 100 mM-N-hydroxysuccinimide (NHS), 400 mM-N-ethyl-N'-(3-di-ethylaminopropyl) carbodiimide (EDC) and ethanolamine hydrochloride pH 8.5 were all prepared with reagents from Biacore International SA (Biacore International SA, Uppsala, Sweden).

$\alpha_{S1}$ -,  $\alpha_{S2}$ -,  $\beta$ -CN were purified as described previously with a minimum purity of 85% (Collin et al. 1991; Senocq et al. 2001b).  $\kappa$ -CN,  $\alpha$ -la,  $\beta$ -lg, IgG and BSA were obtained from Sigma-Aldrich (Sigma-Aldrich, St Quentin Fallavier, France).

### Milk samples

**Milk powder:** Skimmed low heat milk powder (SRTAL-INRA, Poligny, France) was used for biosensor calibration. Milk was reconstituted at 120 g/l, 10 mM- $\text{CaCl}_2$ . The concentration of each CN in milk powder has been determined by reverse phase HPLC (RP-HPLC) (Nutrinov, Vezin-le-Coquet, France).

**Milk samples:** Six herds (three Montbeliarde and three Holstein) of ten cows each received different feeding and were milked 8 times over a three month period, providing a total of 48 milk samples. Samples were stored at  $-20^\circ\text{C}$ . Before analysis, the top fat layer was removed by centrifugation (1800 g,  $4^\circ\text{C}$ , 15 min). Thirty milk samples were selected to be analysed by infrared method (International Dairy Federation, 1996) and capillary electrophoresis.

### Biosensor assay

**Apparatus:** The optical biosensor used to perform the assay was a Biacore 3000 (Biacore International SA, Uppsala, Sweden).

**Detection principle:** The Biacore technology allows real-time measurement of molecule interactions using Surface Plasmon Resonance (SPR) detection (Jonsson et al. 1991). One of the reactants is immobilised onto an extended carboxymethyl dextran matrix layered on a gold surface (Sensor chip CM5), and the other is introduced, in a continuous flow over the sensor surface. The SPR detects and measures changes in refractive index due to binding and dissociation of interacting molecules in proximity to the gold surface. The change in refractive index is proportional to the quantity of analyte interacting with the ligand and causes a shift in the angle of index at which the SPR phenomenon occurs. These shifts, monitored continuously over time, are shown as sensorgrams and expressed in resonance units (RU). The integration of SPR detection, a microfluidic system and operator designed sensor surfaces into one automated analytical system provides quantitative analysis of biospecific interactions.

### Peptide immunogens

The peptides were chosen in the  $\alpha_{S1}$ -CN sequence and corresponded to the N- and C-terminal ends of the CN and were called AS1Nter and AS1Cter respectively. The sequence -rpkhpikhqglpqevlne-, corresponding to the fragment 1–18 of  $\alpha_{S1}$ -CN, constituted the peptide AS1Nter. The sequence -pigsensekttmplw-, corresponding to fragment 185–199 of  $\alpha_{S1}$ -CN, constituted the peptide AS1Cter.

The peptides were chemically synthesised by Synt:em (Nîmes, France), with a minimum purity of 85%. A cysteine residue was added at the C-terminal of the AS1Nter peptide and modified by C-terminal amidation. A cysteine residue was added at the N-terminal of the AS1Cter peptide.

The peptides were conjugated 2:1 w/w to Keyhole Limpet Hemocyanin (KLH) to increase their immunogenicity.

### Polyclonal antibodies

Polyclonal antibodies (Pabs) directed against  $\beta$ -,  $\alpha_{S2}$ - and  $\kappa$ -CN were produced as previously described (Senocq et al. 2001a).

### Production of monoclonal antibodies (Mabs)

Female BALB/c mice (IFFA-CREDO, St-Germain sur l'Arbresle, France) were immunised with a mixture of the two conjugated peptides (5  $\mu$ g of each) in Complete Freund Adjuvant (Difco laboratories, Detroit, MI, USA) distributed equally into the rear foot pads. After 14 d, mice were immunised using the same procedure (5  $\mu$ g of each conjugated peptides) in Incomplete Freund Adjuvant (Difco laboratories). On day 17, draining lymph popliteal nodes were removed and pooled. The polyclonal serum of mice was collected to be tested. Fusion of lymphocytes and myeloma cells X63/Ag 8.653 (Kearney et al. 1979) was carried out with 1 ml 45% PEG 1000 following the procedure described by Köhler & Milstein (1975). Supernatants of hybrid clones were assayed by Antigen Coated Plate Enzyme-Linked Immunosorbent Assay (ACP-ELISA) (see below).

Ascites from interesting Mabs were obtained according to the procedure of Jones et al. (1990). Mabs were purified from ascitic fluid by affinity chromatography using a HiTrap NHS-activated HP column (Amersham Pharmacia Biotech, Uppsala, Sweden) according to the manufacturer recommendations. Briefly, 10 mg of  $\alpha_{S1}$ -CN in 1 ml coupling buffer (0.2 M-NaHCO<sub>3</sub>, 0.5 M-NaCl, pH 8.3) were covalently immobilised on the column. Any excess active groups were deactivated by washing with 0.5 M-ethanolamine, 0.5 M-NaCl, pH 8.3 and the non-specifically bound ligands were washed out with 0.1 M-acetate, 0.5 M-NaCl, pH 4. Ascitic fluid (1 ml) diluted in 4 ml running buffer (75 mM-Tris-HCl, pH 8) was then injected. The column was washed with running buffer. Mabs were eluted with

elution buffer (100 mM-glycine-HCl, 0.5 M-NaCl, pH 2.7) and the eluted fraction was neutralised by addition of  $\frac{1}{4}$  volume of 1 M-Tris-HCl, pH 9. The purified antibodies were aliquoted and stored at  $-20^{\circ}\text{C}$ .

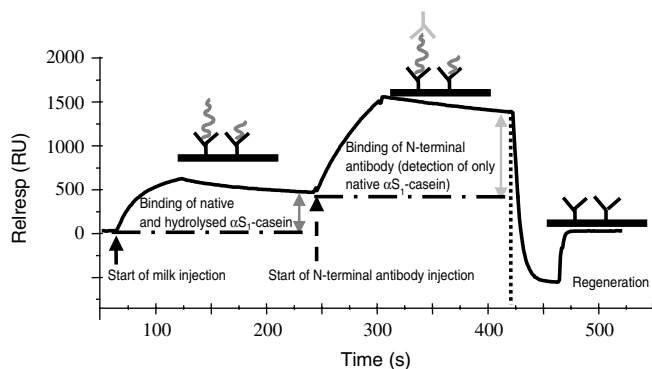
### Characterisation of monoclonal antibodies

**Characterisation by ACP ELISA.** This method was used to test the hybrid clones against peptides AS1Nter, AS1Cter and  $\alpha_{S1}$ -CN. Briefly, 100  $\mu$ l each antigen at 0.5  $\mu$ g/ml 0.1 M-bicarbonate buffer, pH 9.6 were coated onto a microtitre plate (NUNC F96 Maxisorp, Dominique Dutscher, Brumath, France) and incubated 1 h 30 min at  $37^{\circ}\text{C}$ . The remaining binding sites were blocked by incubating 250  $\mu$ l gelatin (VWR International) at 10 g/l phosphate-buffered saline, 0.05% Tween 20 (PBS-T) for 1 h at  $37^{\circ}\text{C}$ . Culture supernatants (50  $\mu$ l) were diluted 1:2 in PBS-T and incubated 1 h at  $37^{\circ}\text{C}$ . Bound Ig were detected by incubating 100  $\mu$ l of donkey anti-mouse immunoglobulin alkaline phosphatase conjugate (Jackson ImmunoResearch, Interchim, Montluçon, France) diluted 1/3000 in PBS-T for 1 h at  $37^{\circ}\text{C}$ . Wells were rinsed between each incubation step for 15 s with four changes of 250  $\mu$ l PBS-T. Following the last rinsing, 100  $\mu$ l *p*-nitrophenyl phosphate (Sigma-Aldrich) at 1 g/l 1 M-diethanolamine-HCl, 1 mM-MgCl<sub>2</sub>, 0.1 mM-Zinc acetate were incubated in the wells. After 30 min, the absorbance at 405 nm was read against a blank, and corrected according to the background signal in the absence of antigen.

**Characterisation by Biacore.** Mabs recognising AS1Nter or AS1Cter peptides and  $\alpha_{S1}$ -CN were tested in Biacore to detect if they were able to capture  $\alpha_{S1}$ -CN.

**Preparation of the sensor surface.** RAM were immobilised covalently on a CM5 sensor chip by amine coupling, as described previously (Jonsson et al. 1991). Briefly, a continuous flow of HBS-EP passing over the sensor surface at 5  $\mu$ l/min was maintained. The CM5 carboxymethylated dextran matrix was activated by the injection of 35  $\mu$ l of a solution containing 0.2 M-EDC and 0.05 M-NHS. Next, 35  $\mu$ l RAM (30 mg/l in Acetate, pH 4.5) were injected, followed by 35  $\mu$ l 1 M-ethanolamine to block remaining NHS-ester groups. The immobilisation level was 10000 RU, corresponding to 10 ng/mm<sup>2</sup> RAM. RAM were immobilised on flow channel Fc2, with Fc1 being used as reference cell.

**Assay principle:** A continuous flow was maintained at 10  $\mu$ l/min. 20  $\mu$ l of supernatant of hybrid clones recognising AS1Nter or AS1Cter and  $\alpha_{S1}$ -CN were injected onto the RAM sensor chip, followed by the injection of 20  $\mu$ l  $\alpha_{S1}$ -CN at 20  $\mu$ g/ml HBS-EP. Regeneration was achieved with 10  $\mu$ l 50 mM-NaOH.



**Fig. 2.** Diagrammatic representation of a sensorgram of a typical milk sample showing the various steps involved in the sandwich method. The response taken into consideration for casein quantification corresponds to the one of the binding of anti-AS1Nter antibodies on the intact  $\alpha_{S1}$ -CN.

### Biosensor immunoassay

**Sample preparation:** To disrupt the casein micelles, several dissociating buffers were tested for milk samples dilution: HBS-EP, HBS-EP+EDTA (10, 30, 50 and 75 mM), 2 and 6 M-urea, 0.4 M-tri-sodium citrate, and SDS, Tween 80, Triton X100, CHAPS (3-[(3-Cholamidopropyl)dimethylammonio]-1-propanesulfonate), sarcosine and Nonidet P40 (NP40) at 10 g/l.

**Assay principle.** Anti-AS1Cter antibodies (1/20 in Acetate pH 4.5) were immobilised on the sensor surface as described previously. A continuous flow was maintained at 30  $\mu$ l/min. 30  $\mu$ l of sample were injected, followed by the injection of 30  $\mu$ l anti-AS1Nter monoclonal antibodies, diluted 1/100 in HBS-EP, as shown in Fig. 1. The regeneration of the sensor surface was accomplished with two 15  $\mu$ l injections of 5 mM-NaOH.

**Calibration curve.** A Calibration curve was produced with serial dilutions (1/20 000 to 1/1250) of milk powder containing a known  $\alpha_{S1}$ -CN concentration in HBS-EP. The calibration curve was established with the response corresponding to the binding of anti-AS1Nter antibodies on the intact  $\alpha_{S1}$ -CN, as shown in Fig. 2.

**Specificity of the assay.** The specificity was assessed by replacing Mab anti-AS1Nter with Pab directed against  $\beta$ -,  $\alpha_{S2}$ - and  $\kappa$ -CN.

**Quantification in milk samples.** Milk samples were diluted 1/5000 in HBS-EP buffer. To determine  $\alpha_{S1}$ -CN concentration, each sample was analysed in duplicate.

**Assay validation.** The detection limit was calculated from the mean of the measured content of a representative

blank sample ( $n=20$ ) plus 3 times the standard deviation of the mean (mean+3sd). Assay precision was defined by determining *intra-assay* (within run) and *inter-assay* (between runs) variation. Intra-assay variation was determined by ten successive analyses of the same sample at three different dilutions (1/6667, 1/5000 and 1/4000). Inter-assay variation was evaluated with the same samples in 10 different runs.

To determine the accuracy, the recovery of exogenous amounts of  $\alpha_{S1}$ -CN added to a milk was calculated. Four different quantities of milk powder corresponding to 0.63, 1.26, 3.78 and 6.3 mg  $\alpha_{S1}$ -CN/ml were added to a raw milk sample. Each sample was analysed, in duplicate, at a 1/6000 dilution.

### Capillary electrophoresis

Capillary electrophoresis was carried out using an Agilent CE 1100 (Agilent GMBH, Karlsruhe, Germany) controlled by its software data system, Agilent chemstation for CE (version A09.01, Agilent). The separation was performed using a bare fused silica column Agilent 24.5 cm. The separation was conducted at 20 kV and sample solutions were injected at 500 mbarsec. The running buffer consisted in 50 mM-Phosphate buffer with 20 mM-DDT and 0.1% Hydroxyethylcellulose, 8 M-urea, pH 2.5. Samples were reduced in waterbath 2 h at 40 °C in reducing buffer (50 mM-Phosphate buffer with 10 mM-DDT and 8 M-urea, pH 8). The run time was 10 min per run; 30 min including conditioning (NaOH followed by H<sub>2</sub>O and run buffer).

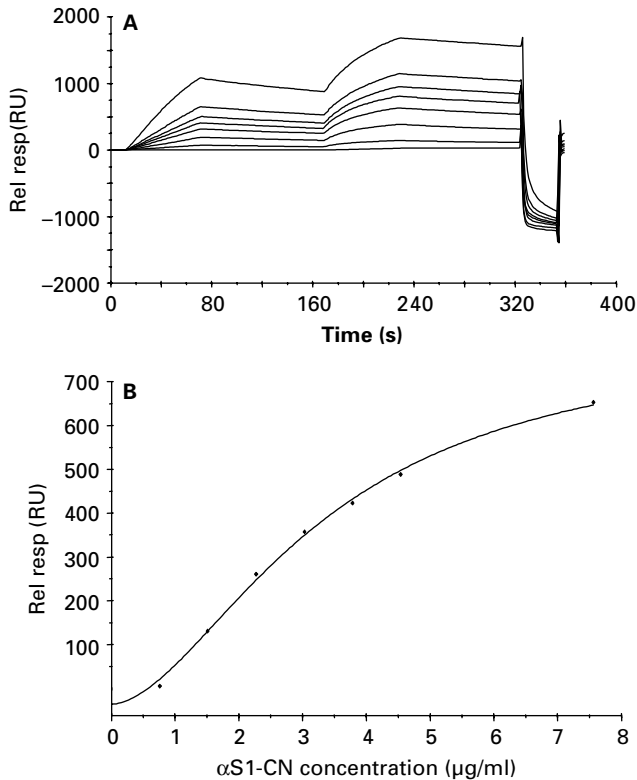
## Results

### Production and characterisation of monoclonal antibodies

One fusion experiment yielded 11 positive clones. Among those, 7 produced Mabs recognizing AS1Cter peptide and 4 Mabs recognizing AS1Nter peptides in ACP ELISA. Mabs produced by the 11 positive clones cross-reacted with  $\alpha_{S1}$ -CN. These Mabs were tested in Biacore via a RAM sensor chip to see if they are able to capture  $\alpha_{S1}$ -CN. Four Mabs directed against the C-terminal end of  $\alpha_{S1}$ -CN and two directed against the N-terminal end recognized  $\alpha_{S1}$ -CN after fixation on the RAM sensor chip. The Mab presenting the best fixation rate of  $\alpha_{S1}$ -CN was chosen as the capture antibody for the immunoassay. It was a Mab directed against the C-terminal end of the protein that was called anti-AS1Cter (data not shown).

The secondary antibody was chosen among the Mabs recognising the N-terminal end of  $\alpha_{S1}$ -CN. The choice was made by a sandwich test via the RAM sensor chip. The antibody was chosen for its capacity to detect the  $\alpha_{S1}$ -CN after capture of the protein by the anti-AS1Cter antibody and was called anti-AS1Nter.





**Fig. 3.** Determination of standard curve A: sensorgram obtained for  $\alpha_{S1}$ -CN concentrations ranging from 0 to 12.1  $\mu\text{g/ml}$ . B: Resulting standard curve calculated with N-terminal antibody response.

#### Characteristics of the assay

**Specificity of the assay.** The specificity of the assay was assessed in two different ways. Firstly, the specificity of the anti-AS1Cter antibodies immobilised on the chip was tested against the principal milk proteins ( $\alpha_{S2}$ -,  $\beta$ -,  $\kappa$ -CN,  $\alpha$ -la,  $\beta$ -lg, IgG and BSA). The different proteins were injected onto the anti-AS1Cter coated sensor chip at 10  $\mu\text{g/ml}$ . No cross-reaction was observed.

In milk, 95% of CN are organised in a micellar structure in association with calcium and phosphate. Therefore, the micelles have to be disrupted for the quantification of single CN. The HBS-EP buffer contains EDTA known to chelate calcium and destabilise the CN association. Several dissociating buffers containing detergents and chelating agents at different concentrations have been tested for their effects on the release of individual casein. Results obtained with these solutions did not differ from those obtained with HBS-EP (data not shown). So, the HBS-EP buffer was used for sample dilution. To verify if the response observed with milk or milk powder was due to the binding of a CN complex and not only  $\alpha_{S1}$ -CN, the secondary antibodies anti-AS1Nter was replaced by Pabs, specific for  $\beta$ -,  $\alpha_{S2}$ - or  $\kappa$ -CN. No binding of these probes on the immobilised antigen was observed,

**Table 1.** Determination of recovery, after exogenous addition of  $\alpha_{S1}$ -CN, in a raw milk sample. Four different quantities of reconstituted milk powder corresponding to 0.63, 1.26, 3.78 and 6.3 mg  $\alpha_{S1}$ -CN/ml were added to a raw milk sample. Each sample analysed was diluted 1/6000. Responses were the mean of two determinations

	Theoretical $\alpha_{S1}$ -CN concentration (mg/ml)	$\alpha_{S1}$ -CN concentration obtained (mg/ml)	Recovery (%)
Milk		6.32	
Milk+0.63 mg/ml	6.95	6.96	100.1
Milk+1.26 mg/ml	7.58	7.75	102.2
Milk+3.78 mg/ml	10.10	9.52	94.24
Milk+6.3 mg/ml	12.62	12.35	97.9

demonstrating that only  $\alpha_{S1}$ -CN had been captured by the anti-AS1Cter.

**Time of analysis.** The analysis of one sample, including regeneration, takes around 10 minutes.

**Stability.** The regeneration conditions were optimal by addition of 5 mM-NaOH. A sensor surface could be used for more than 150 cycles without any significant baseline decrease. However, a new calibration may be necessary after 60 cycles.

**Standard curve.** The curve was established with the anti-AS1Nter antibodies response to  $\alpha_{S1}$ -CN concentrations in reconstituted milk ranging from 0 to 12.1  $\mu\text{g/ml}$  (Fig. 3).

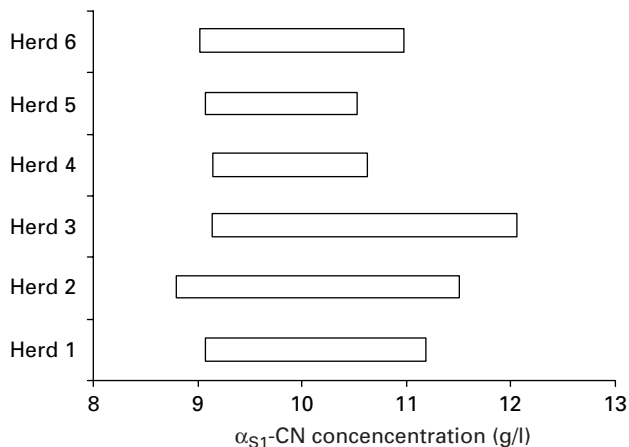
**Detection limit.** The detection limit, determined from the mean of the measured content of a representative blank sample ( $n=20$ ; mean+3SD), was established at 0.87  $\mu\text{g/ml}$ .

**Reproducibility.** The reproducibility determined with different concentrations of a raw milk sample, established for intra- and inter-assays was 2.86% and 5.31% respectively.

**Accuracy.** Exogenous additions of four known  $\alpha_{S1}$ -CN concentrations in a raw milk sample were recovered between 94.2 and 102.2% (Table 1).

#### Analysis of milk samples

The 48 milk samples from 6 cow herds [3 Holstein (herds 1, 2, 3) and 3 Montbeliarde (herds 4, 5, 6)] collected at 8 different milking times were analysed. The concentrations of intact  $\alpha_{S1}$ -CN obtained for milk samples ranged from 8.58 to 12.06 mg/ml (Fig. 4).



**Fig. 4.** Minimal and maximal values obtained for the  $\alpha_{S1}$ -CN concentration (in g/l) calculated in 48 samples of raw milk. Six herds, three Holstein (Herds 1, 2 and 3) and three Montbeliarde (Herds 4, 5, 6) of ten cows each, were milked 8 times over a three month period.

Thirty milk samples selected to have a large range of concentration were analysed by infrared method and capillary electrophoresis. The correlation coefficients between the different methods were presented in Table 2.

## Discussion

The development of an immunoassay for the quantification of  $\alpha_{S1}$ -CN in milk using Biacore is presented in this study. The strategy used is a sandwich assay with two monoclonal antibodies directed against each extremity of the protein. To develop this assay, the immunological tools have been produced using synthetic peptides as immunogens to target the specificity of the antibodies against the selected parts of the CN. Two peptides have been chosen, corresponding to each extremity of the  $\alpha_{S1}$ -CN. The strategy relied on the hypothesis that the peptide would mimic the antigenic determinant exposed by the CN. A primary selection of antibodies produced was realised by ACP-ELISA. All of the positive antibodies obtained recognised the peptide and the entire  $\alpha_{S1}$ -CN but few of them, especially antibodies directed against the N-terminal end of the protein, showed a weaker signal in ELISA for the  $\alpha_{S1}$ -CN. Among these antibodies, a second selection was accomplished with Biacore to choose the antibodies which were used immobilised on the sensor chip to capture the  $\alpha_{S1}$ -CN. The choice was made according to two criteria. The first was the ratio between the binding level of the antibody on the RAM-sensor chip and the binding of  $\alpha_{S1}$ -CN on this antibody. The second was the stability of the antibody-antigen complex. Actually, among the eleven antibodies recognising  $\alpha_{S1}$ -CN in ELISA, five were not able to capture the  $\alpha_{S1}$ -CN after immobilization on the RAM sensor chip and one captured the  $\alpha_{S1}$ -CN but the complex formed was not stable.

**Table 2.** Correlation coefficients observed between the  $\alpha_{S1}$ -CN concentration determined with the Biacore assay, the  $\alpha_{S1}$ -CN concentration determined by capillary electrophoresis and the total protein concentration determined by infrared spectroscopy

	TP/Biacore	TP/CE	CE/Biacore
Correlation coefficient	0.614***	0.059	0.005

\*\*\*  $P < 0.001$

TP: total protein content determined by infrared method includes all milk proteins

CE: capillary electrophoresis

To quantify  $\alpha_{S1}$ -CN in milk, a calibration curve was established with a reference milk powder with a known  $\alpha_{S1}$ -CN concentration in order to reduce the matrix effect.

This technique was applied to quantify  $\alpha_{S1}$ -CN in 48 milk samples. The values obtained in this study varied significantly, with a large range of concentrations. Nevertheless, 87.5% ranged from 9 to 11 mg/ml, which corresponds to the values generally observed in milk. These important variations could be explained by the size of the herd. The limited size of the herds was deliberately chosen in order to increase the variability in the concentrations. The results did not permit a relation to be established between the variation and the different characters (breeds, feeding and lactation stage). The variations seem to be less important for the Montbeliarde herds. The  $\alpha_{S1}$ -CN concentration calculated with the primary response after milk injection, was compared with the concentration determined with the secondary response after the binding of the AS1Nter antibodies (data not shown). For the majority of samples,  $\alpha_{S1}$ -CN concentrations determined with the primary response were higher than those determined with the secondary response. The primary response corresponds to the fixation of  $\alpha_{S1}$ -CN and C-terminal fragments of  $\alpha_{S1}$ -CN onto the chip, whereas the secondary response corresponds to the detection of the entire protein by the specific antibodies from the N-extremity of  $\alpha_{S1}$ -CN. These results confirmed that the strategy developed here quantified only intact  $\alpha_{S1}$ -CN and not its proteolysis products. The difference in concentration between the two responses was not always the same, which tended to demonstrate the fact that the level of proteolysis was different in the milk samples. In whole fresh milk,  $\alpha_{S1}$ -CN may be hydrolyzed by indigenous milk enzymes, plasmin and cathepsin-D (Eigel, 1977; Kaminogawa et al. 1980) and this enzymatic activity can vary from one milk to another (Andrews, 1983; Reimerdes, 1983).

The method was compared with total protein content determination and capillary electrophoresis. A significant correlation was observed between the total protein content and  $\alpha_{S1}$ -CN but not between capillary electrophoresis and the two other methods.  $\alpha_{S1}$ -CN is the most abundant protein in milk, so it seems to be normal to have a correlation between its concentration and the total protein content. So, the results obtained with capillary electrophoresis

seem surprising. Furthermore, no correlation was observed between the total protein content and the additional concentration of the six major milk proteins determined by capillary electrophoresis (data not shown). This absence of correlation is probably due to the fact that CE, as it was used in the present study, is a semi-quantitative technique. Indeed, CN concentrations were determined by integration of the peak areas. A better accuracy could be reached by evaluating the concentrations with a calibration curve obtained with standards ran in parallel.

The immunoassay developed here is able to quantify intact  $\alpha_{S1}$ -CN in milk. It is fast ( $\approx 10$  min per analysis), repeatable, sensitive, automated and requires no pre-treatment of the sample, apart from dilution in the course buffer. It could therefore be of great interest in routine analysis.

The same strategy will be applied to quantify the other CN ( $\beta$ -,  $\alpha_{S2}$ - and  $\kappa$ -CN) using specific antibodies on the same sensor surface. This technique could constitute a progress in the characterization of the quality of milk and could be used for diverse applications in cheese.

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## References

- Andrews AT 1983 Proteinases in normal bovine milk and their action on caseins. *Journal of Dairy Research* **50** 45–55
- Andrews AT, Taylor MD & Owen AJ 1985 Rapid analysis of bovine milk proteins by fast protein liquid chromatography. *Journal of Chromatography* **348** 177–185
- Barry JG & Donnelly WJ 1980 Casein compositional studies. I. The composition of casein from Friesian herd milks. *Journal of Dairy Research* **47** 71–82
- Baxter GA, Ferguson JP, O'Connor MC & Elliott CT 2001 Detection of Streptomycin Residues in Whole Milk Using an Optical Immunobiosensor. *Journal of Agricultural and Food Chemistry* **49** 3204–3207
- Bobe G, Beitz DC, Freeman AE & Lindberg GL 1998 Separation and quantification of bovine milk proteins by reversed-phase high-performance liquid chromatography. *Journal of Agricultural and Food Chemistry* **46** 458–463
- Bordin G, Cordeiro Raposo F, de la Calle B & Rodriguez AR 2001 Identification and quantification of major bovine milk proteins by liquid chromatography. *Journal of Chromatography A* **928** 63–76
- Caselunghe M & Lindeberg J 2000 Biosensor-based determination of folic acid in fortified food. *Food Chemistry* **70** 523–532
- Collard-Bovy C, Marchal E, Humbert G, Linden G, Montagne PM, El-Bari N, Duheille J & Varcin P 1991 Microparticle-enhanced nephelometric immunoassay. 1. Measurement of alpha-casein and kappa-casein. *Journal of Dairy Science* **74** 3695–3701
- Collin JC, Berdague JL, Dognin-Bergeret M, Grappin R, Muttoni MP & Rolet-Repecaud O 1987 Ripening and quality of Gruyere de Comte cheese. IV. Study of proteolysis. *Le Lait* **67** 299–317
- Collin JC, Kokelaar A, Rollet-Repecaud O & Delacroix-Buchet A 1991 Determination of caseins in cow's milk by electrophoresis and fast protein liquid chromatography (FPLC): comparison of results. *Le Lait* **71** 339–350
- De Jong N, Visser S & Olieman C 1993 Determination of milk proteins by capillary electrophoresis. *Journal of Chromatography A* **652** 207–213
- Deshmukh AR, Donker JD, Addis PB & Jenness R 1989 Cellulose acetate and polyacrylamide gel electrophoresis for quantification of milk protein fraction. *Journal of Dairy Science* **72** 12–17
- Eigel WN 1977 Effect of bovine plasmin on alpha<sub>S1</sub>-B and kappa-A caseins. *Journal of Dairy Science* **60** 1399–1403
- El-Bari N, Montagne PM, Humbert G, Cuilliere ML, Varcin P, Linden G & Duheille J 1991 Development of a microparticle-enhanced nephelometric immunoassay for the quantification of beta-casein in milk. *Food and Agricultural Immunology* **3** 63–71
- Ferguson JP, Baxter GA, McEvoy JD, Stead S, Rawlings E & Sharman M 2002 Detection of streptomycin and dihydrostreptomycin residues in milk, honey and meat samples using an optical biosensor. *The Analyst* **127** 951–956
- Gaudin V & Maris P 2001 Development of a biosensor-based Immunoassay for screening of chloramphenicol residues in milk. *Food and Agricultural Immunology* **13** 77–86
- Grandison AS, Ford GD, Millard D & Anderson GP 1985 Interrelationships between the diet fed to cows, composition and properties of milk and composition and quality of Cheshire cheese from farmhouse manufacturers. *Journal of Dairy Research* **52** 41–46
- Guillou H, Miranda G & Pelissier JP 1987 Quantitative analysis of caseins in cow milk by Fast Protein Liquid Chromatography (FPLC). *Le Lait* **67** 135–148
- Haasnoot W & Verheijen R 2001 A direct (non-competitive) immunoassay for gentamicin residues with an optical biosensor. *Food and Agricultural Immunology* **13** 131–134
- Homola J, Dostalek J, Chen S, Rasooly A, Jiang S & Yee SS 2002 Spectral surface plasmon resonance biosensor for detection of staphylococcal enterotoxin B in milk. *International Journal of Food Microbiology* **75** 61–69
- Humbert G, Collard-Bovy C, Marchal E, Linden G, Montagne PM, Duheille J & Varcin P 1991 Microparticle-enhanced nephelometric immunoassay. 3. Application to milk and dairy products. *Journal of Dairy Science* **74** 3709–3715
- International Dairy Federation 1996 *Whole milk: Determination of milk fat, protein and lactose content. Guide for the operation of Mid Infrared instruments*. Brussels: IDF (FIL-IDF Standard no. 141 B)
- Indyk HE, Evans EA, Bostrom Caselunghe MC, Persson BS, Finglas PM, Woollard DC & Filonzi EL 2000 Determination of biotin and folate in infant formula and milk by optical biosensor-based immunoassay. *Journal of AOAC International* **83** 1141–1148
- Jones SL, Cox JC & Pearson JE 1990 Increased monoclonal antibody ascites production in mice primed with Freund's incomplete adjuvant. *Journal of Immunological Methods* **129** 227–231
- Jonsson U, Fagerstam L, Ivarsson B, Johansson B, Karlsson R, Lundh K, Lofas S, Persson B, Roos H, Ronnberg I & et al. 1991 Real-time bio-specific interaction analysis using surface plasmon resonance and a sensor chip technology. *Biotechniques* **11** 620–627
- Kaminogawa S, Yamauchi K, Miyazama S & Koga Y 1980 Degradation of casein components by acid protease of bovine milk. *Journal of Dairy Science* **63** 701–704
- Kearney JF, Radbruch A, Liesegang B & Rajewsky K 1979 A new mouse myeloma cell line that has lost immunoglobulin expression but permits the construction of antibody-secreting hybrid cell lines. *Journal of Immunology* **123** 1548–1550
- Köhler G & Milstein C 1975 Continuous cultures of fused cells secreting antibody of predefined specificity. *Nature* **256** 495–497
- Lawrence RC, Creamer LK & Gilles J 1987 Texture development during cheese ripening. *Journal of Dairy Science* **70** 1748–1760
- Leonil J, Molle D, Gaucheron F, Arpino P, Guenot P & Maubois JL 1995 Analysis of major bovine milk proteins by on-line high-performance liquid chromatography and electrospray ionization-mass spectrometry. *Le Lait* **75** 193–210
- Mas S, Marchesseau S, Lagaude A & Cuq JL 1999 Rapid analysis of bovine caseins by reversed phase and anion-exchange HPLC. *Milchwissenschaft* **54** 606–610



- Montagne P, Cuilliere ML, Marchal E, El-Bari N, Montagne M, Benali M, Faure G, Duheille J, Humbert G, Linden G, Heurtaux N, Blesche JL, Gosselin D, Desmares A & Delahaye D** 1995 Application of micro-particle-enhanced nephelometric immunoassays of alpha, beta and kappa caseins to evaluate quality of milk, from the production to the valorization in cheese industry. *Le Lait* **75** 211–237
- Ng-Kwai-Hang KF & Kroeker EM** 1984 Rapid separation and quantification of major caseins and whey protein of bovine milk by polyacrylamide gel electrophoresis. *Journal of Dairy Science* **67** 3052–3056
- Okigbo LM, Richardson GH, Brown RJ & Ernstrom CA** 1985 Casein composition of cow's milk of different chymosin coagulation properties. *Journal of Dairy Research* **68** 1887–1892
- Rasooly A** 2001 Surface plasmon resonance analysis of staphylococcal enterotoxin B in food. *Journal of Food Protection* **64** 37–43
- Rasooly L & Rasooly A** 1999 Real time biosensor analysis of staphylococcal enterotoxin A in food. *International Journal of Food Microbiology* **49** 119–127
- Reimerdes EH** 1983 New aspects of naturally occurring proteases in bovine milk. *Journal of Dairy Science* **66** 1591–1600
- Remeuf F, Lenoir J & Duby C** 1989 A study of the relations between, physico-chemical characteristics of goat milks and their renneting properties. *Le Lait* **69** 499–518
- Senocq D, Dupont D, Rolet-Repecaud O, Faurie F & Levieux D** 2001a Antipeptide antibodies recognizing plasmin sensitive sites in bovine beta-casein sequence. *Journal of Agricultural and Food Chemistry* **49** 1571–1577
- Senocq D, Dupont D, Rolet-Repecaud O & Levieux D** 2001b Monoclonal antibodies against bovine beta-casein: production and epitope characterization. *Food and Agricultural Immunology* **13** 213–224
- Sternesjo A, Mellgren C & Bjorck L** 1995 Determination of sulfamethazine residues in milk by a surface plasmon resonance-based biosensor assay. *Analytical Biochemistry* **226** 175–181
- Storry JE, Grandison AS, Millard D, Owen AJ & Ford GD** 1983 Chemical composition and coagulating properties of renneted milks from different breeds and species of ruminant. *Journal of Dairy Research* **50** 215–299
- Sutton JD** 1989 Altering milk composition by feeding. *Journal of Dairy Science* **72** 2801–2814
- Vallejo-Cordoba B** 1997 Rapid separation and quantification of major caseins and whey proteins of bovine milk by capillary electrophoresis. *Journal of Capillary Electrophoresis* **4** 219–224
- Visser S, Slangen CJ & Rollema HS** 1991 Phenotyping of bovine milk proteins by reversed-phase high-performance liquid chromatography. *Journal of Chromatography* **548** 361–370