# PLASMIDS CODING FOR p185$^{neu}$ PROTEIN SEQUENCE VARIANTS AND THERAPEUTIC USES THEREOF

The present invention refers to plasmid vectors containing DNA sequences coding for truncated and chimeric forms of p185$^{neu}$ protein, and use thereof in DNA vaccination against Her-2/neu (ErbB-2)-positive tumors that express p185$^{neu}$ protein. Plasmids according to the invention are capable of eliciting a protective immune response which is based on antibody and/or T lymphocyte induction against p185$^{neu}$ protein-expressing tumors. The invention further refers to pharmaceutical compositions containing such plasmids and use thereof in preventive or therapeutic treatment of p185$^{neu}$-positive tumors.

## Background of the invention

Neoplastic cells often differ from normal cells in that they express several proteins abnormally. Due to this anomalous expression, some proteins can act as Tumor Associate Antigens (TAA). This is because the host immune system can recognize these abnormalities and elicit an immune response that might protect the host from tumor onset and development. To be a target of antitumoral immunotherapy, a TAA must:

- have a pathogenetic role in a certain stage of neoplastic growth;
- be detectable by immune system even when the tumor gives rise to clonal variants which no more express major histocompatibility complex (HLA) glicoproteins;
- be recognized by both antibodies and T lymphocytes.

Several TAA have been discovered in human carcinomas in recent years. Among them, p185$^{neu}$, the protein product of Her-2/neu (ErbB2) oncogene, is a particularly suited target for immunotherapy (Lollini and Forni, 2003, *Trends*

*Immunol.* **24**: 62). $p185^{neu}$ is a membrane receptor of class I receptor tyrosin kinase family, which also encompasses the epidermal growth factor receptor (EGF-R or ErbB-1) and other related receptors (ErbB-3, ErbB-4) which play a key role in cell proliferation and differentiation (Hynes and Stern, 1994, *BBA* **1198**: 165).

$p185^{neu}$ receptor protein can be subdivided into three domains: the extracellular domain (EC domain), the transmembrane domain (TM domain), and the intracytoplasmic domain (IC domain). Recently, the EC domain crystallographic structure of human and rat $p185^{neu}$ protein has been published. This domain has been described to be composed of four subdomains (I/L1, II/CR1, III/L2, and IV/CR2) for approximately 630 amino acids in all. It has been further shown that $p185^{neu}$ protein has a rigid conformation, which allows it to interact with other ErbB receptors, dimerize, and induce transduction of proliferation signal even if this protein binds no ligands directly (Cho et al., 2003, *Nature* **421**: 756).

Her-2/neu (ErbB2) oncogene is involved in normal processes of embryonic organogenesis and epithelial growth, while in adults it is expressed only at faint levels (Press *et al.*, 1990, *Oncogene* **5**: 953). In humans, overexpression of this oncogene is mainly caused by gene amplification. Her-2/neu (ErbB2) oncogene is overexpressed in about 30% of mammary carcinomas, and such an overexpression is related to a more rapid tumor progression (Slamon *et al.*, 1989, *Science* **244**: 707). Among the different strategies which have been proposed, DNA vaccination seems to be an effective method to elicit an immune response to Her-2/neu-positive tumors. Even though $p185^{neu}$ protein is a "self" antigen, i.e. a protein which is normally present in the body, patients with $p185^{neu}$-positive mammary carcinomas often exhibit an immune response, both cellular and humoral (Signoretti *et al.*, 2000, *J. Natl. Cancer Inst.* **23**: 1918; Disis *et al.*, 1994, *Cancer Res.* **54**: 16; Peoples *et*

*al.*, 1995, *Proc. Natl. Acad. Sci. USA* **92**: 432). One of the objectives of antitumoral immunotherapies directed towards $p185^{neu}$ protein is to increase the response intensity in patients with a pre-existing immune response, or to generate an immune response in patients in whom this response is undetectable. The fact that $p185^{neu}$ protein is a "self" antigen entails that the vaccine must be able to overcome an immunotolerant state.

The inventors of the instant patent application were the first using and validating the efficacy of DNA vaccination in eliciting an immune protection both to spontaneous mammary carcinomas and transplantable Her-2/neu-positive tumors. These studies have proven that prevention and treatment of preneoplastic lesions is an accessible goal. In particular, in experiments aimed at preventing the development of spontaneous mammary tumors that arise in transgenic mice due to rat Her-2/neu oncogene (FVB/neuT mice and BALB-neuT mice), it has been shown that the plasmid coding for rat $p185^{neu}$ protein EC and TM domains is capable of eliciting a more effective protection compared to the plasmid coding for full-length $p185^{neu}$ protein or plasmid coding for its EC domain only (secreted antigen) (Amici *et al.*, 2000, *Gene Ther.* 7: 703; Rovero *et al.*, 2000, *J. Immunol.* **165**: 5133). Similar data have been reported by Chen *et al.*, (1998, Cancer *Res.* **58**: 1965). Furthermore, it has been shown that efficacy of vaccination with DNA plasmids is strongly increased if it is followed by a very short electric pulse when plasmids are inoculated intramuscularly (Quaglino *et al.*, 2004, *Cancer Res.* **64**: 2858). Other authors have shown that plasmids coding for full-length $p185^{neu}$ protein, if necessary mutated such that it does not possess tyrosine kinase activity, are efficacious in preventing the onset of tumors following the transplant of $p185^{neu}$-positive cancer cells (Wei-Zen *et al.*, 1999, *Int. J. Cancer* **81**: 748). The same plasmids have proven as much effective even when, deprived of the leader signal responsible for protein processing in the endoplasmic reticulum, they

bring about the cytoplasmic localization of $p185^{neu}$ antigen. When plasmids coding for $p185^{neu}$ protein which localizes in membrane thanks to the presence of a leader signal are used, protections depends upon an immune response which relies on antibodies. On the contrary, a T lymphocyte-mediated immune response is observed if vaccine does not contain a leader signal, and hence $p185^{neu}$ protein localizes in the cytoplasm of transfected cells rather than on their plasma membrane (Pilon *et al.*, 2001, *J. Immunol.* 167: 3201). In addition, a combined vaccination obtained by using both plasmids with a leader signal and those in which this leader signal has been deleted, is more effective in protecting against tumor growth (Piechocki *et al.*, 2001, *J. Immunol.* **167**: 3367). This demonstrates that there is a synergistic effect between humoral and cellular responses in the prevention of $p185^{neu}$-positive carcinomas (Reilly et al., 2001, Cancer Res. 61: 880).

Vaccination with the plasmid coding for EC and TM domains (EC-TM plasmid) has proven efficacious not only in preventing the development of spontaneous $p185^{neu}$-positive carcinomas, but also in treating tumor masses of 2 mm in diameter by involving a range of effector immune system mechanisms (T helper and T killer cells, antibodies, macrophages, neutrophils, natural killer cells, Fc receptors, IFN-gamma, and perforins), which coordinately contribute to tumor rejection (Curcio *et al.*, 2003, *J. Clin. Invest.* **111**: 1161).

**Description of the invention**

Several plasmids coding for the full-length TM domain and decreasing portions of EC domain of rat $p185^{neu}$ protein have been constructed. The truncated plasmids, obtained by deleting the $NH_2$-terminal 240 base pairs (bp), or multiples of this length, were used in experiments aimed at preventing growth of transplantable rat $p185^{neu}$ protein-overexpressing tumor cells (TUBO cells). Furthermore, a series of plasmids coding for chimeric $p185^{neu}$ protein forms were created by adding $NH_2$-terminal portions of human ErbB2 cDNA to

sequences coding for the truncated forms of rat protein to reconstitute the whole protein sequence.

Protection achieved following vaccination with plasmid coding for the full-length EC and TM domains is mainly due to antibody production, while protection attained by using plasmids coding for the truncated forms of rat $p185^{neu}$ protein is not associated with a significant antibody production in many cases.

On the basis of the results of the *in vivo* experiments, plasmids capable of inducing a strong immune response, both antibody and T lymphocyte-mediated, were selected.

In a first aspect, the invention refers to plasmids containing a coding sequence for a $p185^{neu}$ protein fragment, which sequence is selected from the group consisting of SEQ ID NO: 1-5; or a sequence coding for a chimeric $p185^{neu}$ protein, which sequence is selected from the group consisting of SEQ ID NO:6-12 (reference sequences for genes coding for human and rat $p185^{neu}$ proteins are deposited in Gene Bank with accession NO. M11730 and X03362, respectively).

DNA sequences coding for the truncated and chimeric forms of $p185^{neu}$ protein according to the invention can be inserted into any plasmid vectors suitable for use in mammals, particularly in humans. Besides the above coding sequences, plasmids can include functional elements to control transcription, in particular promoters, preferably the CMV promoter, located upstream of the coding sequence, transcription initiation and stop sequences; a selection marker, preferably the ampicilline or kanamycine resistance genes; CpG motifs; a polyadenilation site; and in case enhancers or transcription activators. The elements for controlling transcription must be suitable for use of vectors in mammals, particularly in humans.

In another aspect, the invention concerns a pharmaceutical composition

containing a DNA plasmid defined as above, together with pharmaceutically acceptable vehicles and excipients. Alternatively, the compositions can contain admixtures of two or more different plasmids coding for both the truncated and chimeric forms of $p185^{neu}$ protein. The pharmaceutical compositions in a suitable form for parenteral administration, preferably in the form of an injectable solution, are preferably used for DNA vaccination. Principles and methods for DNA vaccination are known to those skilled in the art, and are described, e.g., in Liu, 2003; *J. Int. Med.* **253**: 402.

Utilization of plasmids coding for the $p185^{neu}$ truncated and chimeric forms to preventively and therapeutically vaccinate against $p185^{neu}$-positive (Her-2/neu-, ErbB-2-positive) tumors has a variety of advantages which ameliorate its efficacy. For plasmids coding for the truncated forms, these advantages are:

1) The possibility to obtain a vaccine coding only for definite TAA portions against which it is desired to develop an immune response; this vaccine has a les chance to elicit autoimmune phenomena.
2) The exclusive induction of some selected forms of immune response, i.e. an antibody-mediated form or a T lymphocyte-mediated form.
3) The possibility to produce vaccines which combine multiple epitopes having a defined immunogenicity by binding cDNA fragments each other which code for different truncated forms, not necessarily sequentially.

The use of chimeric plasmids generated by a combination of truncated forms of $p185^{neu}$ from a different animal species allows to:

a) Vaccinate with plasmids coding for protein determinants of the same species to be immunized, e.g. humans, which is able to elicit a specific high-affinity response;
b) Combine plasmids coding for antigenic determinants of the same species to be immunized with cDNA sequences coding for antigenic

determinants from other species, the antigenic determinants showing a substantial similarity but differing in that those from other species elicit a more intense immune response, thus overcoming the tolerance state. These allogeneic determinants, which are recognized as partially exogenous, act as helper determinants facilitating the induction of a more intense response and cytokine release;

c) Combine plasmids coding for antigenic determinants of the same species with cDNA sequences which, by coding determinants of another species, in some individuals can give rise to heteroclytic determinants which bind with higher affinity to HLA molecules and induce more intense immune responses having a higher affinity;

d) Have a vaccine which combines advantages from a) with those from b) and c).

Properly formulated DNA plasmids according to the invention are used in preventive or therapeutic treatment of humans or animals which show a high risk of developing $p185^{neu}$-positive carcinomas, or patients carrying $p185^{neu}$-positive primary tumors, their relapses or metastases. Prevention can be primary, when the tumor is not evident yet; secondary, when the tumor is in its initial stages as a preneoplastic lesion; or tertiary, if a tumor relapse or metastatic process is observed.

Tumors treatable with plasmids or compositions of the invention are primarily those of epithelial origin, particularly pulmonary, ovarian, and mammary adenocarcinomas; squamous head and neck carcinomas, and more generally $p185^{neu}$ protein-expressing tumors.

**Detailed description of the invention**

*Construction of plasmids coding for truncated forms of rat $p185^{neu}$ protein*

The plasmid backbone pCMV3.1 (obtained in our laboratory starting

from pcDNA3.1 from Invitrogen, Milan, Italy) was used to produce the DNA plasmids coding for the full-length TM domain and decreasing portions of EC domain of rat $p185^{neu}$ protein. pCMV3.1 contains the rat Her-2/neu 5' UTR nucleotide sequence (which is transcribed but not translated) and leader sequence (neuL). The secretion signal DNA fragment of rat $p185^{neu}$ protein was obtained by enzymatic amplification of DNA using the pCMV-EC-TM vector (Amici *et al.*, 2000, *Gene Ther.*, 7: 703; Rovero *et al.*, 2000, *J. Immunol.*, **165**: 5133) as a template, T7 primer as a sense oligonucleotide (oligonucleotide #1), and an oligonucleotide (oligonucleotide #2) having a terminal *Eco*RI site as an antisense oligonucleotide. Following purification and digestion with *Hin*dIII and *Eco*RI restriction enzymes, the amplified fragment was cloned into pCMV3.1 plasmid which had been digested with the same enzymes, thus obtaining pCMV3.1-neuL. Subsequently, seven different sequences coding for the deleted fragments of EC domain and full-length TM domain of rat $p185^{neu}$ protein have been inserted in frame into pCMV3.1-neuL vector digested with *Eco*RI and *Xba*I restriction enzymes. The new plasmids so obtained were designated pCMV3.1-neuL-rEC1-TM (-70 amino acids) (**Fig. 1**), pCMV3.1-neuL-rEC2-TM (-150 amino acids) (**Fig. 2**), pCMV3.1-neuL-rEC3-TM (-230 amino acids) (**Fig. 3**), pCMV3.1-neuL-rEC4-TM (-310 amino acids) (**Fig. 4**), pCMV3.1-neuL-rEC5-TM (-390 amino acids) (**Fig. 5**), pCMV3.1-neuL-rEC6-TM (-470 amino acids) (**Fig. 6**), and pCMV3.1-neuL-rEC7-TM (-550 amino acids) (**Fig. 7**). The fragment coded for by the first of these plasmids is 70 amino acids shorter, including the secretion signal amino acid sequence. All other fragments are progressively shorter by 80 amino acids.

These fragments have been produced by enzymatic amplification of DNA using seven different sense oligonucleotides all having a terminal *Eco*RI restriction site (oligonucleotides #3-#9), and an antisense oligonucleotide

(oligonucleotide #10) capable of recognizing a site called "pcDNA3.1/BGH Reverse Priming Site" (830-850 nt) at the 3' end of pCMV3.1 multiple cloning site. As a DNA template for PCR, pCMV-EC-TM vector (Amici A. *et al.* 2000, *Gene Ther.* 7: 703; Rovero *et al.*, 2000, *J. Immunol.* **165**: 5133) was used. Following enzymatic digestion with *Eco*RI and *Xba*I restriction enzymes, amplification products were cloned into pCMV3.1-neuL plasmid.

Vaccination with pCMV3.1-neuL-rEC4-TM plasmid as well as vaccination with pCMV3.1-neuL-rEC-TM plasmid which codes for the full-length EC and TM domains protects 100% of BALB/c mice from developing tumors induced by inoculation of TUBO cells. On the other hand, vaccination with pCMV3.1-neuL-rEC1-TM, pCMV3.1-neuL-rEC2-TM, and pCMV3.1-neuL-rEC3-TM plasmids which code for the first three truncated forms of $p185^{neu}$ protein protects 70-80% of BALB/c mice. pCMV3.1-neuL-rEC5-TM plasmid which codes for the fifth truncated form protects 50% of BALB/c mice, while pCMV3.1-neuL-rEC6-TM and pCMV3.1-neuL-rEC7-TM plasmids which code for the sixth and seventh truncated forms induce no protection. The results obtained demonstrate that cellular response activated by the $p185^{neu}$ protein truncated forms whose localization is cytoplasmic, is sufficient in antitumoral prevention. However, concomitant activation of cellular and humoral responses allows obtaining a more effective therapy (Rielly *et al.*, 2001, *Cancer Res.* **61**: 880). To attain antibody production, vaccination must be carried out with plasmid coding for the full-length EC and TM domains of $p185^{neu}$ protein. Vaccination with pCMV3.1-neuL-rEC4-TM plasmid which codes for the fourth truncated $p185^{neu}$ form lacking amino acids 1-310 is still able to confer a full protection, but antibody response is 10-fold lower compared to that of pCMV3.1-neuL-rEC-TM plasmid (Table 1).

**Table 1**

| Plasmids | N° mice | Protection | Antibodies |
|---|---|---|---|
| **pCMV3.1-neuL** | **5** | **0%** | - |
| **pCMV3.1-neuL-rEC-TM** | **5** | **100%** | +++ |
| **pCMV3.1-neuL-rEC1-TM** | **5** | **80%** | - |
| **pCMV3.1-neuL-rEC2-TM** | **5** | **75%** | - |
| **pCMV3.1-neuL-rEC3-TM** | **5** | **70%** | - |
| **pCMV3.1-neuL-rEC4-TM** | **5** | **100%** | + |
| **pCMV3.1-neuL-rEC5-TM** | **5** | **50%** | - |
| **pCMV3.1-neuL-rEC6-TM** | **5** | **0%** | - |
| **pCMV3.1-neuL-rEC7-TM** | **5** | **0%** | - |

*Construction of chimeric human-rat plasmids capable of coding for seven different fusion forms of p185$^{neu}$ protein (HuRT1-7)*

The majority of epitopes presented by HLA are located on the first subdomain (I/L1) of p185$^{neu}$ protein. Therefore, chimeric plasmids coding for sequences of human ErbB2 protein which are increasingly longer starting from $NH_2$-end (the outermost portion of EC domain) have been constructed to induce a specific immune response against these epitopes. These new plasmids, designated HuRT (Human Rat Transmembrane), were created by adding the lacking portions of human ErbB2 cDNA to sequences which code for the truncated forms of rat p185$^{neu}$ protein.

The first five truncated plasmids coding for full-length TM domain and decreasing fragments of EC domain of rat p185$^{neu}$ protein were digested with *Hin*dIII and *Eco*RI restriction enzymes. The five different human cDNA fragments obtained by PCR and digested at their ends were cloned within these five truncated plasmids, so that reading frame was maintained. The cDNA fragments coding for portions of human p185$^{neu}$ protein to be inserted, including the 5' UTR region and secretion signal to pass through endoplasmic reticulum, were produced by amplification using pcDNA3.1erbB2 plasmid as a

template. Six oligonucleotides were used as primers. The sense oligonucleotide is the same for all six primers and corresponds to T7 primer (oligonucleotide #1), while the five antisense oligonucleotides were designed so that they recognized human ErbB2 oncogene cDNA in increasingly advanced positions of the sequence and had an *Eco*RI restriction site at their 3' ends (oligonucleotides #11-#15). Following purification and digestion with *Hin*dIII and *Eco*RI restriction enzymes, the amplified fragments were inserted into corresponding plasmids (pCMV3.1-rEC1-TM, pCMV3.1-rEC2-TM, pCMV3.1-rEC3-TM, pCMV3.1-rEC4-TM, pCMV3.1-rEC5-TM), which had been previously digested with the same restriction enzymes. In this way five new plasmids have been obtained (pCMV3.1-HuRT1-5) which code for chimeric proteins of 689 amino acids in length, 2 amino acids of which (Glu-Phe) belong to the *Eco*RI restriction site used to join human and rat DNAs. The proteins coded for by these chimeric plasmids differ from each other by increasing portions of human $p185^{neu}$ protein and decreasing portions of rat $p185^{neu}$ protein.

To obtain the chimeric plasmids coding for the sixth and seventh truncated forms of rat $p185^{neu}$ protein, two new plasmids were constructed in which cloning sites other than *Eco*RI could be used, as an *Eco*RI restriction site is present in the position 1450 in human ErbB2 gene sequence. pCMV3.1 was modified by using a synthetic sequence made up of a sense oligonucleotide (oligonucleotide #16) and an antisense oligonucleotide (oligonucleotide #17), so that one of the two restriction sites for *Pme*I enzyme was deleted and the restriction sites for *Hin*dIII and *Nhe*I restriction enzymes, located on its multiple cloning site, were inverted. The new plasmid backbone so obtained was designated pCMV3.1H/N. Fragments for the sixth and seventh truncated forms of rat $p185^{neu}$ protein were produced by amplification using pCMV-EC-TM plasmid (Amici *et al.*, 2000, *Gene Ther.*, 7: 703; Rovero

*et al.*, 2000, *J. Immunol.*, **165**: 5133) as a template and two different sense oligonucleotides with a *Nhe*I restriction site at their ends (oligonucleotides #18 and #19), and antisense oligonucleotide #10.

Following enzymatic digestion with restriction enzymes *Nhe*I and *Pme*I, the amplification products were cloned into pCMV3.1H/N plasmid, thus obtaining the new pCMV3.1H/N-rEC6-TM and pCMV3.1H/N-rEC7-TM plasmids. The cDNA fragments coding for portions of human $p185^{neu}$ protein to be inserted to generate the chimeric pCMV3.1H/N-HuRT6 and pCMV3.1H/N-HuRT7 plasmids were obtained by amplification using pcDNA3.1erbB2 plasmid as a template, T7 primer as a sense oligonucleotide (oligonucleotide #1), and two primers designed so that they recognized human cDNA at suitable positions and had a *Nhe*I restriction site at their ends (oligonucleotides #20 and #21), as antisense oligonucleotides.

Following purification and digestion with *Hin*dIII and *Nhe*I restriction enzymes, the amplified fragments were inserted into corresponding plasmids (pCMV3.1H/N-rEC6-TM; pCMV3.1H/N-rEC7-TM), which had previously digested with the same restriction enzymes. In this way the two new chimeric pCMV3.1H/N-HuRT6 and pCMV3.1H/N-HuRT7 plasmids were obtained, which code for proteins of 689 amino acids in length, 2 amino acids of which (Val-Ser) belong to the *Nhe*I restriction site used to join human and rat DNAs.

These manipulations led to the following plasmids:

- pCMV3.1-HuRT1 plasmid (**Fig. 8**), which codes for 70 amino acids of EC domain of human $p185^{neu}$ protein, 2 amino acids belonging to *Eco*RI site and 618 amino acids of rat $p185^{neu}$ protein
- pCMV3.1-HuRT2 plasmid (**Fig. 9**), which codes for 150 amino acids of human $p185^{neu}$ protein EC domain and 538 amino acids of rat $p185^{neu}$ protein
- pCMV3.1-HuRT3 plasmid (**Fig. 10**), which codes for 230 amino acids

of EC domain of human p185$^{neu}$ protein and 458 amino acids of rat p185$^{neu}$ protein

- pCMV3.1-HuRT4 plasmid (**Fig. 11**), which codes for 310 amino acids of EC domain of human p185$^{neu}$ protein and 378 amino acids of rat p185$^{neu}$ protein
- pCMV3.1-HuRT5 plasmid (**Fig. 12**), which codes for 390 amino acids of EC domain of human p185$^{neu}$ protein and 298 amino acids of rat p185$^{neu}$ protein
- pCMV3.1H/N-HuRT6 plasmid (**Fig. 13**), which codes for 470 amino acids of EC domain of human p185$^{neu}$ protein and 218 amino acids of rat p185$^{neu}$ protein
- pCMV3.1H/N-HuRT7 plasmid (**Fig. 14**), which codes for 550 amino acids of EC domain of human p185$^{neu}$ protein and 138 amino acids of rat p185$^{neu}$ protein.

The indirect evidence of a membrane expression of the chimeric human-rat proteins coded for by these plasmids has been obtained by immunizing mice with the seven new plasmids (pCMV3.1-HuRT1-5 and pCMV3.1H/N-HuRT6-7). The sera from all vaccinated mice have specific antibodies against the chimeric human and rat p185$^{neu}$ protein. Furthermore, animals vaccinated with plasmids coding for the seven different chimeric proteins are protected from a lethal inoculation of TUBO cells and/or human p185$^{neu}$ protein-overexpressing tumor cells (D2F2-E2 cells).

## EXAMPLES

### Example 1: Construction of pCMV3.1-HuRT5 Plasmid

pCMV3.1-rEC5-TM plasmid, which codes for the fifth truncated form of rat p185$^{neu}$ protein, was digested with *Hin*dIII and *Eco*RI restriction enzymes (BioLabs, Beverly, MA) to delete the 5' UTR region and neuL sequence.

The 4794 bp DNA band corresponding to pCMV3.1-rEC5-TM plasmid lacking the 5' UTR region and neuL sequence was separated by agarose gel electrophoresis and eluted using a Qiaquick gel extraction kit (Qiagen, Italy). The cDNA for the 5' UTR region, leader sequence, and sequence coding for the missing part of human ErbB2 gene was obtained by PCR. pcDNA3.1ErbB2 plasmid was used as a template, T7 primer (oligonucleotide #1) was used as a sense oligonucleotide, and a primer with an *Eco*RI restriction site at its 5' end (oligonucleotide #15) was used as an antisense oligonucleotide. To perform the PCR reaction, reagents and a proofreading Taq polymerase of Finnzymes (CELBIO, Milan, Italy) were employed. Following the PCR reaction, the amplified DNA was purified and precipitated by standard methods, resuspended in 50µl $H_2O$, and digested with *Hin*dIII and *Eco*RI restriction enzymes. The cDNA fragment coding for the relevant portion of human ErbB2 and the linearized pCMV3.1-rEC5-TM plasmid were cloned by ligation reaction using T4 DNA ligase (BioLabs, Beverly, MA).

The ligation product was then used to transform DH5α strain *E. coli* bacteria which had been made competent by the calcium chloride technique.

The clones so obtained were analyzed by alcaline lysis to detect the clones containing the chimeric pCMV3.1-HuRT5 plasmid.

pCMV3.1-HuRT5 was then analyzed by the Sanger sequencing method using an ABI PRISM 310 Genetic Analyzer automated sequencer (Applied Biosystem) to verify that insertion of human sequence portion coding for ErbB2 gene into plasmid coding for the fifth truncated form of rat $p185^{neu}$ protein had taken place correctly and without altering the reading frame.

List of oligonucleotides:

#1 T7 primer (SEQ ID No: 13)

#2 neu leader antisense EcoRI (SEQ ID No: 14)

#3 rECD1 sense EcoRI (SEQ ID No: 15)

#4 rECD2 sense EcoRI (SEQ ID No: 16)

#5 rECD3 sense EcoRI (SEQ ID No: 17)

#6 rECD4 sense EcoRI (SEQ ID No: 18)

#7 rECD5 sense EcoRI (SEQ ID No: 19)

#8 rECD6 sense EcoRI (SEQ ID No: 20)

#9 rECD7 sense EcoRI (SEQ ID No: 21)

#10 pcDNA3.1/BGH Reverse priming site (SEQ ID No: 22)

#11 His-Myc sense EcoRI mut (SEQ ID No: 23)

#12 His-Myc antisense EcoRI (SEQ ID No: 24)

#13 70 erbB2 antisense EcoRI (SEQ ID No: 25)

#14 150 erbB2 antisense EcoRI (SEQ ID No: 26)

#15 230 erbB2 antisense EcoRI (SEQ ID No: 27)

#16 310 erbB2 antisense EcoRI (SEQ ID No: 28)

#17 390 erbB2 antisense EcoRI (SEQ ID No: 29)

#18 HindIII-NheI sense (SEQ ID No: 30)

#19 HindIII-NheI antisense (SEQ ID No: 31)

#20 rECD6 sense HheI (SEQ ID No: 32)

#21 rECD7 sense HheI (SEQ ID No: 33)

#22 470 erbB2 antisense HheI (SEQ ID No: 34)

#23 550 erbB2 antisense HheI (SEQ ID No: 35)

**Example 2: *in Vivo* Testing**

*Animals*

BALB/c strain female mice about 7-week old were used for all experiments. Animals came from Charles River Laboratories (Calco, Milan, Italy), where they had been bred aseptically and according to the rules established by European Community.

*Intramuscular Administration Followed by* in Vivo *Electroporation*

To avoid pain and undesired contractions of tibial muscles, each mouse

was anaesthetized by intraperitoneal injection of 300µl Avertin, a solution consisting of 0.58 g tribromoethanol (Sigma-Aldrich) and 310 µl Tert-Amyl alcohol (Aldrich) in 39.5 ml deionized $H_2O$. Tibial muscles of anaesthetized mice were shaved, and 20 µl of a solution containing 25 µg DNA were inoculated in each muscle. The DNA-containing solution was prepared just before use according to Dr. F. Pericle's instructions (Valentis, Inc., The Woodlands, Texas, USA). This solution contained plasmid DNA at a concentration of 1.25 mg/ml, poly-L-glutamate sodium salt (Sigma-Aldrich, S.r.l., Milan, Italy) at a concentration of 6 mg/ml, sodium chloride at a concentration of 150 mM (Fluka, BioChemika, Buchs, Switzerland), and endotoxin-free distillated water (Nucleare Free Water, Promega Corporation) to a final volume of 1ml. After about 5 minutes of inoculation, two electrical pulses, 375 $V/cm^2$ in intensity and 25 msec in duration each, generated by an Electro Square Porator electroporator (T820, BTX, San Diego, CA, USA) were applied to both tibial muscles of mice using two steel electrodes located 3 mm apart in a quadrangular arrangement laterally in the leg. Gene immunization by electroporation was performed twice in each animal 21 and 7 days before inoculating tumor cells.

*Inoculation of Tumor Cells*

Left sides of mice were inoculated with 0.2 ml of a suspension containing 2 x $10^5$ TUBO cells.

In vivo *Tumor Growth Evaluation*

Tumor growth was evaluated by palpation weekly, and tumor size was measured along two perpendicular diameters with a gauge. Neoplastic masses of a size larger than 1 millimeter were considered as tumors. Tumor growth was monitored for 100 days from tumor inoculation or until tumor size exceeded 10 millimeters in diameter, time at which animals were sacrificed. The results obtained demonstrate that chimeric pCMV3.1-HuRT5 plasmid is

able to protect 100% of vaccinated BALB/c mice from a lethal inoculation of TUBO cells (Table 2).

**Table 2**

| Plasmids | N° mice | Protection | Survival (days) |
|---|---|---|---|
| **pCMV3.1-neuL** | **5** | **0%** | **+ 35** |
| **pCMV3.1-neuL-rEC-TM** | **5** | **100%** | **+ 100** |
| **pCMV3.1-HuRT5** | **5** | **100%** | **+ 100** |

*Evaluation of Anti-p185$^{neu}$ Antibody Presence in Sera of Vaccinated Animals*

The day preceding the inoculation of tumor cells, blood was drawn from animals vaccinated with chimeric pCMV3.1-HuRT5 plasmid. Sera were analyzed to assess the presence of rat anti-p185$^{neu}$ antibodies. Sera were incubated for 45 minutes at 4°C with cells overexpressing rat p185$^{neu}$. After washing with a solution called the washing buffer, which consists of phosphate buffer saline (PBS) containing 0.2% bovine serum albumin (BSA, Sigma, Milan, Italy) and 0.1% sodium azide ($NaN_3$, Sigma, Milan, Italy), samples were incubated for 20 minutes at 4°C with an anti-mouse immunoglobulin FITC-conjugated antibody, washed with washing buffer, and analyzed by a FACScan cytofluorimeter (Becton Dickinson Immunocytometry Systems, Mountain View, California, USA). Simultaneously, the same cells were incubated with decreasing concentrations of monoclonal anti-c-ErbB2/c-neu antibody (Ab4, Oncogene), so that a relationship between the fluorescence intensities obtained through cytofluorimeter analysis and concentration of anti-p185$^{neu}$ antibodies in animal sera could be derived. The data obtained show that all vaccinated animals exhibit high levels of anti-rat p185$^{neu}$ antibodies, and therefore chimeric pCMV3.1-HuRT5 plasmid is effective in inducing rejection of transplantable p185$^{neu}$-positive tumors and in eliciting a specific antibody response.

## CLAIMS

1. A plasmid vector for DNA transfer, which plasmid contains a sequence selected from SEQ ID N. 1, 2, 3, 4, 5 coding for a fragment of $p185^{neu}$ protein, or a sequence selected from SEQ ID N. 6, 7, 8, 9, 10, 11, 12 coding for a chimeric $p185^{neu}$ protein.

2. Plasmid vector according to claim 1, further containing a transcription promoter.

3. Plasmid vector according to claim 2, wherein said promoter is the CMV promoter.

4. Plasmid vector according to claims 1-2 which is suitable for use in mammals, particularly in humans.

5. Pharmaceutical composition containing a plasmid vector according to claims 1-3 together with pharmaceutically acceptable vehicles and excipients.

6. Composition according to claim 5 which is suitable for parenteral administration.

7. Composition according to claim 6 in the form of an injectable solution.

8. Composition according to claim 5 in the form of a DNA vaccine.

9 Use of a plasmid vector according to claims 1-4 for the preparation of a therapeutic agent to be used in the prevention or treatment of subjects at risk of developing $p185^{neu}$-positive tumors, or patients carrying primary tumors, metastases or $p185^{neu}$-positive tumor relapses.

10. Use according to claim 9 for the preparation of a DNA vaccine.

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Fig. 1

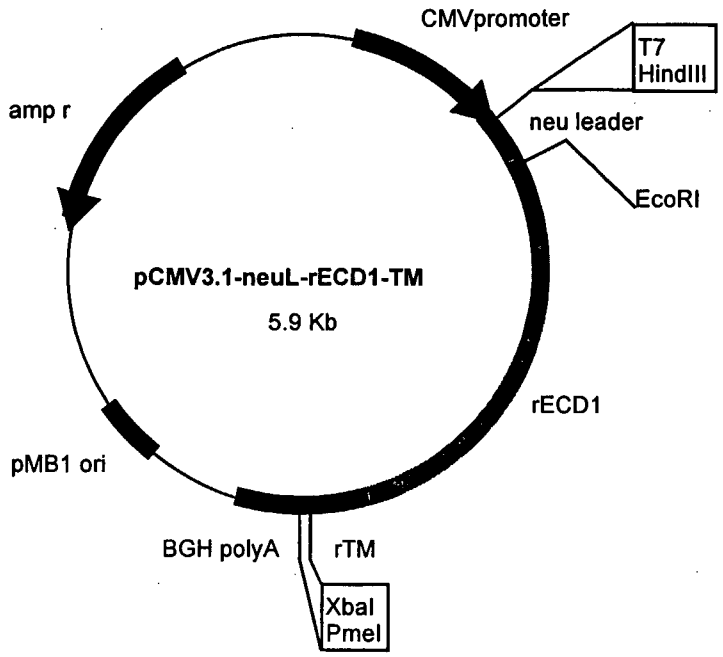
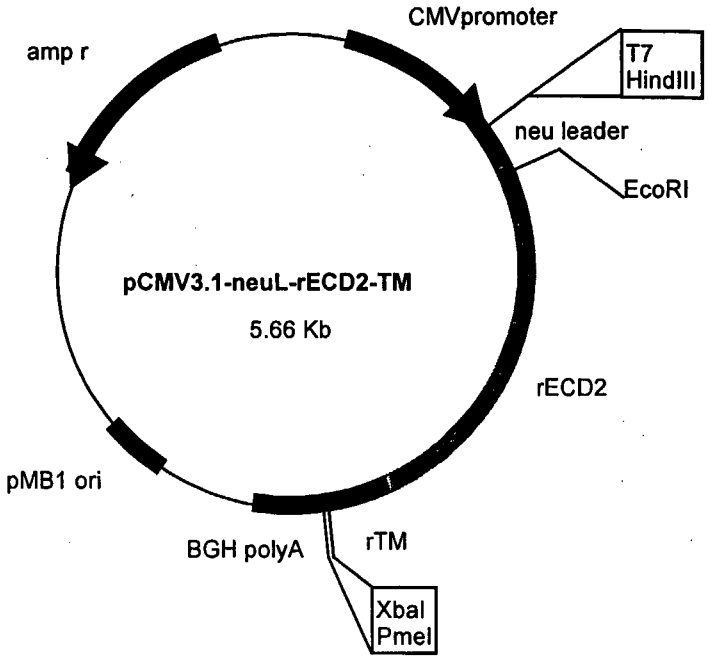


Fig. 2


CMVpromoter
amp r
T7
HindIII
neu leader
EcoRI
pCMV3.1-neuL-rECD2-TM
5.66 Kb
rECD2
pMB1 ori
BGH polyA
rTM
XbaI
PmeI

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Fig. 3

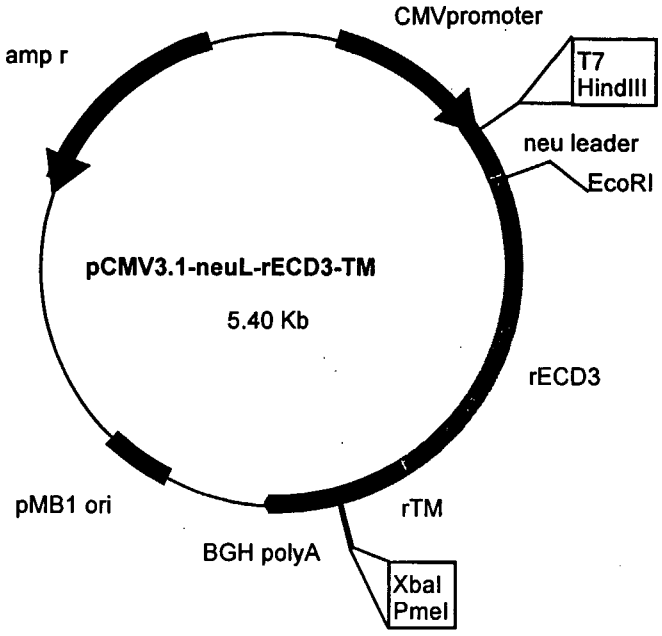
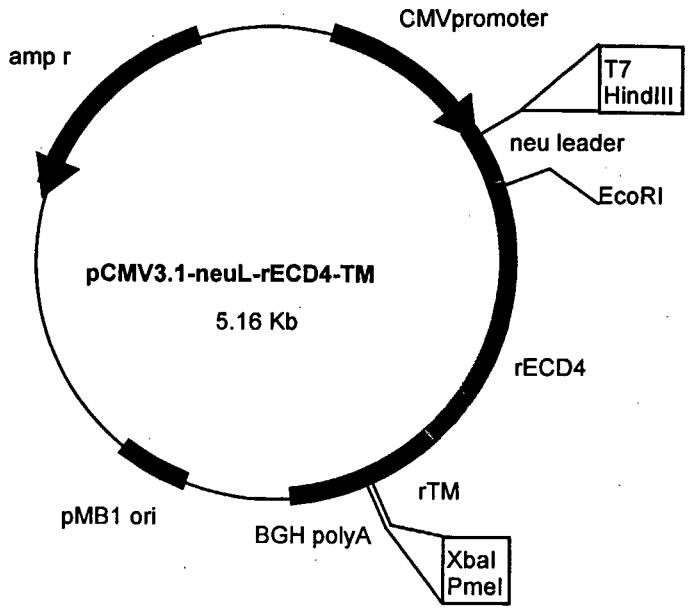
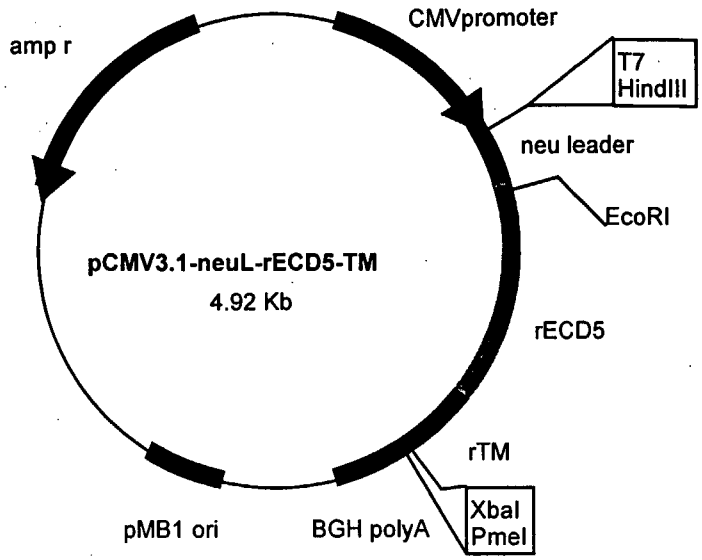


Fig. 4


CMVpromoter
amp r
T7
HindIII
neu leader
EcoRI
pCMV3.1-neuL-rECD4-TM
5.16 Kb
rECD4
rTM
pMB1 ori
BGH polyA
XbaI
PmeI

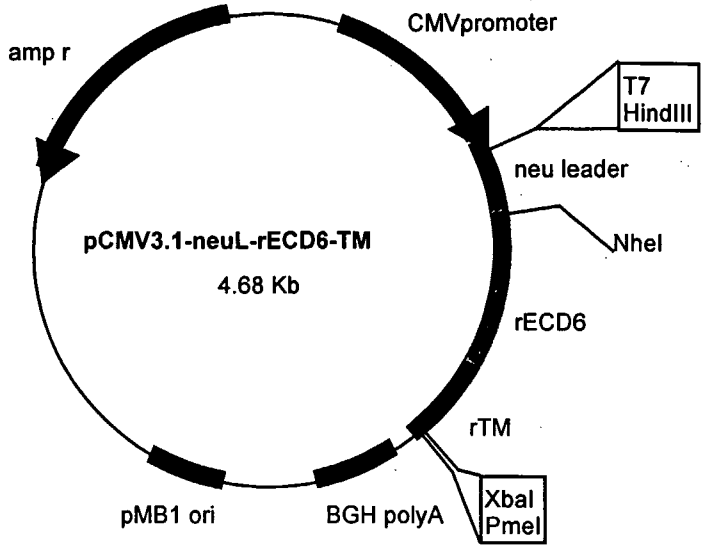
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Fig. 5



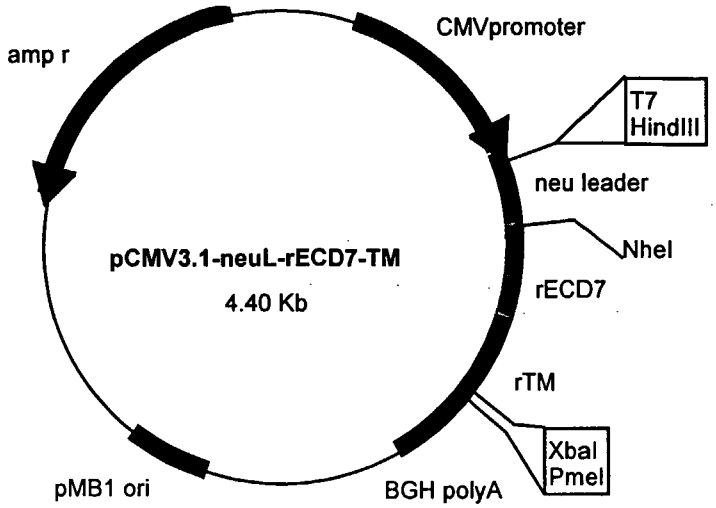
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Fig. 6



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Fig. 7



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Fig. 8

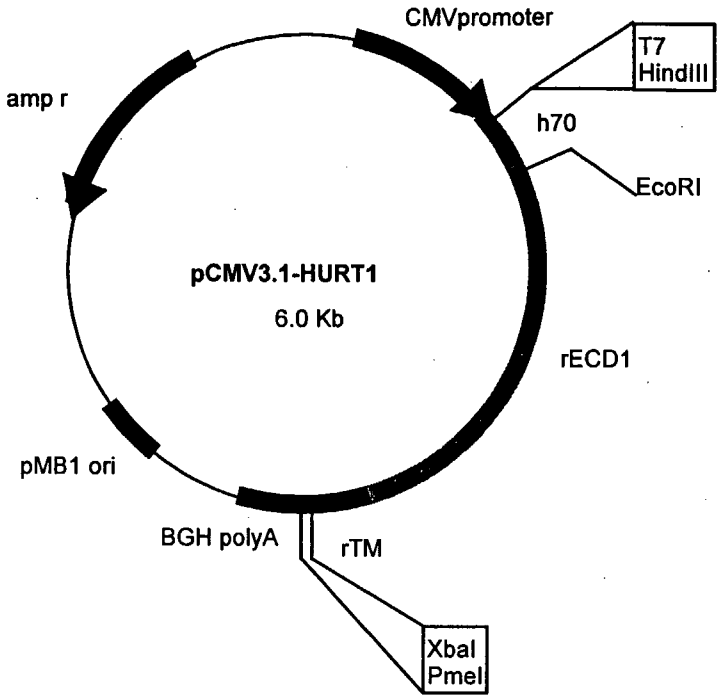
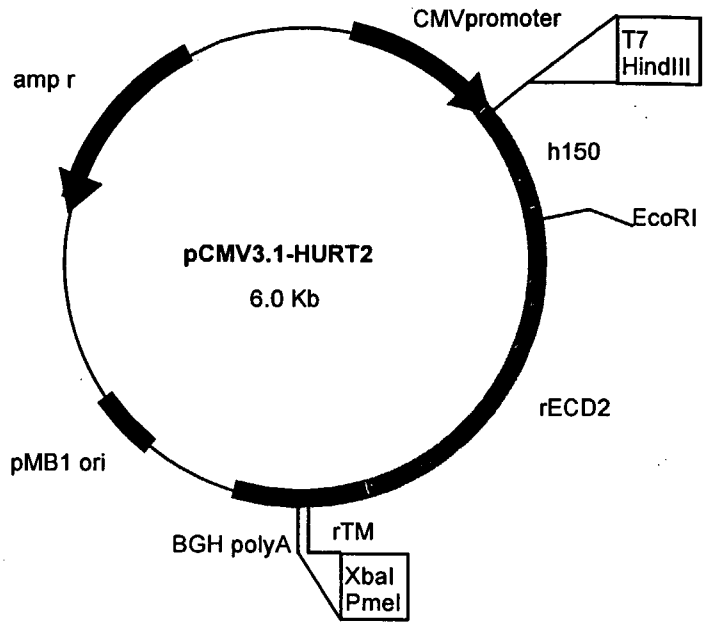


Fig. 9


CMVpromoter
T7
HindIII
amp r
h150
EcoRI
pCMV3.1-HURT2
6.0 Kb
rECD2
pMB1 ori
BGH polyA
rTM
XbaI
PmeI

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Fig. 10

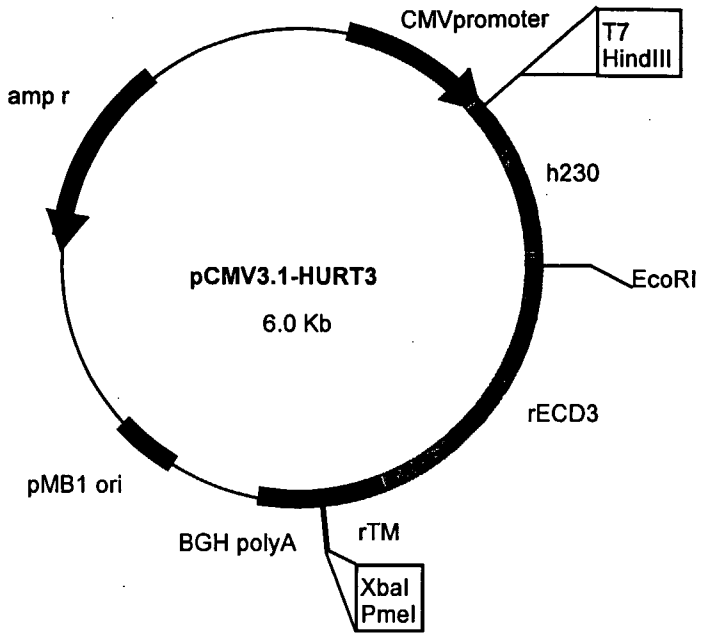
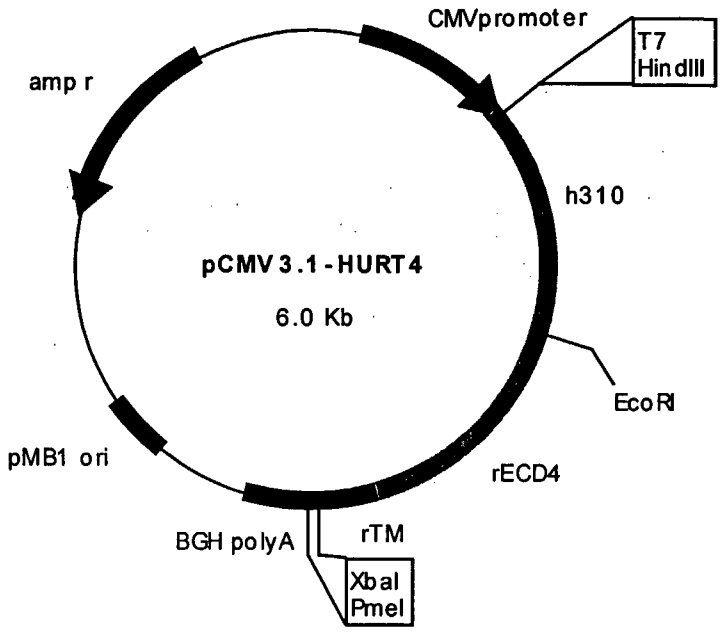
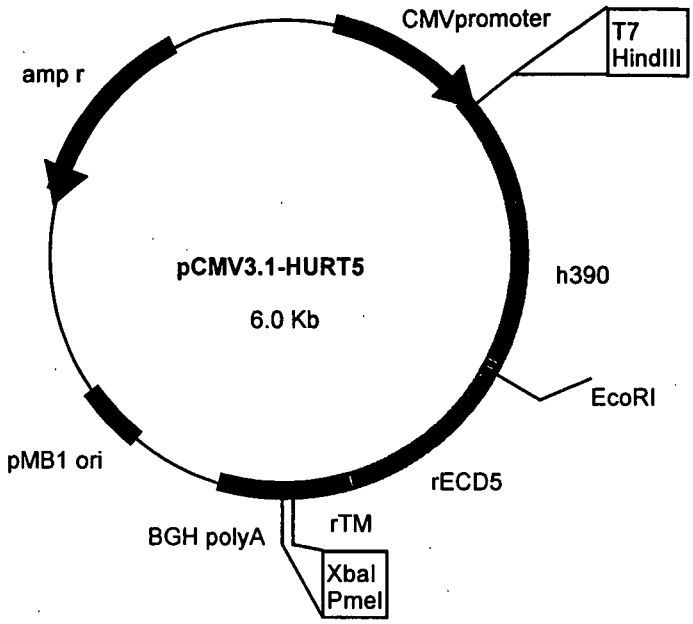


Fig. 11


CMVpromoter
T7
HindIII
amp r
h310
pCMV3.1-HURT4
6.0 Kb
EcoRI
pMB1 ori
rECD4
BGH polyA
rTM
XbaI
PmeI

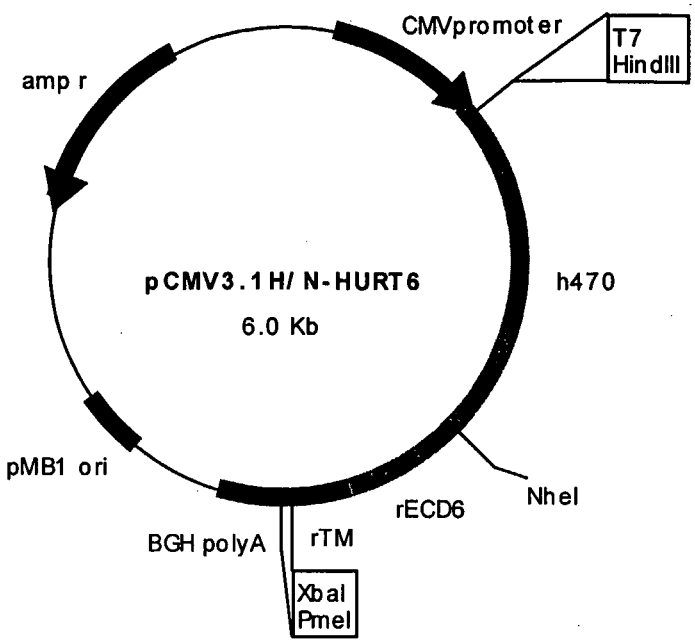
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**Fig. 12**



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Fig. 13



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## Fig. 14

