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(54) Titre : UTILISATION DE COMPOSES A FAIBLE POIDS MOLECULAIRE POUR PREPARER UN MEDICAMENT UTILISE DANS LE TRAITEMENT DE MALADIES MEDIEES PAR LE MUTANT P53

(54) Title: USE OF LOW MOLECULAR WEIGHT COMPOUNDS FOR PREPARING A MEDICAMENT USEFUL IN TREATING MUTANT P53 MEDIATED DISEASES

(57) Abrégé/Abstract:
The present invention provides novel compounds, corresponding to formulae I and II, respectively, which are able to reactivate the apoptosis-inducing function of mutant p53 proteins. This reactivation is provided by restoration of sequence-specific DNA-binding activity and transcriptional transactivation function to mutant p53 proteins, and modulation of the conformation-dependent epitopes of the p53 protein. Accordingly, the substances according to the invention will be used in pharmaceutical compositions and methods for treatment of patients suffering from various types of tumours.

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(54) Title: USE OF LOW MOLECULAR WEIGHT COMPOUNDS FOR PREPARING A MEDICAMENT USEFUL IN TREATING MUTANT P53 MEDIATED DISEASES

(57) Abstract: The present invention provides novel compounds, corresponding to formulae I and II, respectively, which are able to reactivate the apoptosis-inducing function of mutant p53 proteins. This reactivation is provided by restoration of sequence-specific DNA-binding activity and transcriptional transactivation function to mutant p53 proteins, and modulation of the conformation-dependent epitopes of the p53 protein. Accordingly, the substances according to the invention will be used in pharmaceutical compositions and methods for treatment of patients suffering from various types of tumours.

USE OF LOW MOLECULAR WEIGHT COMPOUNDS FOR PREPARING A MEDICAMENT USEFUL IN TREATING MUTANT p53 MEDIATED DISEASES

Field of the invention

The present invention relates to low molecular weight compounds, which are able to restore the apoptosis-inducing function of mutant p53. The compounds used according to the invention are analogues to the compounds PRIMA-1 and MIRA-1, respectively, described in PCT/SE01/02008 (not published). More particularly, the present invention relates to the use of such compounds for preparing pharmaceutical compositions useful for treating mutant p53 mediated diseases, such as, for example cancer, autoimmune diseases and heart diseases.

Background

The most common target for mutations in tumours is the p53 gene. The fact that around half of all human tumours carry mutations in this gene is solid testimony as to its critical role as tumour suppressor. p53 halts the cell cycle and/or triggers apoptosis in response to various stress stimuli, including DNA damage, hypoxia, and oncogene activation (Ko and Prives, 1996; Sherr, 1998). Upon activation, p53 initiates the p53-dependent biological responses through transcriptional transactivation of specific target genes carrying p53 DNA binding motifs. In addition, the multifaceted p53 protein may promote apoptosis through repression of certain genes lacking p53 binding sites, and transcription-independent mechanisms as well (Bennett *et al.*, 1998; Gottlieb and Oren, 1998; Ko and Prives, 1996). Analyses of a large number of mutant p53 genes in human tumours have revealed a strong selection for mutations that inactivate the specific DNA binding function of p53; most mutations in tumours are point mutations clustered in the core domain of p53 (residues 94-292) that harbours the specific DNA binding activity (Béroud and Soussi, 1998).

Both p53-induced cell cycle arrest and apoptosis could be involved in p53-mediated tumour suppression. While p53-induced cell cycle arrest could conceivably be reversed in different ways, p53-induced cell death would have advantage of being irreversible. There is indeed evidence from animal in vivo models (Symonds *et al.*, 1994) and human tumours (Bardeesy *et al.*, 1995) indicating that p53-dependent apoptosis plays a major

role in the elimination of emerging tumours, particularly in response to oncogenic signalling. Moreover, the ability of p53 to induce apoptosis often determines the efficacy of cancer therapy (Lowe *et al.*, 1994). Taking into account the fact that more than 50% of human tumours carry p53 mutations, it appears highly desirable to restore the function of wild type p53-mediated growth suppression to tumours. The advantage of this approach is that it will allow selective elimination of tumour cells carrying mutant p53. Tumour cells are particularly sensitive to p53 reactivation, supposedly for two main reasons. First, tumour cells are sensitized to apoptosis due to oncogene activation (reviewed in (Evan and Littlewood, 1998)). Second, mutant p53 proteins tend to accumulate at high levels in tumour cells. Therefore, restoration of the wild type function to the abundant and presumably "activated" mutant p53 should trigger a massive apoptotic response in already sensitized tumour cells, whereas normal cells that express low or undetectable levels of p53 should not be affected. The feasibility of p53 reactivation as an anticancer strategy is supported by the fact that a wide range of mutant p53 proteins are susceptible to reactivation. A therapeutic strategy based on rescuing p53-induced apoptosis should therefore be both powerful and widely applicable.

Taken together, these findings strongly suggest that pharmacological restoration of p53 function would result in elimination of tumour cells. Consequently, there is a need within this field to identify substances and methods that will enable such restoration of p53 function.

For the above defined purpose, it has been shown that p53 is a specific DNA binding protein, which acts as a transcriptional activator of genes that control cell growth and death. Thus, the ability of the p53 protein to induce apoptosis is dependent on its specific DNA binding function. Mutant p53 proteins carrying amino acid substitutions in the core domain of p53, which abolish the specific DNA binding, are unable to induce apoptosis in cells. Therefore, in order to obtain such substances and methods as defined above, reactivation of p53 specific DNA binding is essential in order to trigger p53-dependent apoptosis in tumours during pathological conditions.

Summary of the invention

The present invention is directed to the use of compounds, corresponding to the general formulae I and II, respectively, and the compound 2-ethylene-4(3 H)-quinazolinone, which are able to reactivate the apoptosis-inducing function of mutant p53 proteins, for preparing a medicament useful in treating mutant p53 mediated diseases. The compounds of formula I and II are analogues to the compounds PRIMA-1 and MIRA-1, respectively, described in PCT/SE01/02008. The reactivation is provided by restoration of sequence-specific DNA-binding activity and transcriptional transactivation function to mutant p53 proteins, and modulation of the conformation-dependent epitopes of the p53 protein. Accordingly, the substances according to the invention will be used in pharmaceutical compositions and methods for treatment of patients suffering from various types of mutant p53 mediated diseases, such as cancer.

Examples of other mutant p53 mediated diseases are for example autoimmune diseases, such as for example rheumatoid arthritis and Sjogren's syndrome, and heart diseases such as hereditary idiopatic cardiomyopathy.

Brief description of the drawings

Figure 1 A-B shows the molecular structures of compounds PRIMA-1 and MIRA-1.

Figure 2 A-C illustrates the growth suppression of tumour cells expressing mutant p53 by substances MIRA-1 and PRIMA-1.

Figure 3 A, B and C illustrates how the substances PRIMA-1 and MIRA-1 induce apoptosis in human tumour cells in a mutant p53-dependent manner.

Figure 4 A-C describes how the compounds MIRA-1 and PRIMA-1 preserve the wild type conformation of the p53 protein.

Figure 5 describes how the substances PRIMA-1 and MIRA-1 are able to preserve the sequence specific DNA binding of the wild type p53 protein upon heat inactivation.

Figure 6 A-B illustrates that the substances PRIMA-1 and MIRA-1 restore wild-type conformation to mutant p53 protein in cells.

Figure 7 A-B illustrates how the substances MIRA-1 and PRIMA-1 reactivate mutant p53 protein for specific DNA binding.

Figure 8 illustrates the correlation between the ability of compounds PRIMA-1 and MIRA-1 to restore the specific DNA binding and apoptosis-inducing function of mutant p53.

Figure 9 A-C shows how PRIMA-1 and MIRA-1 restore transcription transactivation function to mutant p53 in cells.

Figure 10 A-C shows how PRIMA-1 and MIRA-1 transactivate expression of p53 target genes in a mutant p53 dependent manner.

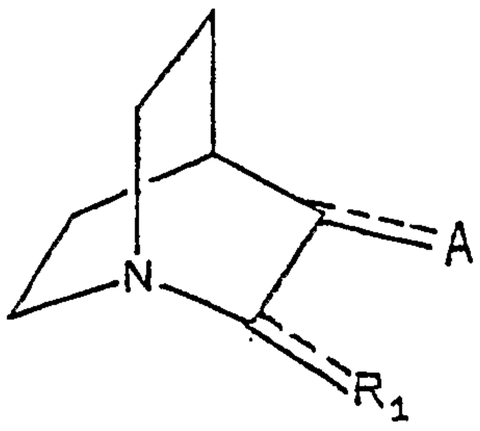
Figure 11 illustrates anti-tumour activity of PRIMA-1 in vivo.

Figure 12 A-B illustrates the growth suppression of tumour cells expressing mutant p53 by substances MIRA-1 and PRIMA-1.

Definitions

In the present application, the following terms are used:

As disclosed herein, the terms "substance T" or "compound T" both relates to compounds according to formula I below, except for 9-(azabicyclo[2.2.2]octane-3-one)-6-chloro-9H-purine (also referred to as PRIMA-2), which compounds are new analogues of PRIMA-1:



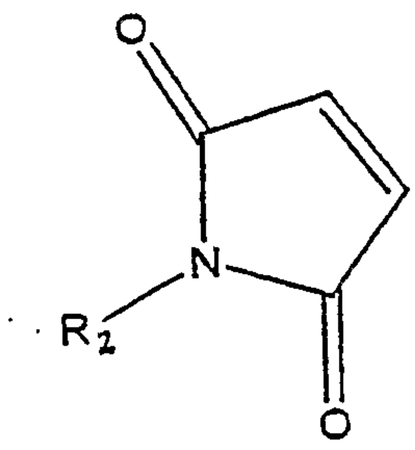
wherein:

R1 is hydrogen or a methylene group, which can be double bonded, as indicated by the broken line, or single bonded and linked to the nitrogen atom of an amine-substituted phenyl group, a nitrogen atom contained in the ring structure of a purine, 8-azapurine, or benzimidazol residue, and;

A is an oxygen-containing moiety, either consisting of an oxygen atom being double bonded, as indicated by the broken line, or a benzoyloxy group, with the proviso that when A is a benzoyloxy group, then R1 is hydrogen.

The phenyl group or the nitrogen-containing ring structure of R1, and the benzoyloxy group of A can optionally be substituted, such as for example with halogen, methyl, methoxy, amino and/or halomethyl containing 1-3 halogen atoms.

As disclosed herein, the terms "substance G" or "compound G" both relate to compounds according to formula II below, which compounds are new analogues of MIRA-1:



wherein:

R2 is chosen from the group consisting of hydrogen, methyl, or benzyl.

The benzyl group of R2, can optionally be substituted, such as for example with halogen, methyl, methoxy, amino and/or halomethyl containing 1-3 halogen atoms

The term halogen or halo refers to a fluorine, chlorine, bromine or iodine atom, of which chlorine generally is preferred. A compound of the invention may be in free form, e.g., amphoteric form, or in salt, e.g., acid addition or anionic salt, form. A compound in free form may be converted into a salt form in an art-known manner and vice-versa.

The pharmaceutically acceptable salts of the compounds of formula I (in the form of water, or oil-soluble or dispersible products) include the conventional non-toxic salts or the quaternary ammonium salts of these compounds, which are formed, e.g., from inorganic or organic acids or bases. Examples of such acid addition salts include acetate, adipate, alginate, aspartate, benzoate, benzenesulfonate, bisulfate, butyrate, citrate, camphorate, camphorsulfonate, cyclopentanepropionate, digluconate, dodecylsulfate, ethanesulfonate, fumarate, glucoheptanoate, glycerophosphate, hemisulfate, heptanoate, hexanoate, hydrochloride, hydrobromide, hydroiodide, 2-hydroxyethanesulfonate, lactate, maleate, methanesulfonate, 2-naphthalenesulfonate, nicotinate, oxalate, paemoate, pectinate, persulfate, 3-phenylpropionate, picrate, pivalate, propionate, succinate, tartrate, thiocyanate, tosylate, and undecanoate. Base salts include ammonium salts, alkali metal salts such as sodium and potassium salts, alkaline earth metal salts such as calcium and magnesium salts, salts with organic bases such as dicyclohexylamine salts, N-methyl-D-glucamine, and salts with amino

acids such as arginine, lysine, and so forth. Also, the basic nitrogen-containing groups may be quaternized with such agents as lower alkyl halides, such as methyl, ethyl, propyl, and butyl chloride, bromides and iodides; dialkyl sulfates like dimethyl, diethyl, dibutyl; and diamyl sulfates, long chain halides such as decyl, lauryl, myristyl and stearyl chlorides, bromides and iodides, aralkyl halides like benzyl and phenethyl bromides and others.

A "derivative" is a substance modified by varying the chemical structure of the original substances G and/or T. Such derivatives of the substances may involve insertion, deletion or substitution of one or more functional groups without fundamentally altering the essential activity of the substance.

A "functional moiety" means a non-substance G and/or T-derived molecule, for example a label, a drug, or a carrier molecule.

The term "label" as used herein means a moiety, which has been joined, either covalently or non-covalently, to the present substance in order to provide a detectable signal. Thus, such a "label" may be detected by spectroscopic, photochemical, biochemical, immunochemical, or chemical means. For example, useful labels include 32-P, fluorescent dyes, electron-dense reagents, enzymes (e.g., as commonly used in a ELISA), biotin, dioxigenin, or haptens and proteins for which antisera or monoclonal antibodies are available (e.g. the substance of formula can be made detectable, e.g. by incorporating a radiolabel into a substance or used to detect antibodies specifically raised against the substance).

The term "antibody" refers to a polypeptide substantially encoded by an immunoglobulin gene or immunoglobulin genes, or fragments thereof which specifically bind and recognize an analyte (antigen).

Detailed description of the invention

Accordingly, the present invention relates to the use of substances G and T capable of restoration of the wild type conformation and the sequence-specific DNA binding, transcriptional transactivation, and apoptosis-inducing functions of mutant p53 for preparing a medicament for treating mutant p53 mediated diseases. The substances T

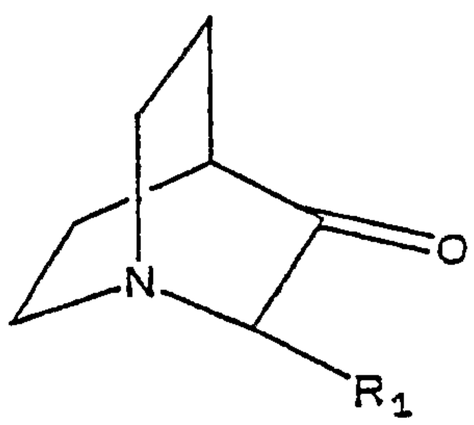
are analogues of 2,2-bis(hydroxymethyl)-1-azabicyclo[2.2.2]octan-3-one (PRIMA-1), which is shown in Figure 1 B for comparison. The substances G are analogues of 1-(propoxymethyl)-maleimide (MIRA-1), which is shown in Figure 1A for comparison. Thus, it is to be understood that said substances need not be identical to the structures of formulae I and II, but may include variations, as long as the activity thereof is preserved. Thus, said substance may also be a derivative of the structures of formulae I and II. Also it is to be understood that in the present application, the human p53 is particularly preferred, even though p53 molecules of other origins may also be contemplated.

Thus, although WO 93/24525 suggested that amino acid sequences derived from human p53 protein may be useful in the treatment of disorders including an overexpression of p53, the present invention is the first to specify that low molecular weight compounds G and T are capable of exerting such an effect by reactivation of the apoptosis-inducing function of the mutant p53 protein.

More specifically, the substance according to the invention is capable of providing said reactivation of the apoptosis-inducing function of p53 by restoration of the sequence-specific DNA binding activity to mutant (defective) p53. Thus, even though WO 95/19367 suggested that the binding of p53 to DNA binding sites may influence the expression of apoptosis-regulating genes, the reactivation of the apoptosis-inducing function of mutant p53 by substances G and T has never been identified prior to the present invention.

Preferred examples of compound T are 2-(adenine-9-methylene)-3-quinuclidinone, 2-methylene-3-quinuclidinone, 2-(-2-amino-3-chloro-5-trifluoromethyl-1-methylaniline)-3-quinuclidinone, 2-(6-trifluoromethyl-4-chlorobenzimidazole-1-methylene)-3-quinuclidinone, 2-(6-methoxypurine-9-methylene)-3-quinuclidinone, 2-(8-azaadenine-9-methylene)-3-quinuclidinone, 1-azabicyclo [2.2.2]oct-3-yl benzoate, 2-(5,6-dimethyl-benzimidazole-1-methylene)-3-quinuclidinone, 2-(8-azaadenine-7-methylene)-3-quinuclidinone, 2-(7-methylene-1,3-dimethyluric acid)-3-quinuclidinone, 2-(2,6-dichloro-9-methylenepurine)-3-quinuclidinone.

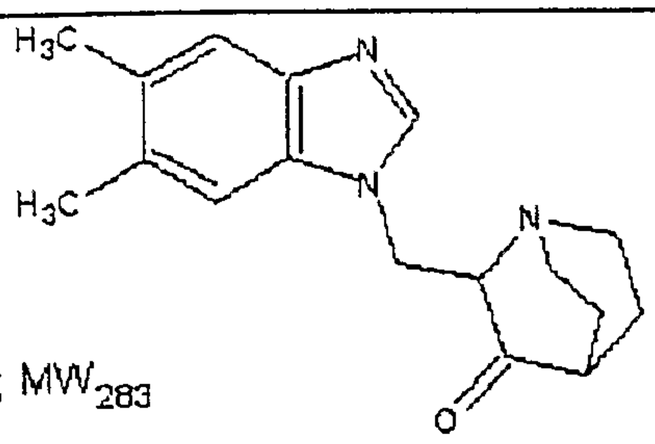
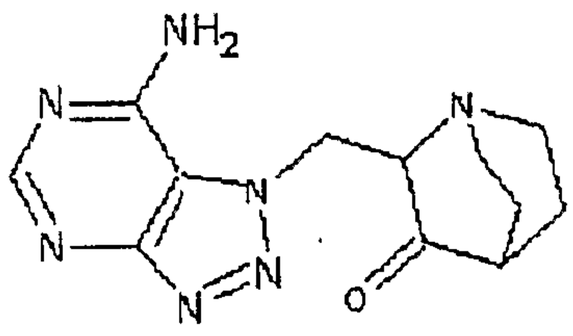
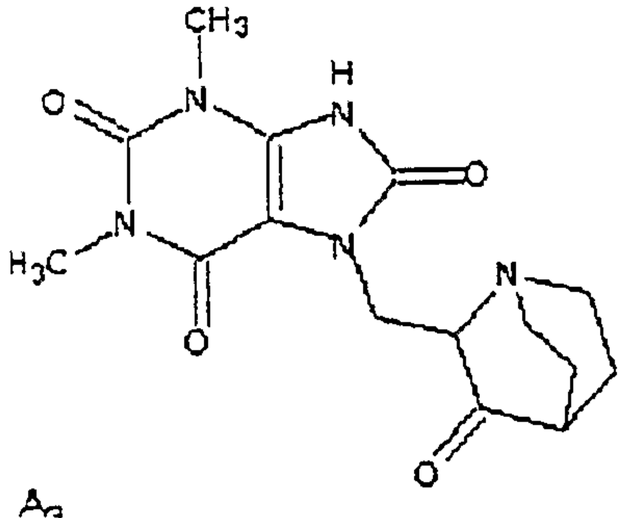
More preferably, substance T has the structure of the following general formula I'

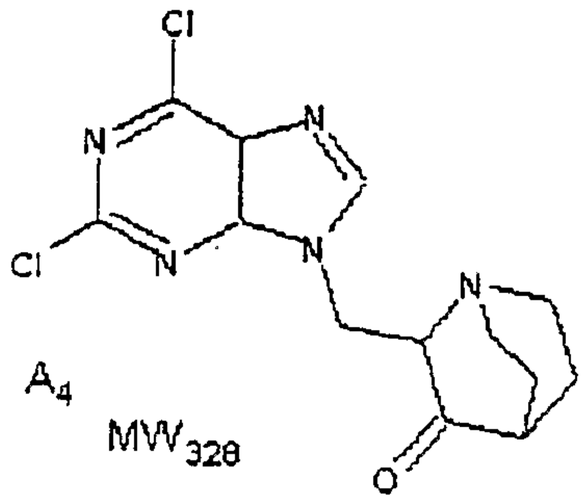
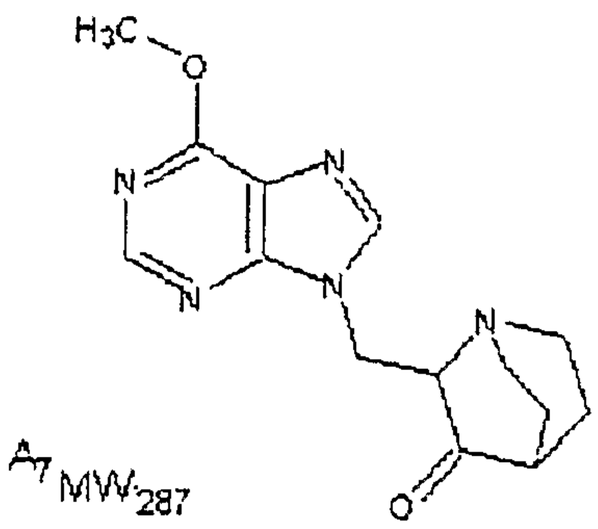


wherein

R1 is a methylene group linked to the nitrogen atom of an amine-substituted phenyl group, a nitrogen atom contained in the ring structure of a purine, 8-azapurine, or benzimidazol residue, and, most preferably R1 is a methylene group linked to a nitrogen atom contained in the ring structure of a purine, 8-azapurine, or benzimidazol residue.

Particularly preferred examples of compound T are given in the Table below together with activity data (IC50, μM):

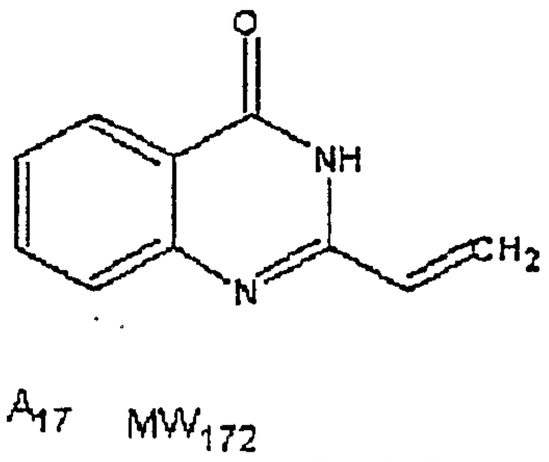
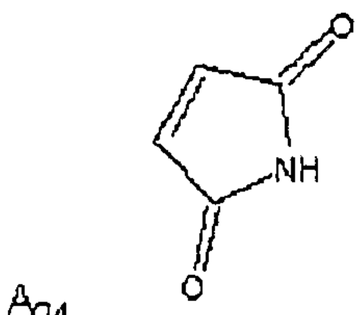
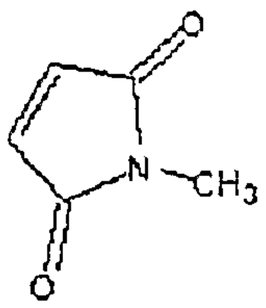
Compounds	**IC50, μM**					
	Saos-2His273		**R**	**H1299-His175**		**R**
	Dox-	**Dox+**		**Dox-**	**Dox+**	
 A_1; MW_{283} 2-(5,6-dimethyl-benzimidazole-1-methylene)-3-quinuclidinone	4	9.24	**2.31**	4,75	7,1	**1,51**
 A_2 MW_{273} 2-(8-azaadenine-7-methylene)-3-quinuclidinone	2.79	7.27	**2.61**	3,3	4,2	**1,27**
 A_3 MW_{333} 2-(7-methylene-1,3-dimethyluric acid)-3-quinuclidinone	2.74	5.51	**2.01**	4,1	5,2	**1,26**

Compounds	IC50, μM					
	Saos-2His273		R	H1299-His175		R
	Dox-	Dox+		Dox-	Dox+	
 A_4 MW_{328} 2-(2,6-dichloro-9-methylenepurine)-3-quinuclidinone	2.54	6.2	**2.44**	3.2	4,9	**1,53**
 A_7 MW_{287} 2-(6-methoxypurine-9-methylene)-3-quinuclidinone	13.73	26.03	**1.9**	15,5	23,2	**1,5**

The above listed particularly preferred compounds exhibit a specific activity towards mutant p53 similar or greater than that of PRIMA-1.

Preferred examples of compound G are the following: N-benzyl maleimide, N-methylmaleimide and maleimide.

Activity data for the two most preferred compounds G are listed in the Table below. In said Table, activity data for another preferred compound, 2-ethylene-4(3 H)-quinazolinone, exhibiting similar activity as the most preferred examples of compounds T and G are also included.

Compounds	IC50, μM					
	Saos-2His273		R	H1299-His175		R
	Dox-	Dox+		Dox-	Dox+	
 A_{17} MW_{172} 2-ethylene-4(3 H)-quinazolinone	3.97	5.05	**1.27**	1,4	3,9	**2,8**
 A_{24} MW_{97} maleimide	3.37	7.59	**2.25**	3	5,2	**1,73**
 A_{29} MW_{111} N-methylmaleimide	4.04	6.45	**1.6**	2,9	5,4	**1,86**

The above listed particularly preferred compounds exhibit a specific activity towards mutant p53 similar or greater than that of PRIMA-1.

In a preferred embodiment of the invention, the substance is coupled to a functional moiety, which enhances the p53 reactivating effect of said substance. As mentioned above, such a moiety may be for example a label, a drug, or a carrier molecule. In one embodiment, the functional moiety is a carrier molecule coupled to the present substance. In an alternative embodiment, the functional moiety is a p53 reactivating molecule.

Thus, in one embodiment, the present substance is coupled to a label, providing a detectable signal. A wide variety of labels and conjugation techniques are known and

reported extensively in both the scientific and patent literature. Suitable labels include various radiolabels, enzymes, substrates, co-factors, inhibitors, fluorescent moieties, chemiluminescent moieties, magnetic particles and the like.

WO 95/17213 relates to molecules binding to the same DNA as p53 does, whereby the transcription thereof may be activated. Thus, although it relates to activation of transcription of p53-regulated genes, WO 95/17213 solves another problem than the present invention by use of different molecules.

WO 97/14794 and a publication by Foster et al., (1999) also relates to the problem of how to activate the sequence-specific DNA binding activity of latent p53. To obtain this, a fragment of the C-terminal regulatory domain of p53 or low weight compounds are used. However, the C-terminal regulatory domain (WO 97/14794) was used to activate wild type but not mutant p53 protein, as the present invention describes. Moreover, low molecular weight synthetic compounds which have a pharmacophore different from that described in Foster et al. (1999) are forming the basis of the present invention.

Accordingly, low molecular weight compounds have been identified that can be used to reactivate the apoptosis-inducing function of p53. The restoration of mutant p53 function can be achieved in living cells upon treatment of the cells with the substances in tissue culture media. In addition, it has also been found that the substances G and T are capable of reactivating the sequence-specific DNA binding activity of p53. Substances G and T are shown to restore p53 DNA binding in vitro and the transactivation function of p53 in living cells.

The compounds of the invention can thus be used in treating mutant p53 mediated cancers, and, by virtue of their ability to restore the apoptosis-inducing function of p53, are also believed to be useful in treating other mutant p53 mediated diseases, such as, for example autoimmune diseases, such as rheumatoid arthritis and Sjogren's syndrome (e.g. Yamanishi Y. et al., *Proc. Natl. Acad. Sci.* USA 99(15):10025-30 (**2002**), Inazuka M. et al., *Rheumatology*, 39(3):262-6 (**2000**), Firestein G.S. et al., *Proc. Natl. Acad. Sci. USA* 30;94(20):10895-900 (**1997**), and Tapinos N.I. et al., *Arthritis Rheum.*42(7):1466-72 (1999)), and heart diseases such as hereditary idiopatic cardiomyopathy (e.g. Gudkova A.Ya. et al. in Identification of the TP53 tumor suppressor mutations in patients with family idiopatic cardiomyopathy. Abstract at the

International Congress of the European Society of Pathology, May 19-21, 2002, Baveno, Lago Maggiore, Italy.

A pharmaceutical composition for use in accordance with the invention, may comprise, in addition to one of the above active substances, a pharmaceutically acceptable excipient, buffer or stabilizer, or any other material well known to those skilled in the art and appropriate for the intended application. Such materials should be non-toxic and should not interfere with the efficacy of the active ingredient. Examples of techniques and protocols to this end may e.g. be found in Remingtonís Pharmaceutical Sciences, 16th edition, Osol, A. (ed.), 1980.

The composition according to the invention may be prepared for any route of administration, e.g. oral, intravenous, cutaneous or subcutaneous, nasal, intramuscular, or intraperitoneal. The precise nature of the carrier or other material will depend on the route of administration. For a parenteral administration, a parenterally acceptable aqueous solution is employed, which is pyrogen free and has requisite pH, isotonicity, and stability. Those skilled in the art are well able to prepare suitable solutions and numerous methods are described in the literature (for a brief review of methods of drug delivery, see Langer, Science 249:1 527-1533 (1990)). Preservatives, stabilizers, buffers, antioxidants and/or other additives may be included, as required. Dosage levels can be determined by those skilled in the art, taking into account the disorder to be treated, the condition of the individual patient, the site of delivery, the method of administration and other factors. Examples of the techniques and protocols mentioned above can be found in Remingtonís Pharmaceutical Sciences, 16th edition, Osol, A. (ed), 1980.

In another embodiment, the composition according to invention further comprises one or more additional p53 reactivators.

Finally, the present invention also relates to methods of medical treatment wherein the substances according to the invention are used.

Detailed description of the drawings

Figure 1 shows structural formulas of 1-(Propoxymethyl)-maleimide (**A**) and 2,2-bis(hydroxymethyl)-1-azabicyclo[2.2.2]octan-3-one (**B**).

Figure 2 illustrates how substances MIRA-1 and PRIMA-1 suppressed the growth of cells expressing mutant p53 but did not affect the growth of cells lacking p53 expression. More specifically, **Figure 2A** shows how MIRA-1 and PRIMA-1 compound suppress growth of Saos-2 His-273 cells expressing mutant p53. In contrast, the effect of treatment on Saos -2 cells lacking p53 expression was rather minor. The graph illustrates the difference between viability of cells treated by compounds MIRA-1 and PRIMA-1 in the presence and absence of mutant p53, expressed as the percentage of reduction of WST-1 cell proliferation reagent in comparison with untreated cells. The degree of WST-1 reduction, which reflects a number of living cells, was measured by microplate reader at λ 490 nm according to manufacturer (Roche). The growth suppression was calculated as a difference in absorbance at λ 490 nm between untreated and treated cells and expressed in a percent from untreated control. Growth suppression = 100% x (control $_{absorbance}$ – treated $_{absorbance}$)/ control $_{absorbance}$. Two compounds were identified, compound MIRA-1 and PRIMA-1, that suppressed the growth of cells expressing mutant p53 but did not affect the growth of cells lacking p53 expression. **Figure 2B** shows that PRIMA-1 suppresses growth of 3 cell lines expressing His-273 and His-175 mutants of p53 under control of doxycycline-dependent promoter. In these three cell lines PRIMA-1 shows growth suppression effect on cells in a mutant p53-dependent manner. **Figure 2C** shows growth curves of PRIMA-1-treated Saos-2-His-273 cells in the absence or presence of mutant p53. **Figure 2D** shows that compounds PRIMA-1 and MIRA-1 suppress predominantly the growth of mutant p53 expressing cells. The ability of compounds MIRA-1 and PRIMA-1 to suppress the growth was tested using 16 cell lines with different p53 status: cells which do not express p53 (p53 null), cells expressing wild type p53 and cells expressing different mutant p53 proteins. The experimental set up was as described in **Figure 2A**. The differences in a viability were statistically significant according to an independent *t*-test.

Figure 3 illustrates the p53-dependent induction of apoptosis by PRIMA-1 and MIRA-1 in Saos-2-His-273 cell line. More specifically, **Figure 3A** shows how caspase inhibitors suppress the cell death induction by compounds PRIMA-1 and MIRA-1 in Saos-2-His-273 cells. Induction of apoptosis was determined by FACS analysis of

ethanol fixed cells stained with propidium iodide (PI) as percentage of a sub-G1 population. Caspase inhibitors Z-DEVD-FMK and BOC-D-FMK (Enzyme Systems Products, CA) were added to Saos-2-His-273 grown in the absence of doxycycline at a concentration 5 μg/ml prior to treatment with compounds PRIMA-1 and MIRA-1 (25 μM and 100 μM, respectively). The percentage of dead cells in non-treated cultures and in controls treated with caspase inhibitors only was subtracted. **Figure 3B** presents TUNEL staining of Saos-2-His-273 cells treated with PRIMA-1 at a concentration of 25μM for 48h. Hoechst staining was used to stain cell nuclei. **Figure 3C** shows the induction of apoptosis by compounds PRIMA-1 and MIRA-1 in Saos-2 and Saos-2-His-273 cells. The percentage of apoptotic cells was measured by FACS analysis as it was described in **Figure A**. Upper panel: apoptosis was induced in Saos-2-His-273 cells expressing p53 (no doxycycline) after 48 hours of treatment with 10 ΞM of MIRA-1, but not in p53-null Saos-2 cells. substances PRIMA-1 (50, 75 and 125 μM) and MIRA-1 (10 μM). Lower panel, apoptosis was induced by PRIMA-1 (50, 75 and 125 ΞM) in mutant p53 expressing Saos-2-His- 273 cells, whereas in the absence of p53 expression in Saos-2 cells PRIMA-1 was much less efficient.

Figure 4 shows how compounds PRIMA-1 and MIRA-1 stabilize the native (wild type) conformation of p53 using ELISA. More specifically, **Figure 4A** illustrates how compounds PRIMA-1 and MIRA-1 preserve the conformation-dependent PAb1620 epitope upon heat inactivation of p53 proteins by incubation for 30 min at 37°C. Upper panel, GST-wild type p53 protein; middle panel, GST-His-175 mutant p53 protein; lower panel, GST-Gln-248 mutant p53 protein. Protein preparations were heated either in the presence or absence of PRIMA-1 and MIRA-1 and analyzed in ELISA. Absorbance of the control sample incubated on ice was taken as 100%. **Figure 4B** shows how compounds PRIMA-1 and MIRA-1 prevent unfolding of p53 proteins measured as appearance of PAb240 epitope in p53 proteins upon heating at 37°C. Upper panel, GST-wild type p53 protein; lower panel, GST- His-175 mutant p53 protein. **Figure 4C** shows that PRIMA-1 and MIRA-1 do not affect the conformation-independent epitope DO1. No changes in D0-1 epitope were observed upon incubation of p53 proteins at 37°C. Upper panel, GST-wild type p53 protein; lower panel, GST- Gln-248 mutant p53 protein.

Figure 5 illustrates the preservation of the specific DNA binding of the GST- wild type p53 protein by the substances PRIMA-1 and F. The band shift assay performed

essentially as described before (Selivanova *et al.*, 1996). The GST- wild type p53 protein was inactivated by 30 min incubation at 37°C in the presence or absence of substances PRIMA-1 and MIRA-1 and then tested for the DNA binding. *In lanes 1 and 2, PRIMA-1 and monoclonal antibody PAb421 were added.* Lane 3, inactivation of DNA binding of wtp53 by heating. Lanes 4-7 and 8-11, restoration of the specific DNA binding by incubation with increasing concentrations of compounds MIRA-1 and PRIMA-1, respectively.

Figure 6 shows the restoration of wild-type p53 epitope PAb1620 in SKOV-His-175 cells expressing His-175 p53 mutant. PAb1620 mouse monoclonal antibody was used to detect wild type conformation of p53 whereas staining with anti-p53 rabbit polyclonal antibody shows overall level of p53. The cell nuclei were stained with Hoechst. Figure 6A, appearance of PAb1620 epitope after treatment with PRIMA-1. Figure 6B, restoration of PAb1620 epitope after incubation with MIRA-1.

Figure 7 shows the restoration of the specific DNA binding of the GST-His-175 mutant p53 protein by compounds PRIMA-1 and MIRA-1. **Figure 7A** Lane 1-3, GST-His-175 mutant p53 is unable to bind DNA. Lanes 4-6 and lanes 7-9, restoration of the mutant p53 specific DNA binding by incubation with increasing concentrations (45 ng, 450 ng, and 18 μg) of compounds MIRA-1 and PRIMA-1, respectively. PAb421 antibody was added to all reaction mixtures. **Figure 7B**, compounds PRIMA-1 and MIRA-1 are able to restore the sequence-specific DNA binding of the endogenous Trp-282 mutant p53 in cell extracts from Burkitt lymphoma BL-60 cells, as detected by a band shift assay. Lane 1, endogenous Trp-282 mutant p53 in cell extracts from Burkitt lymphoma BL-60 cells does not bind DNA. Lanes 2 and 9, monoclonal antibodies PAb421 and/or PAb1801 do not restore the DNA binding of Trp-282 mutant p53. Incubation with increasing concentrations (90 ng, 900 ng, and 18 μg) of compound MIRA-1 (lanes 3-5 and 10-12) or compound PRIMA-1 (lanes 6-8 and 13-15) restored the DNA binding of the Trp-282 mutant p53 protein. Monoclonal antibody PAb421 was added to the reaction mixtures in lanes 2-8; PAb1801 was added to the reaction mixtures in lanes 9-15.

Figure 8 illustrates the correlation between the ability of compounds PRIMA-1 and MIRA-1 to restore the specific DNA binding and apoptosis-inducing function of mutant p53. More specifically, the apoptosis-inducing function of Phe-176 mutant

p53 protein in KRC/Y renal carcinoma cells was not restored by compounds PRIMA-1 and MIRA-1, in contrast to the His-273 mutant p53 in Saos-2-His-273 cells, as measured by FACS analysis. The percentage of apoptotic cells was detected by FACS analysis as it was described in **Figure 3A**. Apoptosis was induced in Saos-2-His-273 cells expressing p53 (no doxycycline) after 48 hours of treatment with substances PRIMA-1 and MIRA-1, but not in KRC/Y cells or in p53-null Saos-2 cells.

Figure 9 demonstrates restoration of transcriptional transactivation activity to mutant p53 by PRIMA-1 and MIRA-1. **Figure 9A**, PRIMA-1 and MIRA-1 induced the wild-type p53-responsive LacZ reporter in A-431 cells carrying His-273 mutant p53. **Figure 9B**, mutant p53-dependent activation of the wild-type p53-responsive EGFP reporter in PRIMA-1-treated SKOV-His-175 cells. Only cells cultured in the absence of doxycycline (express mutant p53) showed EGFP expression. **Figure 9C**, MIRA-1 induced wild-type p53-responsive EGFP reporter in SKOV-His-175 cells.

Figure 10 demonstrates induction of p53 target genes p21 and MDM-2. **Figure 10A** shows induction of endogenous p21 and MDM-2 in H1299-His-175 cells treated with 25 μM of PRIMA-1 or with 10 μM of MIRA-1. The expression of proteins was analyzed using Western blot. **Figure 10B**, shows that p53 target genes in H1299-His-175 cells are induced by PRIMA-1 only in the presence of mutant p53. **Figure 10C** pictures induction of p53 target genes in PRIMA-1-treated SW480 colon carcinoma cells carrying endogenous His-273/Ser-309 mutant p53. PRIMA-1 did not induce the same p53 target genes in HCT-116 colon carcinoma cells carrying wild-type p53.

Figure 11 describes an anti-tumour activity of PRIMA-1. SCID mice were injected with Saos-2-His-273 cells. Intravenously (20 or 100 mg/kg) or intratumour (20 mg/kg) Injection with PRIMA-1 started 3 days after injection of cells and continued for 3 consecutive days two times per day. Tumour volumes were measured once in three days for two months.

Figure 12 illustrates how MIRA-1 (**Figure 12A**) and PRIMA-1 (**Figure 12B**) suppressed the growth of cells expressing mutant p53 but did not affect the cells without p53 expression. Experimental setting was as described in **Figure 2A**.

EXPERIMENTAL

Below, the present invention will be described in more detail by way of examples that are not intended to limit the scope of the invention in any way. All references given below and elsewhere in the present specification are hereby included herein by reference.

Materials and Methods

Plasmids

The plasmids encoding the GST-human wild type p53 fusion protein and the GST-human mutant p53 proteins His 175 were described earlier (Selivanova *et al..*, 1996). The p53-EGFP plasmid contains 13 synthetic p53 consensus DNA binding sites in front of the EGFP coding sequence. Transient transfections experiments were performed with Lipofectamine 2000 according to the manufacturer's recommendations (Invitrogen™ Life Technologies, Groningen, The Netherlands).

Chemical library

A library of low molecular weight compounds was obtained from National Cancer Institute (NCI), Bethesda, USA. For more information, see web site http://dtp.nci.nih.gov

Screening of the chemical library and growth suppression assays

Saos-2-His-273 cell line stably transfected with construct allowing expression of mutant His-273 p53 in a tetracycline-dependent manner was used for screening (Selivanova *et al.*, 1997). p53 expression was inhibited by incubation of cells with doxycycline (5 μg/ml). Cells were grown in 96-well plates at a density of 3000 cells per well with or without doxycycline and treated with 25μM of the compounds from the NCI library of low molecular weight (LMW) compounds. After 48 hours of incubation the proliferative cell reagent WST-1 (Roche) was added to the cells. The degree of WST-1 reduction, which reflects cell viability, was measured by microplate reader at λ 490 nm according to the manufacturer (Roche).

FACS analysis

Cells were placed on 12-well plate at a density of 30000/cm^2 and treated with compounds. After 48h incubation cells were harvested by trypsinization, fixed with

70% ethanol, treated with RNase A (0.25 mg/ml) and stained with propidium iodide (0.02 mg/ml). Samples were analyzed on a Becton Dickinson FACScan. Data were analyzed by the CellQuest software, version 3.2.1.

Colony formation assay

Cells were treated with the compounds PRIMA-1 and MIRA-1 and seeded in plates at 500 cells per plate. Colonies were stained with Giemsa and counted 14 days after seeding.

Luciferase assays

Transactivation assays using p53-responsive promoter constructs linked to the luciferase reporter gene (PG-luc) were performed by the Dual Luciferase Reporter Assay System (Promega) according to the manufacturer. Saos-2-His273 cell line stably transfected with luciferase reporter plasmid PG-luc (2 mg) was treated with compounds PRIMA-1 and MIRA-1 at concentration of 50 and 10 μM, respectively. A luciferase activity was assayed 1; 3.5 and 15 hours post-treatment.

DNA binding assays

The GST-p53 proteins were prepared as described (Selivanova *et al.*, 1997). Band shift assays were performed in binding buffer containing 100 mM HEPES pH 7.5, 50 mM KCl, 1 mg/ml BSA, 0.1% Triton X-100, 2 mM MgCl2 and 1 mM DTT essentially as in (Selivanova *et al.*, 1996).

ELISA

20 ng of GST-wtp53, GST-mtp53-175 and GST-mtp53-248 were heated at 37°C for 30 min or kept on ice. The procedure was performed with or without tested compounds. The ELISA analyses were done as described by (Foster *et al.*, 1999). Briefly, after the treatment, samples were diluted with coating buffer (150 mM KCL, 25 mM HEPES) supplemented with 10 mM DTT. The whole mixture was apply to ELISA plates (MaxiSorp, Nunc) and incubated at +4°C for 35 min. The wells were washed with coating buffer. The wells were blocked by 5% skim milk in PBS by incubating at +4°C for 1h. Wells were rinsed twice with PBS followed by addition of mouse primary antibodies (PAb 1620 or PAb 240) diluted 1:250 in coating buffer. Samples were incubated at +4°C for 30 min. Wells were rinsed twice with PBS. After that, a secondary antibody (anti-mouse, conjugated with horse radish peroxidase)

was incubated with samples at +4°C for 30 min. Then plates were washed 5 times with PBS and a peroxidase substrate was added. An absorbance at λ 405nm was monitored by ELISA reader.

TUNEL staining, immunostaining, lacZ staining, preparation of cell extracts, ELISA with cell extracts and Western blotting were performed according to standard procedures.

In vivo experiments

All animal studies were approved by the local animal ethical committee and animal care was in accordance with institutional guidelines. For toxicity assessment, 12 SCID mice (average weight 25g) were divided in 4 groups. Three groups received daily i.v. injections of 1, 10 and 100 mg/kg of PRIMA-1 in PBS for 5 days. Control animals were injected with PBS. We measured weights of the mice for 1 month after the last injection. For assessment of the anti-tumor activity of PRIMA-1, 12 SCID mice were inoculated with 1 x 10^6 Saos-2-His-273 cells in 90% Matrigel (Becton Dickinson, Le Pont-De-Claix, France) subcutaneously and unilaterally into the right flanks. After 3 days the mice were divided into 4 groups. Two groups received i.v. injections of PRIMA-1 at a dose of either 20 or 100 mg/kg, one group received intratumour injections of PRIMA-1 at a dose of 20 mg/kg, and the last group was used as a control. Injections were performed twice daily for 3 days. Tumour volume was measured during 2 months.

Results and discussion

Growth suppression by compounds PRIMA-1 and MIRA-1 depends on mutant p53 expression

According to the present invention, the NCI library of low molecular weight compounds has been screened for compounds that can suppress the growth of human tumour cells in a mutant p53-dependent manner.

Saos-2-His-273 cell line stably transfected with construct allowing expression of mutant His-273 p53 in a tetracycline-dependent manner was used for screening

(Selivanova *et al.*., 1997). Cells were grown in 96-well plates at a density of 3000 cells per well with or without doxycycline. The treatment was done at a concentration of 25μM of each chemical from the NCI library of low molecular weight (LMW) compounds. After 48 hours of incubation the proliferative cell reagent WST-1 (Roche) was added to the cells. The degree of WST-1 reduction, which is proportional to the cell viability, was measured by a microplate reader at λ 490 nm according to the manufacturer (Roche). Two compounds were identified which were able to suppress the growth of Saos-2-His-273 cells expressing p53, but did not affect the growth of Saos-2 cells which do not express mutant p53 (Fig.1A).

The ability of the compounds PRIMA-1 and MIRA-1 to suppress the growth of mutant p53-expressing cells was further evaluated using a colony formation assay. Saos-2 or Saos-2-His-273 cells were treated with different doses of the compounds MIRA-1 and PRIMA-1 and seeded in plates. The cells were Giemsa stained and scored for the appearance of colonies after 14 days. As shown in Table II, treatment with 5 μM of the compound MIRA-1 dramatically reduced the number of colonies formed by His-273 expressing Saos-2 cells (15% of untreated control), but was less efficient in inhibiting Saos-2 cells lacking p53 (48% inhibition). Treatment with the compound PRIMA-1 was inhibitory in a mutant p53-dependent manner at higher doses, around 50-100 μM.

Next we tested the ability of compounds PRIMA-1 and MIRA-1 to suppress the growth of tumour cells in a mutant p53-dependent manner using series of human tumour cell lines with different p53 status (p53 null, wild type p53, mutant p53). The human cell lines were as follows. p53 null: Saos-2 osteosarcoma, K562 acute myeloid leukemia, and HL60 promyelocytic leukemia. Wild type p53 expressing cells: NHF normal human fibroblasts, HeLa cervical carcinoma (carries HPV E6 protein, leading to p53 degradation), U2OS osteosarcoma, and EBV-positive IARC 171 lymphoblastoid cell line. Mutant p53 expressing lines: Burkitt lymphoma lines BL41 (Gln-248 mutant p53); DG75 (His-283), Raji (Gln-213, His-243), Ramos (Asp-254); BJAB (Arg-193), and Saos-2-His-273, SKOV-His-175, SKOV-His-273 and H1299-His-175 expressing p53 mutants under the control of doxycycline-dependent promoter. In addition, mouse p53 null J3D T-cell lymphoma line was used. As could be seen in Table I, compounds MIRA-1 and PRIMA-1 suppressed the growth of mutant p53-expressing cells more efficiently then p53 null and wild type p53

containing cells. The data from these experiments were summarized in a graph shown in Figure 2B. The differences in responses between the groups of cell lines (p53 null, wild type p53 and mutant p53) were statistically significant as verified by an independent *t*-test.

As shown in Figure 2C, PRIMA-1 completely inhibited growth of Saos-2-His-273 cells expressing mutant p53. In the absence of mutant p53 expression, PRIMA-1 only caused a minor reduction in growth rate.

Restoration of the apoptosis-inducing function to mutant p53 by compounds MIRA-1 and PRIMA-1

To address the question whether growth suppression induced by compounds MIRA-1 and PRIMA-1 occur due to the induction of apoptosis, we tested whether caspase inhibitors can inhibit MIRA-1 and PRIMA-1 induced growth suppression. Saos-2-His 273 cells were treated with compounds MIRA-1 and PRIMA-1 in the presence or absence of caspase inhibitors inhibitors Z-DEVD-FMK and BOC-D-FMK (Enzyme Systems Products, CA). Induction of cell death was determined by FACS analysis of ethanol- fixed cells stained with propidium iodide (PI) as percentage of sub-G1 population. As it is evident from Figure 2A, caspase inhibitors suppressed the cell death induced by compounds PRIMA-1 and MIRA-1. Therefore we conclude that compounds MIRA-1 and PRIMA-1 can induce apoptosis. In addition, apoptotic morphology was detected in Saos-2-His-273 cells stained with Hoechst dye after treatment with compound PRIMA-1. TUNEL staining of Saos-2-His-273-cells treated with compound PRIMA-1 also confirmed apoptosis induction (data not shown). We also observed a difference in the kinetics of apoptosis induction by compounds PRIMA-1 and F: whereas apoptosis induced by PRIMA-1 was evident after 48 hours of treatment, compound MIRA-1 induced cell death much faster, within 6-12 hours after treatment (data not shown). These results suggest that compounds PRIMA-1 and MIRA-1 trigger different apoptotic pathways.

We examined whether apoptosis induced by compounds PRIMA-1 and MIRA-1 is p53-dependent using Saos-2-His-273 cells grown in the presence or absence of doxycyclin. As shown in Figure 3B, the induction of apoptosis by compounds PRIMA-1 and MIRA-1 occurred only in the presence of p53 expression. Taken together, these

results clearly indicate that growth suppression by compounds MIRA-1 and PRIMA-1 is mediated by a mutant p53 and is not due to the nonspecific cellular toxicity.

Modulation of the conformation of the p53 core domain by compounds MIRA-1 and PRIMA-1

To get insight into the molecular mechanism of compounds MIRA-1- and PRIMA-1-mediated reactivation of mutant p53, we tested whether the conformation of p53 was affected by these compounds. It has been shown that point mutations in p53 result in destabilization of the native conformation of the p53 core domain, resulting in the loss of wild type-specific conformation-dependent epitope for the monoclonal antibody PAb1620 and appearance of a new epitope recognized by the monoclonal antibody PAb240 (Cho *et al.*., 1994). In addition, heat denaturation of the wild type p53 has a similar effect. Therefore we examined whether compounds PRIMA-1 and MIRA-1 can stabilize the native (wild type) conformation of p53. Results presented in Figure 4A demonstrate that compounds PRIMA-1 and MIRA-1 preserve the conformation-dependent epitope for PAb1620 antibody of the recombinant wild type and mutant p53 proteins heated for 30 min. at 37°C. For the GST-wtp53 protein the difference between treated and untreated samples in remaining PAb1620 epitope after treatment with the compound PRIMA-1 has reached statistical significance at p = 0.05 (n = 5) according to a paired *t*-test. Importantly, results presented in Figure 4B demonstrate that compounds PRIMA-1 and MIRA-1 are able to prevent unfolding of p53 proteins measured as appearance of PAb240 epitope in p53 proteins upon heating at 37°C. According to a paired t-test the difference in the appearance of PAb240 epitope between control and PRIMA-1-treated samples for the GST-wtp53 and GST mutant p53-His175 proteins reached statistical significance at p = 0.01 and p = 0.1, respectively. Figure 4C shows that non-conformational epitope in the N-terminus of p53 recognized by DO-1 antibody is not affected by incubation with compounds MIRA-1 and PRIMA-1. Thus, the compounds MIRA-1 and PRIMA-1 are able to preserve the native conformation of mutant p53 proteins.

Restoration of wild type p53 conformation in vitro and in living cells

To test whether PRIMA-1 can convert mutant p53 into wild-type p53 conformation, we used the conformation-specific antibodies PAb1620 and PAb240. Treatment of

recombinant GST-wild type p53 protein with PRIMA-1 resulted in a 40% increase in the PAb1620+ fraction and a corresponding decrease in the PAb240+ fraction, while the DO-1+ fraction remained unchanged. About 40% increase in PAb1620+ fraction and ~20% reduction in PAb240+ fraction were observed in similar experiments with MIRA-1. We measured the fraction of PAb1620+ p53 in protein extracts from PRIMA-1-treated SKOV-His-175 cells using ELISA. After treatment with 150 μM of PRIMA-1, the PAb1620+ fraction reached 146 ± 18% (the value for untreated cells was set to 100%), whereas the DO-1 fraction was 88 ± 9%. This demonstrates that PRIMA-1 can stabilize mutant p53 in a wild type conformation, both *in vitro* and in living cells.

Furthermore, immunostaining with PAb1620 demonstrated the ability of PRIMA-1 to convert mutant p53 to wild type conformation in living cells. As shown in Figure 6A, treatment of SKOV-His-175 cells with PRIMA-1 resulted in the appearance of PAb1620-positive p53 in cells and a concomitant decrease in total p53 levels according to staining with polyclonal anti-p53 antibodies. A similar effect was observed for cells treated with MIRA-1 (Figure 6B).

Compounds MIRA-1 and PRIMA-1 can restore the sequence-specific DNA binding of mutant p53 proteins

Next we addressed the question whether the restoration of the apoptosis-inducing function of mutant p53 proteins by compounds MIRA-1 and PRIMA-1 operates through the specific DNA binding activity of p53. Do compounds PRIMA-1 and MIRA-1 restore the specific DNA binding of p53? We investigated the DNA binding of p53 proteins in the presence or absence of compounds MIRA-1 and PRIMA-1 in a band shift assay, as described before (Selivanova *et al.*., 1996; Selivanova *et al.*., 1997). Results presented in Figure 5A demonstrate that compounds MIRA-1 and PRIMA-1 are able to restore the specific DNA binding of the GST- wild type p53 protein inactivated by incubation at 37°C for 30 min. Moreover, the compounds MIRA-1 and PRIMA-1 were able to restore the specific DNA binding of the GST-His-175 mutant p53 protein, as shown in Figure 5B. Substitution of arginin at position 175 causes a gross unfolding of the DNA binding core domain of p53. Therefore, the restoration of the DNA binding of this mutant was regarded as an exceptionally difficult task. Restoration of the DNA binding of His-175 p53 mutant demonstrates a high potency of the identified compounds. Since His-175 mutant was shown to gain an oncogenic

function, this result appears to be of particular importance. Compounds PRIMA-1 and MIRA-1 were also able to restore the sequence-specific DNA binding of the endogenous Trp-282 mutant p53 in cell extracts from Burkitt lymphoma BL-60 cells, as shown in Figure 6B.

We tested the ability of compounds PRIMA-1 and MIRA-1 to restore the specific DNA binding properties of a broad series of hot spot p53 mutants, using cellular extracts of human tumor cell lines carrying different p53 mutants as a source for endogenous p53 protein. The compound PRIMA-1 restored the specific DNA binding of 13 out of 14 mutant p53 proteins tested in band shift assays, irrespective on the residual DNA binding (see Table III). The compound MIRA-1 restored the DNA binding of 3 out of 14 mutant p53 proteins (Table III). Thus, the compounds MIRA-1 and PRIMA-1 were not only capable of restoring the DNA binding of recombinant mutant p53 proteins, but reactivated the DNA binding of a number of endogenous mutant p53 proteins in cell extracts. The only exception for compound PRIMA-1 was the Phe-176 mutant, which was not reactivated by either of the compounds.

Taking into consideration our results that compounds MIRA-1 and PRIMA-1 are not capable of restoring the specific DNA binding of the Phe-176 mutant p53 protein in KRC/Y cells, we tested whether the apoptosis-inducing function of this mutant could be reactivated by compounds MIRA-1 and PRIMA-1. KRC/Y cells were treated with 50 μM and 75 μM concentrations of compounds MIRA-1 and PRIMA-1, respectively, and the percentage of dead cells was measured by FACS analysis as described above. As demonstrated in Figure 5, the induction of apoptosis in KRC/Y cells was much less prominent as compared to Saos-2-His-273 cells. In fact, the response of KRC/Y cells to treatment was comparable with that of Saos-2 cells that do not express p53. Thus, it appears that the defect caused by substitution of the Cys residue at position 176 is irreversible. The substitution of this Cys residue abolishes the binding of a Zn atom which holds together the DNA-binding loops of the p53 core domain. Therefore, the unfolding of this mutant p53 protein is probably too extensive to be restored.

PRIMA-1-induced apoptosis depends on the transactivation function of p53

To further ascertain that PRIMA-1 exerts its effect through p53-mediated transcriptional transactivation and *de novo* protein synthesis, we tested the effect of

cycloheximide on PRIMA-1-induced growth inhibition/apoptosis. Pretreatment of SKOV-His-175 cells with cycloheximide before addition of PRIMA-1 caused a 4-fold increase in cell survival according to the WST-1 proliferation assay. The cycloheximide treatment renders SKOV-His-175 resistant to MIRA-1 as well, resulting in about 4 fold increase in cell survival. Moreover, we have found that the viability of SKOV cells carrying His-175-22/23 mutant p53 that has an inactivated transactivation domain was at least twice as high as that of SKOV-His-175 cells after PRIMA-1 treatment. In addition, SKOV-His-175 cells were at least 3 fold more sensitive to treatment with MIRA-1 in comparison with SKOV-His-175-22/23 cells. Taken together, these results provide a convincing evidence that transcriptional transactivation by p53 is critical for PRIMA-1- and MIRA-1-induced cell death.

Compounds MIRA-1 and PRIMA-1 can restore the transcriptional transactivation function of mutant p53 in living cells

Having established that compounds MIRA-1 and PRIMA-1 can reactivate the specific DNA binding of mutant p53 in vitro, we addressed the question whether compounds MIRA-1 and PRIMA-1 can restore the transcriptional transactivation function of mutant p53 function in living cells. Saos-2-His-273 cells carrying a p53-responsive PG-luciferase reporter gene were treated with compounds MIRA-1 and PRIMA-1 and luciferase activity was measured using the Dual Luciferase Reporter Assay System (Promega) according to the manufacturer. As shown in Table IV, compounds MIRA-1 and PRIMA-1 stimulated transcription of the luciferase gene 1.5-2 fold. Interestingly, the kinetics of the induction of luciferase gene expression differed between compounds MIRA-1 and PRIMA-1. Whereas compound MIRA-1 stimulated luciferase expression 2-fold already after 3.5 hours, 2-fold induction by compound PRIMA-1 was achieved only after 15 hours of treatment. The kinetics of induction of luciferase gene expression correlates with the fast and slow induction of apoptosis by compounds MIRA-1 and PRIMA-1, respectively.

Treatment of A431 cells that carry endogenous His-273 mutant p53 and a transfected p53-responsive lacZ reporter with 50 μM of PRIMA-1 for 20 hours resulted in the appearance of lacZ-positive cells whereas untreated cells were negative (Figure 9A). Similar results were obtained after treatment with 5 μM of MIRA-1 for 12 hours.

We also transiently transfected SKOV-His-175 cells with a p53-responsive EGFP reporter. Figure 9B shows a strong induction of EGFP expression in SKOV-His-175 cells expressing mutant p53 after treatment with PRIMA-1 for 24 hours. In contrast, SKOV-His-175 cells grown in the presence of doxycycline (p53 off) did not express detectable levels of EGFP. The induction of EGFP was also observed in cells treated with 5μM of MIRA-1 for 24 hours (Figure 9C).

As a final confirmation that PRIMA-1 and MIRA-1 can rescue transcriptional transactivation of mutant p53, we examined if PRIMA-1 or MIRA-1 were able to induce two classical p53 target genes, p21 and MDM2. Treatment of H1299-His-175 cells expressing mutant p53 with either PRIMA-1 or MIRA-1 resulted in a solid induction of both MDM2 and p21 (Figure 10A). Importantly, treatment with, PRIMA-1 or MIRA-1 compound of the same cells in the absence of mutant p53 expression did not cause any induction of MDM2 nor p21 (Figure 10B). In addition, both chemicals induced MDM2 and p21 in SW480 colon carcinoma cells carrying endogenous His-273 mutant p53 (Figure 10C), but did not cause any significant changes of MDM2 and p21 protein levels in HCT116 colon carcinoma cells that carry wild type p53.

Stimulation of transcriptional transactivation function by compounds MIRA-1 and PRIMA-1 correlated with the data obtained in band shift experiments and demonstrates that compounds MIRA-1 and PRIMA-1 can work both in vitro and in vivo as reactivators of the specific DNA binding and transactivation functions of p53.

Toxicity and anti-tumour activity of PRIMA-1 in vivo

Intravenous injections of PRIMA-1 in mice did not cause any obvious changes in behavior or weight compared with untreated control animals. The average weight of untreated control mice was 20 ± 0.6 g (means ± SE, n = 3) and the average weight of mice treated with PRIMA-1 at the highest used dose of 100 mg/kg was 20 ± 0.2 g after one month of observation. To assess the effect of PRIMA-1 on human tumour xenografts, we inoculated mice with Saos-2-His-273 cells expressing mutant p53. The animals received intratumour (20 mg/kg) or intravenous (20 or 100 mg/kg) injections of PRIMA-1 twice a day for three days. In the untreated control group, the

average tumour volume after 59 days was 555.7 ± 284 mm^3 (means ± SE, n = 3). At this time, mice that received intravenous injections of PRIMA-1 at a dose of 100 mg/kg had an average tumour volume of 11.7 ± 8 mm^3, and mice that treated with 20 mg/kg PRIMA-1 i.v. had an average tumour volume of 53 ± 48.5 mm^3 (Fig. 5). Mice that got intratumour injections of 20 mg/kg of PRIMA-1 had an average tumour volume of 5.3 ± 2.7 mm^3. The differences in tumour volume between untreated control mice and animals treated with PRIMA-1 are all statistically significant (P=0.041 for intratumour injections of 20 mg/kg, P=0.066 for intravenous injection of 20 mg/kg, and P=0.045 for intravenous injection of 100 mg/kg, according to the paired t-test for the entire observation period). Thus, PRIMA-1 has in vivo anti-tumour activity in this animal tumour model.

Identification of structural analogues of compounds MIRA-1 and PRIMA-1 of the present invention which are able to specifically suppress growth of mutant p53-expressing cells.

In order to identify the active groups of the p53-reactivating compounds PRIMA-1 and MIRA-1 series of structural analogues of compounds MIRA-1 and PRIMA-1 were tested. Saos-2-His-273 osteosarcoma and H1299-His-175 lung adenocarcinoma cells grown in the presence (p53 null) or absence (mutant p53 expression) of doxycycline were placed on ELISA plates at a density of 3000 cells per well. After 12h cells were treated with analogues and incubated with compounds for 48h. Then WST-1 cell proliferating reagent was added to each well and cell survival was estimated by reading absorbance at 450nm by ELISA reader. The effect of structural analogues on cell growth was tested using different concentrations of the compounds, ranging from 0.1; 1; 5; 10 and 25 μM. After that curves of growth inhibition were generated based on a rational function Y= (b+cx)/1+ax by using Microcal Origin software. The coefficients (a,b,c) of the equation were determined by employing Levenberg-Marquardt algorithm. IC50 values were calculated from the equation by taking Y=50% of growth inhibition.

The specificity of each compound was determined by calculation of ratio IC50p53null/IC50mtp53. Ratios equal to 1 or less are indicating non-specific activity. Compounds that did not show any effect at the concentrations up to 25μM were regarded as inactive.

Thus, the analogoues of MIRA-1 and PRIMA-1 are able to restore the growth suppression function of the three most common hot spot p53 mutants at lower concentration than the original compounds and independently of genetic background.

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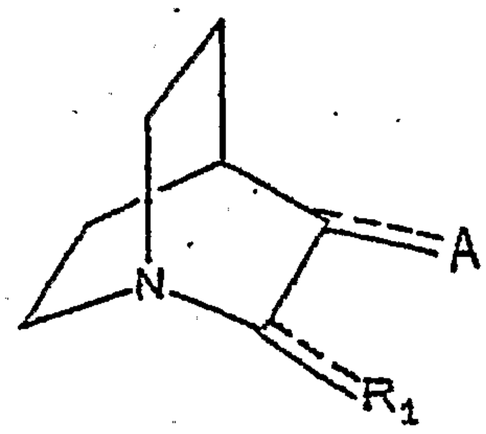
Amended set of claims 10.03.2004 under Art. 34 (2)(b)

1. Use of a compound other than 9-(azabicyclo[2.2.2]octane-3-one)-6-chloro-9H-purine having the ability to restore the apoptosis-inducing function of mutant p53 proteins, which compound is selected from compounds having a structure according to the formula I



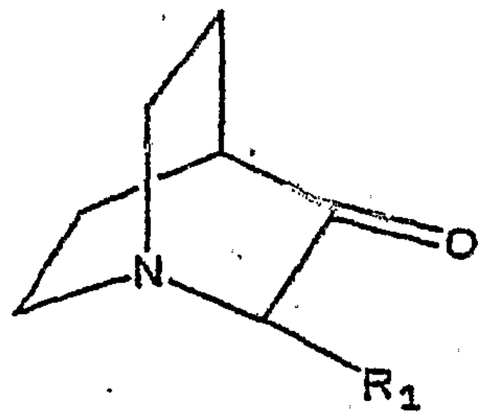
wherein:

R1 is hydrogen or a methylene group, which can be double bonded, as indicated by the broken line, or single bonded and linked to the nitrogen atom of an amine-substituted phenyl group, to a nitrogen atom contained in the ring structure of a purine, 8-azapurine, or benzimidazol residue, and;

A is an oxygen-containing moiety, either consisting of an oxygen atom being double bonded, as indicated by the broken line, or a benzoyloxy group, with the proviso that when A is a benzoyloxy group, then R1 is hydrogen,
for the preparation of a medicament for treating mutant p53 mediated diseases.

2. The use of claim 1, wherein the compound is selected from 2-(adenine-9-methylene)-3-quinuclidinone, 2-methylene-3-quinuclidinone, 2-(-2-amino-3-chloro-5-trifluoromethyl-1-methylaniline)-3-quinuclidinone, 2-(6-trifluoromethyl-4-chlorobenzimidazole-1-methylene)-3-quinuclidinone, 2-(6-methoxypurine-9-methylene)-3-quinuclidinone, 2-(8-azaadenine-9-methylene)-3-quinuclidinone, 1-azabicyclo [2.2.2]oct-3-yl benzoate, 2-(5,6-dimethyl-benzimidazole-1-methylene)-3-quinuclidinone, 2-(8-azaadenine-7-methylene)-3-quinuclidinone, 2-(7-methylene-1,3-dimethyluric acid)-3-quinuclidinone, or 2-(2,6-dichloro-9-methylenepurine)-3-quinuclidinone.

3. The use of claim 1 or 2, wherein the compound is selected from compounds having the structure of the general formula I'



wherein

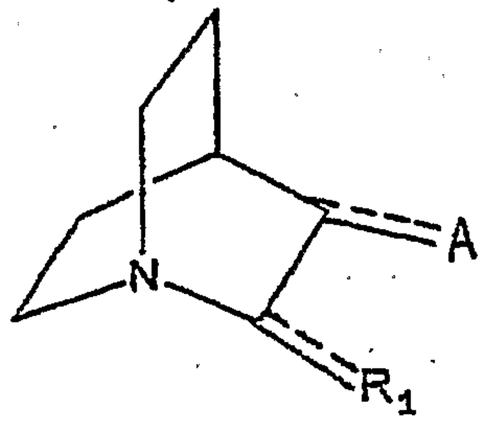
R1 is a methylene group linked to the nitrogen atom of an amine-substituted phenyl group, a nitrogen atom contained in the ring structure of a purine, 8-azapurine, or benzimidazol residue, and, more preferably R1 is a methylene group linked to a nitrogen atom contained in the ring structure of a purine, 8-azapurine, or benzimidazol residue.

4. Use of 2-ethylene-4(3H)-quinazolinone having the ability to restore the apoptosis-inducing function of mutant p53 proteins for the preparation of a medicament for treating mutant p53 mediated diseases.

5. The use of anyone of the claims 1-4 together with a pharmaceutically acceptable carrier, diluent and/or excipient.

6. The use of anyone of the claims 1-5, wherein the mutant p53 mediated disease is cancer.

7. A method of treating a mutant p53 mediated disease, comprising administrating to a mammal in need thereof a pharmaceutically efficient amount of a compound selected from compounds having a structure according to the formula I

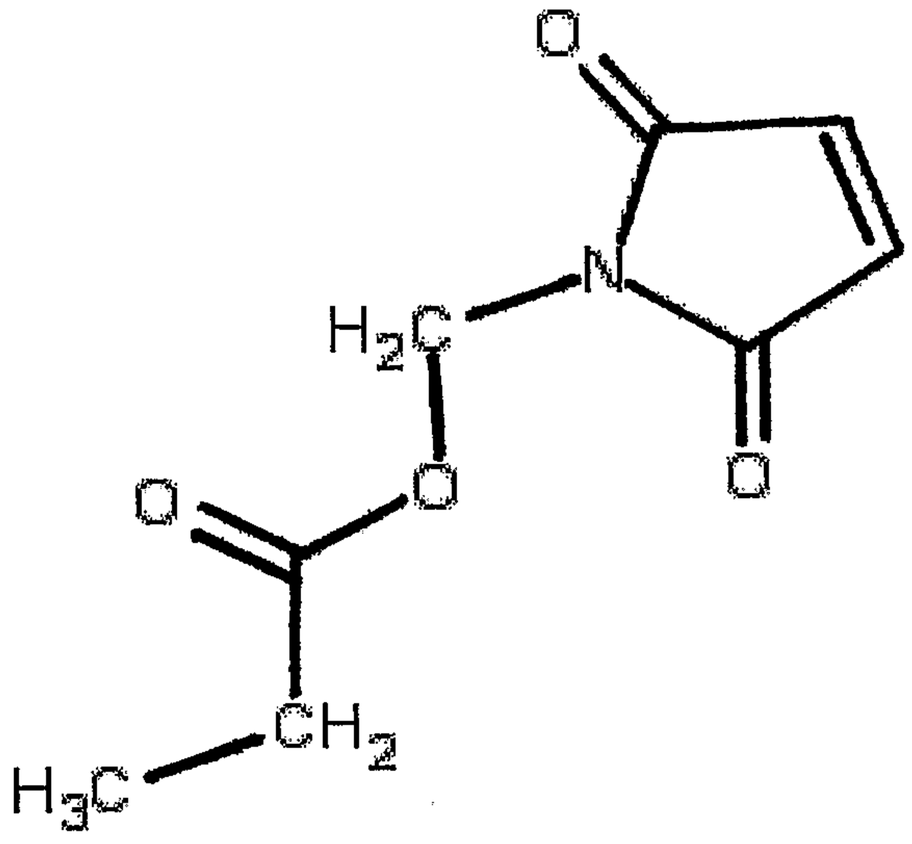


wherein:

R1 is hydrogen or a methylene group, which can be double bonded, as indicated by the broken line, or single bonded and linked to the nitrogen atom of an amine-substituted phenyl group, to a nitrogen atom contained in the ring structure of a purine, 8-azapurine, or benzimidazol residue, and;

A is an oxygen-containing moiety, either consisting of an oxygen atom being double bonded, as indicated by the broken line, or a benzoyloxy group, with the proviso that when A is a benzoyloxy group, then R1 is hydrogen.

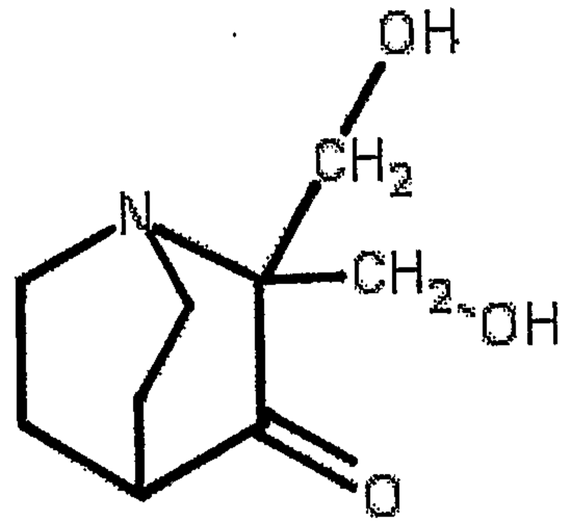
8. The method of claim 7, wherein the mutant p53 mediated disease is cancer.



1-(Propoxymethyl)- maleimide

MIRA–1

Fig. 1A



2,2-bis(hydroxymethyl)-1-azabicyclo[2,2,2]octan-3-one

PRIMA-1

Fig. 1B

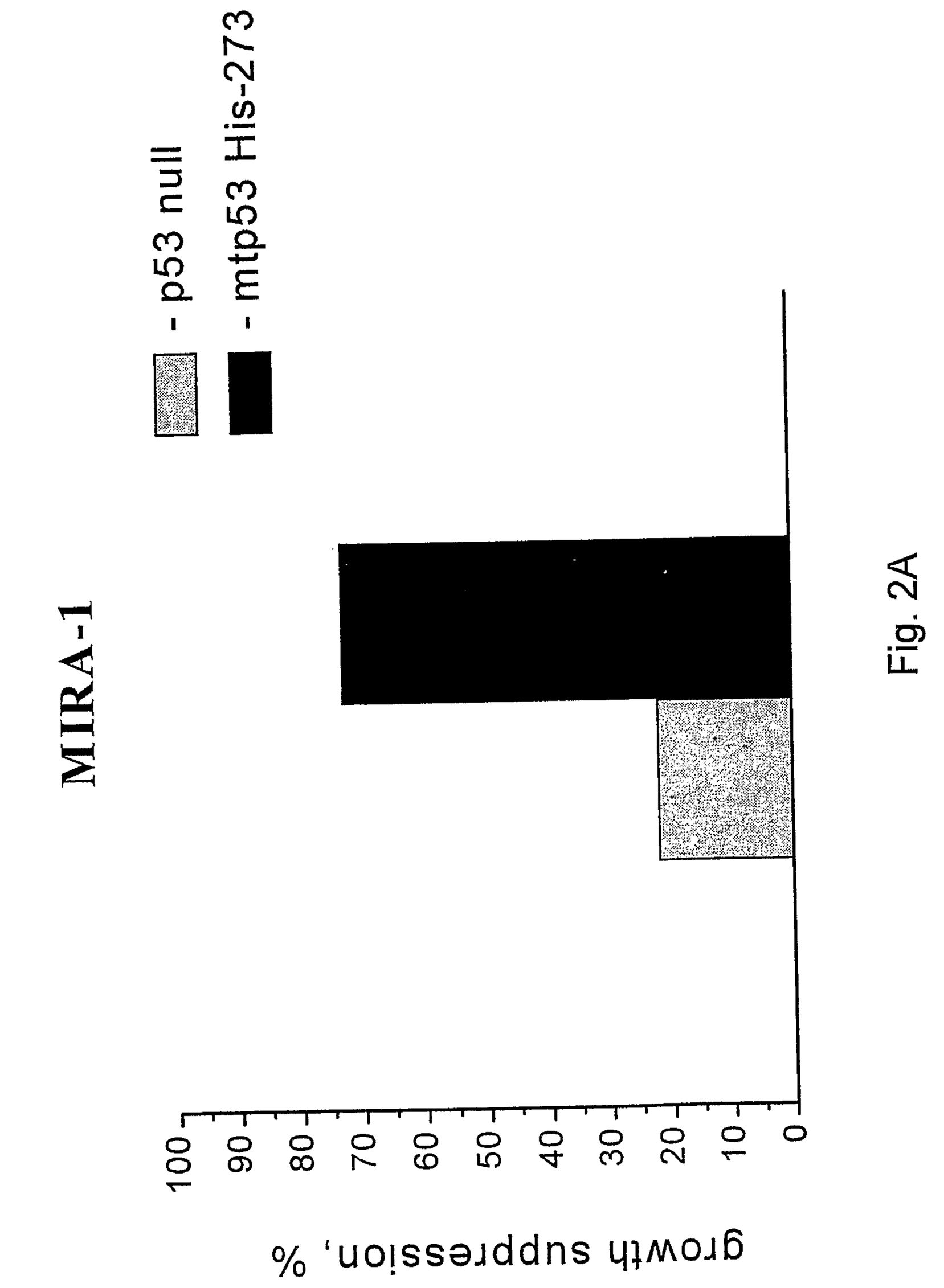

MIRA-1
- p53 null
- mtp53 His-273
growth suppression, %
0
10
20
30
40
50
60
70
80
90
100

Fig. 2A

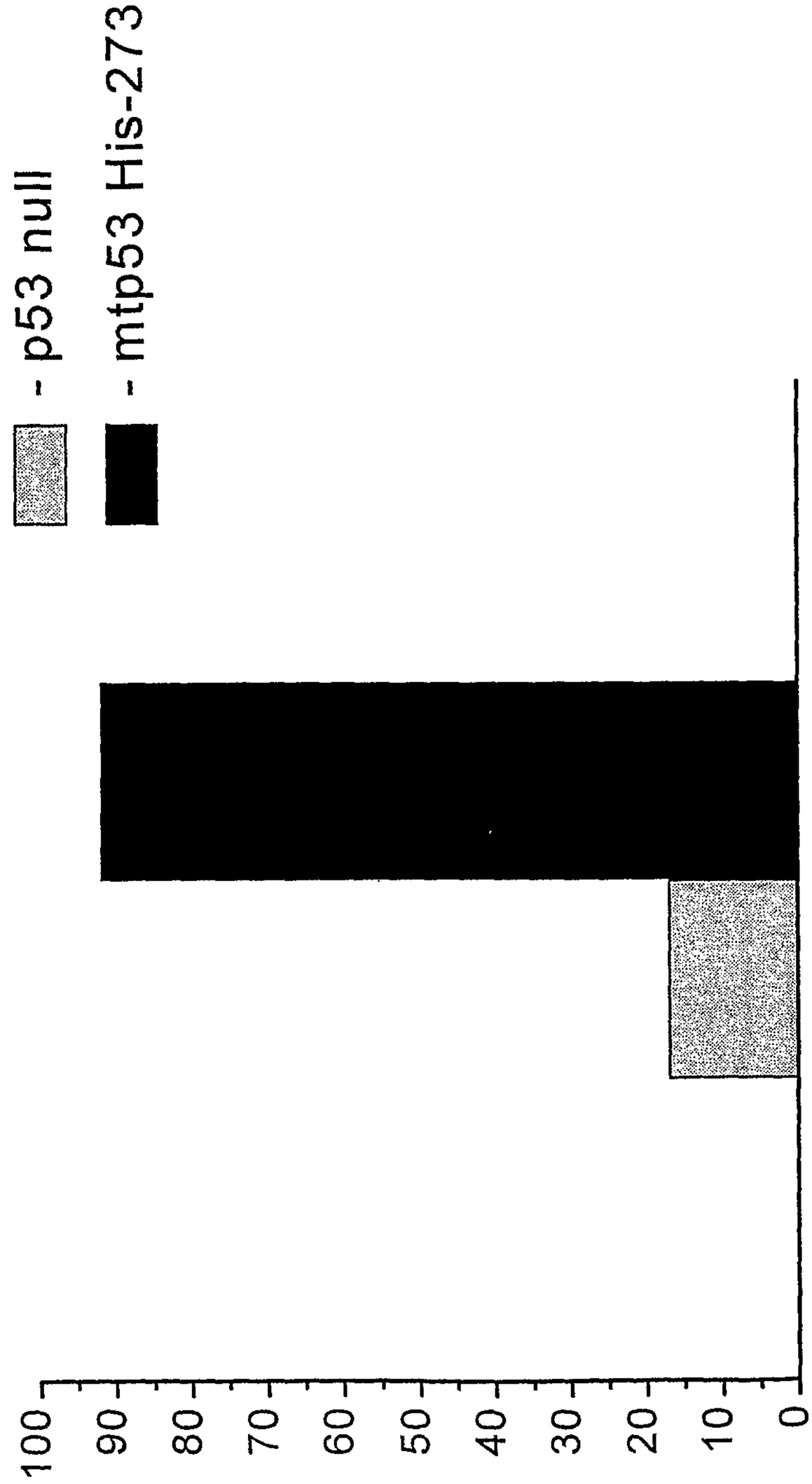

PRIMA-1
- p53 null
- mtp53 His-273
100
90
80
70
60
50
40
30
20
10
0
growth suppression, %

Fig. 2A

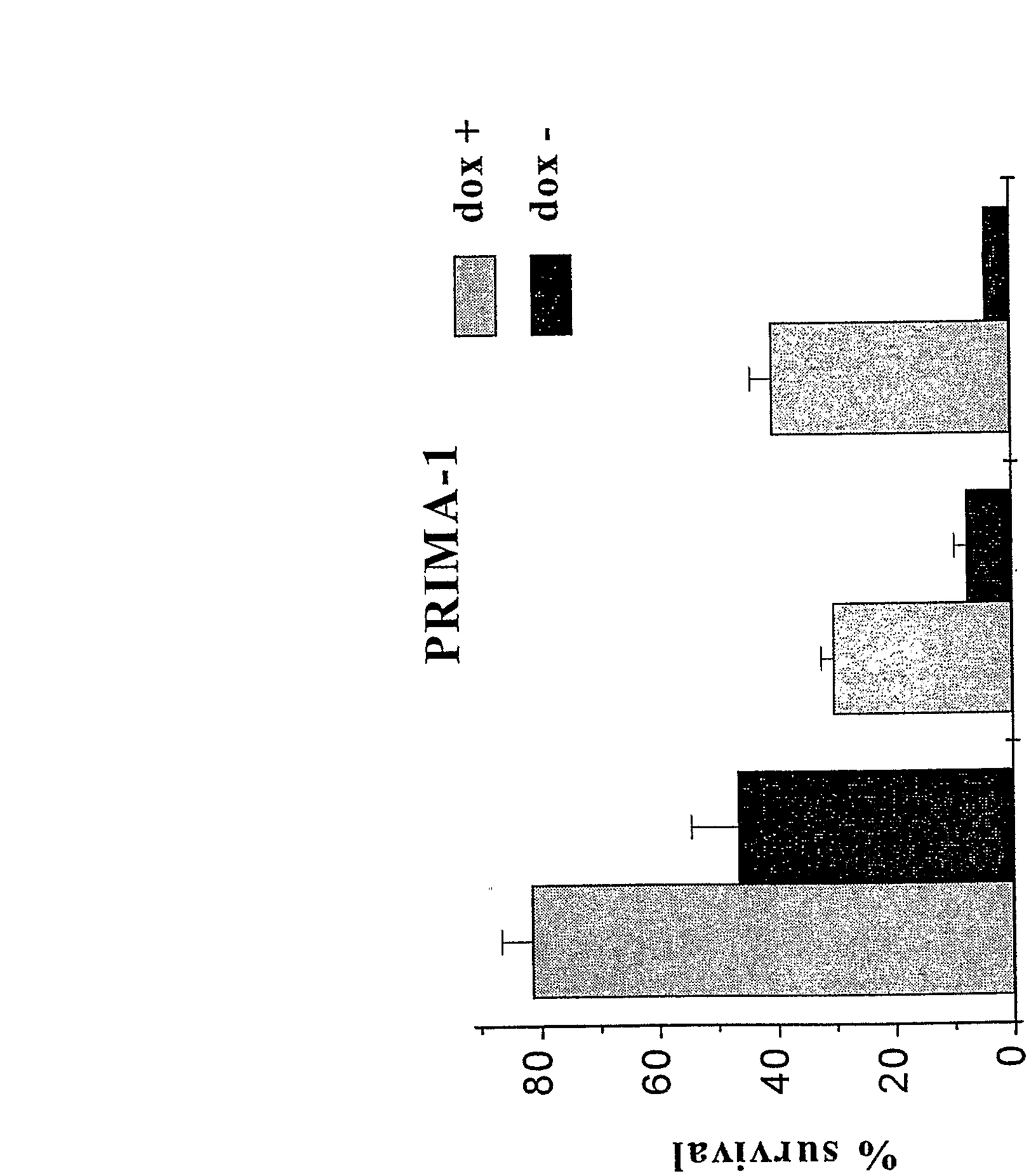

% survival
0
20
40
60
80
SKOV-His-273
SKOV-His-175
H1299-His-175
means ± SE, n = 2
PRIMA-1
dox +
dox -

Fig. 2B

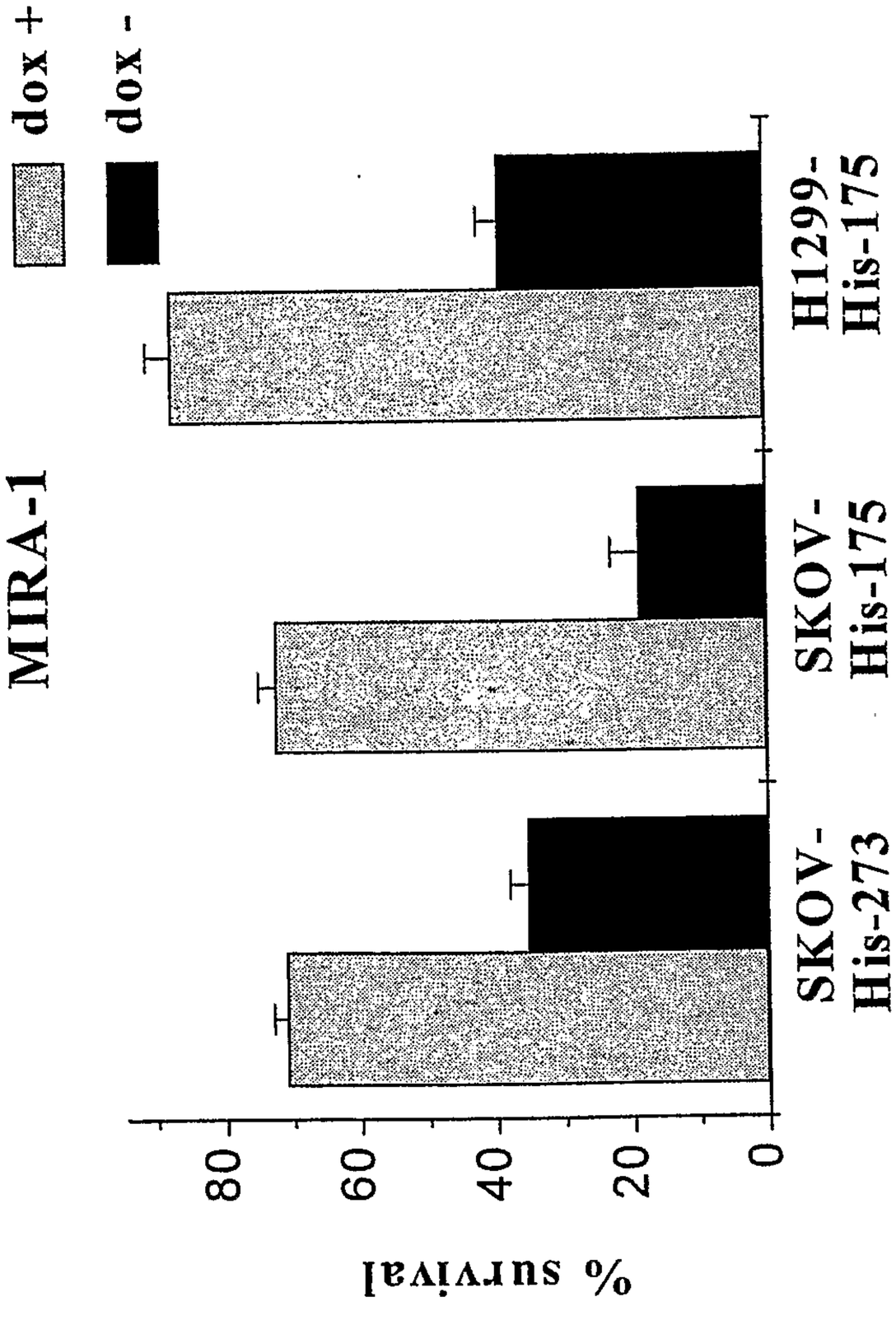

dox +
dox -
MIRA-1
% survival
0
20
40
60
80
SKOV-His-273
SKOV-His-175
H1299-His-175

Fig. 2B

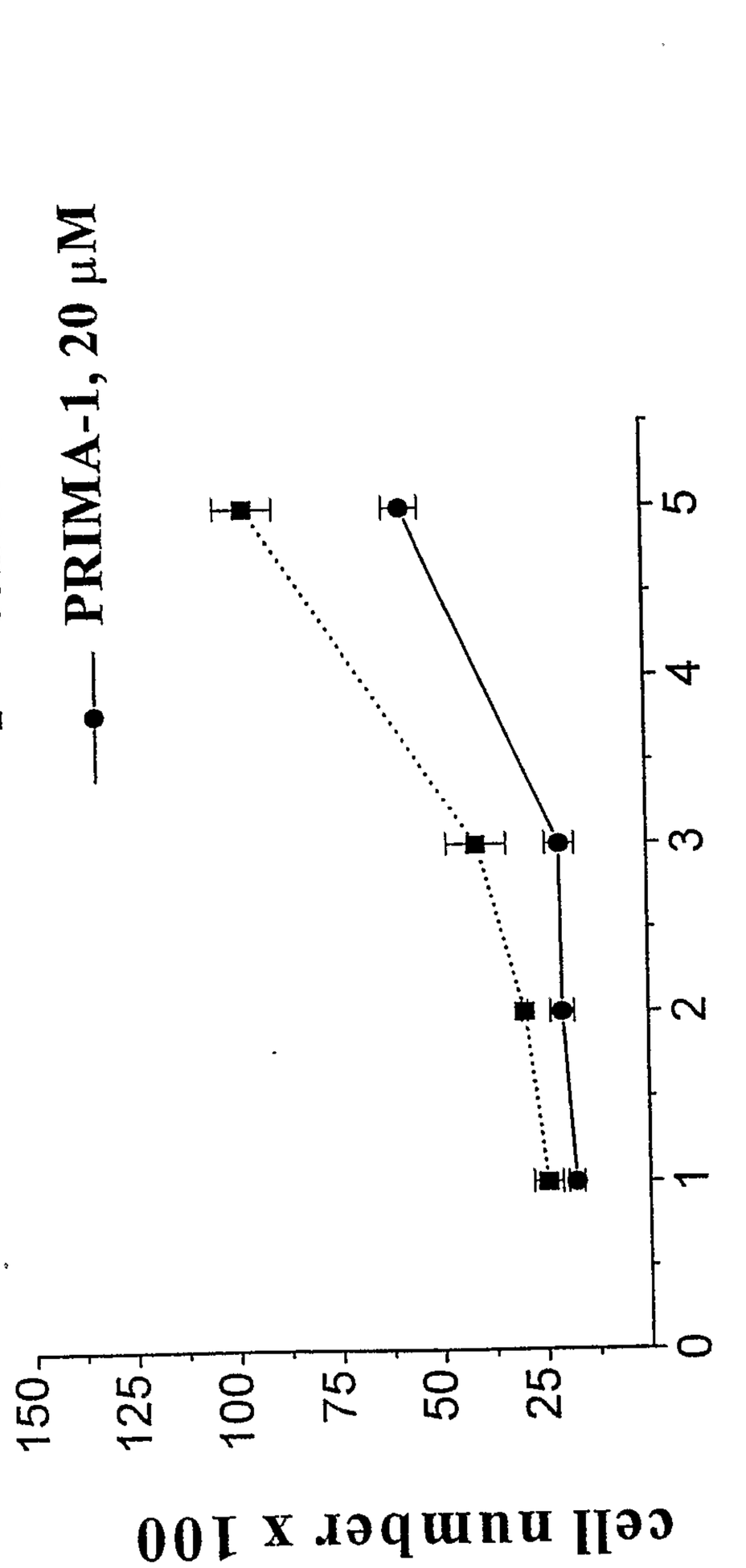

Saos-2-His-273 (dox +)
control
PRIMA-1, 20 μM
cell number x 100
150
125
100
75
50
25
0
1
2
3
4
5
days after treatment
mean ± SE, n=3

Fig. 2C

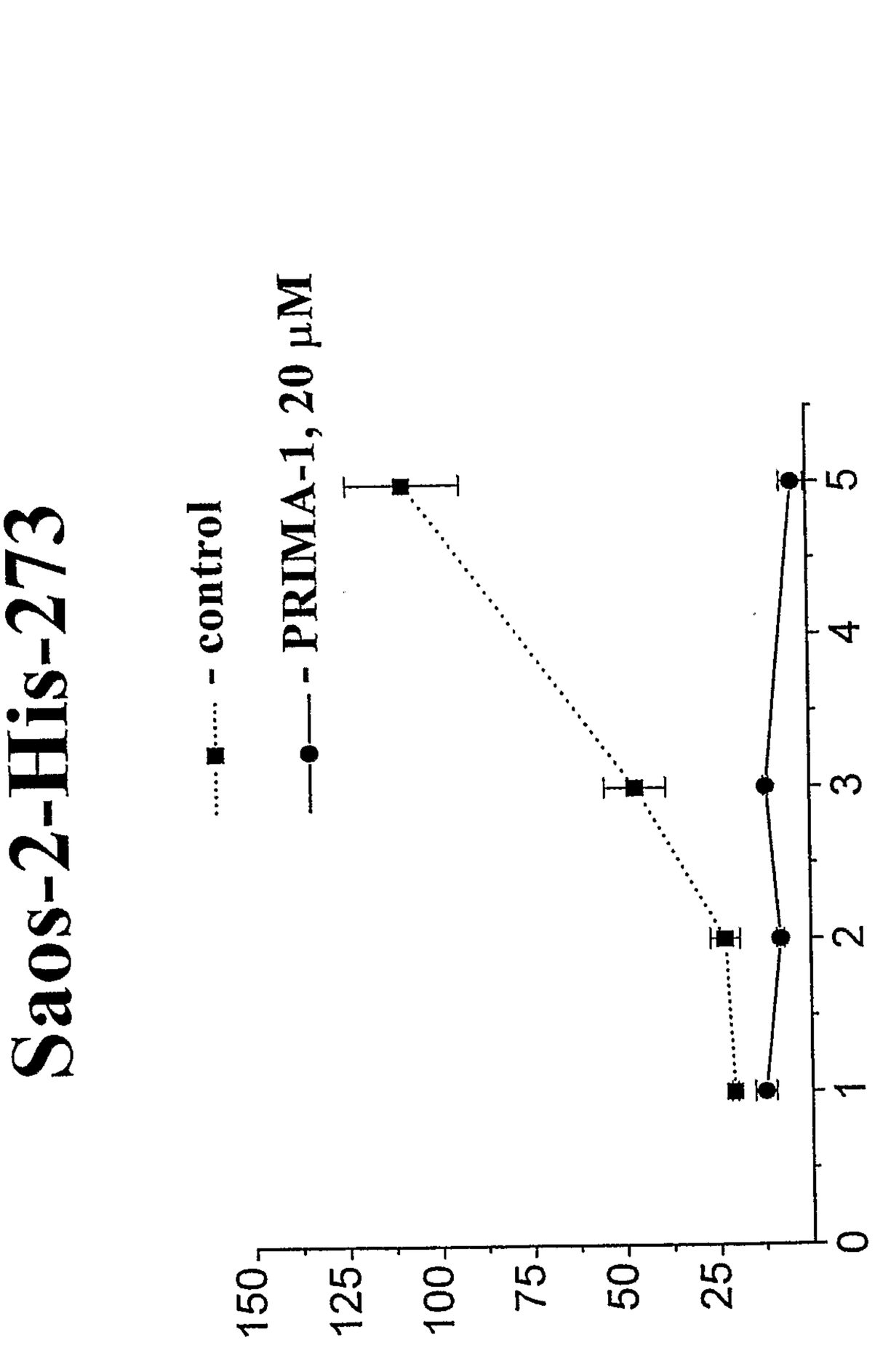

Saos-2-His-273
.... - control
— - PRIMA-1, 20 μM
mean ± SE, n=3
days after treatment
cell number x 100
0
1
2
3
4
5
25
50
75
00
25
50

Fig. 2C

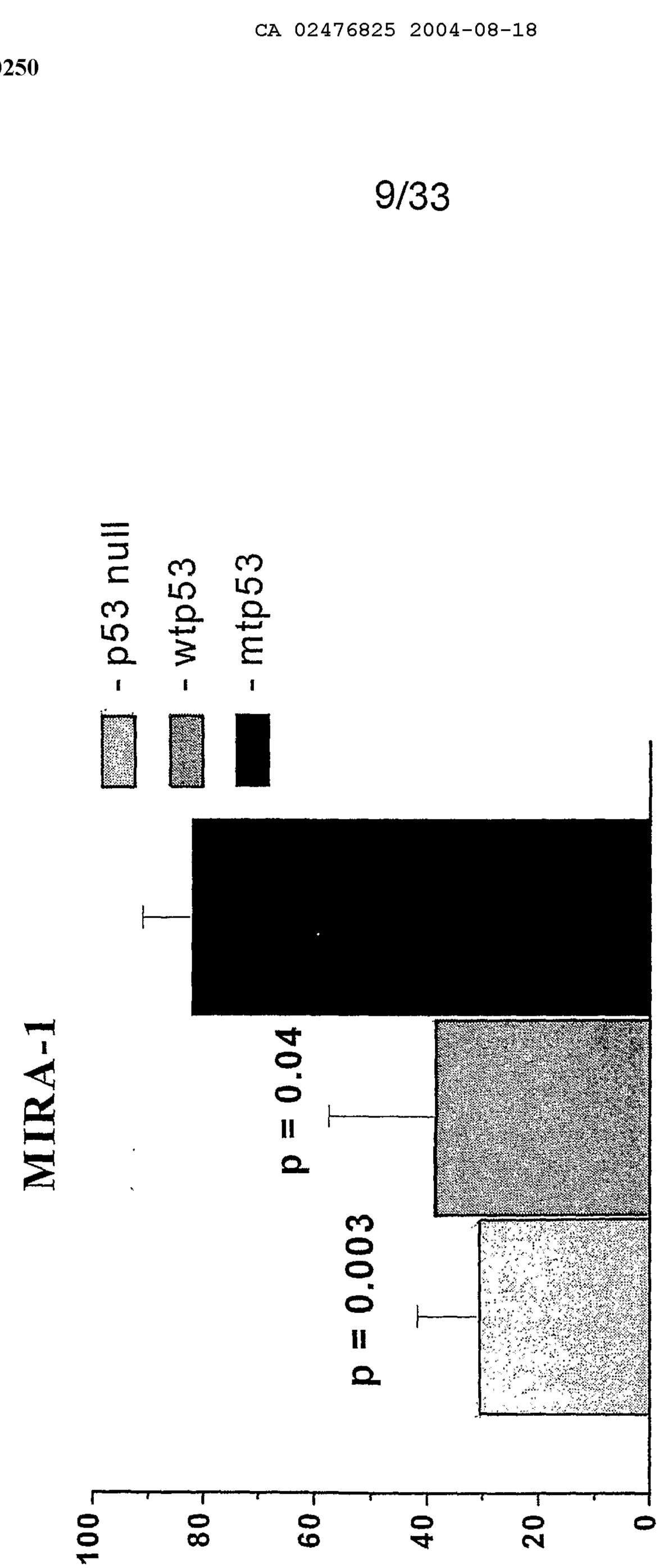

- p53 null
- wtp53
- mtp53
MIRA-1
p = 0.04
p = 0.003
100
80
60
40
20
0
growth suppression, %

Fig. 2D

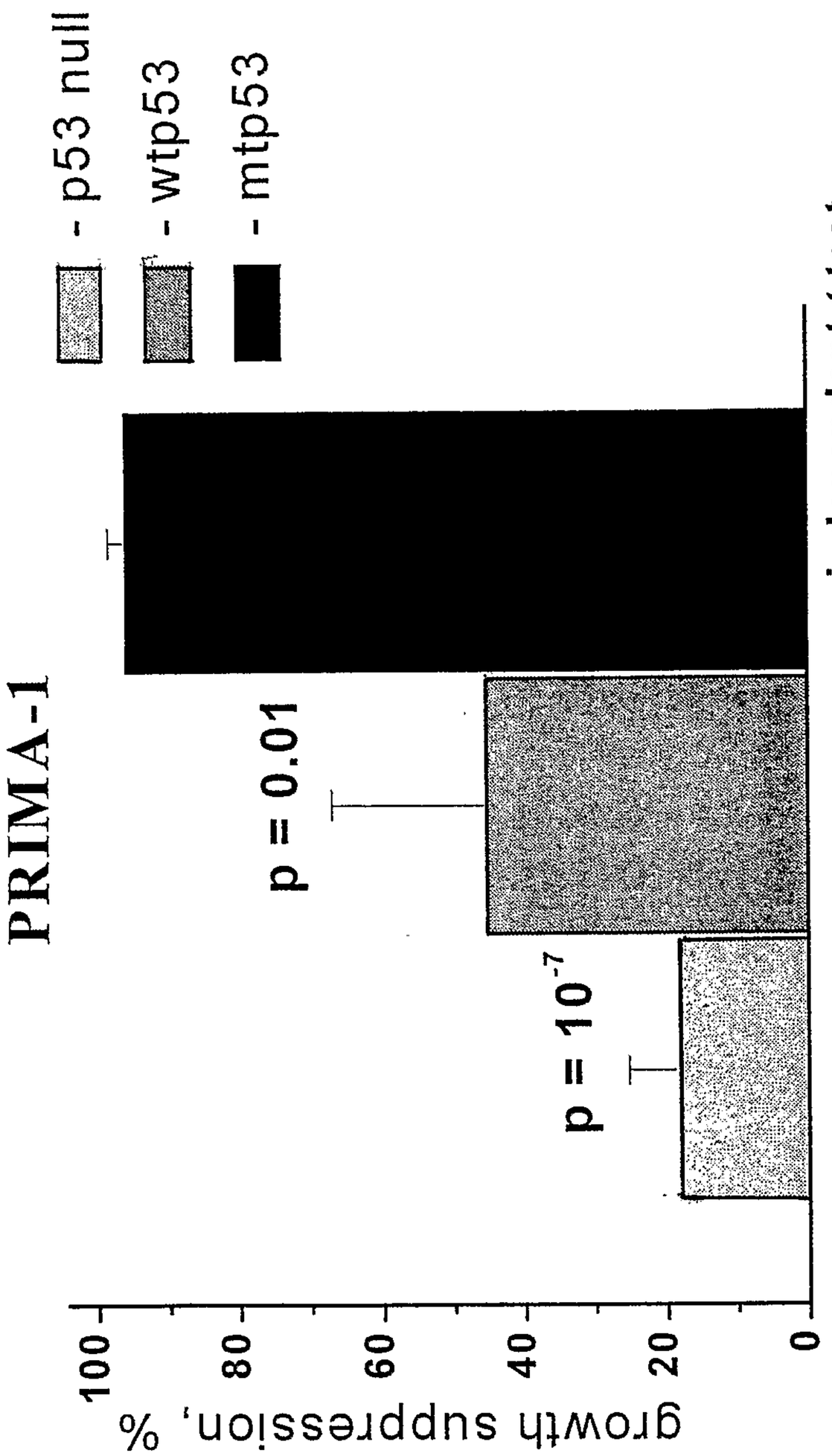

PRIMA-1
growth suppression, %
100
80
60
40
20
0
p = 0.01
p = 10-7
independent t-test
means ± SE
- p53 null
- wtp53
- mtp53

Fig. 2D

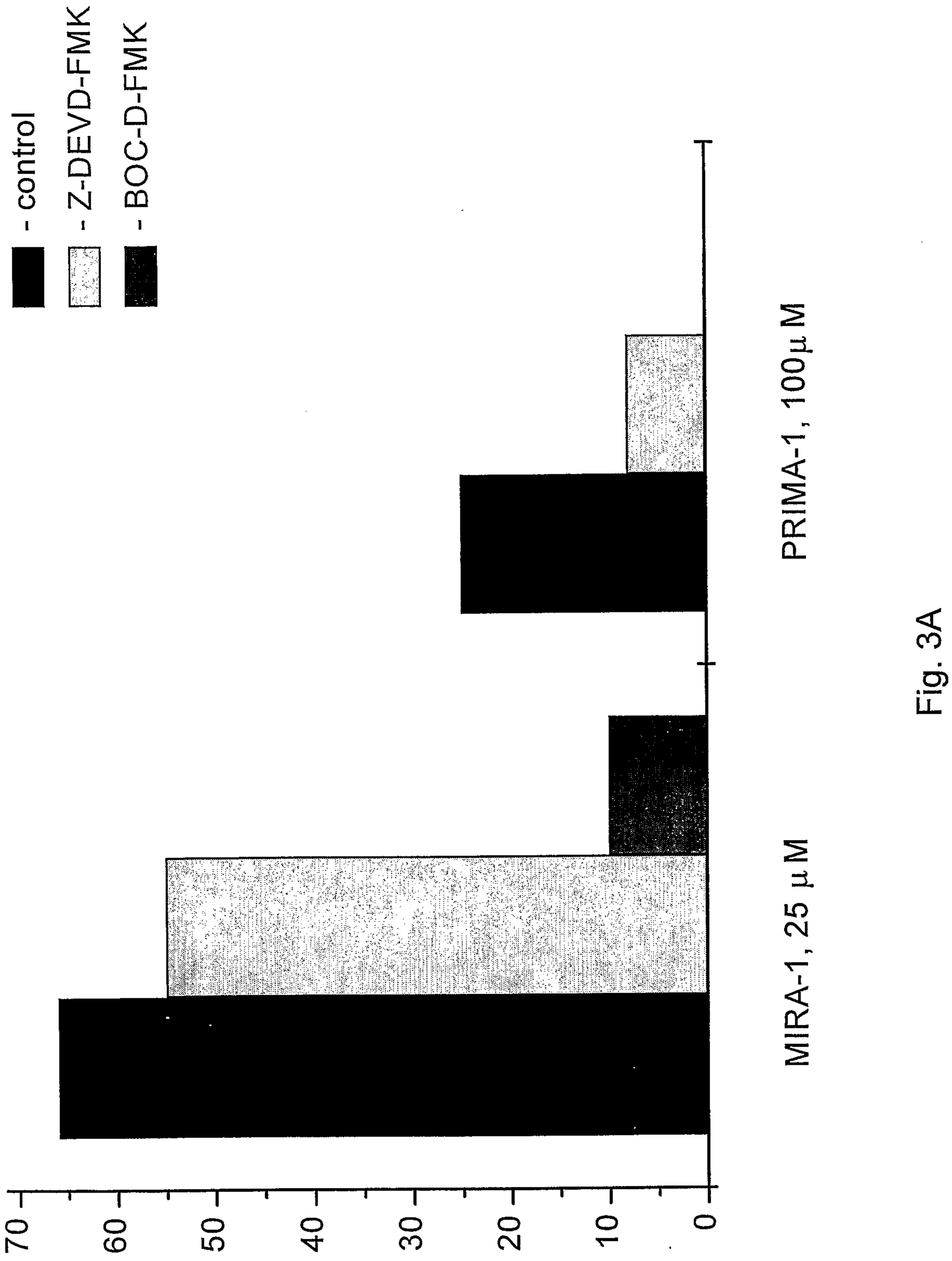

control
Z-DEVD-FMK
BOC-D-FMK
PRIMA-1, 100μM
MIRA-1, 25 μM
70
60
50
40
30
20
10
0
% of dead cells

Fig. 3A

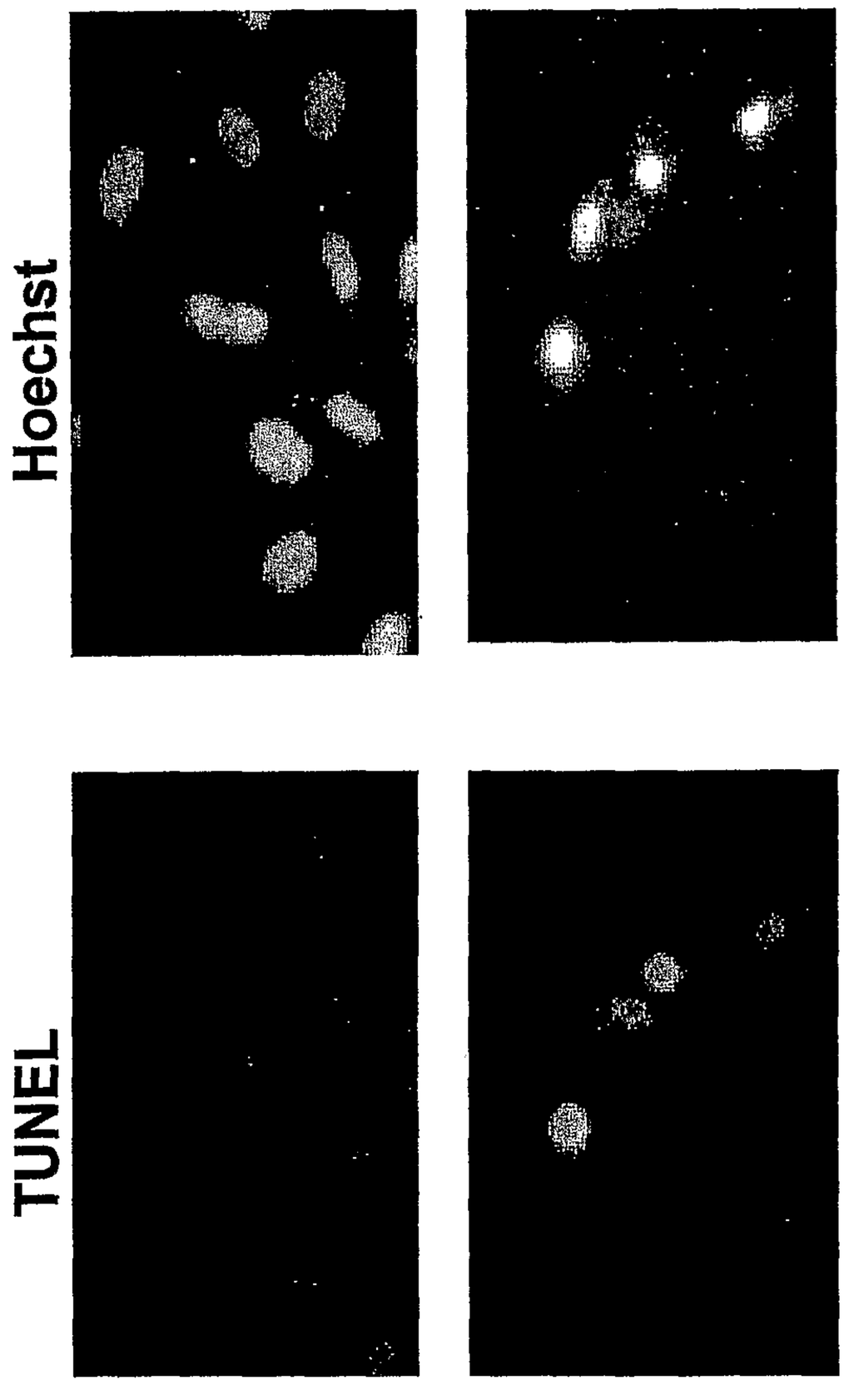


Fig. 3B

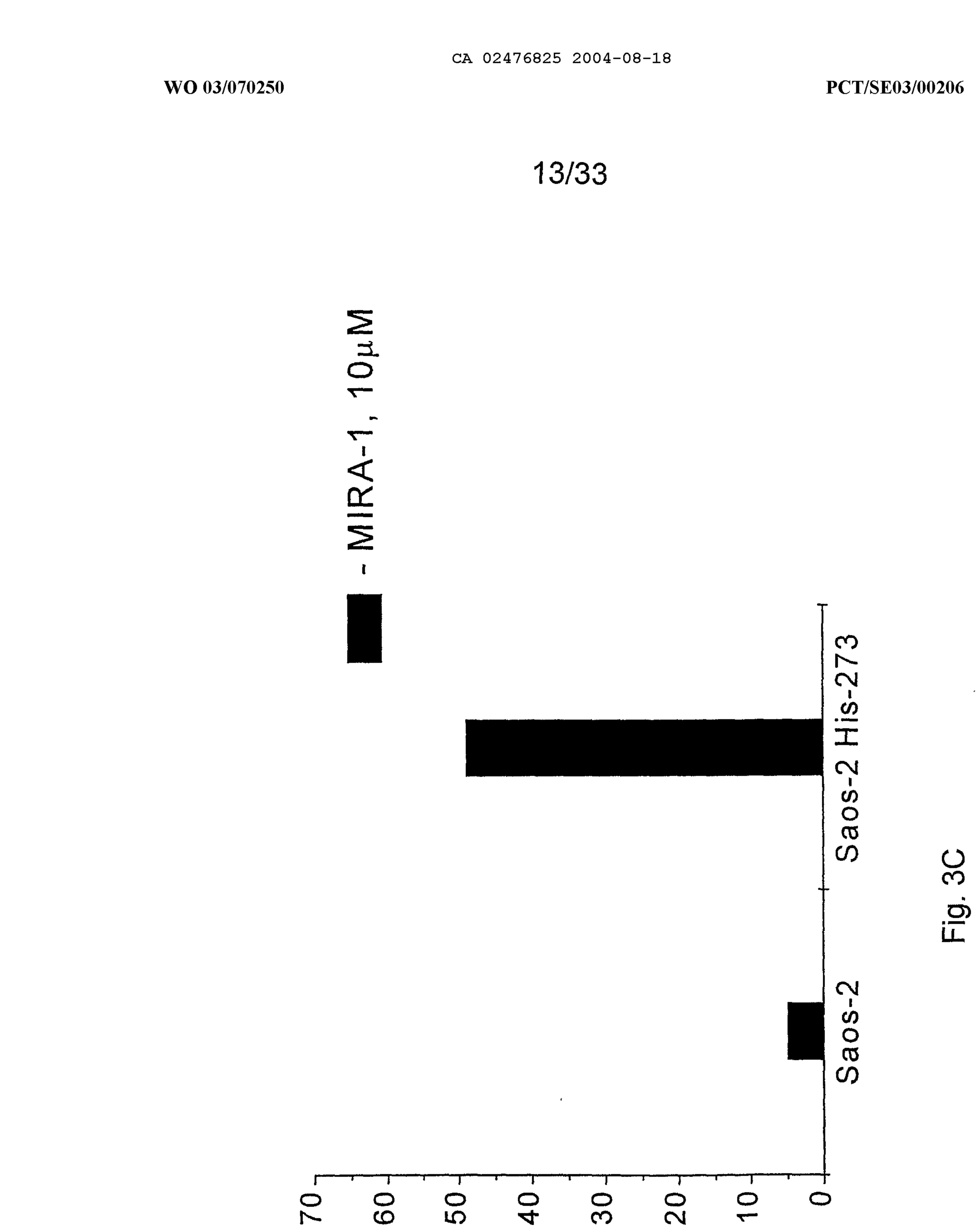

% of dead cells, FACS
70
60
50
40
30
20
10
0
Saos-2
Saos-2 His-273
- MIRA-1, 10μM

Fig. 3C

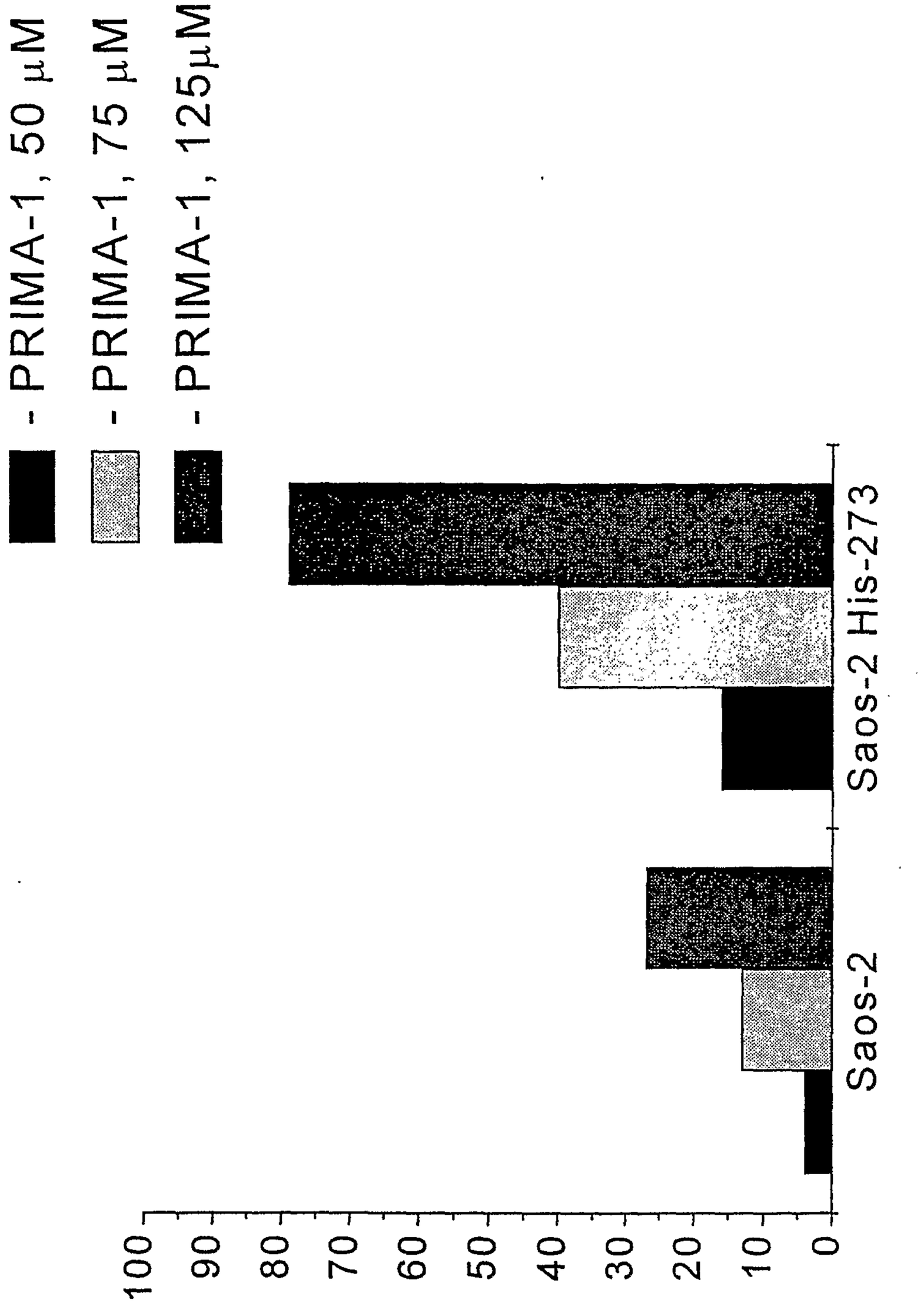

- PRIMA-1, 50 µM
- PRIMA-1, 75 µM
- PRIMA-1, 125µM
Saos-2 His-273
Saos-2
% of dead cells, FACS
100
90
80
70
60
50
40
30
20
10
0

Fig. 3C

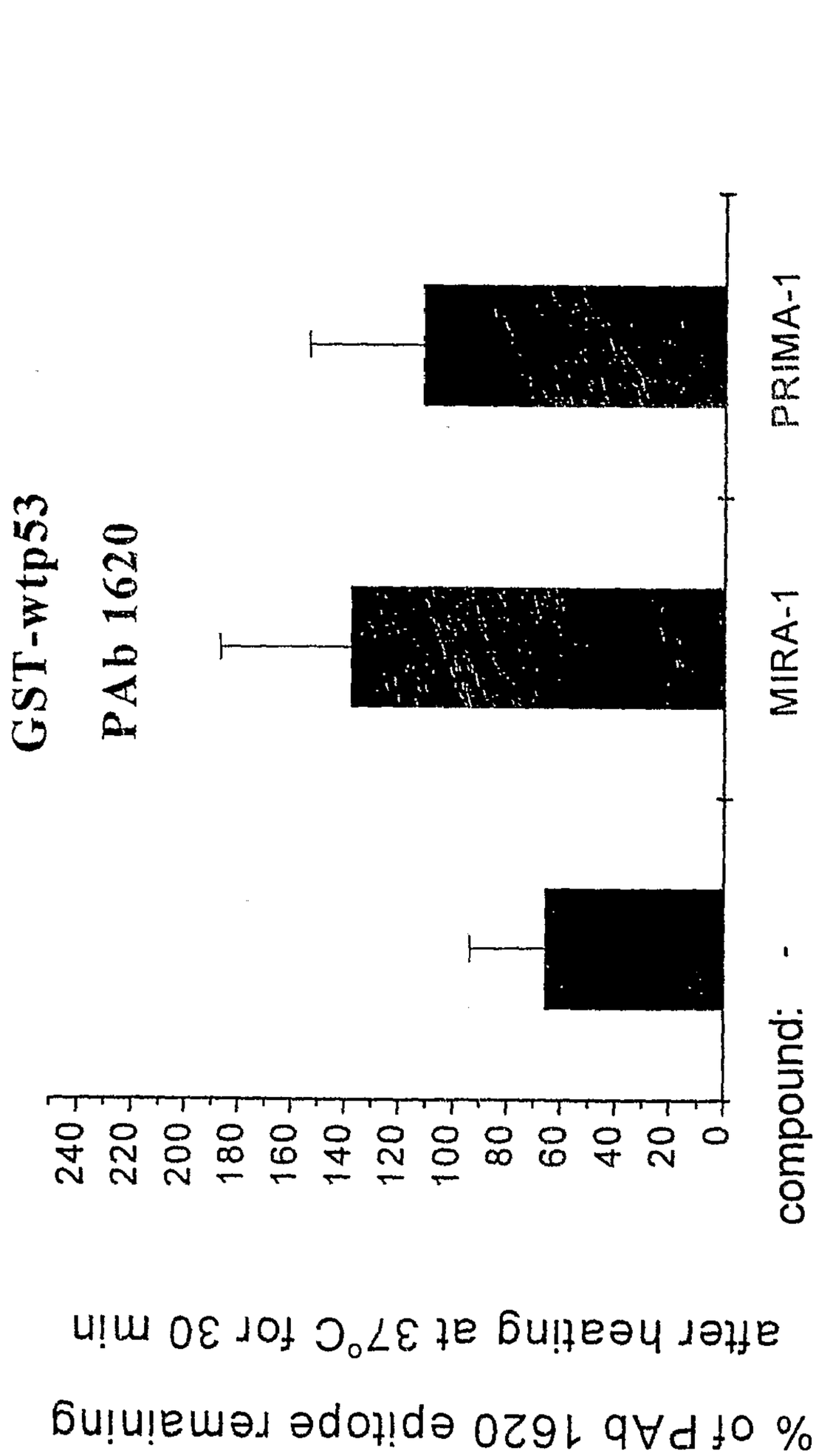

GST-wtp53
PAb 1620
MIRA-1
PRIMA-1
compound: -
240
220
200
180
160
140
120
100
80
60
40
20
0
after heating at 37°C for 30 min
% of PAb 1620 epitope remaining

Fig. 4A

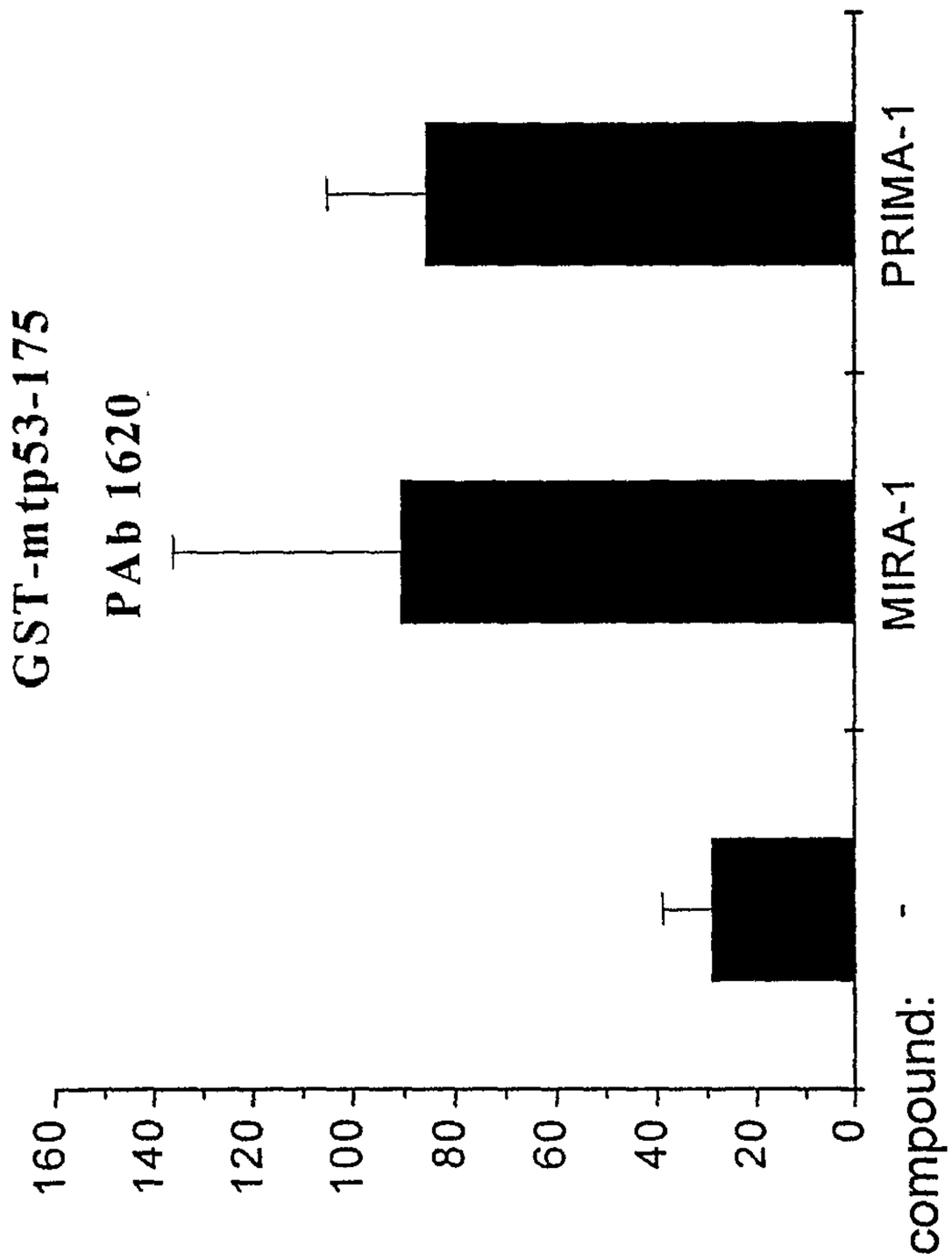


Fig. 4A

% of 1620 epitope remaining after heating at 37°C for 30 min

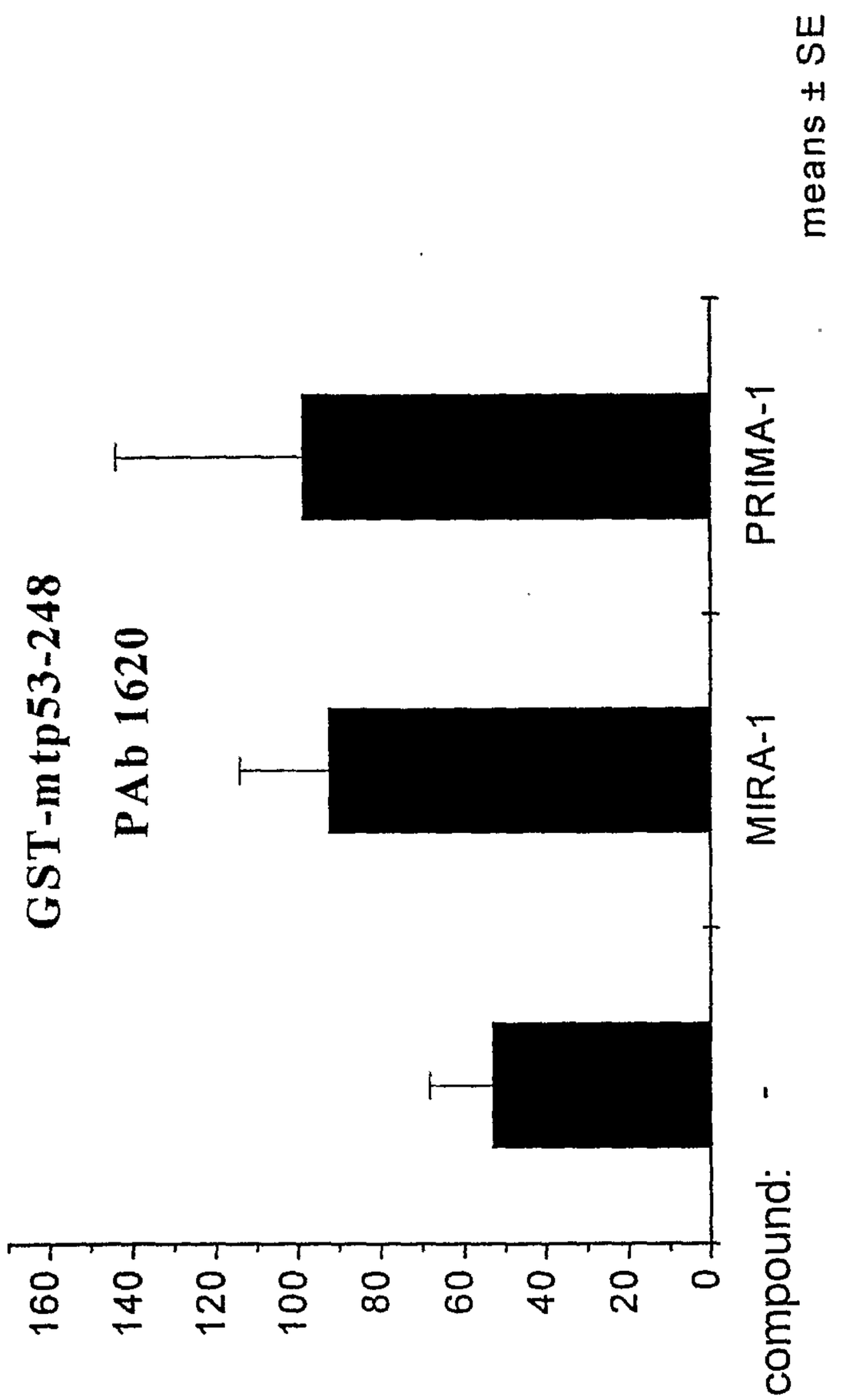

% of PAb 1620 epitope remaining
after heating at 37°C for 30 min
GST-mtp53-248
PAb 1620
means ± SE
PRIMA-1
MIRA-1
Compound: -
0
20
40
60
80
100
120
140
160

Fig. 4A

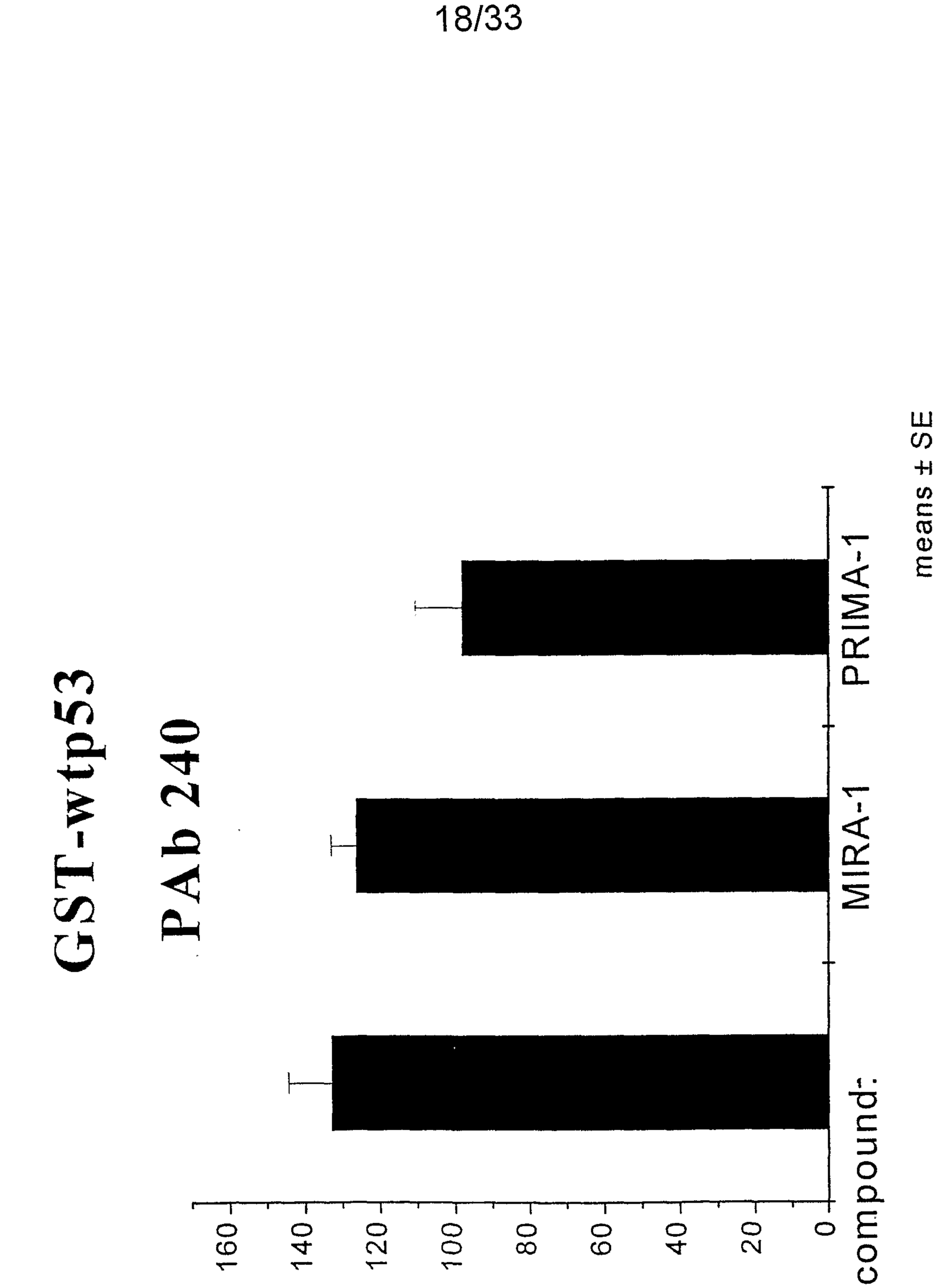

GST-wtp53
PAb 240
0
2
4
6
8
10
12
14
16
% of PAb 240 epitope remaining
after heating at 37°C for 30 min
Compound:
CO
MIRA-1
PRIMA-1
means ± SE

Fig. 4B

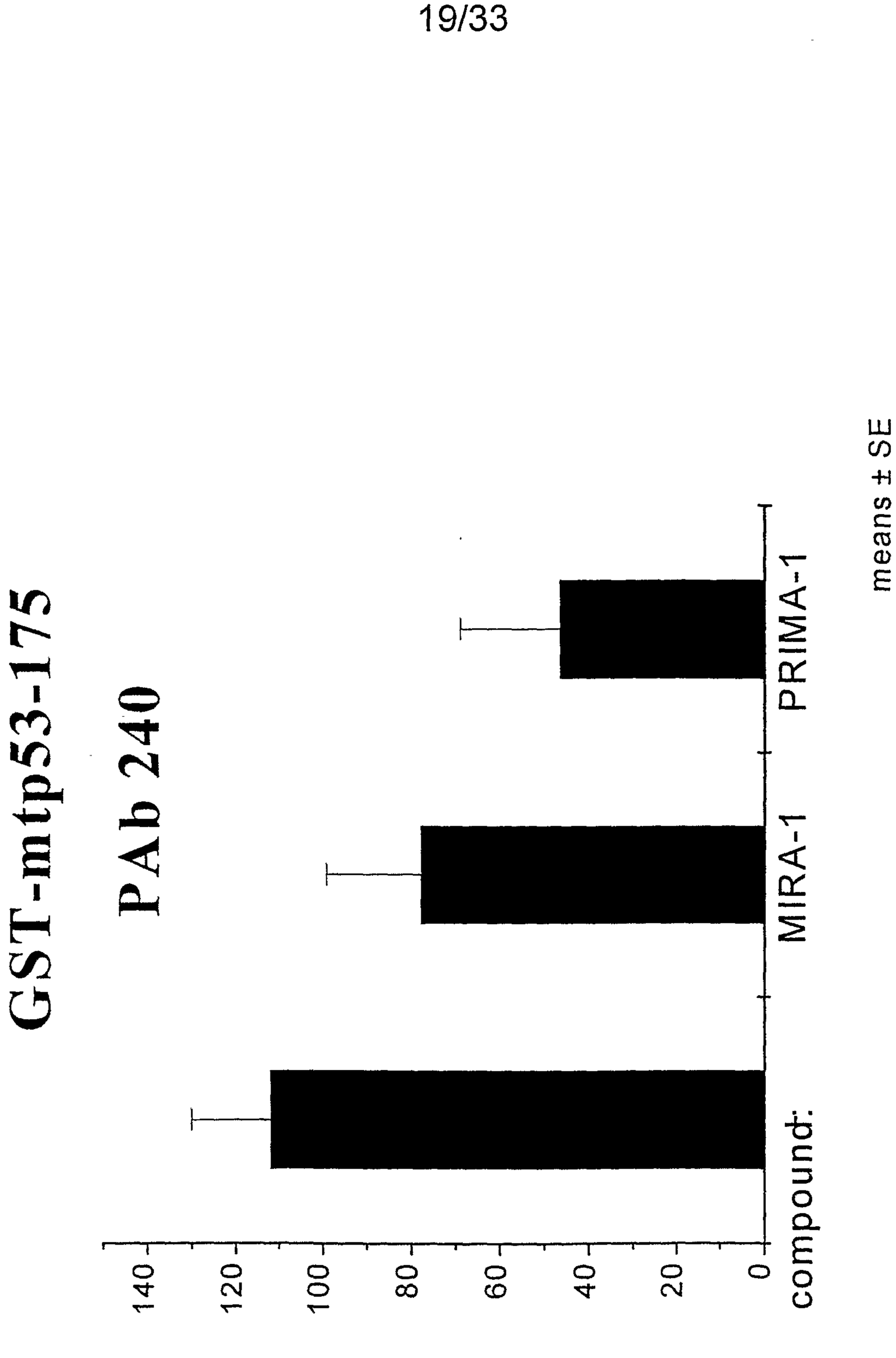

GST-mtp53-175
PAb 240
% of PAb 240 epitope remaining after heating at 37°C for 30 min
0
20
40
60
80
100
120
140
compound:
MIRA-1
PRIMA-1
means ± SE

Fig. 4B

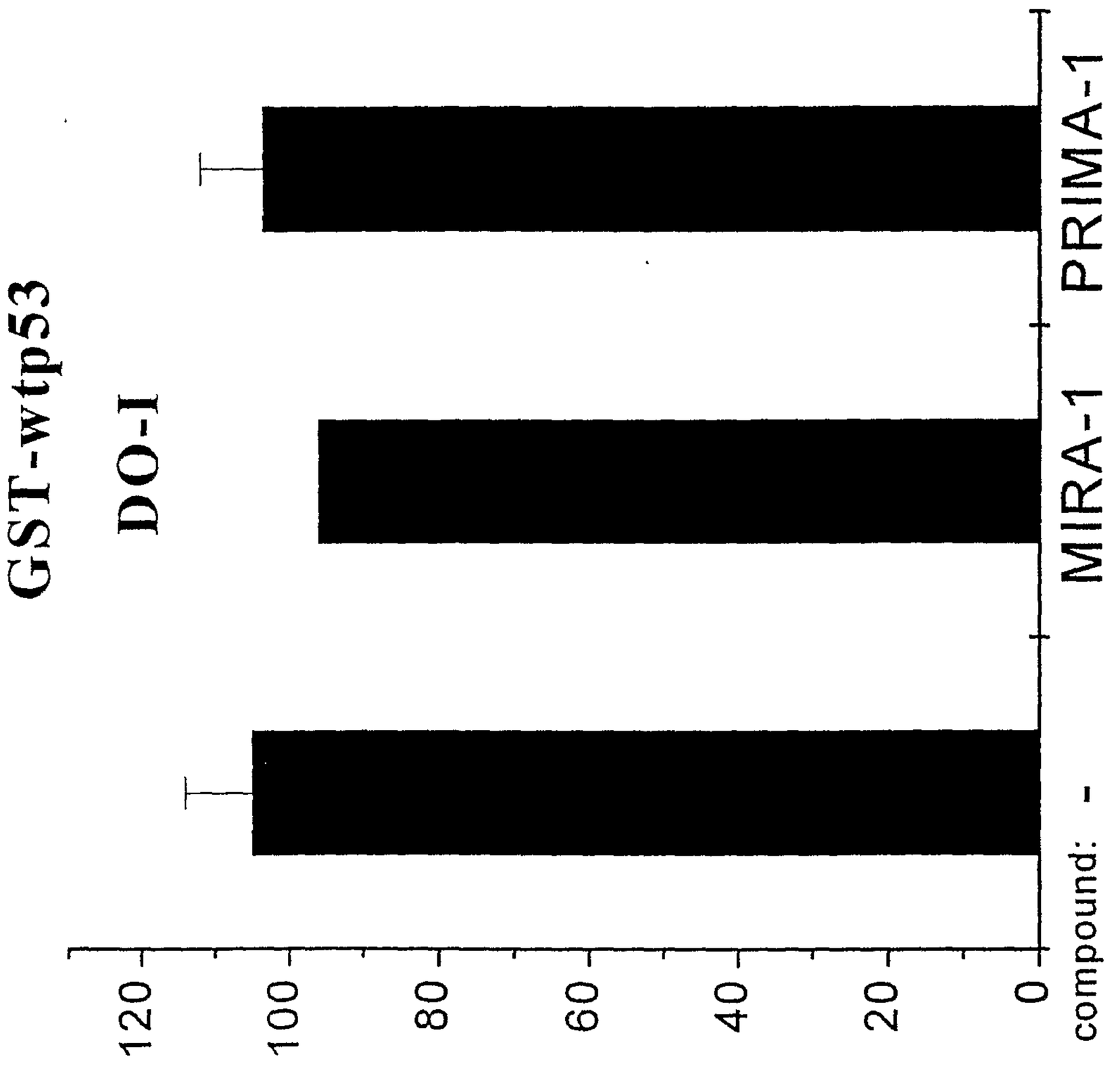

GST-wtp53
DO-I
% of DO-I epitope remaining
after heating at 37°C for 30 min
0
20
40
60
80
100
compound: -
MIRA-1
PRIMA-1

Fig. 4C

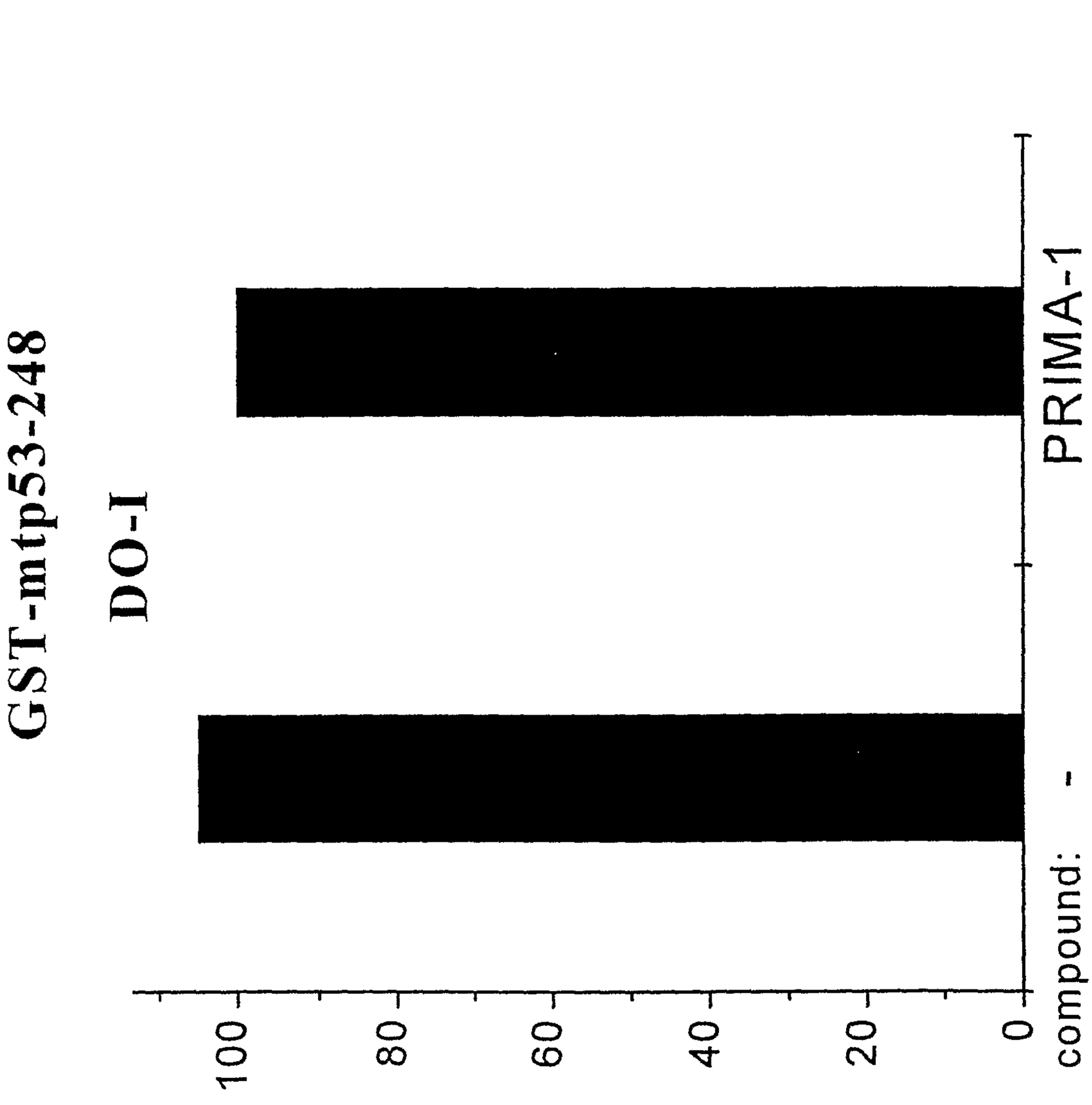

GST-mtp53-248
DO-I
% of PAb DO1 epitope remaining after heating at 37°C for 30 min
100
80
60
40
20
0
compound: -
PRIMA-1

Fig. 4C

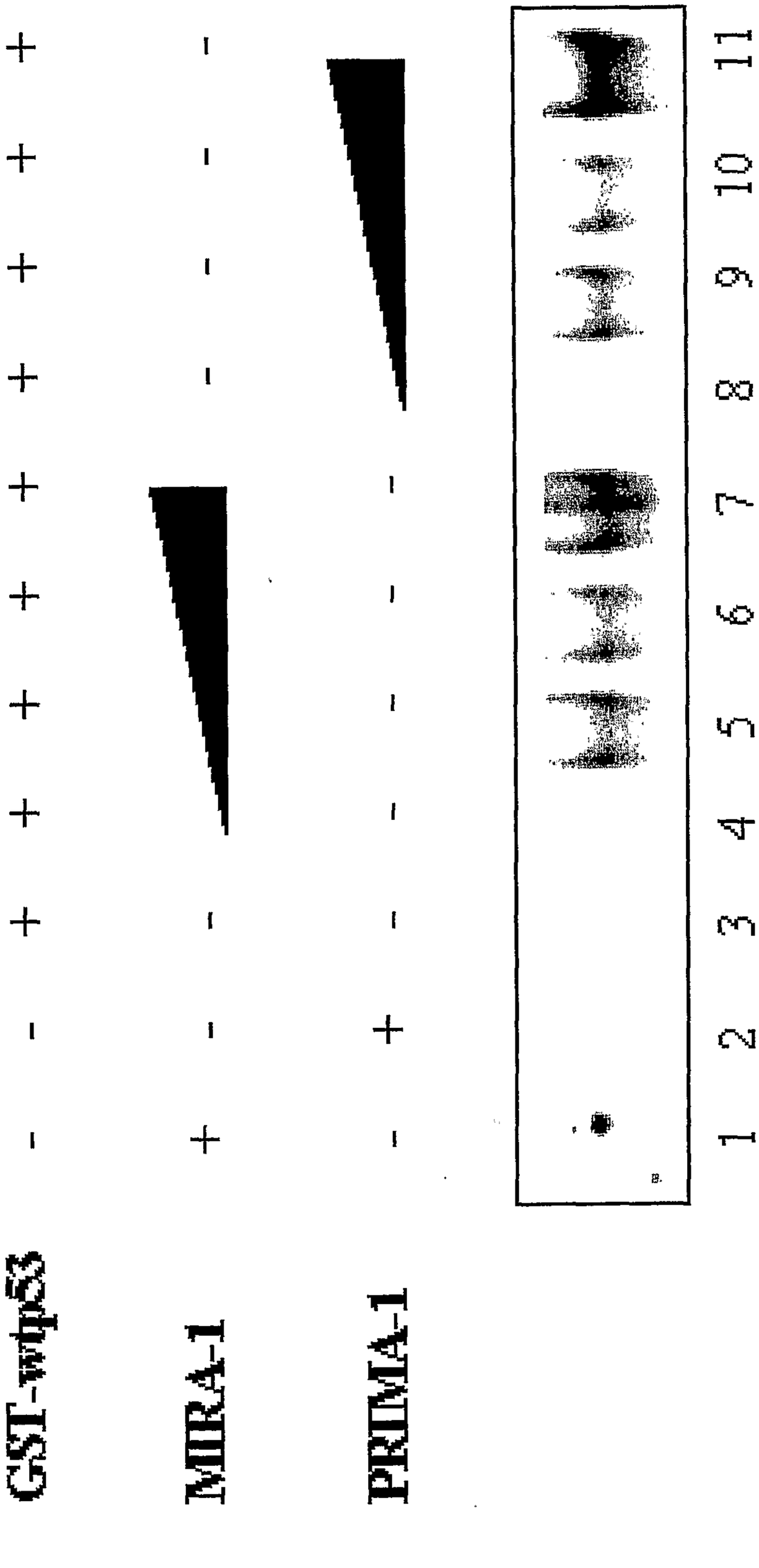


Fig. 5

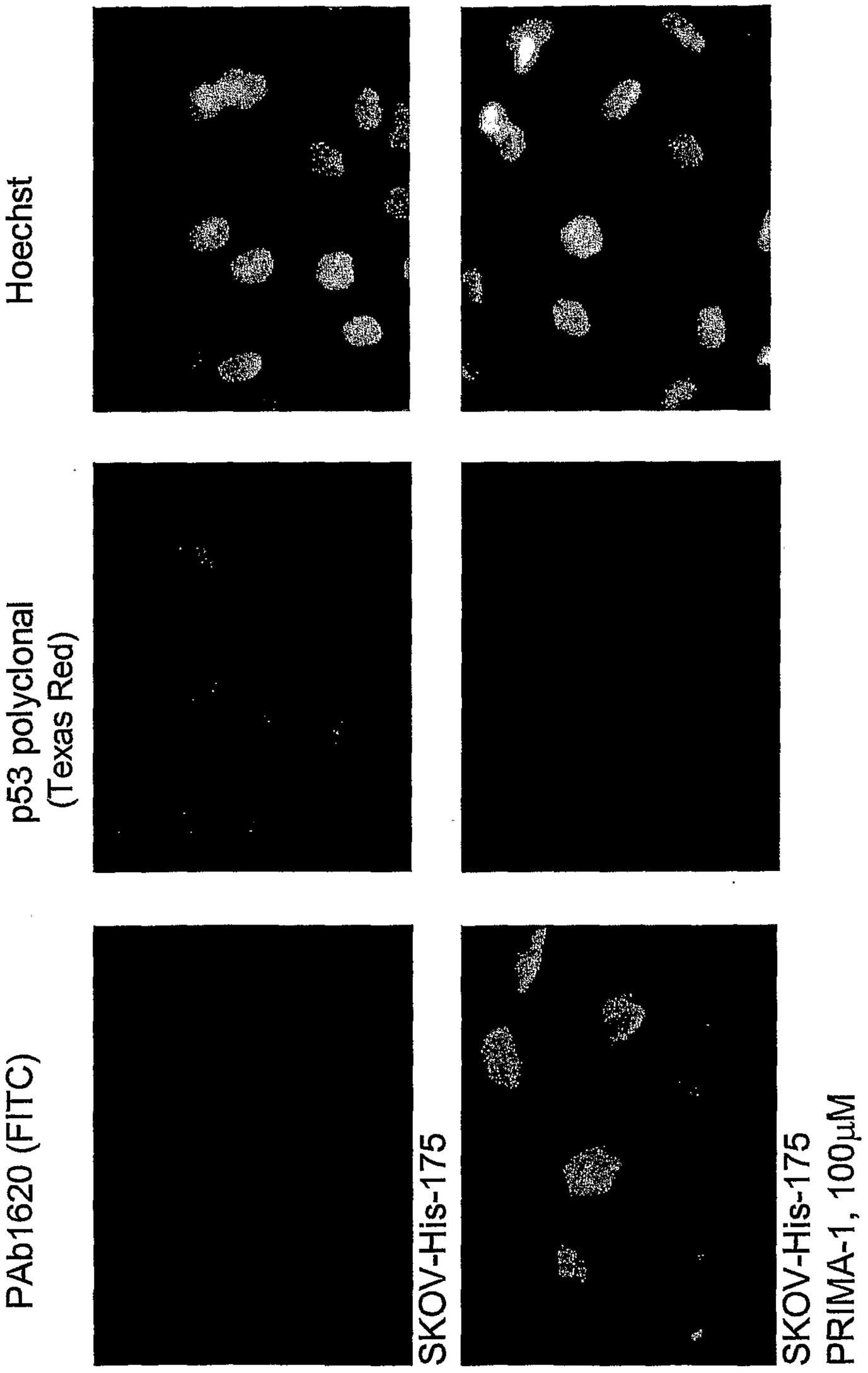

Hoechst
p53 polyclonal (Texas Red)
PAb1620 (FITC)
SKOV-His-175
SKOV-His-175
PRIMA-1, 100μM

Fig. 6A

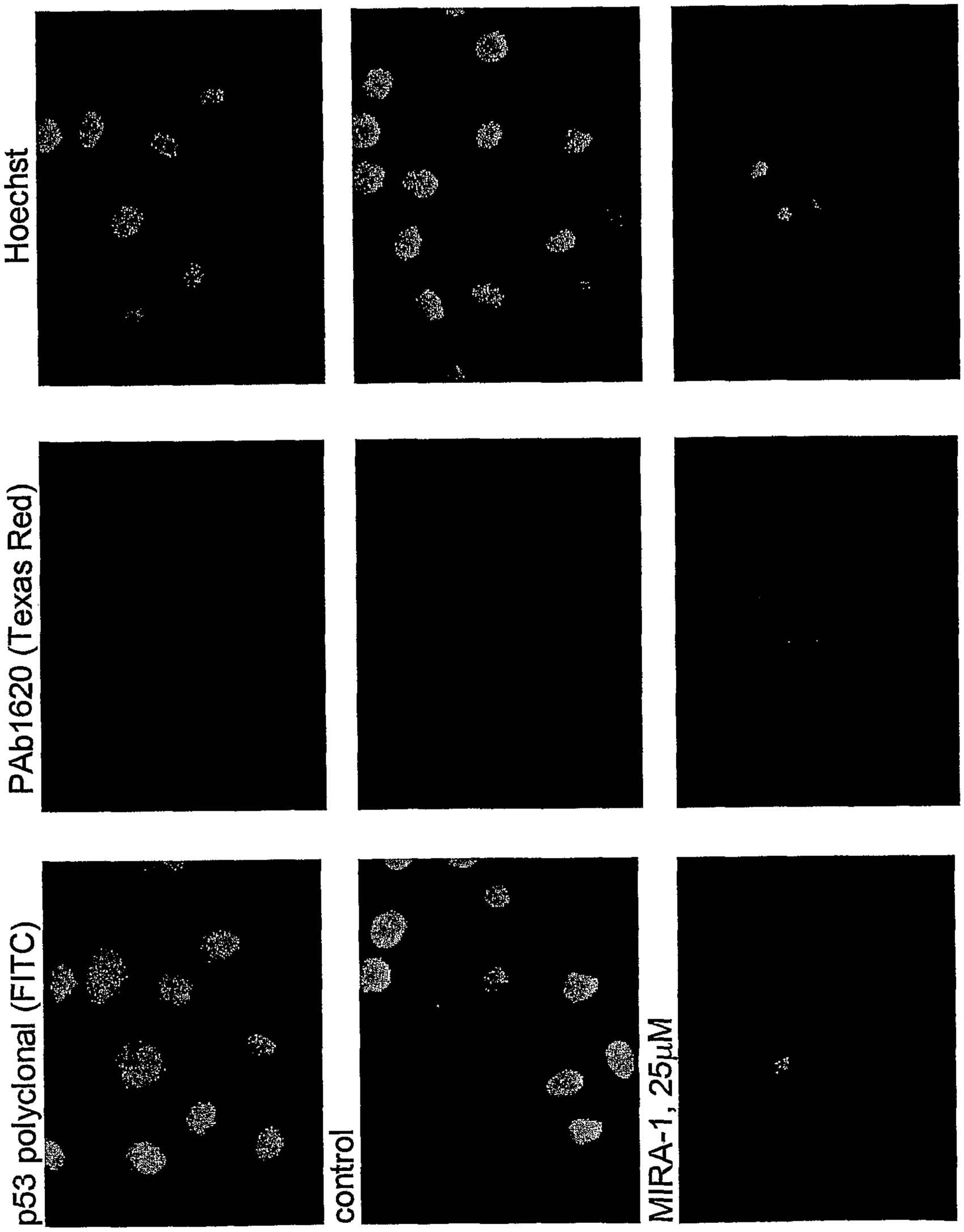

Hoechst
PAb1620 (Texas Red)
p53 polyclonal (FITC)
control
MIRA-1, 25μM
MIRA-1, 50μM

Fig. 6B

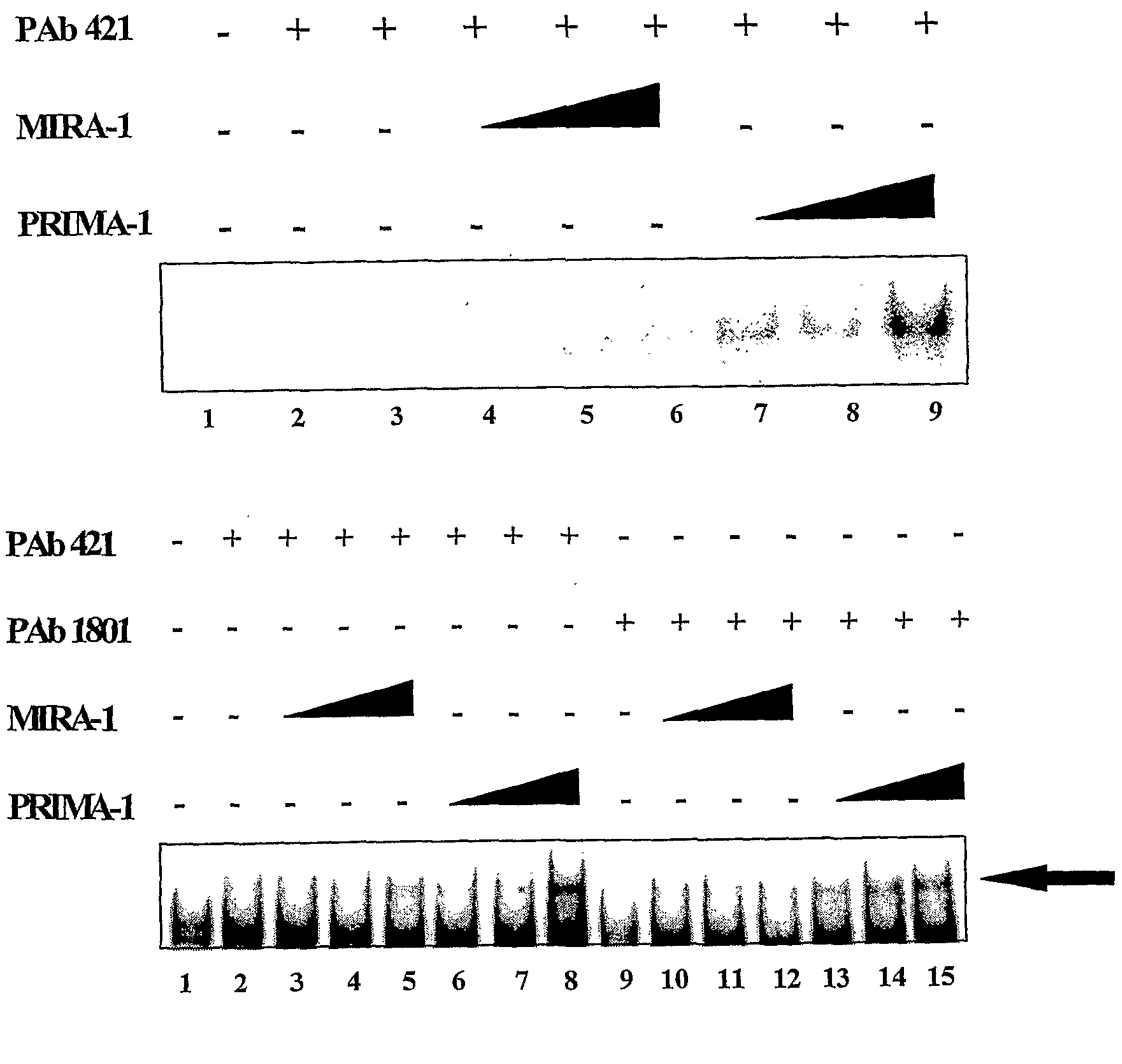

PAb 421
MIRA-1
PRIMA-1
1 2 3 4 5 6 7 8 9
A
PAb 421
PAb 1801
MIRA-1
PRIMA-1
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
B

Fig. 7

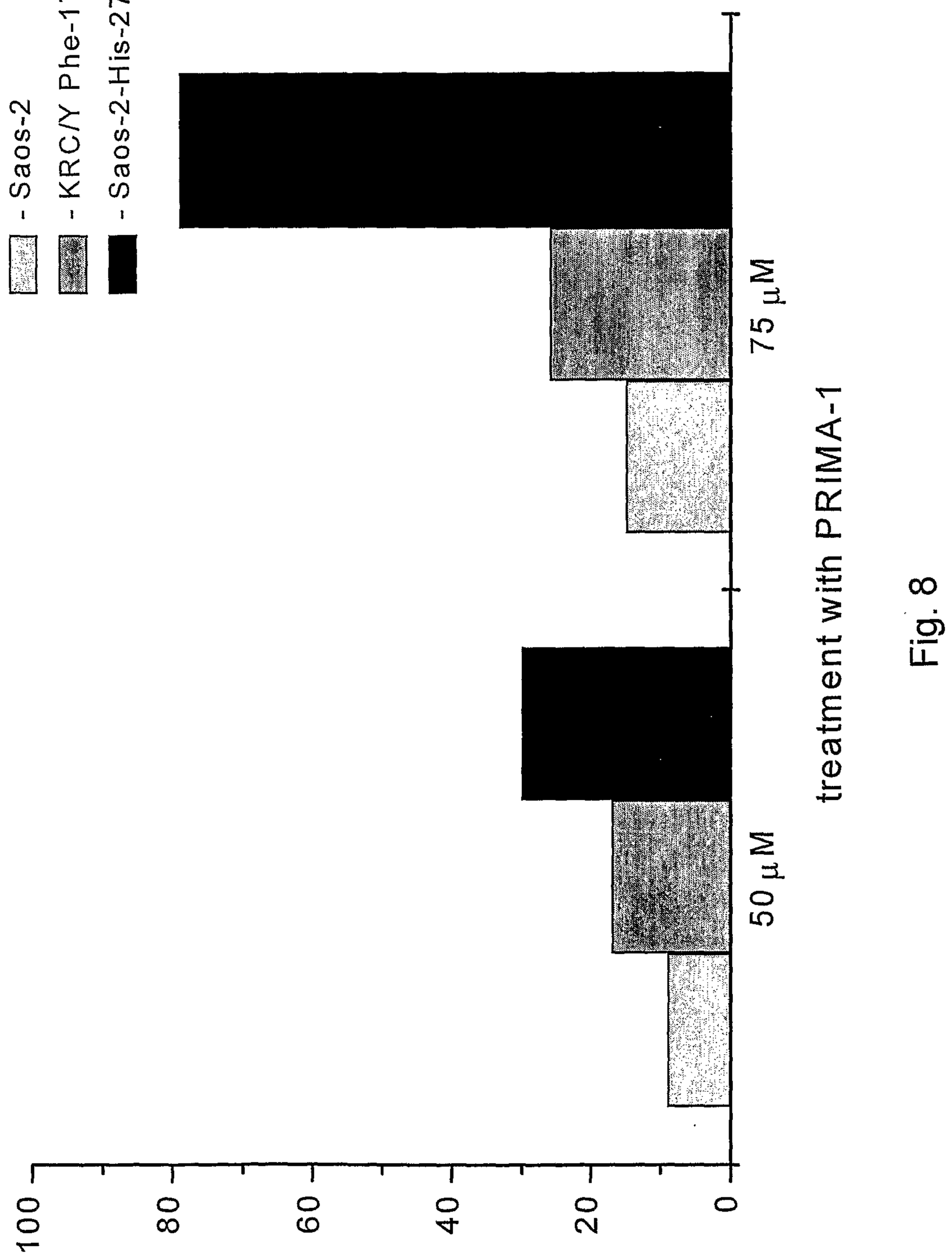

- Saos-2
- KRC/Y
- Saos-2-His-273
- Saos-2-Phe-176
75 µM
50 µM
treatment with PRIMA-1
% of dead cells
100
80
60
40
20
0

Fig. 8

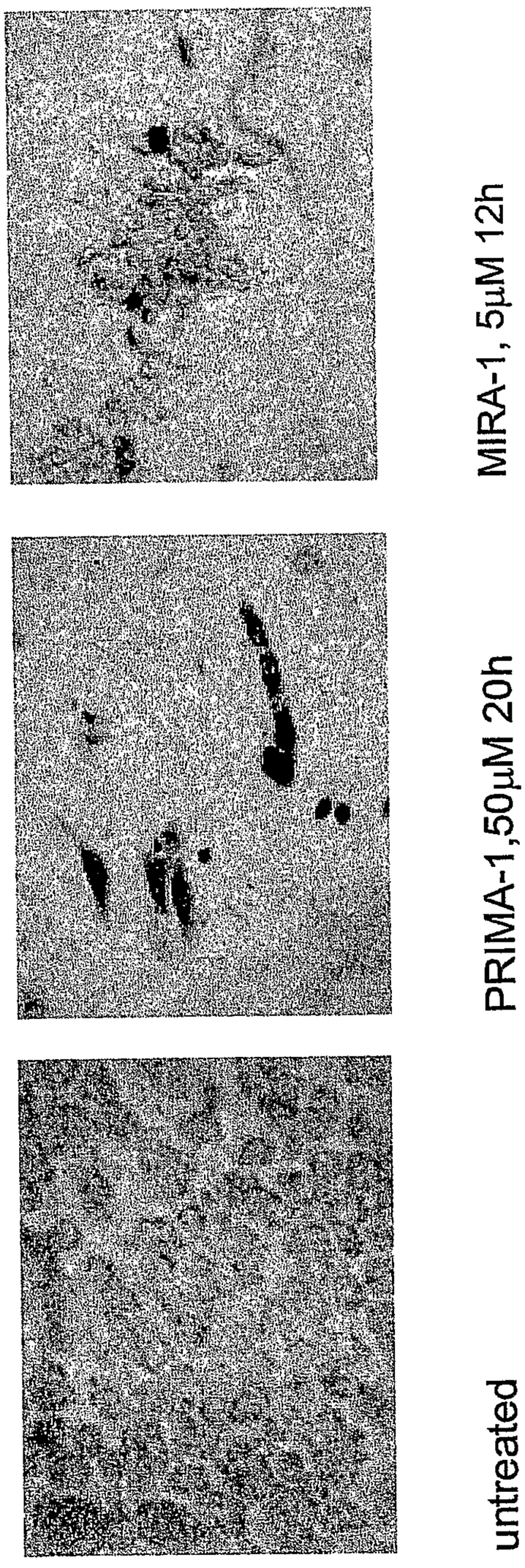


Fig. 9A

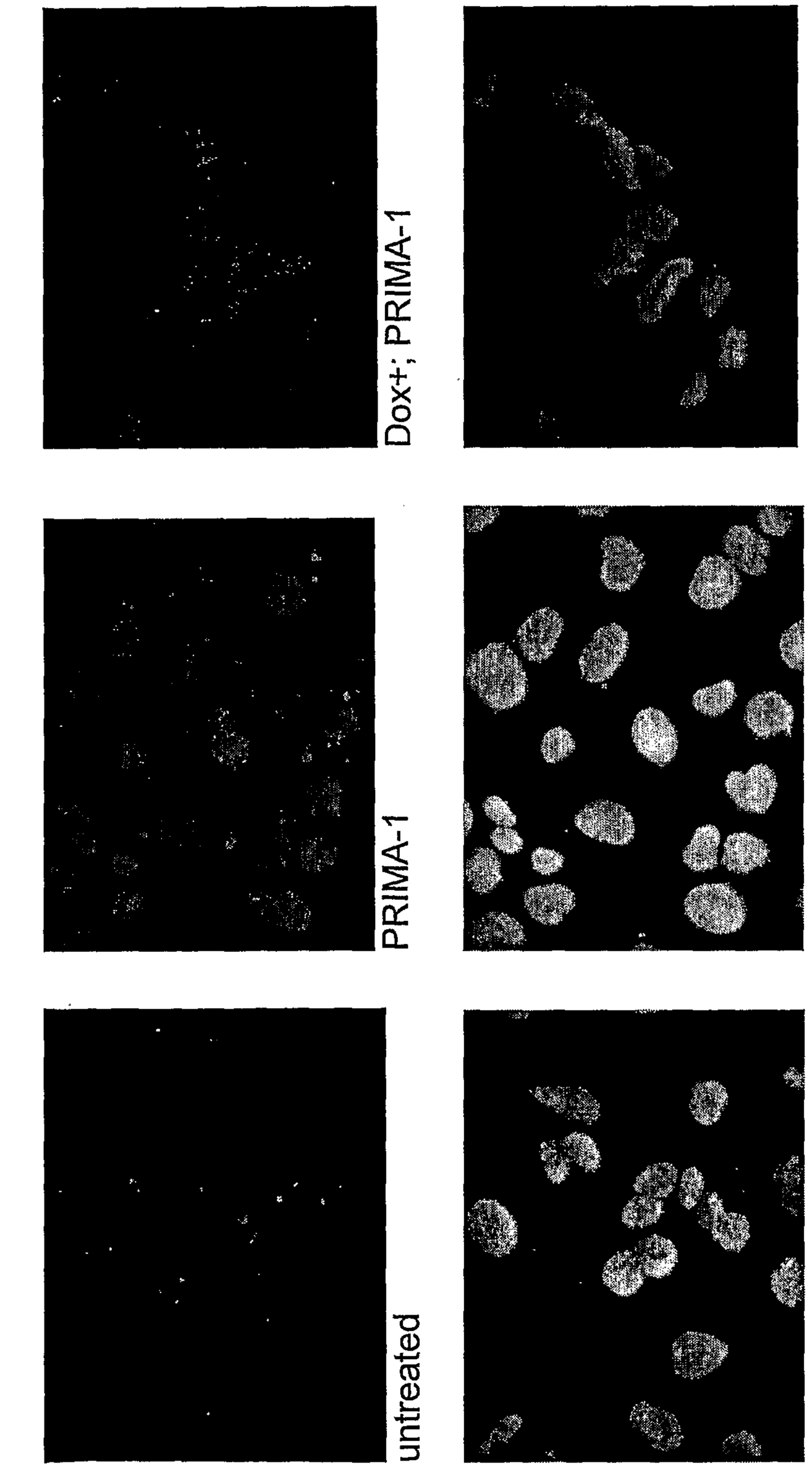


Fig. 9B

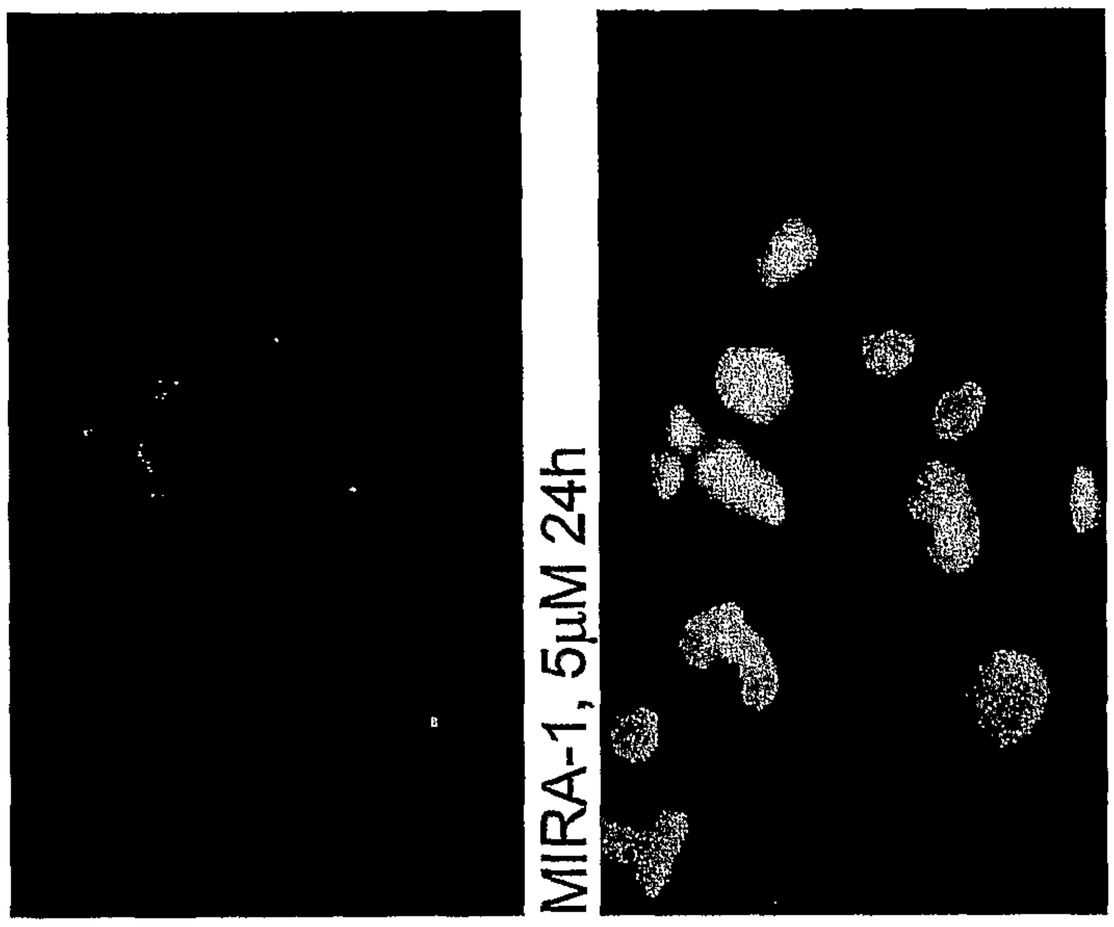
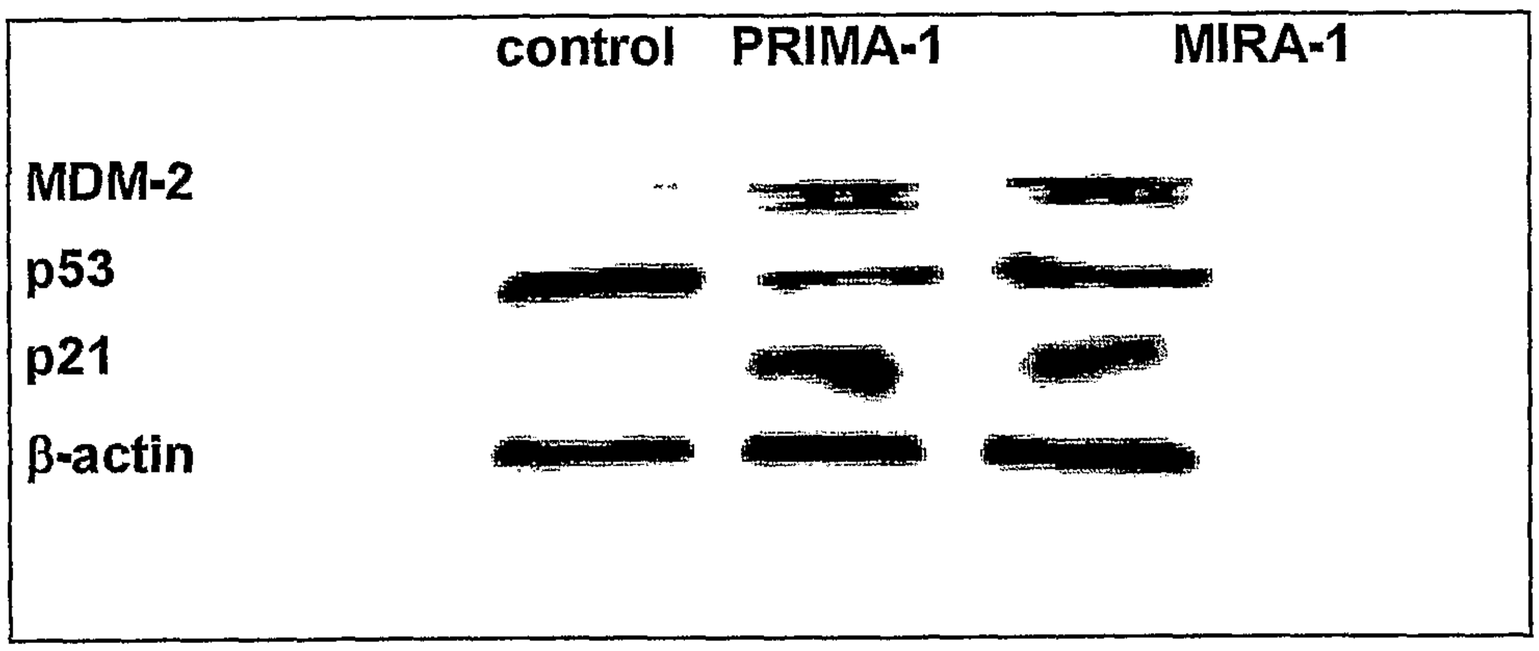
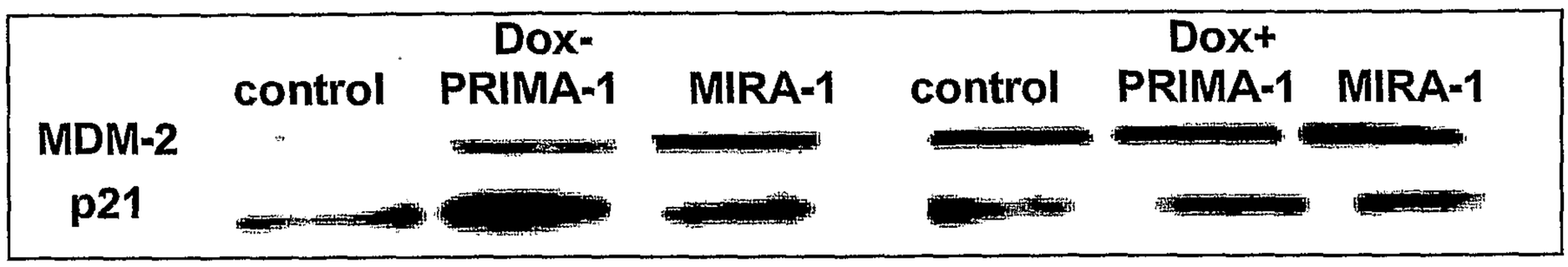


Fig. 9C

A


control
PRIMA-1
MIRA-1
MDM-2
p53
p21
β-actin

B


Dox-
Dox+
control
PRIMA-1
MIRA-1
control
PRIMA-1
MIRA-1
MDM-2
p21

C

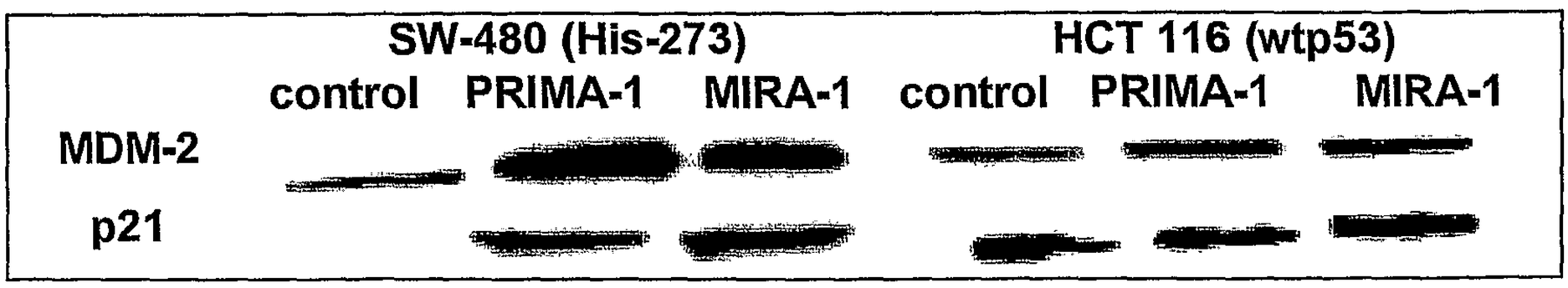

SW-480 (His-273)
HCT 116 (wtp53)
control
PRIMA-1
MIRA-1
control
PRIMA-1
MIRA-1
MDM-2
p21

Fig.10

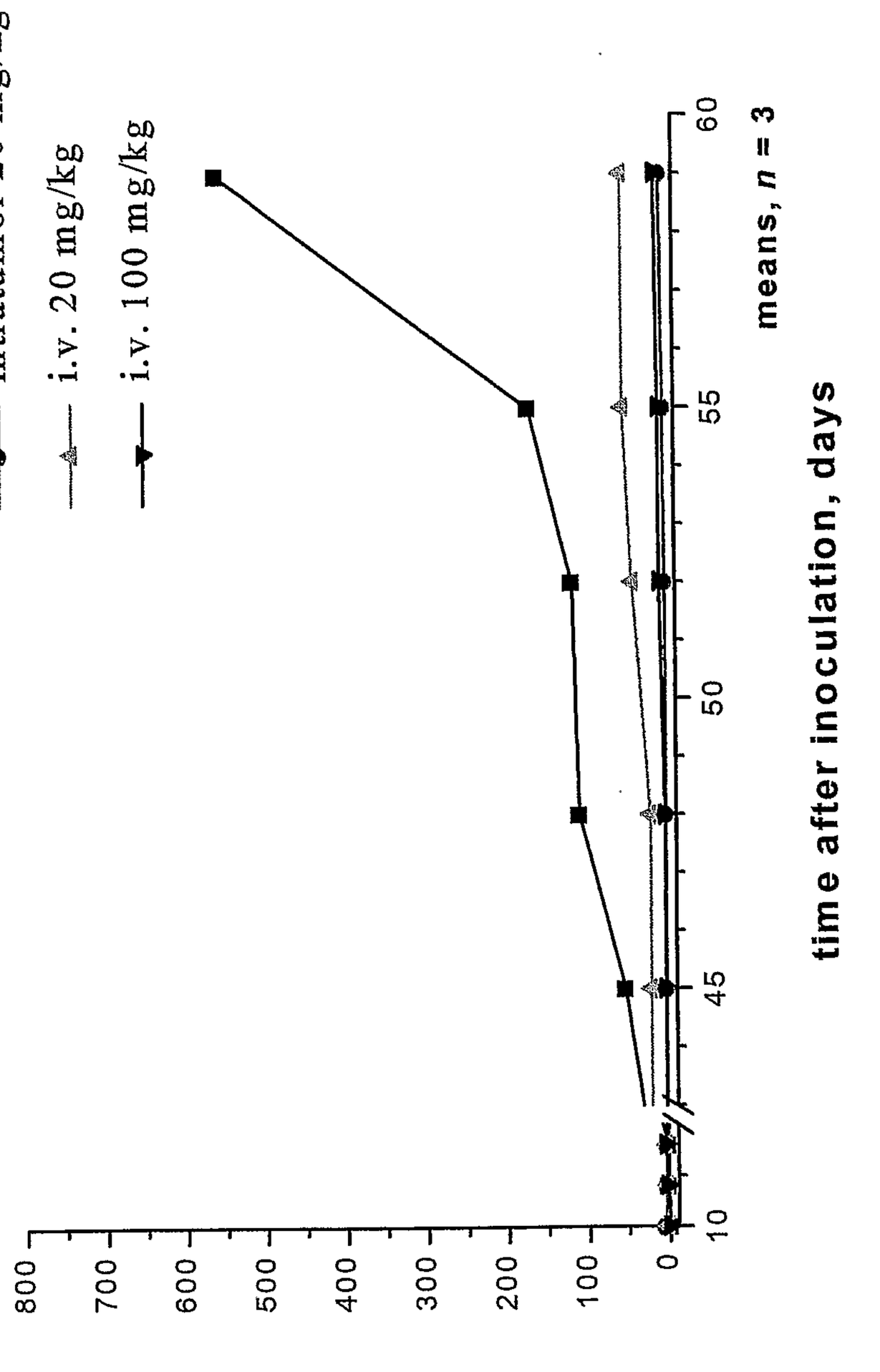

untreated
intratumor 20 mg/kg
i.v. 20 mg/kg
i.v. 100 mg/kg
tumor volume, mm3
800
700
600
500
400
300
200
100
0
10
45
50
55
60
time after inoculation, days
means, n = 3

Fig. 11

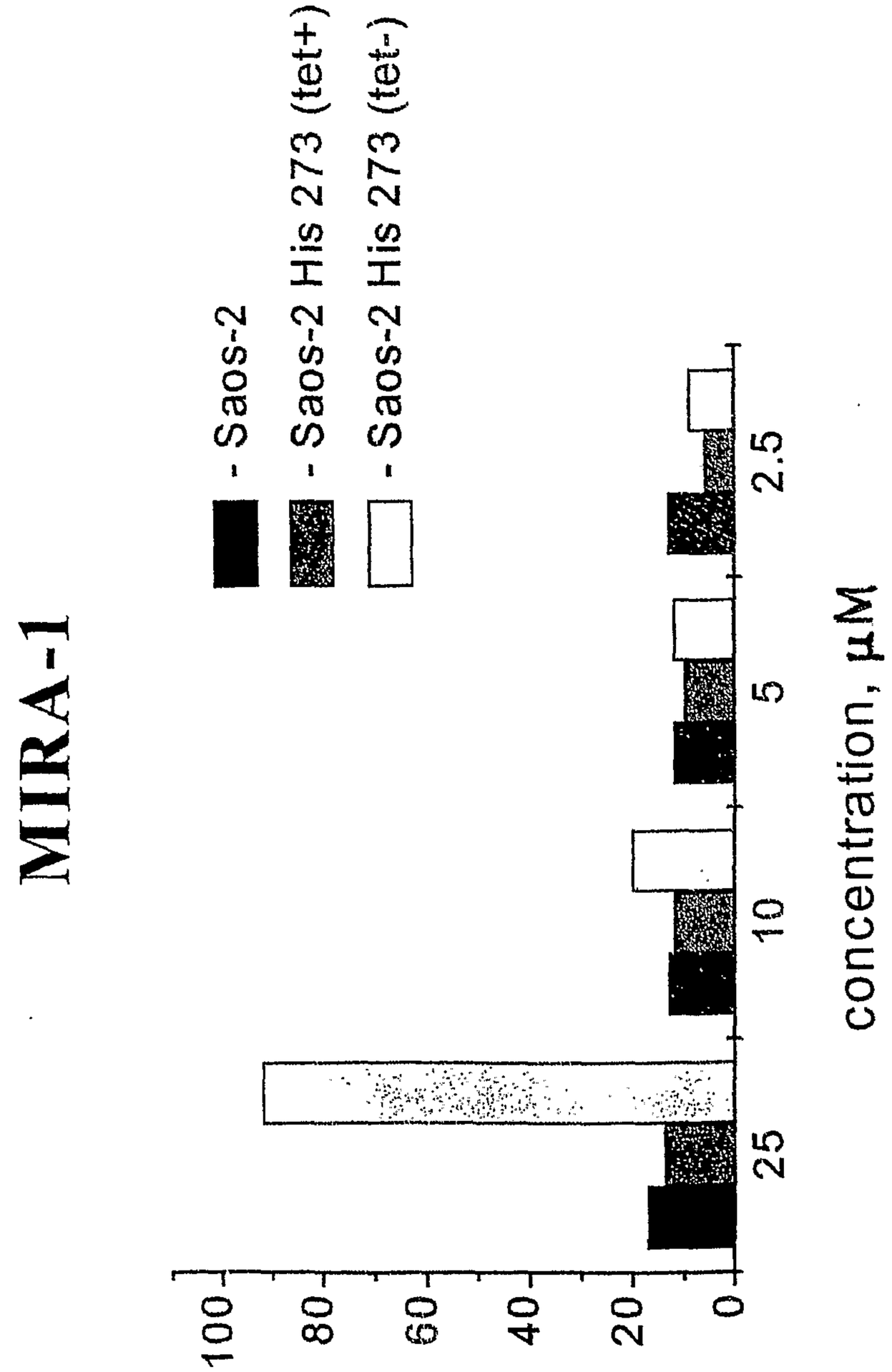

MIRA-1
- Saos-2
- Saos-2 His 273 (tet+)
- Saos-2 His 273 (tet-)
0
0
0
0
0
10
8
6
4
2
25
10
5
2.5
concentration, μM
growth suppression, %

Fig. 12A

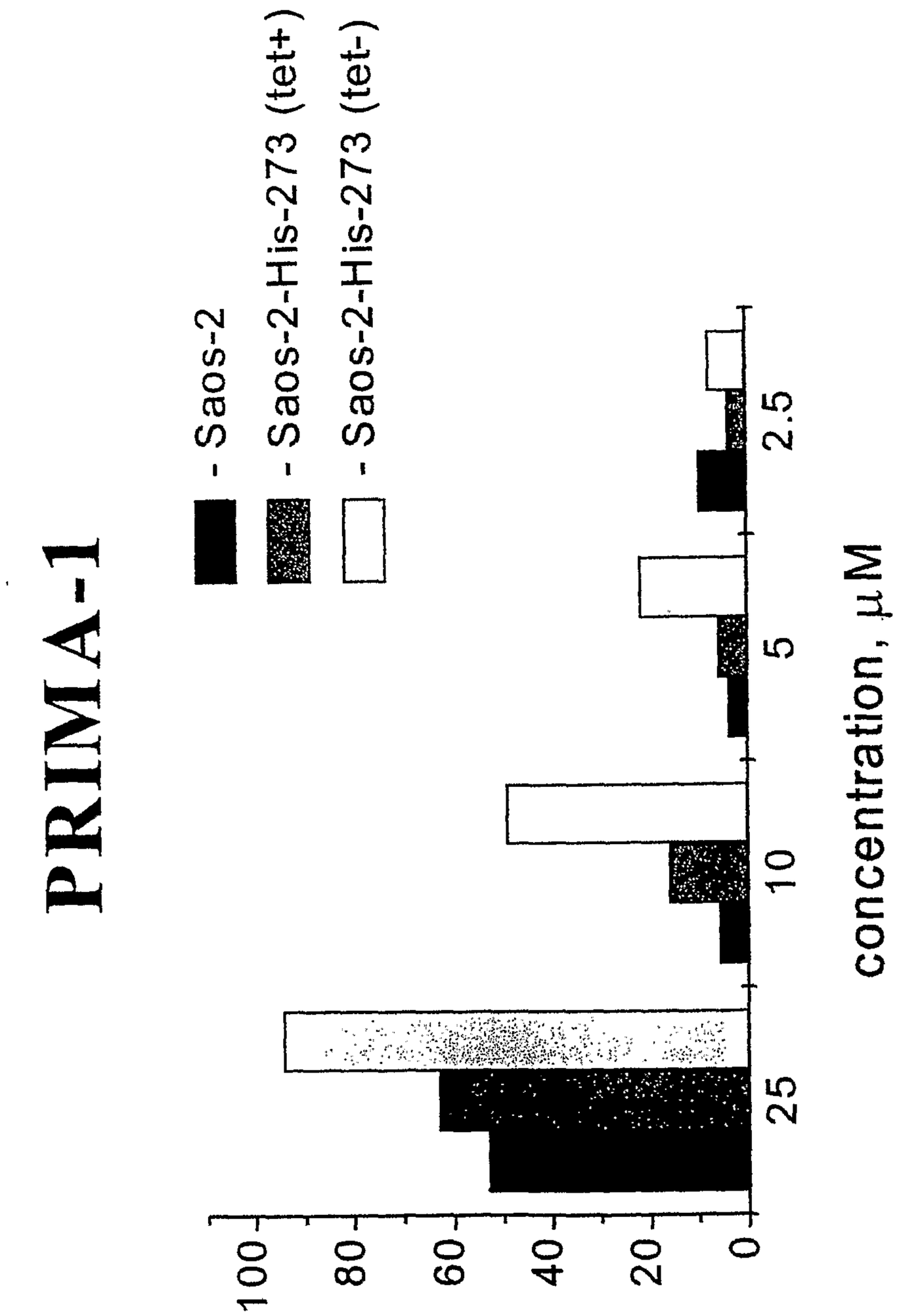

PRIMA-1
- Saos-2
- Saos-2-His-273 (tet+)
- Saos-2-His-273 (tet-)
2.5
5
10
25
concentration, µM
100
80
60
40
20
0
growth suppression, %

Fig. 12B