Monoclonal antibodies having homosubtype cross-neutralization properties against influenza A viruses subtype H1

The present invention in general relates to the field of immunology.

More specifically, the invention concerns a monoclonal antibody directed against the H1-subtype HA (hemagglutinin) antigen of the influenza A virus, which is capable of recognizing and neutralizing both of strains isolated from man and strains isolated from animals.

The influenza viruses are capable of infecting different animal species, among which especially several avian, porcine and equine species. Only a few of these viruses have succeeded in adapting to man, i.e. infecting it and especially spreading itself from man to man. The main factor that allows for this adaptation is connected with the features of the most important surface protein of the virus, hemagglutinin. In particular, 16 subtypes (H1-H16) have been distinguished based on the antigenic features of this protein, and only three of these (H1, H2 and H3) have succeeded in adapting completely to man, becoming responsible for the three great influenza pandemics of the past century. Presently there are two subtypes circulating in man which cause the seasonal influenza epidemics, subtype H1 and subtype H3. The H1 subtype, recognized by the antibody that is the object of the present invention, appeared in man in 1918 causing the terrible pandemic designated as "Spanish influenza", named after the European country where the first cases were reported. Recent studies have demonstrated that the virus responsible for the "Spanish influenza" was an avian virus that infected birds, which, as a result of a few mutations, developed the ability to infect man and spread itself from man to man. The 1918 isolate is the common progenitor of all the H1-subtype viruses found in man and other animals, such as swine. The H1-subtype viruses were responsible for the annual human influenza epidemics until 1957, during which year they were displaced by a virus having an H2-subtype hemagglutinin, which has been responsible for the so-called "Asian" pandemic. No more cases caused by the H1 subtype were reported until 1977, during which year a few H1 isolates turned up again in Russia for reasons that are still non completely understood. Thus, nowadays H1-subtype viruses are still circulating, in association with H3-subtype viruses that appeared in man since 1967. For instance, notifications in Europe for the 2007-08 influenza season,

within the period comprised between the 40th week of 2007 and the 16th week of 2008, evidenced that a good 30% of isolates were associated with an H1-subtype hemagglutinin (*European Influenza Surveillance Scheme- Weekly Electronic Bulletin-* April 28, 2008).

The annual influenza virus epidemics have a considerable impact on the public health service and on the costs associated therewith. In the United States of America alone it is estimated that more than 200,000 people are hospitalized each year for syndromes connected to influenza viruses, with about 40,000 deaths more or less directly related thereto (Thompson et al., JAMA, 2003, 289:179-186). To these data we must add all the cases, in exponentially higher numbers, of infected subjects that do not go to work for more or less long periods, with inevitable economic repercussions due to the loss of working days. A recent work (Molinari et al., Vaccine, 2007, 25: 5086-5096) has estimated the medical costs directly related to annual influenza epidemics at 10.4 billions of US dollars per year, to which another 16.3 billions of US dollars must be added for lost earnings due to absence from work. If in the calculation we consider other items too, such as the monetization of the economical losses linked to the death of the infected subjects, the amount rises to the incredible figure of 87.1 billions of US dollars per year.

Currently, the only available tool for facing the annual influenza epidemics in some way is an inactivated trivalent vaccine containing H1- and H3-subtype viral isolate antigens (in addition to a B-type isolate), which presumably will be responsible for the epidemic of the next influenza season. This kind of prediction, based on epidemiological data linked to early isolations in some sentinel geographic areas, does not always turn out to be correct. Thus, there is a not at all negligible risk, which is present year after year, that the trivalent vaccine developed for a certain influenza season instead might prove substantially ineffective.

In that case, as well as in the case of a new pandemic, the only available prophylactic/therapeutic aid would be to resort to the two available classes of antiviral drugs: the M2 protein inhibitors (amantadine and rimantadine), and the neuraminidase inhibitors (oseltamivir and zanamivir). However, in this situation too, a series of problems can be already

expected, related both to the need to administer the antivirals in a very early stage of the infection, and to the rapid appearance, which has already occurred however, of resistant viral isolates.

An alternative effective strategy could be based on neutralizing antibody preparations directed against critical viral proteins and capable of recognizing portions of such proteins which are shared among the different isolates of influenza viruses.

For a better understanding of the potential of an approach based on the passive administration of antibodies, it is useful to briefly mention the main structural features of the influenza viruses. The influenza viruses belong to the *Orthomyxoviridae* family and are characterized by the presence of an envelope derived from infected cell membranes, on which approximately 500 spikes are present, also referred to as projections. Such projections consist of trimers and tetramers from two important viral surface proteins, i.e. the aforementioned hemagglutinin (HA) and neuraminidase (NA), which is also used for the subtyping of type A viruses. An integral membrane protein (M2) is also found on the envelope surface, which protein is present in much lower numbers compared to hemagglutinin and neuraminidase, and also organized in tetramers.

The influenza virus is further characterized by the presence, within the core, of a segmented genome comprised of 8 single stranded RNA fragments. The three known influenza virus types are recognizable based on the features of some proteins within the virion (NP and M1): type A, type B, and type C. Those responsible for the annual epidemics are the type A and type B viruses. Instead, type C viruses are responsible for less severe syndromes.

The role of the surface proteins is essential in the viral replication cycle. In particular, hemagglutinin is the protein that allows the virus to recognize the sialic acid present on the surface of some cells, and to infect them. Instead, neuraminidase operates at the end of the viral replication cycle, that is during the release of new virus particles from the infected cells. Its function is to promote the release of hemagglutinin of the newly formed virions

from the sialic acid present on the surface of the cell that produced them. The key role played by these two proteins, as well as their display on the virus surface, explain why they represent the main target of the immune response, and why they are susceptible to a high rate of mutation. In fact, the annual epidemics are caused by viruses that are more or less different from the ones of the previous years, and therefore are more or less effectively able to escape the immune response they stimulated. In other words, the progressive accumulation of point mutations in hemagglutinin (mostly) and neuraminidase (secondarily) makes the protective antibodies, produced in the course of previous epidemics, on the whole progressively ineffective.

The main protective role within the anti-influenza immune response is played by the humoral component. Antibodies exert their protective role primarily interfering with the binding of hemagglutinin to sialic acid, thereby preventing infection of the cells. Such a selective pressure determines the high rate of mutation in hemagglutinin. Within such a high variability, however, some unchanged amino acid residues have been found, indicative of their essential role in the function of the protein. These hemagglutinin portions represent a potential target for a cross-neutralizing response. However, it is predictable that such regions will not be able to induce an effective antibody response in most patients, in that the hiding of such targets in immunosilent areas has certainly represented a very favorable evolutionary step for the virus.

In view of the prophylactic and therapeutic aspect, it would be extremely useful to provide antibody molecules capable of recognizing such common regions within one subtype. Such antibodies could in fact represent a useful prevention tool when administered to subjects at risk, since they would be able to recognize a broad range of viruses of the same subtype but evolutionarily far away from one another, and thus would potentially be able to protect from most of the viruses belonging to such a subtype, including possible new viruses that acquire the ability to spread from animals to humans. This type of immunity, which is lost when the circulating isolates show a high rate of mutation compared to those of the previous years, is known as HOMOSUBTYPE ANTI-INFLUENZA IMMUNITY.

The present inventors have now succeeded in obtaining monoclonal antibodies with the above-mentioned desirable features.

Thus, a first aspect of the invention is a monoclonal antibody directed against the influenza A virus, which is able to bind a plurality of isolates, both human and animal, of the influenza A virus which express the H1-subtype hemagglutinin.

A second aspect of the present invention is a monoclonal antibody directed against the influenza A virus, characterized on that it has a neutralizing activity towards human and animal isolates of the H1-subtype influenza A virus. Preferably, such a neutralizing monoclonal antibody recognizes hemagglutinin (HA) of the H1-subtype influenza A virus as the antigen.

The monoclonal antibody of the invention is preferably human or humanized.

Such antibodies represent a valuable prevention tool when administered to patients at risk.

Moreover, the use of a human or humanized monoclonal antibody for human patients is a further advantage, in that the human or humanized antibody is certainly well tolerated.

In addition, by representing a component of the human antibody response to this virus, the monoclonal antibody of the invention constitutes a key factor for the design of innovatory vaccines that are able to induce an immunity that is extremely more effective, protective and broad-range towards the H1-subtype viruses, compared to the one induced by the presently used vaccines.

The steps that led to the attainment of the monoclonal antibody of the invention are described in detail in the experimental section that follows, which also illustrates its binding and neutralizing properties. The monoclonal antibody attainable by the procedure specifically described in the experimental section is a human antibody.

The preparation of humanized antibodies can be performed by any per se known methodol-

ogy, as for example described in Baca et al, 1997 J. Biol. Chem 272:10678-84 or Carter et al, 1992, Proc.Natl. Acad. Sci 89:4285. Such bibliographic references are provided exclusively for illustration and not limitation. In fact, other methodologies for the preparation of humanized antibodies are known in the prior art and can be used within the present invention.

The attainment of one clone (designated as INF49) capable of producing monoclonal antibodies in the form of Fab fragments with the *in vitro* ability of binding multiple human and animal isolates from the H1-subtype influenza A virus is specifically described in the experimental section.

The monoclonal antibodies produced by clone INF49 (designated as Fab49) represent one preferred embodiment of the invention, as the inventors have experimentally proved that these antibodies display a neutralizing activity towards multiple human and animal isolates from the H1-subtype influenza A virus. For the sake of brevity, such an immunological property concerning the ability of neutralizing human and animal isolates from the H1-subtype influenza A virus will sometimes be referred to herein below as "homosubtype cross-neutralizing activity for subtype H1".

The sequence listing shows the amino acid sequence of the heavy chain variable domain (SEQ ID NO:1) and of the light chain variable domain (SEQ ID NO:2) of Fab49 of the invention. It further shows their respective encoding nucleotide sequences, designated as SEQ ID NO:3 and SEQ ID NO:4, respectively.

In particular, the experimental section describes the manufacture of the Fab49 monoclonal antibodies as Fab fragments. However, it is understood that the monoclonal antibodies can be manufactured and used in other forms too, such as for example whole immunoglobulins, or in the form of other types of antibody fragments, such as for instance $F(ab')_2$ fragments or antibody fragments smaller than Fabs (for example, single chain antibodies, single domain antibodies), as well as in the form of peptides at least 8 amino acids in length which have the same immunological properties as the Fab.

Single chain antibodies can be constructed according to the method described in US patent 4,946,778 by Ladner et al., hereby included as reference. Single chain antibodies comprise the light and heavy chain variable regions linked by a flexible linker. The antibody fragment designated as single domain antibody is even smaller than the single chain antibody, as it comprises only one isolated VH domain. Techniques for obtaining single domain antibodies having, at least partially, the same binding ability as the whole antibody, are described in the prior art. Ward, et al., in "Binding Activities of a Repertoire of Single Immunoglobulin Variable Domains Secreted from *Escheria coli*," Nature 341:644-646, describes a screening method for obtaining the variable region of an antibody's heavy chain (VH single domain antibody) with a sufficient affinity for the target epitope to bind to it in an isolated form.

In the description that follows, the term "antibody" will then be used to refer to all the embodiments mentioned above, including whole immunoglobulins, Fab fragments or other antibody fragment types, single chain antibodies, single domain antibodies, etc.

The monoclonal antibodies of the invention may be generated and used in a free form or in a carrier-conjugated form. A carrier is any molecule or chemical or biological entity capable of conjugating with an antibody and making it immunogenic or increasing its immunogenicity. Non-limiting examples of carriers are proteins such as KLH (keyhole limpet hemocyanin), edestin, thyroglobulin, albumins as bovine serum albumin (BSA) or human serum albumin (HSA), erythrocytes such as sheep erythrocytes (SRBC), tetanus anatoxin, cholera anatoxin, polyamino acids such as for example poly(D-lysine:D-glutamic acid) and the like. In order to facilitate the binding of the antibody to the carrier, the antibody C-terminus or N-terminus may be modified, for example, by the insertion of additional amino acid residues, for instance one or more cysteine residues that are able to form disulfide bridges.

Because of its properties, which will be shown in detail in the experimental section that follows with reference to Fab49, the monoclonal antibody of the invention is particularly

suited for use in medical applications, particularly in the manufacture of a medicament for the broad-range prophylactic or therapeutic treatment of H1-subtype influenza A virus infections.

Thus, the use of the monoclonal antibody of the invention for preparing a medicament for the prophylactic or therapeutic treatment of pathologies caused by H1-subtype influenza A virus infections, such as for instance the influenza syndrome, falls within the scope of the invention.

In this context too, the expression "Fab49 antibody" includes not only the Fab fragments but also any other form into which the antibody can be prepared, for example whole immunoglobulins, other kinds of antibody fragments, single chain antibodies, etc.

As described in detail in the experimental section, the present monoclonal antibody has been obtained by molecular biology techniques starting from an EBV-transformed human lymphocyte capable of producing human cross-reactive monoclonal antibodies, thus able to recognize MDCK (Madin-Darby canine kidney) (ATCC ® n°CCL-34TM) cell lysates infected with a few human reference isolates of the influenza A virus as referred to herein below, which express H1-subtype hemagglutinin: A/Puerto Rico/8/34 (ATCC ® n° VR-1469TM); A/Wilson-Smith/33 (ATCC ® n° VR-1520); A/Malaya/302/54 (ATCC ® n° VR-98). The antibody in question also resulted to be capable of recognizing NSK (Newborn swine kidney) (Istituto Zooprofilattico di Brescia) cell lysates infected with an animal-derived "field" isolate, and in particular swine-derived (SW1), as demonstrated by the sequence of the HA2 fragment of H1-subtype hemagglutinin expressed by it (SEQ ID NO:5).

A further particularly advantageous property of the monoclonal antibody of the invention is its ability to bind the recombinant HA protein from the A/California/04/2009 influenza virus isolate, recently identified as one of the isolates responsible for the so-called "swine influenza", officially designated as "new influenza" by the WHO.

Binding assays performed with the recombinant HA protein from the A/California/04/2009 iso-

late and the recombinant HA protein from the A/PR/08/1934 isolate, used as a positive control, are described in the following experimental section. The assays prove that the monoclonal antibody Fab49 of the invention is able to bind both of the recombinant HA proteins.

The performed assays further demonstrate that the monoclonal antibody Fab49 is able to neutralize HA protein pseudo-particles from both of the above-mentioned influenza virus isolates.

The specific procedures used for generating the transformed B cell lines from patients' peripheral blood are described in the following experimental section.

The procedures used for cloning the genes encoding the Fd portion of the heavy and light chains of the Fab49 antibody of the invention are also described, as well as those for producing them recombinantly, both as single peptides and Fab fragments.

The abilities of the monoclonal antibody of the invention to react with cells infected with different human and animal isolates from the H1-subtype influenza A virus were verified by ELISA and immunofluorescence. In addition, a neutralizing assay was carried out in order to verify the *in vitro* biological activity of the antibody. In this assay, the Fab49 antibody showed a homosubtype cross-neutralizing activity towards the human and animal type A and subtype H1 viral isolates as indicated above.

The obtained data indicate that the antibody of the invention is potentially effective in conferring a passive immunity towards the H1-subtype influenza A virus to the subjects to whom it is administered in one of the forms described, and its usefulness in the broad-range prophylaxis and therapy of pathologies caused by infection with the H1-subtype influenza A virus, such as for instance the influenza syndrome.

Thus, a further aspect of the invention is a pharmaceutical composition comprising an effective amount of the monoclonal antibody of the invention as the active ingredient and a pharmaceutically acceptable carrier and/or diluent. An effective amount is the one which is able to induce a favourable effect in the subject to which the composition is administered,

for example to neutralize the H1-subtype influenza A virus.

In this context, the term "subject" designates any animal host to which the composition can be administered, including humans.

Non-limiting examples of pharmaceutically acceptable carriers or diluents usable in the pharmaceutical composition of the invention include stabilizers such as SPGA, carbohydrates (for example, sorbitol, mannitol, starch, sucrose, glucose, dextran), proteins such as albumin or casein, protein-containing agents such as bovine serum or skimmed milk, and buffers (for example phosphate buffer).

The monoclonal antibody of the invention can also be advantageously used as a diagnostic reagent in an *in vitro* method for the detection of anti-H1-subtype influenza A virus antibodies with identical or similar neutralizing properties in a biological sample previously obtained from a patient (such as for example a serum, plasma, blood sample or any other suitable biological material).

"Anti-influenza A virus antibodies with identical or similar neutralizing properties" are antibodies that display a homosubtype cross-neutralizing activity versus the human or animal H1-subtype influenza A virus. These antibodies may be found in the biological sample from the patient (or animal) as a result of a previous exposure to an influenza A virus, or because the patient had been previously administered with the monoclonal antibody of the invention for therapeutic or prophylactic or research purposes.

An assay method for detecting, in a biological sample previously obtained from a patient or an animal host, the presence of anti-influenza A virus antibodies having a homosubtype cross-neutralizing activity towards the H1 subtype, comprising contacting the said biological sample with the monoclonal antibody of the invention, as a specific assay reagent, is thus included in the scope of the invention.

The assay can be qualitative or quantitative. The detection or quantification of the anti-H1-

subtype influenza A virus antibodies having a homosubtype cross-neutralizing activity may be carried out by, for example, a competitive ELISA assay. Thus, a diagnostic kit comprising the monoclonal antibody according to the invention as a specific reagent is also within the scope of the invention, the said kit being particularly designed for the detection or quantification of anti-influenza A virus antibodies having a homosubtype cross-neutralizing activity towards the H1-subtype influenza A virus in a biological sample previously obtained from a patient or an animal host.

Similarly, the monoclonal antibody of the invention can be used as a specific reagent in an assay method for detecting or quantifying, in a previously prepared immunogenic or vaccine composition, epitopes capable of evoking, in the subject to which such a composition has been administered, anti-H1-subtype influenza A virus antibodies having neutralizing properties identical or similar to those of the monoclonal antibody of the invention, that is a homosubtype cross-neutralizing activity towards the H1-subtype influenza A virus.

Such a method is predicted to be useful for the assessment of any preparation to be used as a vaccine or immunogenic preparation, as the recognition by the monoclonal antibody of the invention could be indicative of the presence, in the immunogenic preparation and/or vaccine, of one or more epitopes capable of stimulating the production of antibody clones capable of recognizing an advantageous epitope, such as for example an epitope capable of eliciting a homosubtype immunity against the H1-subtype influenza A virus.

Finally, the monoclonal antibody of the invention may be used for preparing anti-idiotype antibodies according to methods per se known. Anti-idiotype antibodies are antibodies specifically directed towards the idiotype of the broad-range neutralizing antibodies used to prepare them, and as such are able to mimic the key epitopes they recognize.

Anti-idiotype antibodies directed against the monoclonal antibody of the invention are therefore included in the scope of the invention.

The following experimental section is provided purely by way of illustration and not limi-

tation.

EXPERIMENTAL SECTION

Selection of the patients

The patients enrolled in the study were selected so as to increase the chances of cloning therefrom cross-reactive anti-influenza antibodies, that is antibodies capable of recognizing, and potentially of neutralizing, different influenza virus isolates. In particular, it is described that some individuals, despite continuous exposure to the influenza virus (sometimes for professional reasons, as physicians, pediatricians, people working in kindergartens and schools), do not contract the disease. For this reason they were thought to be the best candidates for the generation of human monoclonal antibodies. In particular, the following inclusion criteria were obeyed:

- between 25 and 55 years of age;
- recent pathological medical history, for the ten years preceding the study, negative for clinical influenza syndromes;
- antibody titer higher than 1:1000 against H1N1-subtype virus isolates, responsible for the annual epidemics during the five years preceding the study;
- detectable neutralizing titer (IC50 >=1:20) against two human reference H1N1-subtype virus A isolates (A/Puerto Rico/8/34; A/Malaya/302/54);
- no prior anti-influenza vaccination;
- compliance to receive anti-influenza vaccination.

At vaccination, and about 3 weeks post-vaccination, approximately 20 ml of blood were drawn from each patient into heparinized test-tubes.

Culture of the reference virus isolates

MDCK (Madin-Darby canine kidney) cells (ATCC® no. CCL-34TM) propagated in Modified Eagle Medium (MEM) (GIBCO), supplemented with 10% inactivated (treatment at

56°C for 30 minutes) fetal bovine serum (FBS) (EuroClone), 50 μg/ml penicillin, 100 μg/ml streptomycin (GIBCO) and 2 mM L-glutamine (EuroClone) were used as the cell line. As for the field swine isolate SW1 (characterized in an unequivocal way by the HA2 region sequence attached to the patent application), NSK (Newborn swine kidney) cells (Istituto Zooprofilattico di Brescia) were used instead, which were treated similarly. The cells were incubated at 37°C in a 5% CO_2 atmosphere and were passaged at a 1:3 ratio twice a week. For the experiments described in this patent application, the following H1N1-subtype influenza virus isolates were used: A/Puerto Rico/8/34 strain (ATCC ® no. VR-1469TM); A/Wilson-Smith/33 strain (ATCC ® no. VR-1520), and A/Malaya/302/54 strain (ATCC ® no. VR-98). With regard to H1N1 subtype, a swine-derived isolate (SW1) was also used, characterized on the basis of the sequence of the hemagglutinin HA2 portion (SEQ ID NO:5). Three other reference virus isolates were also used, two belonging to type A subtype H3N2 (A/Port Chalmers/1/73 - ATCC® no. VR-810 and A/Aichi/2/68 - ATCC ® no. VR-547), and one belonging to type B (B/Lee/40 - ATCC ® no. VR-101). As the culture medium to grow the virus, MEM supplemented with 1 μg/ml serum-free trypsin (SIGMA) was used. The virus stocks were obtained from the culture supernatant as extracellular viruses. In short, after infecting the cells, the monolayer was observed daily to monitor the appearance of a cytopathic effect. Generally 4 days after the infection the supernatant was collected, centrifuged at 1000 RCF (relative centrifugal force) for 10 minutes to eliminate the cell debris and filtered with 0.22 μm filters (MILLIPORE). The supernatant was then aliquoted and stored at -80°C as cell-free viruses.

Selection of monoclonal anti-influenza virus antibodies from peripheral blood B lymphocytes

The production of monoclonal antibodies from patients was carried out by using a transformation method via infection with Epstein-Barr virus (EBV), previously described by Cole et al, 1984 Cancer Research 22:2750-2753. The supernatant from the different clones obtained was assessed for the presence of antibodies by ELISA. Clones capable of producing IgG antibodies in the supernatant which are able to react in the ELISA against the cell lysates infected with the above-mentioned three human isolates and the H1N1-subtype

swine isolate SW1, but not against the ones infected with the two H3N2-subtype isolates and with the B isolate, were then selected for a subsequent characterization. In particular, MDCK cells were infected with the aforesaid isolates at a high multiplicity of infection. About 48 hours post-infection, the cells were detached from the flask and washed twice in PBS. The cell pellets were then suspended in 300 µl of lysis solution (100mM NaCl, 100mM Tris pH 8 and 0.5% Triton-X) and stored in ice for 20 minutes. The cell debris were centrifuged away at 10000g for 5 minutes and the supernatant was stored at -20°C as a protein extract. As for the preparation of the control antigen, non-infected cells were treated in the same way. The supernatant protein concentration was determined in duplicate using the BCA™ Protein Assay Kit (Pierce). Briefly, the sample protein dosage was determined by referring to a standard curve obtained by a series of known-concentration dilutions of bovine serum albumin (BSA). The absorbance of every sample was measured with a spectrophotometer at a wavelength of 540nm. The lysates so obtained were then used (300 ng per well) to coat an ELISA plate (COSTAR) that was incubated at 4°C overnight. The following day, the plate was washed with distilled water and blocked with PBS/1% BSA (Sigma) for 45 minutes at 37°C. Then, 40 µl of supernatant from each clone were added to each well, which were incubated for 1 hour at 37°C. After 5 washings (WASHER ETI-SYSTEM, DiaSorin) with PBS/0.5% Tween-20 (Sigma), 40 µl of peroxidase-conjugated anti-human Fc (1:4000 in PBS/1% BSA, Sigma) were added to each well and the plate was incubated for 1 hour at 37°C. After 5 more washings with PBS/0.5% Tween-20, 40 µl of TMB peroxidase substrate (Pierce) were added to each well. Approximately 15 minutes later, the enzymatic activity was blocked by adding 40 µl of H_2SO_4 and the signal was measured with a spectrophotometer set at 450nm. In particular, one clone (designated as cINF49) proved to be able to produce antibodies capable of recognizing in a specific way all the lysates obtained from the cells infected with the different H1N1-subtype isolates, including the animal isolate. Instead, no signal was detectable in the cultures infected with the two H3N2-subtype viruses and in those infected with the B isolate.

Preparation of Fab fragments from clone cINF49

The genes encoding for the Fab49 chains were cloned into a prokaryotic expression vector.

This allows to avoid problems due to instability of antibody-producing cell clones, to better characterize the encoding genes from the molecular point of view, in order to have molecules that are certainly monoclonal at one's disposal, as well as increased amounts of the antibody itself.

The messenger RNA (mRNA) was extracted from the cultured cINF49 clone and reverse transcribed using an oligo-dT according to methods per se known. The cDNAs encoding the light chain and the Fd fragment (i.e. the heavy chain variable portion and the part of the constant portion present within the Fab fragment) were then amplified by described methods (CSH press, Phage display manual, ed. D.R.Burton, p. A1.6). The so obtained cDNAs were then cloned into an expression vector per se known, designated as RBCaf (Burioni et al, J. Imm. Meth, 1988). In short, the gene (amplified DNA) encoding the heavy chain Fd portion was digested with restriction enzymes XhoI and SpeI (Roche) for 1.5 hours at 37°C, and subsequently inserted into the vector's cloning site for heavy chains, in turn digested with the same enzymes. Instead, the light chain (amplified DNA) was digested with enzymes SacI and XbaI (Roche) and cloned into the vector similarly digested.

The so obtained recombinant construct was used to electro-transform *E. coli* strain XL1Blue (made competent by cold washings in glycerol), according to standardized protocols for the use of 0.2 cm cuvettes (Voltage: 2500 V; Capacitance: 25 μF; Resistance: 200 Ω). In parallel, the DNA sequences of the light chain variable part and the heavy chain variable part were analyzed. The sequences are those provided in the Sequence Listing. The molecular analysis of the mutational pattern showed a picture ascribable to antigen-induced somatic mutation processes.

ELISA assessment of Fab49 obtained by cloning into RBCaf

40 recombinant bacterial clones transformed with the Fab49 construct were analyzed by ELISA using crude lysates obtained by subjecting cultures to heat shock. In particular, clones of bacteria transformed with the construct were inoculated into 10 ml of SB medium containing ampicillin and tetracycline at the concentrations of 50μg/ml and 10μg/ml, re-

spectively, and were grown under shaking at 37°C until reaching an O.D.600 = 1. Subsequently, a specific inducer (IPTG - isopropylβ-D-thiogalactopyranoside) was added at the final concentration of 1mM and the culture was left shaking at 30°C overnight. The cells were lysed by heat shock (3 freeze/thawing rounds, at -80°C and 37°C, respectively) and then centrifuged to separate the cell debris from the Fab-containing supernatant. The soluble Fabs obtained were assayed by ELISA. 96-Well microtiter plates (Nunc) were coated with lysates from cells infected with the above-mentioned virus isolates. Lysates obtained from uninfected cells were used as a negative control. The ELISA plates coated with 300 ng of the lysates obtained as described were then left at 4°C overnight. The next day, after removal of the unbound antigen, the plates were washed 5 times with PBS, and the unspecific binding sites were blocked with 3% albumin in PBS for 1 hour at 37°C. After removal of the blocking solution, the supernatants of the cell cultures treated as described above and containing the soluble Fabs were added thereto. This was followed by an incubation step at 37°C for 2 hours. After 10 washing cycles with PBS/0.05% Tween 20, 40 µl of a 1:700 dilution of a polyclonal preparation of radish peroxidase-conjugated goat anti-human Fab immunoglobulins (Sigma) in PBS/1% BSA was added thereto. After a 1-hour incubation at 37°C and a further series of 10 washes, the substrate (OPD-o-phenylenediamine) was added to the wells. The plates were then incubated for 30 minutes at room temperature in the dark. The reaction was quenched with 1N sulfuric acid and the optical density was assessed by spectrophotometric reading at 450nm. All the assayed clones displayed a specific reactivity towards every lysate obtained from the cells infected with the H1N1-subtype viruses. One bacterial clone transformed with the expression vector containing the genes for the light chain and the heavy chain Fd fragment of Fab49 was thus selected. The selected bacterial clone was designated as INF49.

Purification of the Fab49 and assessment of the same by ELISA on infected cell lysates

The Fab produced from clone INF49 (from here on indifferently referred to as "clone" or "Fab") was thus immunoaffinity purified with columns composed of a sepharose resin containing the protein G (~ 2 mg/ml), to which a polyclonal preparation of goat antibodies capable of binding human Fabs (PIERCE, Illinois) was covalently linked. In short, one col-

ony of clone INF49 was inoculated into 10 ml of SB medium containing ampicillin and tetracycline at the concentrations of 50μg/ml and 10μg/ml, respectively. The culture, which was grown overnight at 37°C, was sub-inoculated into a flask with 500 ml of SB added with the same concentration of antibiotics as before. The cells, subsequently induced by 1mM IPTG, were left shaking overnight at 30°C. The culture was centrifuged at 5000 rpm for 25 minutes and the pellet resuspended in PBS was sonicated. A further centrifugation at 18,000 rpm for 25 minutes was necessary in order to remove the cell debris. The supernatant was filtered, and then it was slowly passed through the above-described sepharose column. Thereafter, the resin was washed with 10 PBS volumes, and finally the bound Fabs were eluted with an acidic solution (elution buffer - H_2O/HCl pH 2.2). The various fractions collected were neutralized with an appropriate solution (1M Tris pH 9) and concentrated by ultrafiltration (Centricon, Millipore). The purity of the purified Fab was assessed by running one aliquot on a 12% polyacrylamide/sodium dodecyl sulfate gel (SDS-PAGE). Finally, sequential dilutions of the purified Fab were assayed by ELISA as described. Into each plate, preparations of monoclonal Fabs directed against HCV E2 glycoprotein were included as negative controls. The results of this experiment confirmed those previously obtained with the bacterial lysates, confirming the specific reactivity of the clone towards the cells infected with H1N1-subtype viruses.

Immunofluorescence assessment of Fab49 obtained by cloning into RBCaf

In order to confirm the data achieved by ELISA, Fab49 was also analyzed by an immunofluorescence assay. Briefly, the cells from the cultures infected with all the mentioned reference viruses were trypsinized and, after two washes in PBS, counted under a microscope with a hematocytometer. The cell suspension was thus used for the preparation of slides by centrifugation in a cytocentrifuge (Cytospin4, Shandon Southern Products) at 90 g for 3 minutes. The so prepared slides each contained a total of 2×10^5 cells. Control slides were prepared similarly with uninfected cells. The cells were then fixed and permeabilized at room temperature with a methanol-acetone solution (used at the temperature of -20°C) for 10 minutes. After 3 washes in PBS, the cells were incubated with Fab49 (100 μg/ml) for 30 minutes at 37°C in a humid chamber and subsequently washed three times in PBS.

The cells were then incubated for 30 minutes at 37°C in the humid chamber in the dark with a fluoresceine isothiocyanate-conjugated goat Fab (Sigma) diluted 1:200 in Evans Blue. The slides were examined under a fluorescence microscope (Olympus). A commercial mouse monoclonal (Argene) specific for the M1 influenza virus protein was used as a positive control. An antibody directed against the E2 glycoprotein of the hepatitis C virus (e509; Burioni et al, Hepatology, 1998) was used as a negative control. Fab49 showed, by immunofluorescence, a specific reactivity for all the cells infected with the human H1N1-subtype isolates, that is A/Puerto Rico/8/34 isolate, A/Wilson-Smith/33 isolate and A/Malaya/302/54 isolate. A similar result was obtained with the cells infected by the swine isolate SW1 used in the study. The fluorescence pattern displayed was clearly a cytoplasm-type pattern. Instead, no fluorescence was seen in uninfected cells, cells infected with H3N2-subtype virus and those infected with the B type isolate, or with the negative control antibody.

Neutralization assay

In order to characterize the *in vitro* biological activity of the selected clone, a neutralization assay was designed for some of the reference virus isolates used in the study. In short, MDCK cells (NSK in the case of the swine isolate SW1) were seeded into MEM-10% FBS in a 96-well plate ($2x10^4$ cells/well). Serial dilutions (from 10^{-1} to 10^{-8}) of the virus stocks, obtained as described above, were prepared in maintenance medium (MEM with 2% FBS). Each dilution was repeated six times. When the cultured cells were confluent, the growth medium was removed and 100 µl of each of the virus dilutions were added to each well. After 1 hour at 37°C, the inocula were removed and 200 µl of MEM medium added with 1 µg/ml trypsin were placed into each well. The viral titer, expressed as $TCID_{50}$ (the dose that infects 50% of the cell culture), was calculated by applying Reed-Muench's formula:

$$TCID_{50} = \frac{\text{infectivity} > 50\% - 50\%}{\text{infectivity} > 50\% - \text{infectivity} < 50\%} \times \text{dilution factor}$$

In the light of the obtained data, the virus stock was diluted so as to use a multiplicity of in-

fection (M.O.I.) of approximately 0.01 (1 virus particle per 100 cells) in the neutralization experiment. In the actual neutralization assay, the cells were seeded in a 24-well plate, with each well containing a sterile slide. The neutralization experiment was performed on 80%-90% confluent cells, i.e. about 48 hours after the seeding thereof. Dilutions of the purified Fab49 were then prepared, so as to attain final concentrations of 1 μg/ml, 5 μg/ml, 10μg/ml and 20 μg/ml. Corresponding dilutions of the e509 anti-HCV antibody were prepared as a negative control. The various Fab concentrations were then incubated with the same volume of diluted virus stock (M.O.I.: 0.01) for 1 hour at 37°C. 250 μl of the virus-Fab mix were subsequently added to the wells containing the cells. A positive control for the infection was achieved by adding the culture medium alone to the virus stock. The plate was incubated for 1 hour at 37°C in order to allow the non-neutralized virus to adsorb. The inoculum was then removed and the cells were washed twice with PBS. 1.5 ml of serum-free medium with 1 μg/ml trypsin were added to each well. After a 6-hour incubation at 37°C, the cell monolayer was washed with PBS and fixed with a cold methanol-acetone solution (1:2 ratio, stored at -20°C) for 10 minutes at room temperature. The fixed cells were washed and incubated with 250 μl of a commercial monoclonal anti-M1 antibody (Argene) for 30 minutes at 37°C in a humid chamber. The cells were washed with PBS and finally incubated with a fluoresceine-conjugated goat anti-mouse antibody, diluted in Evans blue, for 30 minutes at 37°C in a humid chamber in the dark. After three washes in PBS, the slides were finally examined under a fluorescence microscope. The neutralizing activity of Fab49 was determined by counting the single positive cells and calculating the percentage decrease in the number of infected cells, compared to the positive control infected with the virus alone. The neutralization assays were carried out in three separate sessions for each of the isolates used for the neutralization assays (see figures 1-3). In each experiment, the different Fab49 dilutions were repeated in triplicate, similarly to what performed for the negative (Fab e509 anti-E2/HCV) and positive (virus and Fab-free medium) controls of infection.

The Fab produced by clone INF49 showed a homotype cross-neutralizing activity against human and animal H1N1-subtype virus A isolates. Instead, no reduction was detected in the infecting ability of the two H3N2-subtype viruses and of type B virus used in the study,

confirming the specificity of the homosubtype neutralizing activity observed for subtype H1N1. In particular, the Fab produced by clone INF49 (called Fab49) showed an IC_{50} (the Fab concentration that inhibits 50% of infection by the virus isolate assayed) below 5 μg/ml for each of the H1N1-subtype isolates assayed, i.e. a concentration that is easily obtainable by an *in vivo* administration of the molecules in question even without taking into account the usually considerable increase in the neutralizing biological activity observed when Fabs are converted into the whole immunoglobulin form, one of the possible pharmaceutical formulations included within the scope of the invention.

Figures 1 to 3 summarize the results obtained with Fab 49, produced by clone INF49, in the different neutralization sessions performed on the various H1N1-subtype influenza virus isolates used in the study.

Particularly, Figure 1 is a graph that illustrates the neutralization percentage of the virus A/Puerto Rico/8/34 by different Fab 49 concentrations. The results obtained with the human e509 anti-HCV Fab are reported as a negative control.

Figure 2 is a graph that illustrates the neutralization percentage of the A/Wilson-Smith/33 isolate by different Fab 49 concentrations. The results obtained with the human e509 anti-HCV Fab are reported as a negative control.

Figure 3 illustrates the neutralization percentage of the field swine isolate SW1 used herein by different Fab 49 concentrations. The results obtained with the human e509 anti-HCV Fab are reported as a negative control.

Characterization of the antigen recognized by Fab49: Western blot on a lysate from infected cells

10 μg of a cell lysate infected with the A/Puerto Rico/8/34 isolate, prepared as described earlier, were run under native conditions on a 10% polyacrylamide gel. For this purpose, the samples were run at 100V for 1 hour in a proper refrigerated tank (BIORAD). Thereafter,

the gel was removed from the electrophoresis apparatus and incubated for 10 minutes in Transfer Buffer (Tris base 3g; Glycine 14.41 g, dH_2O 800 ml, Methanol 200 ml) in order to eliminate any detergent residue. The transfer onto a nitrocellulose membrane (Hybond-ECL; Amersham Biosciences) was then carried out. overnight at 30V and 90mA. The membrane was then blocked for 1 hour with 5% dried milk dissolved in 1X PBS and thereafter washed three times in 1X PBS – 0.1% Tween. During each wash, the membrane was left shaking on a swinging platform for 10 minutes. After which, the different Fabs, diluted in PBS with 5% dried milk, were added at the concentration of 5 μg/ml. Besides Fab49, the following controls were added: e509 as a negative control; commercial mouse anti-HA whole IgG1 (COVANCE); commercial mouse anti-M1 whole IgG1 (ARGENE); mouse anti-M2 whole IgG1 (ABCAM); human serum diluted 1:200. Each antibody was left shaking for 1 hour at room temperature. Thereafter, the membrane was washed again in PBS as described earlier. The same secondary mouse (1:1000) or human (1:2000) antibodies as described for the ELISA assay were then added, depending on the source of the antibody to be detected. For the detection of the signal, a working solution was prepared by mixing two substrates (SuperSignal® West Pico Chemiluminescent Substrate Pierce) in a 1:1 ratio, being particularly careful not to expose it to sources of light. The nitrocellulose membrane was incubated for 5 minutes with the working solution and then removed and mounted in a HyperCassette (AMERSHAM). This was developed on a Kodak film in the dark room after the necessary exposure time. The described assay was performed in two different sessions, and in each of them the membrane portion incubated with Fab49 showed the presence of a band weighing slightly less than 80 KDa, consistent with the weight of the immature form of the viral hemagglutinin (HA0). This was confirmed by the same band being also displayed on the strip incubated with the anti-hemagglutinin control antibody. An analogous band, more intense than the others, was also detected in the membrane portion incubated with human serum. The result of this experiment shows that the antibody is directed against the influenza virus hemagglutinin, perfectly consistent with the neutralization data, since hemagglutinin is known to be the main target of the humoral neutralizing response.

Binding and neutralization assays for HA from the subtype A influenza (H1N1) (swine in-

fluenza)

The HA proteins of the influenza viruses A/PR/08/1934 and A/California/04/2009 were amplified, respectively, from the supernatant of MDCK cells infected or synthesized in vitro (GenART, Ragensburg, Germany) and were cloned into pcDNA3.1 expression vectors (Invitrogen), thereby obtaining one construct H1 HA (A/PR/08/1934) and one construct H1 HA (A/California/04/2009).

The cDNA and amino acid sequences of the HA proteins of the two above-indicated isolates are displayed in the sequence listing as SEQ ID No: 6 (cDNA sequence of the HA protein from A/PR/08/1934), SEQ ID No: 7 (amino acid sequence of the HA protein from A/PR/08/1934), SEQ ID No: 8 (cDNA sequence of the HA protein from A/California/04/2009) and SEQ ID NO: 9 (amino acid sequence of the HA protein from A/California/04/2009), respectively.

Human epithelial kidney (HEK) 293T cells were transfected with 3 µg of the recombinant vector pcDNA3.1 containing the construct H1 HA (A/PR/08/1934) or the construct H1 HA (A/California/04/2009). After centrifugation and fixation, the transfected cells were incubated with Fab49 (10 µg/ml). After further washes, the cells were incubated with a FITC-conjugated human anti-Fab monoclonal antibody and assayed by FACS. The data were analyzed as described by Perotti et al., J Virology, 2008 Jan;82(2):1047-52. The experiment demonstrated that Fab49 recognizes 293T cells transfected with either of the recombinant vectors.

For the neutralization assay, retrovirus vectors modified so as to express influenza HA proteins on their pericapsid (pseudo-typing), including the reporter gene Luc, were produced from 293T cells co-transfected with FuGene 6 (Roche) and the following plasmids: Luc system (5 µg pCMVΔR8.2 and 5.5 µg pHR'CMV-Luc) plus 3 µg of construct H1 HA (A/PR/08/1934) or H1 HA (A/California/04/2009). The supernatants were collected 48 hours after the transfection, filtered through a 0.45 µm low protein-binding filter and used immediately or frozen at -80°C. The titers of the HA pseudo-types were measured on 293T and MDCK cells. Briefly, 48 hours after infection of the cells with 100 µl of the lentivirus Luc HA-pseudotyped vector (HA-Luc) at different dilutions, the cells in 96-well plates were lysed in a Luc assay cell lysis buffer (lucife-

rase assay reagent, Promega) according to the manufacturer's instructions. The titers of the pseudo-types have been expressed as relative luminescence units (RLU/ml).

Fab49's neutralization activity was tested by using a neutralization assay based on influenza pseudo-particles. This approach showed that Fab49 has a strong neutralization activity towards all the influenza virus pseudo-particles generated with the two H1N1-subtype isolates (A/PR/08/1934 and H1 HA (A/California/04/2009), with an [IC50] of approximately 2 μg/ml.

CLAIMS

1. A human monoclonal antibody directed against the influenza A virus, which recognizes hemagglutinin as the antigen, characterized in that it has a neutralizing activity against a plurality of H1-subtype influenza A virus isolates.

2. The human monoclonal antibody according to claim 1, wherein said plurality of H1-subtype influenza A virus isolates comprises at least one human-derived isolate and one animal-derived isolate.

3. The human monoclonal antibody according to claim 1, wherein said plurality of H1-subtype influenza A virus isolates comprises at least the following isolates: A/Puerto Rico/8/34, A/Wilson-Smith/33, A/Malaya/302/54 and A/California/04/2009.

4. The human monoclonal antibody according to any of claims 1 to 3, comprising at least one heavy chain variable domain and one light chain variable domain, the heavy chain variable domain having the amino acid sequence SEQ ID NO:1 and the light chain variable domain having the amino acid sequence SEQ ID NO:2.

5. The human monoclonal antibody according to claim 4, comprising at least one heavy chain variable domain and one light chain variable domain, the heavy chain variable domain being encoded by the nucleotide sequence SEQ ID NO:3 and the light chain variable domain being encoded by nucleotide sequence SEQ ID NO:4.

6. The human monoclonal antibody according to any of claims 1 to 5, which is selected from the group consisting of whole immunoglobulins and immunoglobulin fragments comprising at least one heavy chain variable domain and one light chain variable domain.

7. The human monoclonal antibody according to claim 6, wherein the said immunoglobulin fragments are selected from the group comprising Fab fragments, Fab' fragments, $F(ab')_2$ fragments, Fv fragments, single chain antibodies (scFv).

8. An isolated polypeptide selected from SEQ ID NO:1 and SEQ ID NO:2.

9. The isolated polypeptide according to claim 8, which has a neutralizing activity against a plurality of influenza A virus isolates expressing the H1-subtype hemagglutinin.

10. An anti-idiotype antibody that is specifically directed against the idiotype of a monoclonal antibody according to any of claims 1 to 7.

11. An isolated nucleotide sequence selected from SEQ ID NO:3 and SEQ ID NO:4.

12. An expression vector comprising nucleotide sequence SEQ ID NO:3, or nucleotide sequence SEQ ID NO:4, or both the nucleotide sequences SEQ ID NO:3 and SEQ ID NO:4.

13. A host cell transformed with an expression vector according to claim 12.

14. A pharmaceutical composition comprising an effective amount of at least one antibody or one polypeptide according to any of claims 1 to 10 and a pharmaceutically acceptable carrier and/or diluent.

15. An antibody or polypeptide according to any of claims 1 to 10 for use as a prophylactic or therapeutic medicament for the treatment of pathologies directly or indirectly caused by infection with an influenza A virus expressing the H1-subtype hemagglutinin.

16. The use of an antibody or polypeptide according to any of claims 1 to 10 for prepar-ing a prophylactic or therapeutic medicament for the treatment pathologies caused by infec-

tion with an influenza A virus expressing the H1-subtype hemagglutinin.

17. The use according to claim 16 wherein the pathology caused by infection with an influenza A virus expressing the H1-subtype hemagglutinin is the influenza syndrome.

18. The use according to claim 17 wherein the said pathology is caused by infection with the H1N1 influenza A virus, also designated as swine influenza virus or the new influenza virus.

19. An assay method for detecting, in a biological sample from a patient, the presence of anti-influenza virus antibodies having homosubtype cross-neutralizing properties for influenza A viruses expressing the H1-subtype hemagglutinin, comprising contacting the said biological sample with a monoclonal antibody according to any of claims 1 to 7 as a specific assay reagent.

20. An assay method for detecting, in an immunogenic or vaccine composition, the presence of epitopes from the influenza A virus expressing the H1-subtype hemagglutinin capable of eliciting anti-influenza A virus antibodies having a homosubtype cross-neutralizing property against influenza A viruses expressing the H1-subtype hemagglutinin, in a subject to which the composition is administered, comprising contacting the said composition with a monoclonal antibody according to any of claims 1 to 7 as a specific assay reagent.

21. A kit comprising a monoclonal antibody according to any of claims 1 to 7 as a specific reagent, for detecting or quantifying anti-influenza A virus antibodies having a homosubtype cross-neutralizing property against influenza A viruses expressing the H1-subtype hemagglutinin, in a biological sample obtained from a patient or an immunogenic or vaccine composition.