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(54) Title: SITE SPECIFIC BINDING SYSTEM, IMAGING COMPOSITIONS AND METHODS

(57) **Abrégé/Abstract:**

A method for ligand-based binding of lipid encapsulated particles to molecular epitopes on a surface in vivo or in vitro comprises sequentially administering (a) a site-specific ligand activated with a biotin activating agent; (b) an avidin activating agent; and (c) lipid encapsulated particles activated with a biotin activating agent, whereby the ligand is conjugated to the particles through an avidin-biotin interaction and the resulting conjugate is bound to the molecular epitopes on such surface. The conjugate is effective for imaging by x-ray, ultrasound, magnetic resonance or positron emission tomography. Compositions for use in ultrasonic imaging of natural or synthetic surfaces and for enhancing the acoustic reflectivity thereof are also disclosed.

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(21) International Application Number: PCT/US96/10425 (22) International Filing Date: 6 June 1996 (06.06.96) (30) Priority Data: 08/488,743 8 June 1995 (08.06.95) US 08/647,277 23 May 1996 (23.05.96) US (71) Applicant: BARNES-JEWISH HOSPITAL D/B/A [US/US]; The Jewish Hospital of St. Louis, 216 South Kingshighway, St. Louis, MO 63178 (US). (72) Inventors: LANZA, Gregory, M.; 216 South Kingshighway, St. Louis, MO 63178 (US). WICKLINE, Samuel, A.; 216 South Kingshighway, St. Louis, MO 63178 (US). (74) Agents: SENNIGER, Stuart, N. et al.; Senniger, Powers, Leavitt & Roedel, 16th floor, One Metropolitan Square, St. Louis, MO 63102 (US).		(81) Designated States: AU, BR, CA, JP, NO, European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE). Published <i>With international search report.</i>
(54) Title: SITE SPECIFIC BINDING SYSTEM, IMAGING COMPOSITIONS AND METHODS (57) Abstract <p>A method for ligand-based binding of lipid encapsulated particles to molecular epitopes on a surface <i>in vivo</i> or <i>in vitro</i> comprises sequentially administering (a) a site-specific ligand activated with a biotin activating agent; (b) an avidin activating agent; and (c) lipid encapsulated particles activated with a biotin activating agent, whereby the ligand is conjugated to the particles through an avidin-biotin interaction and the resulting conjugate is bound to the molecular epitopes on such surface. The conjugate is effective for imaging by x-ray, ultrasound, magnetic resonance or positron emission tomography. Compositions for use in ultrasonic imaging of natural or synthetic surfaces and for enhancing the acoustic reflectivity thereof are also disclosed.</p>		

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**SITE SPECIFIC BINDING SYSTEM,
IMAGING COMPOSITIONS AND METHODS**

Background of the Invention

5 This invention relates to a novel site specific binding system and novel compositions, and more particularly, to such a system and compositions which are useful in improved methods for ultrasonic imaging, drug or chemotherapeutic agent delivery, and diagnostic assays and detection systems.

10 Heretofore, with respect to ultrasonic imaging, although ultrasonic contrast agents based upon "bubble" technology have been demonstrated to develop an acoustic impedance mismatch by virtue of gas encapsulated either in protein (Feinstein et al., J. Am. Coll. Cardiol. 1990; 16:316-324 and Keller et al., J. Am. Soc. Echo. 1989; 2:48-
15 52), polysaccharide (Corday et al., J. Am. Coll. Cardiol. 1984; 3:978-85) biodegradable polymers (Schneider et al., Invest. Radiol., 1993; 27:134-139 and Bichon et al., European Patent Application No. 890810367.4: 1990) or lipids (D'Arrigo et al., J. Neurormag., 1991; 1:134-139;
20 Simon et al., Invest. Radiol., 1992; 27:29-34; and Unger et al., Radiology 1992; 195:453-456), no experimental evidence of site-specific targeting of an acoustic contrast or imaging agent with resultant changes in the acoustic properties of the targeted tissue, surface or support are
25 known. This lack of results has occurred despite numerous methods described in the literature for modifying such agents for targeting purposes, and the failure of past

targeting approaches may be due to the chemical nature of the agents, production process limitations or particle instabilities.

5 Nongaseous acoustic contrast agents have been described including lipid emulsions (Fink etp al., Ultrason. Imaging, 1985 7:191-197) liposomes (Lanza et al., J. Am. Coll. Cardiol., 1992 (abstract); 19 (3 Suppl A) 114A), and perfluorocarbon emulsions (Mattrey et al., Radiology 1982; 145: 759-762 and Mattrey et al., Ultrasound
10 Med. 1983; 2:173-176). As with the contrast agents discussed above, no demonstration of site targeted emulsion or liposome has been reported. Again, such failure may reflect instability of the particles, process incompatibilities or the chemical nature of the contrast
15 agent. Lipid emulsions were evaluated by Fink et al. supra and did not exhibit adequate echogenicity in studies examining hepatic imaging. A unique chemical formulation of liposomes described by Lanza et al. supra was suggested to have the potential to be a targetable ultrasonic
20 contrast but such has not been demonstrated to date. Perfluorocarbon emulsions, Perflubron (perfluorooctylbromide, P100) and Flusol (perfluorodecalin and perfluorotripropylamine, F20) have been used as ultrasonic contrast agents and have been reported to
25 accumulate in liver, spleen and tumors secondary to phagocytic uptake of emulsion particles at these sites (Mattrey et al. 1983, supra). These perfluorocarbon emulsions have also been noted to enhance Doppler signals and opacify lumens. Fluorocarbons and fluorocarbon
30 emulsions for use as contrast agents are disclosed in U.S. Patent Nos. 4,927,623, 5,077,036, 4,838,274, 5,068,098, 5,114,703, 5,362,477, 5,362,478, 5,171,755, 5,304,325, 5,350,571 and 5,403,575. However, no demonstration of perfluorocarbon emulsions as a ligand targeted acoustic
35 contrast system has been reported.

Previous descriptions of tissue or organ targeting in biomedical ultrasonics has referred to the collection of acoustically reflective particles within or around structural tissue abnormalities. Localized acoustic enhancement of tissue pathologies (e.g. malignancies) has not been ligand-directed but rather has depended upon differential dynamic rates of particle uptake and/or clearance between normal and malignant tissues. Such contrast agents have included aqueous solutions (Ophir et al., *Ultrason. Imaging* 1979, 1:265-279; Ophir et al., *Ultrasound Med. Biol.* 1989, 15:319-333; and Tyler et al., *Ultrason. Imaging*, 3:323-329), emulsions (Fink et al., *Ultrason. Imaging*, 1985, 7:191-197), and suspensions (Mattrey et al. 1982 *supra* and Mattrey et al., *Radiology*, 1987, 163:339-343). Although the possibility of ligand-directed ultrasonic contrast targeting with acoustically reflective liposomes has been suggested, no successful applications of this concept have been reported (Lanza et al. 1992, *supra* and Valentini et al., *J. Am. Coll. Cardiol.*, 1995, 25:16A). Previous approaches to targeting in vivo of particles have involved direct conjugation of a ligand (e.g. monoclonal antibody) to a vesicle by a variety of methods (see, for example, Torchlin et al., *Biochem. Biophys. Res. Commun.* 1978, 85:983-990; Endoh et al., *J. Immunol. Methods*, 1981, 44:79-85; Hashimoto et al., *J. Immunol. Methods*, 1983, 62:155-162 and Martin et al., *Biochemistry*, 1981, 20:4229-4238).

There remains a need for new and improved methodologies for ligand-based binding systems which can be adapted as an ultrasonic contrast system permitting detection of molecular moieties such as peptides, carbohydrates or nucleic acids and whose uses can range from ultrasound-based ELISA-like laboratory diagnostic assays in liquid and solid phase systems and in cell cultures; electrophoretic, chromatographic and hybridization detection systems to the detection of

thrombi, infections, cancers and infarctions in patients with the use of conventional ultrasonic imaging methods.

Summary of the Invention

Among the several objects of the invention may be noted the provision of a novel method for ligand-based binding of lipid encapsulated particles to molecular epitopes on a surface in vivo or in vitro, the provision of such a method in which the ligand is conjugated to the lipid encapsulated particles through an avidin-biotin interaction and the resulting conjugate is bound to molecular epitopes on a surface; the provision of such a method which is useful for enhancing the acoustic reflectivity of a biological surface for ultrasonic imaging; the provision of a method of this type wherein the conjugate formed is effective for imaging by x-ray, ultrasound, magnetic resonance or positron emission tomography; the provision of compositions for use in ultrasonic imaging of a biological surface and for enhancing the acoustic reflectivity of such a surface; the provision of ultrasonic contrast agents which become highly reflective when bound to the desired site or biological surface through the ligand-based binding system of the invention; and the provision of such methods and compositions which are capable of targeting and altering the echogenic properties of a tissue surface for improved and specific identification of pathological processes. Other objects will be in part apparent and in part pointed out hereinafter.

Briefly, in its broadest embodiment, the present invention is directed to a method for ligand-based binding of lipid encapsulated particles to molecular epitopes on a surface in vivo or in vitro which comprises sequentially administering (a) a site-specific ligand activated with a biotin activating agent; (b) an avidin activating agent; and (c) lipid encapsulated particles activated with a

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biotin activating agent, whereby the ligand is conjugated to the particles through an avidin-biotin interaction and the resulting conjugate is bound to the molecular epitopes on such surface. The conjugate is effective for imaging by x-ray, ultrasound, magnetic resonance or positron emission tomography. In a more specific embodiment, the invention is directed to a method for enhancing the acoustic reflectivity of a biological surface through the sequential administration of the above-noted components whereby the resulting conjugate is bound to a natural or synthetic surface to enhance the acoustic reflectivity thereof for ultrasonic imaging. The invention is also directed to compositions for use in ultrasonic imaging of such surfaces and for enhancing the acoustic reflectivity thereof.

According to one aspect of the present invention, there is provided a composition comprising an emulsion of lipid encapsulated particles having cores consisting substantially of liquid fluorocarbon, said particles coupled to a ligand for ligand-based binding of said particles to a molecular epitope or receptor, for use in a subject in an *in vivo* targeted diagnostic procedure, wherein said diagnostic procedure comprises imaging said target in the presence of said emulsion, wherein during said imaging, said emulsion is of lipid encapsulated particles having cores consisting substantially of liquid fluorocarbon said particles coupled to said ligand.

According to another aspect of the present invention, there is provided a use of a composition comprising an emulsion of lipid encapsulated particles having cores consisting substantially of liquid fluorocarbon, said particles coupled to a ligand for ligand-based binding of said particles to a molecular

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epitope or receptor, in the preparation of a formulation for an *in vivo* targeted diagnostic procedure in a subject, wherein said diagnostic procedure comprises imaging said target in the presence of said emulsion, wherein during said
5 imaging, said emulsion is of lipid encapsulated particles having cores consisting substantially of liquid fluorocarbon said particles coupled to said ligand.

According to yet another aspect of the present invention, there is provided use of a composition comprising
10 an emulsion of lipid encapsulated particles having cores consisting substantially of liquid fluorocarbon, said particles coupled to a ligand for ligand-based binding of said particles to a molecular epitope or receptor, in an *in vivo* targeted diagnostic procedure in a subject, wherein
15 said diagnostic procedure comprises imaging said target in the presence of said emulsion, wherein during said imaging, said emulsion is of lipid encapsulated particles having cores consisting substantially of liquid fluorocarbon said particles coupled to said ligand.

Brief Description of the Drawings

Figure 1 is a graph showing changes in aggregate particle size of biotinylated and control perfluorocarbon emulsions with increasing avidin concentration;

Figure 2 shows ultrasonic images of control and biotinylated perfluorocarbon emulsion before and after the addition of avidin;

Figure 3 is a graphic illustration of dialysis tubing images and region of interest placement for gray scale analysis;

Figure 4 is a graph showing changes in average pixel gray scale associated with the addition of avidin to control or biotinylated perfluorocarbon emulsion;

Figure 5 is a graph showing the effect of control and biotinylated perfluorocarbon emulsion on apparent backscatter transfer function and integrated backscatter of

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avidinized nitrocellulose membranes;

Figure 6 is a graph showing the apparent backscatter transfer function of biotinylated and control perfluorocarbon emulsions targeted to D-dimer covalently conjugated to nitrocellulose membranes;

Figure 7 is a graph showing the apparent backscatter transfer function (dB) of biotinylated and control perfluorocarbon emulsions at low ultrasonic frequencies;

5 Figure 8 is a graph showing the apparent backscatter transfer function of biotinylated and control perfluorocarbon large particle size emulsions targeted to avidinized nitrocellulose membranes;

10 Figure 9 shows ultrasonic images of plasma thrombi before and after exposure to control or biotinylated emulsions;

Figure 10 is a graph showing the average pixel grayscale level of plasma thrombi pre-targeted with antifibrin monoclonal antibody and exposed to control or
15 biotinylated perfluorocarbon emulsion;

Figure 11 shows ultrasonic images of femoral artery thrombus acoustically enhanced with biotinylated perfluorocarbon emulsion in vivo;

20 Figure 12 is a graph showing the net change in apparent backscatter transfer function of biotinylated and control perfluorocarbon emulsions targeted to prostate specific antigen in prostatic carcinoma relative to normal regions;

25 Figure 13 is a graph showing the net change in integrated backscatter between normal prostatic stroma and cancer regions for control versus biotinylated perfluorocarbon emulsions;

30 Figure 14 is a graph showing the net change in apparent backscatter transfer function of biotinylated and control perfluorocarbon emulsions targeted to OC-125 antigen in ovarian carcinoma relative to normal regions;

35 Figure 15 is a graph showing the net change in integrated backscatter between normal ovarian tissue and carcinoma regions for control versus biotinylated perfluorocarbon emulsions;

Figure 16 shows ultrasonic and optical images of tonsil using perfluorocarbon contrast and horseradish peroxidase targeted to epithelium with anticytokeratin antibodies;

5 Figure 17 shows peak detected ultrasonic images of tonsil epithelium acoustically enhanced with anticytokeratin antibody targeted perfluorocarbon emulsion.

Fig. 18 is a graph showing avidin titration curves for three biotinylated perfluorocarbon emulsions
10 incorporating varying concentrations of gadolinium-DTPA-BOA;

Fig. 19 shows the enhancement of the acoustic reflectivity of plasma clots treated with targeted perfluorocarbon dual ultrasonic and MRI contrast; and

15 Fig. 20 shows the femoral artery thrombus detected by both magnetic resonance and ultrasound.

Description of the Preferred Embodiments

In accordance with the present invention, it has now been found that a ligand-based binding system having
20 broad application may be achieved through ligand-based binding of lipid encapsulated particles to molecular epitopes on a surface in vivo or in vitro by sequentially administering (a) a site-specific ligand activated with a biotin activating agent; (b) an avidin activating agent;
25 and (c) lipid encapsulated particles activated with a biotin activating agent, whereby the ligand is conjugated to the lipid encapsulated particles through an avidin-biotin interaction or complexing and the resulting conjugate is bound to the molecular epitopes on the
30 surface. The ligand-based binding system of the present invention thus permits detection of molecular moieties such as peptides, carbohydrates or nucleic acids with a specific ligand probe (e.g. an antibody or antibody fragment) complexed or conjugated with avidin and biotin, the latter
35 being carried by lipid encapsulated particles (e.g.

biotinylated lipid encapsulated emulsion or liposome). The ligand-based binding system of the invention may be employed in an ultrasonic contrast agent system, ultrasound-based ELISA-like laboratory diagnostic assays in liquid and solid phase systems and in cell cultures, electrophoretic, chromatographic and hybridization detection systems, and for the detection of thrombi, infections, cancers and infarctions in patients with the use of conventional ultrasonic imaging methods. The invention may also be applied for therapeutic purposes by delivery of chemotherapeutic agents or drugs to desired sites due to the specificity of the binding system coupled with the ability to monitor the progress of the therapeutic treatment through repeated imaging at such sites. In this regard, the above-referred to conjugate of the ligand to the lipid encapsulated particles through an avidin-biotin interaction or complexing is effective for imaging by x-ray, ultrasound, magnetic resonance or positron emission tomography.

In one embodiment of the invention, there is provided a method for enhancing the reflectivity of a biological surface by sequentially administering to the surface (a) a site-specific ligand activated with a biotin activating agent; (b) an avidin activating agent; and (c) lipid encapsulated particles activated with a biotin activating agent; whereby the ligand is conjugated to the lipid encapsulated particles through an avidin-biotin interaction and the resulting conjugate is bound to the biological surface to enhance the acoustic reflectivity thereof for ultrasonic imaging. This novel triphasic approach utilizes an avidin-biotin interaction to permit administration of the targeting ligand separate from the acoustic lipid encapsulated particles. In a specific application of the method in accordance with the invention, a biotinylated ligand is first systemically administered to a patient to pretarget the tissue or biological surface of

interest and to circulate for a period of time necessary or sufficient to optimize the percentage bound. In the second phase, avidin is administered, circulates and binds to the biotinylated ligand attached to the target tissue or surface and to any residual, free circulating ligand. Avidin cross-linking increases the avidity and stability of the ligand on the target tissue or surface while promoting the rapid clearance of circulating avidin-ligand complexes via the reticuloendothelial system. In the third phase, the biotinylated lipid encapsulated particles are administered, binding to avidin through unoccupied biotin binding sites, and imparting increased acoustic contrast to the targeted tissue surface. Repeated sequential administration of avidin and the biotinylated lipid encapsulated particles may be carried out to amplify the acoustic contrast effect of the lipid encapsulated particles bound to the targeted surface.

In the practice of the invention, the ligand employed may be, for example, constituted by monoclonal or polyclonal antibodies, viruses, chemotherapeutic agents, receptor agonists and antagonists, antibody fragments, lectin, albumin, peptides, hormones, amino sugars, lipids, fatty acids, nucleic acids and cells prepared or isolated from natural or synthetic sources. In short, any site-specific ligand for any molecular epitope or receptor to be detected through the practice of the invention may be utilized.

The ligand is activated with a biotin activating agent. As employed herein, the term "biotin activating agent" or "biotinylated" encompasses biotin, biocytin and other biotin analogs such as biotin amido caproate N-hydroxysuccinimide ester, biotin 4-amidobenzoic acid, biotinamide caproyl hydrazide and other biotin derivatives and conjugates. Other derivatives include biotin-dextran, biotin-disulfide-N-hydroxysuccinimide ester, biotin-6 amido quinoline, biotin hydrazide, d-biotin-N hydroxysuccinimide

ester, biotin maleimide, d-biotin p-nitrophenyl ester, biotinylated nucleotides and biotinylated amino acids such as Nε-biotinyl-L-lysine.

5 In the second phase, as previously mentioned, an avidin activating agent is administered. As employed herein, the term "avidin activating agent" or "avidinized" encompasses avidin, streptavidin and other avidin analogs such as streptavidin or avidin conjugates, highly purified and fractionated species of avidin or streptavidin, and non
10 or partial amino acid variants, recombinant or chemically synthesized avidin analogs with amino acid or chemical substitutions which still accommodate biotin binding.

The lipid encapsulated particles or contrast agent employed in the third phase may be constituted, for
15 example, by a biotinylated emulsion or liposome which may contain a gas, liquid or solid. In a specific example, the lipid encapsulated particles may be constituted by a perfluorocarbon emulsion, the emulsion particles having incorporated into their outer coating a biotinylated lipid
20 compatible moiety such as a derivatized natural or synthetic phospholipid, a fatty acid, cholesterol, lipolipid, sphingomyelin, tocopherol, glucolipid, stearylamine, cardiolipin, a lipid with ether or ester linked fatty acids or a polymerized lipid. Thus, the
25 biotinylated contrast agent constituting the lipid encapsulated particles may be produced by incorporating biotinylated phosphatidylethanolamine into the outer lipid monolayer of a perfluorocarbon emulsion.

Perfluorocarbon emulsions are particularly well
30 suited for biomedical applications and for use in the practice of the present invention. They are known to be stable, biologically inert and readily metabolized, primarily by trans-pulmonic alveolae evaporation. Further, their small particle size easily accommodate transpulmonic
35 passage and their circulatory half-life (4-8 hours) advantageously exceeds that of other agents. Also,

perfluorocarbons have been used to date in a wide variety of biomedical applications, including use as artificial blood substitutes. For use in the present invention, various fluorocarbon emulsions may be employed including those in which the fluorocarbon is a fluorocarbon-hydrocarbon, a perfluoroalkylated ether, polyether or crown ether. Useful perfluorocarbon emulsions are disclosed in U.S. Patent Nos. 4,927,623, 5,077,036, 5,114,703, 5,171,755, 5,304,325, 5,350,571, 5,393,524, and 5,403,575 and include those in which the perfluorocarbon compound is perfluorotributylamine, perfluorodecalin, perfluorooctylbromide, perfluorodichlorooctane, perfluorodecane, perfluorotripropylamine, perfluorotrimethylcyclohexane or other perfluorocarbon compounds. Further, mixtures of such perfluorocarbon compounds may be incorporated in the emulsions utilized in the practice of the invention. As a specific example of a perfluorocarbon emulsion useful in the invention may be mentioned a perfluorodichlorooctane emulsion wherein the lipid coating thereof contains between approximately 50 to 99.5 mole percent lecithin, preferably approximately 55 to 70 to mole percent lecithin, 0 to 50 mole percent cholesterol, preferably approximately 25 to 45 mole percent cholesterol and approximately 0.5 to 10 mole percent biotinylated phosphatidylethanolamine, preferably approximately 1 to 5 mole percent biotinylated phosphatidylethanolamine. Other phospholipids such as phosphatidylserine may be biotinylated, fatty acyl groups such as stearylamine may be conjugated to biotin, or cholesterol or other fat soluble chemicals may be biotinylated and incorporated in the lipid coating for the lipid encapsulated particles. The preparation of an exemplary biotinylated perfluorocarbon for use in the practice of the invention is described hereinafter in accordance with known procedures.

When the lipid encapsulated particles are constituted by a liposome rather than an emulsion, such a liposome may be prepared as generally described in the literature (see, for example, Kimelberg et al., CRC Crit. Rev. Toxicol. 6,25 (1978) and Yatvin et al., Medical Physics, Vol. 9, No. 2, 149 (1982)). Liposomes are known to the art and generally comprise lipid materials including lecithin and sterols, egg phosphatidyl choline, egg phosphatidic acid, cholesterol and alpha-tocopherol.

With respect to the particle size of the lipid encapsulated particles constituted by a perfluorocarbon emulsion or liposome, the particle size may range between approximately 0.05 to 5 microns and preferably between approximately 0.05 and 0.5 micron. Small size particles are thus preferred because they circulate longer and tend to be more stable than larger particles.

As indicated, the ligand is conjugated to the lipid encapsulated particles or perfluorocarbon emulsion through an avidin-biotin interaction. The ligand may also be conjugated to the emulsion directly or indirectly through intervening chemical groups or conjugated directly or indirectly to biotin or a biotin analog through intervening chemical groups such as an alkane spacer molecule or other hydrocarbon spacer. The use of spacer molecules between the ligand and biotin or between biotin and the emulsion is not required but aids in rendering the biotin more available for binding to avidin.

As previously mentioned, the emulsion or liposome constituting the lipid encapsulated particles or vesicles may contain a gas, liquid or solid. The gas may be nitrogen, oxygen, carbon dioxide or helium and may, for example, be evolved from the fluorocarbon component of the emulsions described above.

Alternatively, but less preferably, the ligand-based binding method of the invention may be carried out by sequentially administering a site-specific ligand activated

with a biotin or avidin activating agent and lipid encapsulated particles activated with a biotin or avidin activating agent, a biotin activating agent being used where an avidin activating agent was employed in the first step and an avidin activating agent being used where a biotin activating agent was employed in the first step. The direct conjugation of the ligand to a perfluorocarbon emulsion, for example, is less preferable since it may accelerate in vivo clearance of the emulsion contrast agent.

In the practice of the invention, it has been unexpectedly found that the individual components of the ultrasonic contrast agents as described above are poorly reflective or have low echogenicity in the bloodstream but become highly reflective when the ligand-avidin-emulsion complex is formed in vivo at the desired site or biological surface and thereby substantially enhances the acoustic reflectivity thereof for ultrasonic imaging. This is in sharp contrast to previously known sonographic contrast agents which are inherently bright or of high reflectivity in the bloodstream. The improved acoustic reflectivity achieved through the present invention provides the advantage of enhancing the signal-to-noise ratio because the background contrast from lipid encapsulated particles in the blood is minimal. Thus, the present invention offers an improved noninvasive method for forming an acoustic contrast agent which can be targeted in vitro or in vivo and which when bound to a specific desired site alters the acoustic reflectivity of a tissue surface or support media in a manner detectable with ultrasonic transducers suitable for biomedical and diagnostic applications within a frequency range of at least 5 to 50 MHz (nominal center frequencies may be wider ranging based on the knowledge that these are broad band transducers). The method of the invention advantageously provides a practical means for detecting any molecular epitope or

receptor for which a biotinylated monoclonal antibody or other ligand is available without the need for use of ionizing radiation with or without associated invasive procedures in various clinical applications and while
5 employing standard, commercially available ultrasonic technology. The present invention does not employ ultrasonic contrast systems or agents to delineate blood flow as in the prior art but rather to detect physiologic and pathologic events by sensing the accumulation of the
10 contrast agent at specific binding sites.

In the application of the invention to diagnostic assays such as ultrasound-based ELISA-type laboratory diagnostic assays in liquid and solid phase systems, the surface on which ligand-based binding of lipid encapsulated
15 particles to molecular epitopes occurs may be, for example, nylon, nitrocellulose membranes or a gel as well as a biological surface.

The ligand-based binding system of the invention may also be applied to provide a chemotherapeutic agent or
20 gene therapy delivery system combined with ultrasonic imaging. For example, chemotherapeutic agents or immune activating drugs such as tissue plasminogen activator, adriamycin, vincristine, urokinase, streptokinase, methotrexate, cytarabine, thioguanine, doxorubicin, 5-
25 fluorouracil, cisplatin, etoposide, ifosfamide, asparaginase, deoxycoformycin, hexamethyl melamine and including radioactive agents may be incorporated in the lipid encapsulated particles and become part of the conjugate bound to a specific biological surface site for
30 therapeutic action. The present invention would also advantageously permit the site to be ultrasonically imaged in order to monitor the progress of the therapy on the site and to make desired adjustments in the dosage of therapeutic agent subsequently directed to the site. The
35 invention thus provides a noninvasive means for the

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detection and therapeutic treatment of thrombi, infections, cancers and infarctions in patients while employing conventional ultrasonic imaging systems.

5 The following examples illustrate the practice of the invention.

Example 1

The procedure for preparing a biotinylated lipid encapsulated perfluorodichlorooctane emulsion for use in ultrasound imaging is as follows.

10 The biotinylated lipid perfluorodichlorooctane (PFDCO) emulsion is comprised of the following components: PFDCO (40% v/v), safflower oil (2.0%w/v), a surfactant co-mixture (2.0% w/v) and glycerin (1.7% w/v). The surfactant co-mixture is composed of approximately 64 mole% lecithin,
15 35 mole % cholesterol and 1 mole % N-(6-biotinoyl)amino) hexanoyl)dipalmitoyl-L-alpha-phosatidylethanolamine. These components are weighed together into a test tube and dissolved in chloroform. The chloroform is stripped from the material and the resulting surfactant mixture is dried
20 in a 50°C vacuum oven overnight. The co-mixture is dispersed into water by sonication resulting in a liposome suspension. The suspension is transferred into a 30 mL capacity blender cup (Dynamics Corporation of America, New Hartford, CT) along with the PFDCO and oil. The mixture is
25 blended for 30-60 seconds to a pre-emulsion. The preemulsified sample is transferred to the reservoir of a microfluidizer, model S110 (Microfluidics, Newton, MA), and emulsified for three minutes at 10,000 psi. To prevent the emulsion from heating excessively during homogenization,
30 the shear valve and mixing coil of the microfluidizer are immersed in a room temperature water bath during processing. The final temperature of the emulsion is approximately 35°C. The finished emulsion is bottled in 10 mL serum vials, blanketed with nitrogen gas and sealed with
35 stopper/crimp seal. The average particle size of the

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finished product, measured by a laser light scatter particle sizer (Brookhaven Instruments Corporation, Holtsville, NY), is 250 nm.

Example 2

5 The incorporation of biotinylated phosphatidylethanolamine into the encapsulating lipid monolayer of perfluorocarbon emulsion is prepared as described in Example one and demonstrated to increase aggregate particle size in the presence of titrated
10 concentrations of avidin (Pierce, Rockford, IL 61105). An identically prepared control emulsion is prepared which incorporates nonbiotinylated phosphatidylethanolamine into the outer lipid monolayer of the perfluorocarbon emulsion. Avidin is resuspended in isotonic phosphate buffered saline
15 (PBS, Fisher Inc., Fair Lawn, NJ). Within a polystyrene cuvette, a 3.0 ml reaction mixture is prepared containing PBS, biotinylated or control perfluorocarbon emulsion (20 μ l) and avidin, at 0.0, 0.5, 1.0, 1.5 or 2.0 μ g/ml. Contents are mixed by gentle inversion and react for thirty
20 minutes at room temperature. Emulsion particle sizes are determined in triplicate with a Brookhaven BI-90 particle size analyzer (Holtsville, NY) at 37°C. Aggregate particle size of the biotinylated emulsion increased progressively from a baseline of 263 \pm 2.54 nm to greater than 2000 nm with
25 increasing concentration of avidin (Figure 1). Marked flocculation and sedimentation are noted when avidin concentrations exceed 2.0 μ g/ml. The particle size of the control emulsion is 234 \pm 3.81 nm in diameter and addition of 2.0 μ g of avidin to the reaction mixture does not affect
30 particle size. These results clearly demonstrate that the biotinylated phosphatidylethanolamine is incorporated and oriented appropriately into the outer lipid monolayer of the perfluorocarbon emulsion and that surface biotins are adequately available to avidin in the media. Multiple
35 biotin binding sites on the avidin molecule as well as

multiple biotin residues on the surface of the emulsion progresses towards a rapid complexing of particles in vitro.

Example 3

5 Biotinylated perfluorocarbon emulsion particles, approximately 250 nm in diameter, with low independent acoustic reflectivity, are complexed with avidin in solution which eventuates aggregation and enhances echogenicity. Biotinylated and control perfluorocarbon
10 emulsion (200 μ l) prepared as described previously are diluted in PBS (15 ml) and placed within dialysis tubing (Spectra/Por 4, 25 mm, MWCO 12,000-14,000, Spectrum Medical Industries, Inc., Los Angeles, CA), ultrasonically imaged within a PBS water bath at room temperature using a 7.5 MHz
15 focused transducer and a Hewlett Packard (HP) Sonos 2500 Phased Array Imaging System (Andover, MA). Real-time images are recorded to SVHS video tape for subsequent image analysis. Pixel grayscale and homogeneity are assessed on selected freeze-frame images using NIH Image 1.47 (National
20 Institutes of Health). Avidin (30 μ g/ml) is added to each emulsion suspension, mixed by gentle inversion and allowed to complex for 30 minutes. The emulsion suspensions are optically opaque but ultrasonically undetected prior to the addition of avidin. Complexing of the biotinylated
25 perfluorocarbon emulsion ensues rapidly with the addition of avidin and a white, flocculant precipitate soon appears. Avidin induces no changes in control emulsion suspension. Insonification of the suspensions reveals that the biotinylated perfluorocarbon emulsion particles opacify the
30 dialysis tubing; whereas, the control particles are not appreciated acoustically (Figure 2). Gray scale echo intensity analysis of freeze-frame images of the control and biotinylated emulsion suspensions before and after avidin are summarized in Figures 3 and 4. The increased
35 average grayscale level of the biotinylated emulsion

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(71.3±22.1) suspension relative to its pre-avidin pixel gray scale level (2.2±4.4) demonstrates the acoustic enhancement achieved. Average pixel gray scale levels of the control emulsion before (3±7.33) and after (1.0±1.3) avidin addition are similar. These results demonstrate the low acoustic reflectivity of the perfluorocarbon emulsion when imaged as independent particles in comparison with the enhanced echogenic nature of the aggregated biotinylated particles. The lack of acoustic change in the control emulsion suspension in the presence of avidin confirms the ligand specificity of the biotinylated emulsion.

Example 4

Biotinylated perfluorocarbon emulsion, approximately 250 nm diameter, are specifically targeted to avidin, covalently bound to a modified nitrocellulose membrane and increases the acoustic reflectivity of the membrane surface at high ultrasonic frequencies (30 to 60 MHz). Briefly, nitrocellulose membranes (S+S NC™, Schleicher & Schuell, Keane, NH) were conjugated to avidin using a diaminohexane (Sigma Chemical Co., St. Louis, MO) spacer and glutaraldehyde (Sigma Chemical Co., St. Louis, MO) activation as described by Másson et al. (Electrophoresis 1993, 14, 860-865). Nitrocellulose discs (2 cm diameter) are soaked in 2.5% diaminohexane dissolved in deionized water for 60 minutes with constant slow rotary agitation. Membranes are washed with 1M acetic acid for 6-7 hours followed by an 18+ hour deionized water wash with constant agitation. The membranes are placed in 1% glutaraldehyde in 0.1M sodium bicarbonate buffer, pH 10.0 for 15 minutes then washed for three hours with deionized water. Nitrocellulose membranes are stored and dried at 4°C until use; storage does not exceed three days.

Fifty (50) µl of avidin (250 µg) are spotted dropwise upon the center of six membranes with a microliter syringe and allowed to dry. Each membrane is extensively

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washed with a 0.1% Tween-20TM (Sigma Chemical Co., St. Louis, MO) in PBS then placed in 3% bovine serum albumin (BSA, crystallized, Sigma Chemical Company, St. Louis, MO) dissolved in PBS-0.1% Tween-20TM for 20 minutes to blockade nonspecific protein binding sites around the periphery of the disc. After the BSA blockade, each disc is extensively washed with PBS and placed in 300 μ l of either biotinylated or control perfluorocarbon emulsion suspended in 4 ml PBS for 20 minutes. Unbound emulsion is removed in serial PBS washes. Each disc is reexposed to avidin and control or biotinylated emulsion to ensure saturated coverage of the nitrocellulose surface. The nitrocellulose discs are washed and stored in PBS at 4°C until imaged with acoustic microscopy.

For acoustic microscopic imaging, each nitrocellulose disc is placed flat above a polished stainless steel plate in a polystyrene holder with a 2 X 2 cm central window removed. The mounted specimen is immersed into PBS at ambient temperature for ultrasonic insonification. A custom designed acoustic microscope, utilizing a 50MHz (nominal frequency) broadband, focused, piezoelectric delay-line transducer (1/4 inch diameter, 1/2 inch focal length, Model V390, Panametrics Co., Waltham, MA) operated in the pulse-echo mode is utilized for insonification. Backscattered radio frequency (RF) data is collected and digitized at 500 megasamples per second utilizing a TektronixTM DSA 601 digitizing oscilloscope (Beaverton, OR) with 8-bit resolution. A variable gain system is used to increase the effective dynamic range of this digitizer. Radio frequency data are acquired from approximately 100 independent sites from each region of interest with 100 micron lateral step resolution.

A radio frequency peak-detected scan of the data is converted into a gray scale (0=lowest scattering, 255=highest scattering) map to allow selection of regions of interest for integrated backscatter analysis. Radio

frequency (RF) ultrasonic data are stored in a raster scan format and analyzed with custom software. Segments of the RF lines are gated for integrated backscatter analysis to encompass the front and back surfaces of the nitrocellulose disc. The data are multiplied by a rectangular window and their power spectra are determined by fast-Fourier transformation. The power spectra from the specimens referenced to the power spectrum returned from a near-perfect steel planar reflector and the frequency-dependent backscatter transfer function across the useful bandwidth of the transducer (30 to 60 MHz) are computed and expressed in decibels relative to acoustic scattering from the near perfect steel plate reflector (Wong et al., Ultrasound in Med & Biol. 1993; 19: 365-374). Integrated backscatter (IB) is computed as the average of the frequency-dependent backscatter transfer function across the useful bandwidth of the transducer.

Discs incubated with biotinylated perfluorocarbon emulsion have central regions with high acoustic scattering in comparison with the peripheral (i.e. background) regions of the same disc. Nitrocellulose discs incubated with the control emulsion have no central high scattering regions and no differences in acoustic character is detected by changes in the RF signature between the central and peripheral regions of the disc. IB from the centrally-located, biotinylated emulsion region (-17.8 ± 0.2 db) is 6.3 ± 0.1 dB(4-fold) greater ($p < 0.05$) than IB from the analogous region on the control disc (-24.1 ± 0.2 dB). The frequency-dependent variation in apparent backscatter transfer function (mean \pm SEM) from the avidin spotted regions of the biotinylated and control emulsion discs are presented in Figure 5. A smooth and consistently greater acoustic response is noted across the frequency spectrum due to the bound biotinylated emulsion. These results demonstrate the effectiveness of the biotinylated perfluorocarbon emulsion to specifically target a surface

bound antigen and dramatically alter the acoustic reflectivity of the surface with the bathing medium, increasing the ultrasonic backscattered power at high frequencies.

5 Example 5

 Biotinylated perfluorocarbon emulsion (250 nm diameter) is specifically targeted to D-dimer covalently attached to a modified nitrocellulose membrane utilizing a biotinylated anti-D-dimer F_(ab) fragment-avidin complex and
10 results in a marked increase in the acoustic power reflected from the surface. D-dimer is covalently linked to nitrocellulose discs modified with a diaminohexane spacer arm and activated with glutaraldehyde as previously described in Example 4. Fifty (50) µg of D-dimer is
15 spotted with a microliter syringe upon the center of three of six membranes and allowed to air dry. Unbound D-dimer is exhaustively washed from the membranes with phosphate buffered saline (PBS)-0.1% Tween-20TM. Nonspecific protein binding sites of all membranes are blocked with 3% bovine
20 serum albumin (BSA) in PBS-0.1% Tween-20TM for 20 minutes followed by serial PBS washes. D-dimer spotted membranes are incubated with 12.5 µg biotinylated anti-D-dimer F_(ab) antibody in 4.0 ml 3% BSA for 2 hours, washed with PBS buffer and then incubated with 250 µg avidin in 4 ml PBS
25 for 30 min. After removing unbound avidin with PBS washes, the discs are exposed to either biotinylated or control perfluorocarbon emulsion (300 µl) in 4.0 ml PBS for 20 minutes. Excess emulsion is removed with PBS buffer washes. Discs are reexposed to avidin and perfluorocarbon
30 emulsion as described above and the membranes are stored in PBS at 4°C until imaging.

 For acoustic microscopic imaging, each nitrocellulose disc is placed flat above a polished stainless steel plate in a polystyrene holder, immersed in
35 PBS at ambient temperature, and insonified with a custom

designed acoustic microscope, utilizing a 50MHz (nominal frequency) broadband, focused, piezoelectric delay-line transducer (1/4 inch diameter, 1/2 inch focal length, Model V390, Panametrics Co., Waltham, MA) operated in the pulse-echo mode. Backscattered radio frequency (RF) data is collected and digitized at 500 megasamples per second utilizing a TektronixTM DSA 601 digitizing oscilloscope (Beaverton, OR) with 8-bit resolution. A variable gain system is used to increase the effective dynamic range of this digitizer. Radio frequency data are acquired from approximately 100 independent sites from each region of interest with 100 micron lateral step resolution.

A radio frequency peak-detected scan of the data is converted into a gray scale (0=lowest scattering, 255=highest scattering) map of the disc to allow visual inspection and selection of regions of interest for integrated backscatter (IB) analysis. Radio frequency (RF) ultrasonic data are stored in a raster scan format and analyzed with custom software. Segments of the RF lines are gated for integrated backscatter analysis to encompass the front and back surfaces of the nitrocellulose disc. The data are multiplied by a rectangular window and their power spectra are determined by fast-Fourier transformation. The power spectra from the specimens referenced to the power spectrum returned from a near-perfect steel planar reflector and the frequency-dependent backscatter transfer function across the useful bandwidth of the transducer (30 to 60 MHz) are computed and expressed in decibels relative to acoustic scattering from the near perfect steel plate reflector (Wong et al., Ultrasound in Med & Biol. 1993; 19: 365-374). Integrated backscatter is computed as the average of the frequency-dependent backscatter transfer function across the useful bandwidth of the transducer.

Biotinylated, anti-D-dimer $F_{(ab)}$ fragment is specifically bound to the central region of the D-dimer

spotted discs and crosslinked by avidin through its biotin moiety. As in previous examples, biotinylated perfluorocarbon emulsion specifically binds to the antibody bound avidin; whereas, the nonspecific binding of the control emulsion have no binding and are not detected acoustically. IB of the biotinylated emulsion coated nitrocellulose (-18.0 ± 0.2 dB) was greater by 4.6 ± 0.1 dB ($p < 0.05$) than that from the control disc (-22.6 ± 0.1 dB) over the 30 to 60 MHz frequency range. The frequency-dependent variation in apparent backscatter transfer function (mean \pm SEM) of the biotinylated and control emulsion discs are presented in Figure 6. A smooth and consistently greater acoustic response is noted across the frequency spectrum due to the bound biotinylated emulsion. These data confirm and extend the findings of Example 4 with avidin alone, demonstrating that biotinylated perfluorocarbon emulsion bound through a specific, targeting ligand system can significantly enhance the acoustic backscatter of a solid support surface.

20 Example 6

Biotinylated perfluorocarbon emulsion (250 nm diameter) is specifically targeted to avidin conjugated to nitrocellulose discs and insonified at clinically relevant frequencies (5 to 15 MHz) and significantly increases the acoustic backscatter of the membrane. Briefly, nitrocellulose membranes (S+S NC™, Schleicher & Schuell, Keane, NH) are conjugated to avidin using a diaminohexane (Sigma Chemical Co., St. Louis, MO) spacer and glutaraldehyde (Sigma Chemical Co., St. Louis, MO) activation as described by Másson et al. (Electrophoresis 1993, 14, 860-865). Nitrocellulose discs (2 cm diameter) are soaked in 2.5% diaminohexane dissolved in deionized water for 60 minutes with constant, slow rotary agitation. Membranes are transferred to and washed with 1M acetic acid for 6-7 hours then transferred for continued washing in

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deionized water for at least 18 additional hours with constant agitation. The membranes are placed in 1% glutaraldehyde in 0.1M sodium bicarbonate buffer, pH 10.0 for 15 minutes. After glutaraldehyde activation is complete, the membranes are washed with continued agitation for three hours. The nitrocellulose membranes stored and dried at 4°C until use; storage does not exceed three days.

Fifty (50) μ l of avidin (250 μ g) are spotted dropwise upon the center of a nitrocellulose membrane with a microliter syringe and allowed to dry. Each membrane is washed with 0.1% Tween-20TM (Sigma Chemical Co., St. Louis, MO) in phosphate buffered saline (PBS) then placed in 3% bovine serum albumin (BSA, crystallized, Sigma Chemical Company, St. Louis, MO) dissolved PBS-0.1% Tween-20TM for 20 minutes to blockade nonspecific protein binding sites around the periphery of the disc. After the BSA blockade, each disc is washed with PBS and placed in 300 μ l of either biotinylated or control perfluorocarbon emulsions suspended in 4 ml PBS for 20 minutes with mild, rotary agitation. The unbound emulsion is removed with washes of PBS. Each disc is reexposed to avidin, washed with PBS, reexposed to control or biotinylated perfluorocarbon emulsion and rewashed with PBS as previously described. The nitrocellulose discs are stored in PBS at 4°C until imaged with the acoustic microscope.

For acoustic microscopic imaging, each nitrocellulose disc is placed flat above a polished stainless steel plate in a polystyrene holder with a 2 cm x 2 cm central window removed. The mounted specimen is immersed into PBS at ambient temperature for ultrasonic insonification. A custom designed acoustic microscope, utilizing a 10 MHz (nominal frequency) broadband, focused, piezoelectric delay-line transducer (1/2 inch diameter, 2 inch focal length, Model V311, Panametrics Co., Waltham, MA) operated in the pulse-echo mode is utilized for insonification. Backscattered radio frequency (RF) data is

collected and digitized at 500 megasamples per second utilizing a TektronixTM DSA 601 digitizing oscilloscope (Beaverton, OR) with 8-bit resolution. A variable gain system is used to increase the effective dynamic range of this digitizer. Radio frequency data are acquired from approximately 100 independent sites from each region of interest with 250 micron lateral step resolution.

A radio frequency peak-detected scan of the data is converted into a gray scale (0=lowest scattering, 255=highest scattering) map of the disc to allow visual inspection and selection of regions of interest for integrated backscatter analysis. Radio frequency ultrasonic data are stored in a raster scan format and analyzed with custom software. Segments of the RF lines are gated for integrated backscatter analysis to encompass the front and back surfaces of the nitrocellulose disc. The data are multiplied by a rectangular window and their power spectra are determined by fast-Fourier transformation. The power spectra from the specimens referenced to the power spectrum returned from a near-perfect steel planar reflector and the frequency-dependent backscatter transfer function across the useful bandwidth of the transducer (5 to 15 MHz) are computed and expressed in decibels relative to acoustic scattering from the near perfect steel plate reflector (Wong et al., Ultrasound in Med & Biol. 1993; 19: 365-374). Integrated backscatter (IB) is computed as the average of the frequency-dependent backscatter transfer function across the useful bandwidth of the transducer.

Discs incubated with biotinylated perfluorocarbon emulsion have central regions with high acoustic scattering relative to the peripheral regions of the same disc or the central regions of the control emulsion disc. Nitrocellulose discs incubated with the control emulsion have no high scattering regions. IB of the biotinylated emulsion coated nitrocellulose (0.5 ± 0.5 dB) was greater by

9.6±0.1 dB (8-fold) ($p < 0.05$) than that from the control disc (-9.2±0.5 dB) over the 5 to 15 MHz frequency range. The frequency-dependent variation in apparent backscatter transfer function (mean ± SEM) of the biotinylated and control emulsion discs are presented in Figure 7. A smooth and consistently greater acoustic response is noted across the frequency spectrum due to the bound biotinylated emulsion. These data confirm and extend the findings of Examples 4 and 5 with avidin and D-dimer, demonstrating that biotinylated perfluorocarbon emulsion bound through a specific, targeting ligand system can significantly enhance the acoustic backscatter of a solid support surface and that this improved acoustic backscatter is detected at low, clinically useful ultrasonic frequencies (5 to 15 MHz) as well as high frequencies (30 to 60 MHz).

Example 7

Biotinylated perfluorocarbon contrast, approximately 3000 nm diameter, is specifically targeted to avidin conjugated to nitrocellulose discs and insonified at clinically relevant frequencies (at least 5 to 15 MHz bandwidth). Briefly, nitrocellulose membranes (S+S NC™, Schleicher & Schuell, Keane, NH) are conjugated to avidin using a diaminohexane (Sigma Chemical Co., St. Louis, MO) spacer and glutaraldehyde (Sigma Chemical Co., St. Louis, MO) activation as described by Másson et al. (Electrophoresis 1993, 14, 860-865). Nitrocellulose discs (2 cm diameter) are soaked in 2.5% diaminohexane dissolved in deionized water for 60 minutes with constant, slow rotary agitation. Membranes are transferred to and washed with 1M acetic acid for 6-7 hours then transferred for continued washing in deionized water for at least 18 additional hours with constant agitation. The membranes are placed in 1% glutaraldehyde in 0.1M sodium bicarbonate buffer, pH 10.0 for 15 minutes. After glutaraldehyde activation is complete, the membranes are washed with

continued agitation for three hours. The nitrocellulose membranes stored and dried at 4°C until use; storage does not exceed three days.

5 Fifty (50) μ l of avidin (250 μ g) are spotted dropwise upon the center of two of four membranes with a microliter syringe and allowed to dry. Each membrane is washed with 0.1% Tween-20TM (Sigma Chemical Co., St. Louis, MO) in phosphate buffered saline (PBS) then placed in 3% bovine serum albumin (BSA, crystallized, Sigma Chemical
10 Company, St. Louis, MO) dissolved PBS-0.1% Tween-20TM for 20 minutes to blockade nonspecific protein binding sites around the periphery of the disc. After the BSA blockade, each disc is washed with PBS and placed in 300 μ l of either biotinylated or control perfluorocarbon emulsions,
15 approximately 3000 nm particle size, suspended in 4 ml PBS for 20 minutes with mild, rotary agitation. The unbound emulsion is removed with washes of PBS. Each disc is reexposed to avidin, washed with PBS, exposed to perfluorocarbon emulsion and rewashed with PBS as
20 previously described. The nitrocellulose discs are stored in PBS at 4°C until imaged with the acoustic microscope.

For acoustic microscope imaging, each nitrocellulose disc is placed flat above a polished stainless steel plate in a polystyrene holder with a 2 cm
25 x 2 cm central window removed. The mounted specimen is immersed into PBS at ambient temperature for ultrasonic insonification. A custom designed acoustic microscope, utilizing a broadband 10 MHz (nominal frequency) focused, piezoelectric delay-line transducer (1/2 inch diameter, 2
30 inch focal length, Model V311, Panametrics Co., Waltham, AM) operated in the pulse-echo mode is utilized for insonification. Backscattered radio frequency (RF) data is collected and digitized at 500 megasamples per second utilizing a TektronicTM DSA 601 digitizing oscilloscope
35 (Beaverton, OR) with 8-bit resolution. A variable gain system is used to increase the effective dynamic range of

this digitizer. Radio frequency data are acquired from approximately 100 independent sites from each region of interest with 250 micron lateral step resolution.

5 A radio frequency peak-detected scan of the data is converted into a gray scale (0=lowest scattering, 255=highest scattering) map of the disc to allow visual inspection and selection of regions of interest for integrated backscatter analysis. Radio frequency ultrasonic data are stored in a raster scan format and
10 analyzed with custom software. Segments of the RF lines are gated for integrated backscatter (IB) analysis to encompass the front and back surfaces of the nitrocellulose disc. The data are multiplied by a rectangular window and their power spectra are determined by fast-Fourier
15 transformation. The power spectra from the specimens referenced to the power spectrum returned from a near-perfect steel planar reflector and the frequency-dependent backscatter transfer function across the useful bandwidth of the transducer (5 to 15 MHz) are computed and expressed
20 in decibels relative to acoustic scattering from the near perfect steel plate reflector (Wong et al., Ultrasound in Med & Biol. 1993; 19: 365-374). Integrated backscatter is computed as the average of the frequency-dependent backscatter transfer function across the useful bandwidth
25 of the transducer.

Discs incubated with biotinylated perfluorocarbon emulsion have central regions with high acoustic scattering relative to the peripheral regions of the same disc and central regions of the control disc. Nitrocellulose discs
30 incubated with the control emulsion have no central high scattering regions and no differences in acoustic character are detected between the central and peripheral regions of the disc. IB of the biotinylated emulsion coated nitrocellulose (-2.4 ± 0.7 dB) was greater by 8.8 ± 0.3 dB
35 (approximately 8-fold ($p < 0.05$)) than that from the control disc (-11.2 ± 0.4 dB) over the 5 to 15 MHz frequency range.

The frequency-dependent variation in apparent backscatter transfer function (mean \pm SEM) of the biotinylated and control emulsion discs are presented in Figure 8. A smooth and consistently greater acoustic response is noted across the frequency spectrum due to the bound biotinylated emulsion. These data confirm and extend the findings of Examples 4, 5 and 6 with avidin and D-dimer, demonstrating that biotinylated perfluorocarbon emulsions with large particle sizes can be bound through a specific, targeting ligand system and significantly enhance the acoustic backscatter of a solid support surface. This improved acoustic backscatter is detected at clinically relevant ultrasonic frequencies, 5 to 15 MHz.

Example 8

Biotinylated perfluorocarbon emulsion is targeted to a plasma thrombi using biotinylated antifibrin monoclonal antibodies (NIB1H10; Tymkewycz et al. 1993. Blood Coagulation and Fibrinolysis 4:211-221) and avidin. In a representative study (1 of 5), whole porcine blood is obtained and anticoagulated (9:1, v/v) with sterile sodium citrate. Blood is centrifuged at 1500 RPM at room temperature and the plasma fraction is obtained and stored at 4°C. Two porcine plasma thrombi are produced by combining plasma, 100 mM calcium chloride (3:1 v/v) and 2-5 U thrombin in a plastic tube through which 5-0 Vicryl suture is passed. Thrombi are allowed to coagulate at room temperature.

One thrombus is incubated with 150 μ g antifibrin monoclonal antibody in 10 ml PBS with 1% bovine serum albumin (BSA) for two hours and a second control thrombus is incubated in PBS with 1% BSA. The antibody treated thrombus is then incubated with 0.5 mg avidin in 10 ml PBS with 1% BSA for 30 minutes. The control thrombus remains in PBS with 1% BSA. Both thrombi are washed extensively with PBS. Each thrombus is incubated with 300 μ l/10 ml PBS

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of either biotinylated or control emulsion for 30 minutes. All thrombi are reexposed to emulsion twice to ensure uniform coverage and ultrasonically insonified (Figure 9). Ultrasonic imaging is performed using a 7.5 MHz focused, linear phased array transducer and a Hewlett Packard SonosTM 2500 Imaging System (Hewlett Packard, Inc., Andover, MA). All ultrasonic recordings are produced with fixed gain, compensation and time-gain compensation levels and are recorded on to SVHS videotape for subsequent image analysis. Average pixel grayscale over an extensive region of interest was sampled for 21 independent freeze-frame images for each thrombus using NIH Image 1.47 (National Institutes of Health; Figure 10). The biotinylated perfluorocarbon emulsion is found to provide a marked acoustic enhancement of the surface. Average pixel grayscale levels of the biotinylated emulsion thrombus are 79.5 ± 2.5 whereas the brightness of the control was markedly less (34.8 ± 2.2 , $p < 0.05$). These results demonstrate the ability of biotinylated perfluorocarbon emulsion to target and acoustically enhance a biological tissue (i.e. thrombus) in vitro.

Example 9

Biotinylated perfluorocarbon emulsion is targeted via biotinylated antifibrin antibodies (NIB5F3 and NIB1H10 Tymkewycz et al. 1993. Blood Coagulation and Fibrinolysis 4:211-221) to an isolated femoral artery thrombus in six mongrel dogs. A mongrel dog is anesthetized with sodium pentobarbital induction and halothane anesthesia. The right femoral artery and all branches are isolated at the level of the saphenous branch. A silver plated copper wire attached to a 22 ga. right angled needle point, insulated with plastic tubing (polyethylene P-240), is inserted into the femoral artery and secured with 4-0 Prolene suture. A current of 200-400 μ A is applied for up to two hours. Thrombus formation is monitored with continuous wave

doppler and discontinued after an approximately 50% increase in circulation velocity is noted distal to the electrical injury. Adventitial discoloration secondary to the current is appreciated proximal to the entry point of the wire. A 20 ga. catheter is inserted into a proximal branch of the femoral artery and secured with 4-0 silk suture. A pressurized 0.9% NaCl drip is attached through a three-way stopcock to the catheter. Blood flow into the isolated segment is disrupted by proximal snare ligature. Excess blood is flushed from the arterial segment to inhibit further thrombus formation by infusion of saline for 15 minutes. The distal draining branches of the femoral artery are ligated or snared with suture. Biotinylated antifibrin monoclonal antibody (50 μ g/1.0 ml PBS) is injected via the catheter and flushed with a few drops of saline. The antibody is allowed to incubate for one hour then the snare ligature distal to the wire insertion is released and excess antibody is flushed through with saline for five minutes. The distal femoral artery is reoccluded and avidin (250 μ g/1.0 ml PBS) is infused and incubates for 30 minutes. The distal ligature is again released and excess avidin is flushed through with saline for five minutes. The distal ligature is reestablished and biotinylated perfluorocarbon emulsion is infused and incubates for 30 minutes. After the initial exposure of the thrombus to the emulsion, the unbound emulsion is washed through with saline. Thrombi are each exposed to avidin and biotinylated perfluorocarbon emulsion as described above. In three animals, the contra lateral artery is also isolated, partially occluded with electrically induced thrombi and exposed to a control perfluorocarbon emulsion analagous to the administration of biotinylated emulsion described above. Femoral arteries exposed to either control or biotinylated perfluorocarbon emulsion are ultrasonically imaged at 7.5 MHz with a focused, linear phased array transducer and a clinical

Hewlett-Packard Sonos 2500 Ultrasonic Imaging System before and after contrast administration. Acutely formed thrombi, both control and contrast targeted, are not ultrasonically appreciated. For 6 of 6 femoral arteries, partially occlusive thrombi are markedly enhanced using the antifibrin targeted biotinylated perfluorocarbon contrast. In 3 of 3 femoral arteries thrombi, exposure to the control perfluorocarbon emulsion does not accentuate their acoustic reflectivity and these thrombi remain ultrasonically undetectable. Figure 11 reveals a representative example of a femoral artery site of thrombus formation after electrical induction before and after exposure to antifibrin antibody and biotinylated contrast. In the pre-contrast image, the femoral artery is observed with a bright echogenic wire point anode protruding into the lumen but no thrombus is appreciated. After treatment with the biotinylated contrast emulsion, a large partially occluded thrombus is clearly noted by the enhanced acoustic reflectivity (Figure 11). Again, no thrombus is appreciated in the control artery before or after exposure to control emulsion. These results demonstrate the concept of using bound perfluorocarbon emulsion to acoustically enhance biological surfaces, such as thrombotic tissue, in vivo to enable detection with a commercially available ultrasound imaging system.

Example 10

Biotinylated perfluorocarbon emulsion, approximately 250 nm diameter, is targeted to prostatic carcinoma using monoclonal antibodies specific for prostate specific antigen (PSA) and are acoustically detected using polar, high frequency, high resolution acoustic microscopy. Representative examples of human prostatic carcinoma tissues are routinely processed by immersion fixation in 10% neutral buffered formalin and embedded in paraffin. Twenty micron sections are prepared for acoustic

microscopy; 5 micron sections are used for optical studies. All histologic sections are mounted on acid cleaned glass slides that have been coated with poly-L-lysine. All mounted sections are heated at 55°C for 1 hour in an oven.

5 Prior to immunostaining, all sections are dewaxed in three changes of Americlear, and dehydrated in successive changes of 95% and 100% ethanol. Endogenous peroxidase activity is blocked only in sections prepared for optical studies by immersion in absolute methanol
10 containing 0.6% (v/v) hydrogen peroxide for 30 minutes. These and all sections for acoustic microscopy are then rehydrated through graded ethanols and distilled water and placed in isotonic PBS (pH 7.4). All sections are incubated with target specific monoclonal antibodies.

15 Prostate sections are incubated with anti-PSA primary monoclonal antibodies per the recommendations of the vendor for 18 hours at 4°C in moisture chambers. After primary incubation, sections are rinsed in isotonic PBS, then overlain with a polyclonal biotinyl-horse anti-mouse
20 immunoglobulin (VectaStain Elite Kits, Vector Laboratories, Burlingame, CA) for 1 hour at room temperature. After rinsing in PBS, a 30 micron section is prepared for acoustic microscopy. A section for light microscopy (5 micron) is incubated with avidin-biotin-peroxidase complex
25 (VectaStain Elite Kit, Vector Lab) for 1 hour at room temperature. This section is rinsed in phosphate buffer (pH 7.6) and immersed in a solution of 3,3'-diaminobenzidine tetrahydrochloride (Sigma Chemicals, St. Louis, MO; 0.5 mg/ml in phosphate buffer, pH 7.6,
30 containing 0.003% [v/v] hydrogen peroxide) for approximately ten minutes. The chromogenic precipitate is optically enhanced by brief immersion of stained sections in 0.125% (w/v) osmium tetroxide. The section is then rinsed in tap water, counterstained in Harris' hematoxylin,
35 dehydrated in graded ethanols and Americlear, and mounted in a synthetic mounting medium.

After the second biotinylated antibody is incubated and washed, slides for acoustic microscopy are incubated in avidin (1.0 mg/~20cc PBS) using a bath on a rotating table for 30 min. Excess avidin is washed away with isotonic PBS buffer, pH 7.4-7.5 in three minute washes. Slides are incubated with biotinylated or control perfluorocarbon emulsion for twenty minutes (0.5 cc/~20.0 ml PBS), washed briefly with isotonic PBS 3X for 5 minutes each and reincubated with avidin (1.0 mg/~20cc) for 15 minutes. Excess avidin is rinsed off with three, 5 min. washes in PBS. The slide is then reincubated at above concentrations with biotinylated or control perfluorocarbon emulsion for 20 minutes. Unbound emulsion is washed away in three changes of PBS (5 minutes each) and the slides are transferred to the acoustic microscope for analysis.

The mounted specimens are each immersed into isotonic, phosphate buffered saline at room temperature for ultrasonic insonification. A custom designed acoustic microscope is used to collect ultrasonic data. The microscope consists of 50 MHz broadband, focused, piezoelectric delay-line transducer (1/4 inch diameter, 1/2 inch focal length, 62 micron beam diameter, Model V390, Panametrics Co., Waltham, MA) operated in the pulse-echo mode. A Tektronix DSA 601 digitizing oscilloscope (Beaverton, OR) is used to digitize 35 degree polar backscattered radio frequency (rf) data at 500 megasamples per second with 8-bit resolution. A variable gain system is used to increase the effective dynamic range of this digitizer. Radio frequency data is acquired from approximately 100 independent sites from each specimen with 50 micron lateral step resolution.

The rf data is stored in a low resolution raster scan format and analyzed with custom software. Segments of the rf lines are gated for integrated backscatter analysis to encompass the front surface (i.e. excluding the back wall). The gated data are multiplied by a Hamming window

and their power spectra are determined by fast-Fourier transformation. Power spectra within a tissue section are compared directly without reference to a steel plate. Integrated backscatter (IB) is computed from the average of the frequency-dependent backscatter transfer function across the useful bandwidth of the transducer (30 to 55 MHz). Immunostained tissues are reviewed using a Nikon Optiphot-2 microscope for regions of PSA positive staining and the acoustic characteristics are compared.

The net change in the apparent backscatter transfer function between the normal prostatic stroma and carcinomatous regions are clearly increased in sections treated with PSA targeted biotinylated versus the control perfluorocarbon emulsion across the frequency spectrum (30 to 55 MHz; Figure 12). Biotinylated perfluorocarbon emulsion increases ($p < 0.05$) the integrated backscatter from regions of prostatic cancer ($47.17 \pm \text{dB}$) versus normal stromal ($40.79 \pm 1.18 \text{ dB}$) by 6.38 dB (approximately 4-fold). In the control tissue sections, the integrated backscatter from the region of prostatic carcinoma ($39.63 \pm 1.63 \text{ dB}$) was greater ($p < 0.05$) than that from the normal stromal areas ($36.13 \pm 2.17 \text{ dB}$) by approximately 3.5 dB (2-fold), reflecting inherent differences in acoustic character between normal and cancerous prostatic tissue. However, the targeted biotinylated perfluorocarbon emulsion amplified ($p < 0.05$) these inherent differences by approximately 2-fold (2.87 dB; Figure 13). These results clearly demonstrate the ability of site-targeted biotinylated perfluorocarbon emulsion to specifically enhance acoustic detection of prostate cancer in vitro.

Example 11

Biotinylated perfluorocarbon emulsion, approximately 250 nm diameter, is targeted to ovarian carcinoma using monoclonal antibodies specific for OC-125 antigen and are acoustically detected using polar, high

frequency, high resolution acoustic microscopy. Representative examples of human ovarian, carcinoma tissues are routinely processed by immersion fixation in 10% neutral buffered formalin and embedded in paraffin. Twenty
5 micron sections are prepared for acoustic microscopy; 5 micron sections are used for optical studies. All histologic sections are mounted on acid cleaned glass slides that have been coated with poly-L-lysine. All mounted sections are heated to 55°C for 1 hour in an oven.

10 Prior to immunostaining, all sections are dewaxed in three changes of Americlear, and dehydrated in successive changes of 95% and 100% ethanol. Endogenous peroxidase activity is blocked only in sections prepared for optical studies by immersion in absolute methanol
15 containing 0.6% (v/v) hydrogen peroxide for 30 minutes. These and all sections for acoustic microscopy are then rehydrated through graded ethanols and distilled water and placed in isotonic PBS (pH 7.4). All sections are incubated with target specific monoclonal antibodies.

20 Ovarian sections are incubated with anti-OC-125 primary monoclonal antibodies per the recommendations of the vendor for 18 hours at 4°C in moisture chambers. After primary incubation, sections are rinsed in isotonic PBS, then overlain with a polyclonal biotinyl-horse anti-mouse
25 immunoglobulin (VectaStain Elite Kits, Vector Laboratories, Burlingame, CA) for 1 hour at room temperature. After rinsing in PBS, duplicate 30 micron sections are prepared for acoustic microscopy. Sections for light microscopy (5 micron) are incubated with avidin-biotin-peroxidase complex
30 (VectaStain Elite Kit, Vector Lab) for 1 hour at room temperature. Sections are rinsed in phosphate buffer (pH 7.6) and immersed in a solution at 3,3'-diaminobenzidine tetrahydrochloride (Sigma Chemicals, St. Louis, MO; 0.5 mg/ml in phosphate buffer, pH 7.6, containing 0.0003% [v/v]
35 hydrogen peroxide) for approximately ten minutes. The chromogenic precipitate is optically enhanced by brief

immersion of stained sections in 0.125% (w/v) osmium tetroxide. Sections are then rinsed in tap water, counterstained in Harris' hematoxylin, dehydrated in graded ethanols and Americlear, and mounted in a synthetic mounting medium.

After the second biotinylated antibody is incubated and washed, slides are incubated in avidin (1.0 mg/~20 cc PBS) using a bath on a rotating table for 30 min. Excess avidin is washed away with isotonic PBS buffer, pH 7.4-7.5 in three 5 minute washes. The prepared slides are incubated with biotinylated or control perfluorocarbon emulsion for twenty minutes (0.5 cc/~20.0 ml PBS), washed briefly with isotonic PBS 3X for 5 minutes each and rewashed in avidin (1.0 mg/~20 cc) for 15 minutes. Excess avidin is rinsed off with three, 5 min. washes in PBS. Slides are then reincubated at above concentrations with biotinylated or control perfluorocarbon emulsion for 20 minutes. Unbound emulsion is washed away in three changes of PBS (5 minutes each) and the slides are transferred to the acoustic microscope for analysis.

The mounted specimens are each immersed into isotonic, phosphate buffered saline at room temperature for ultrasonic insonification. A custom designed acoustic microscope is used to collect ultrasonic data. The microscope consists of 50MHz broadband, focused, piezoelectric delay-line transducer (1/4 inch diameter, 1/2 inch focal length, 62 micron beam diameter, Model V390, Panametrics Co., Waltham, MA) operated in the pulse-echo mode. A TektronixTM DSA 601 digitizing oscilloscope (Beaverton, OR) is used to digitize 35 degree polar backscattered radio frequency (rf) data at 500 megasamples per second with 8-bit resolution. A variable gain system is used to increase the effective dynamic range of this digitizer. Radio frequency data is acquired from approximately 100 independent sites from each specimen with 50 micron lateral step resolution.

The rf data are stored in a low resolution raster scan format and analyzed with custom software. Segments of the rf lines are gated for integrated backscatter analysis to encompass the front surface (i.e. excluding the back wall). The gated data are multiplied by a Hamming window and their power spectra are determined by fast-Fourier transformation. Integrated backscatter is computed from the average of the frequency-dependent backscatter transfer function across the useful bandwidth of the transducer (30 to 55 MHz). The power spectra from the specimens are referenced to the power spectrum returned from a glass microscope slide. IB is expressed in decibels relative to the scattering from the glass slide. Immunostained tissues are reviewed using a Nikon Optiphot-2TM microscope for regions of PSA positive staining and the acoustic characteristics are compared.

The net change in the apparent backscatter transfer function between the normal ovarian stroma and carcinomatous regions are clearly increased in sections treated with OC-125 targeted biotinylated versus the control perfluorocarbon emulsion across the frequency spectrum (30 to 55 MHz; Figure 14). Biotinylated perfluorocarbon emulsion increases ($p < 0.05$) the integrated backscatter from regions of ovarian cancer (-28.19 ± 1.39 dB) versus normal stromal (-38.75 ± 0.84 dB) by 10.57 dB (greater than 8-fold). In the control tissue sections, the integrated backscatter from the region of ovarian carcinoma (-33.49 ± 0.86 dB) was greater ($p < 0.05$) than the normal stromal areas (-40.21 ± 0.61 dB), approximately 6.72 dB (4-fold), reflecting inherent differences in acoustic character between normal and cancerous ovarian tissue. However, the targeted biotinylated perfluorocarbon emulsion amplified ($p < 0.05$) these inherent differences by approximately 2-fold (3.84 dB; Figure 15). These results clearly demonstrate the ability of site-targeted

biotinylated perfluorocarbon emulsion to specifically enhance acoustic detection of ovarian cancer in vitro.

Example 12

Biotinylated perfluorocarbon emulsion, approximately 250 nm diameter, is targeted to the epithelial capsule of tonsil using monoclonal antibodies specific for cytokeratin, CD-20, and BCL-2 antigens and are acoustically detected using polar, high frequency, high resolution acoustic microscopy. Representative examples of human tonsil are routinely processed by immersion fixation in 10% neutral buffered formalin and embedded in paraffin. Twenty micron sections are prepared for acoustic microscopy; a 5 micron section is used for optical studies. All histologic sections are mounted on acid cleaned glass slides that have been coated with poly-L-lysine. All mounted sections are heated at 55°C for 1 hour in an oven.

Prior to immunostaining, all sections are dewaxed in three changes of Americlear, and dehydrated in successive changes of 95% and 100% ethanol. Endogenous peroxidase activity is blocked only in sections prepared for optical studies by immersion in absolute methanol containing 0.6% (v/v) hydrogen peroxide for 30 minutes. These and all sections for acoustic microscopy are then rehydrated through graded ethanols and distilled water and placed in isotonic PBS (pH 7.4). All sections are incubated with target specific monoclonal antibodies.

Tonsil sections are incubated with a mixture of anti-CD-20, BCL-2, and cytokeratin primary monoclonal antibodies per the recommendations of the vendor for 18 hours at 4°C in moisture chambers. After primary incubation, sections are rinsed in isotonic PBS, then overlain with a polyclonal biotinyl-horse anti-mouse immunoglobulin (VectaStain Elite Kits, Vector Laboratories, Burlingame, CA) for 1 hour at room temperature. After rinsing in PBS, duplicate 30 micron sections are prepared

for acoustic microscopy. Sections for light microscopy (5 micron) are incubated with avidin-biotin-peroxidase complex (VectaStain Elite Kit, Vector Lab) for 1 hour at room temperature. Sections are rinsed in phosphate buffer (pH 7.6) and immersed in a solution of 3,3'-diaminobenzidine tetrahydrochloride (Sigma Chemicals, St. Louis, MO; 0.5 mg/ml in phosphate buffer, pH 7.6, containing 0.003% [v/v] hydrogen peroxide) for approximately ten minutes. The chromogenic precipitate are optically enhanced by brief immersion of stained sections in 0.125% (w/v) osmium tetroxide. Sections are then rinsed in tap water, counterstained in Harris' hematoxylin, dehydrated in graded ethanols and Americlear, and mounted in a synthetic mounting medium.

After the second biotinylated antibody is incubated and washed, one slide is incubated in avidin (1.0 mg/~20 cc PBS) using a bath on a rotating table for 30 min. Excess avidin is washed away with isotonic PBS buffer, pH 7.4-7.5 in three 5 minute washes. The prepared slide is incubated with biotinylated perfluorocarbon emulsion for twenty minutes (0.5 cc/~20.0 ml PBS), washed briefly with isotonic PBS 3X for 5 minutes each and rewashed in avidin (1.0 mg/~20 cc) for 15 minutes. Excess avidin is rinsed off with three, 5 minute washes in PBS. The slides are reincubated at above concentrations with biotinylated perfluorocarbon emulsion for 20 minutes. Unbound emulsion is washed away in three changes of PBS (5 minutes each) and the slide is transferred to the acoustic microscope for analysis.

The mounted specimen is immersed into isotonic, phosphate buffered saline at room temperature for ultrasonic insonification. A custom designed acoustic microscope is used to collect ultrasonic data. The microscope consists of a 50 MHz broadband, focused, piezoelectric delay-line transducer (1/4 inch diameter, 1/2 inch focal length, 62 micron beam diameter, Model V390,

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Panametrics Co., Waltham, MA) operated in the pulse-echo mode. A TektronixTM DSA 601 digitizing oscilloscope (Beaverton, OR) is used to digitize 35 degree polar backscattered radio frequency (rf) data at 500 megasamples per second with 8 bit resolution. A variable gain system is used to increase the effective dynamic range of this digitizer. Radio frequency data are collected from the entire specimen and a peak detected image is created of the section and compared with the immunostained tissue image.

10 Immunostained tissue is examined and imaged using a Nikon Optiphot-2TM microscope with a Javlin Chromachip IITM camera attachment. Images are routed through a PanasonicTM digital mixer model WJ-AVE5 to PanasonicTM SVHS video recorders, models AG-1960 or AG-1970 and displayed upon an
15 Sony TrinitronTM monitor. Images are captured using NuVistaTM software (Truevision, Inc., Indianapolis, IN 46256) executing on a MacintoshTM LCIII microcomputer.

Figure 16 compares tonsil acoustically imaged as a radio frequency peak detected scan at 100 micron lateral
20 step resolution (a) with an optically imaged section immunostained with horseradish peroxidase (b). The epithelial capsule targeted by a mixture of anti-cytokeratin antibodies is distinctly stained with horseradish peroxidase and homologous regions in the
25 acoustic image are "brightened" by the targeted biotinylated acoustic contrast. In Figure 17 the radio frequency peak detected acoustic image at 100 micron step resolution (a) is enhanced to 50 micron lateral step resolution. The targeted biotinylated perfluorocarbon
30 contrast is clearly seen acoustically enhancing the epithelial rim of the tonsil, analogous to the optical immunostained image. This example clearly demonstrates the fidelity of biotinylated perfluorocarbon contrast targeting for enhanced acoustic contrast of tissues, such as lymph
35 nodes.

Example 13

Method to Prepare control and biotinylated perfluorocarbon microemulsions incorporating gadolinium DTPA into the outer lipid membrane.

5 The biotinylated perfluorocarbon contrast agent was produced by incorporating biotinylated phosphatidylethanolamine into the outer lipid monolayer of a perfluorocarbon microemulsion. Briefly, the emulsion was comprised of perfluorodichlorooctane (40%, v/v, PFDCO, 10 Minnesota Manufacturing and Mining, St. Paul, MN), safflower oil (2.0%, w/v), a surfactant co-mixture (2.0%, w/v) and glycerin (1.7%, w/v). The surfactant co-mixture include (50 to 70 mole % lecithin (Pharmacia Inc., Clayton, NC), 0 to 35 mole % cholesterol (Sigma Chemical Co. St. 15 Louis, MO) and 0.5 to 1 mole % N-(6-(biotinoyl)amino)hexanoyl)-dipalmitoyl-L-alpha-phosphatidylethanolamine Pierce, Rockford, IL) and 0 to 30% gadolinium (diethylenetriaminepentaacetic acid bis(oleylamide) (Gd-DTPA-BOA), (Gateway Chemical 20 Technology, St. Louis, MO) which were dissolved in chloroform. The chloroform-lipid mixture was evaporated under reduced pressure, dried in a 50°C vacuum oven overnight and dispersed into water by sonication, resulting in a liposome suspension. The liposome suspension was 25 transferred into a blender cup (dynamics Corporation of America, New Hartford, CT) with perfluorodichlorooctane, safflower oil and distilled, deionized water and emulsified for 30 to 60 seconds. The emulsified mixture was transferred to an S100 Microfluidics emulsifier 30 (Microfluidics, Newton, MA) and continuously processed at 10,000 PSI for three minutes. The completed emulsion was vialled, blanketed with nitrogen and sealed with stopper crimp seal until use. A control emulsion was prepared identically except a nonbiotinylated 35 phosphatidylethanolamine was substituted into the surfactant co-mixture. Biotinylated and control

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Demonstration of the effect of gadolinium incorporation on increases in particle size associated with avidin addition.

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Whole human blood was obtained fresh and anticoagulated (9:1, v/v) with sterile sodium citrate. In a series of trials, plasma clots (6) were produced by combining plasma and 100 mM calcium chloride (3:1 v/v) with

5 units of thrombin (Sigma Chemical Company, St. Louis, MO) in a plastic mold on a nitrocellulose surface. The plasma was allowed to coagulate slowly at room temperature. Half of the clots (3) were incubated individually with 150 μ g biotinylated antifibrin monoclonal antibody (NIB 5F3; NIBSC, Herts, United Kingdom) in 10 ml PBS for two hours; the remaining clots (3) were maintained in PBS. The antibody treated clots were then incubated with avidin (50 μ g/ml PBS) for 30 minutes followed by 10% gadolinium, biotinylated perfluorocarbon emulsion (30 μ l/ml PBS for 30 minutes. The control clots were treated similarly with control perfluorocarbon emulsion (30 μ l/ml PBS). Targeted and control clots were retreated with avidin and targeted or control perfluorocarbon emulsion, respectively, to optimize surface saturation prior to ultrasonic interrogation. Clots on nitrocellulose disks were placed in a waterbath and imaged with 30MHz intravascular catheters (Boston Scientific Corporation, Maple Grove, MN) and a conventional ultrasonic scanner with a 7.5 MHz linear array transducer (Hewlett Packard Inc.) Ultrasonic images were recorded on to Super-VHS videotape for subsequent image analysis. Figure 19 clearly demonstrates the enhanced acoustic reflectivity of the plasma clot surface with the target acoustic contrast which is not appreciated in the control. These results demonstrate that the targeting capability and the enhanced acoustic reflectivity effects of the biotinylated perfluorocarbon emulsion was retained.

Example 16

30 The Efficacy of the Dual Ultrasound/MRI Contrast Agent in solution to provide T1 shortening in a concentration dependent manner.

Biotinylated emulsions incorporating gadolinium DTPA at overall concentrations of 0.2, 0.4 and 0.6 mole-% into the outer lipid membrane were prepared as described in

Example 13. The dual contrast particles were serially diluted with PBS into 3cc plastic tubes and magnetic resonance imaging was performed using a PhilipsTM Gyroscan S15 ACS-NT (1.5T). A Look-Locker MR pulse sequence was used to map the longitudinal relaxation curve. Briefly, an inversion pulse was applied, followed by acquisition of a series of images with small flip angles and short inter-image spacing. The signal intensity changes between images were directly related to the actual relaxation curve, and T1 (the spin-lattice relaxation time) was determined from this relationship. The pulse sequence parameters used in this experiment were TR 50 ms, TE 10 ms, flip angle 5 degrees, matrix 64 x 64, field of view 160 x 104 mm, 20 images, delay after inversion pulse 16 ms. The experiment was repeated with a Tr of 25 ms in order to measure very short T1's at high GD³⁺ concentration. T1 parametric maps were generated where pixel intensity is the T1 value in milliseconds. Table 1 reveals the direct dependence of T1 shortening on gadolinium concentration. T1 shortening was greater for particles containing higher concentrations of gadolinium whether achieved by formulation or dilution.

Table 1. T1 dependence on Gd concentration

	0.2% Gd		0.4% Gd		0.6% Gd	
Formulation Dilution	[Gd] mM	T1 (ms)	[Gd] mM	T1 (ms)	[Gd] mM	T1 (ms)
1:16 (2.5% PFC)	0.000125	972±2	0.000252	492±1	0.000314	519±1
1:8 (5% PFC)	0.000249	878±7	0.000505	339±2	0.000628	414±4
1:4 (10% PFC)	0.000498	430±7	0.00101	189±2	0.001256	156±2
1:2 (20% PFC)	0.000996	169±1	0.00202	92±1	0.002511	90±1
1:1 (40% PFC)	0.001992	65±1	0.00404	<50	0.005022	<50

The control emulsion (i.e. no gadolinium) had a mean $\%1$ of 1788 ± 9 ms. T1's shorter 50 ms than could not be resolved with the present technique. The relaxivity for each preparation (0.2%, 0.4%, and 0.6% [Gd]) was determined by computing the slope of the line relating [Gd] in mM to $1/\%1$ (Table 2). The relaxivity of the 0.2 gadolinium emulsions was the greatest; whereas, the relaxivity of the 0.4% and 0.6 contrast formulations were shorter and similar.

Table 2. Relaxivity of preparations

	slope (ms-mM)	intercept	r
0.2%	7.89	-0.00093	0.99
0.4%	5.06	0.00049	0.99
0.6%	4.36	0.00034	0.99

Example 17

The Efficacy of the Dual Ultrasound/MRI Contrast Agent targeted in vitro to human plasma clots to provide T1 shortening

Biotinylated emulsions incorporating gadolinium at overall concentrations of 10, 20 and 30 mole % into the outer lipid membrane were prepared as described in Example 13. The actual weight percentage of gadolinium in the applied emulsions are 0.25% (10%), 0.43% (20%), and 0.54% (30%). Whole human blood was obtained fresh and anticoagulated (9:1, v/v) with sterile sodium citrate. In a series of trials, plasma clots (6) were produced by combining plasma and 1000 mM calcium chloride (3:1, v/v) with 5 units of thrombin (Sigma Chemical Company, St. Louis, MO) in a plastic mold on a nitrocellulose surface. The clot dimensions when formed on the nitrocellulose support membrane were: thickness < 0.5 mm; diameter ~ 1 cm. The plasma was allowed to coagulate slowly at room

temperature. Half of the clots (3) were incubated individually with 150 μ g biotinylated antifibrin monoclonal antibody (NIB 5F3; NIBSC, Herts, United Kingdom) in 10 ml PBS for two hours; the remaining clots (3) were maintained in PBS. The antibody treated clots were then incubated with avidin (50 μ g/ml PBS) for 30 minutes followed by 10% gadolinium, biotinylated perfluorocarbon emulsion (30 μ l/ml PBS) for 30 minutes. The control clots were treated similarly with control perfluorocarbon emulsion (30 μ l/ml PBS). Half of the targeted and control clots were retreated with avidin and targeted or control perfluorocarbon emulsion, respectively, to optimize surface saturation prior to imaging.

Clots exposed to control and targeted gadolinium contrast were encased with 10% gelatin in P-30, plastic petri dishes and magnetic resonance imaging was performed using a PhilipsTM Gyroscan S15 ACS-NT (1.5T). A Look-Locker pulse sequence was used to map the longitudinal relaxation curve. Briefly, an inversion pulse was applied, followed by acquisition of a series of images with small flip angles and short inter-image spacing. The pulse sequence parameters were TR 50 ms, TE 10 ms, flip angle 5 degrees, matrix 64 \times 64, field of view 160 \times 104 mm, 20 images, delay after inversion pulse 16 ms. T1 was determined from the resulting parametric T1 map in each clot and in the surrounding gel. T2 (spin-spin relaxation time) was determined from an 8 echo spin-echo sequence with TE 30 ms, and TR 8000 ms. The image voxel dimension for this experiment was \sim 2.5 \times 2.0 \times 2.0 mm.

The mean T1 value for the gel was 582 \pm 8 ms. T2 values for all samples fell in a narrow range between 80 and 92 ms. T2 of the gel was 91 ms. Adding Gd to the preparation resulted in a measurable and significant drop in T1 which plateaued at the lowest paramagnetic concentration (Table 3). Because of the partial volume effect involved in this

measurement (i.e., only a thin layer of gadolinium emulsion on a clot surface relative to the voxel dimension, or approximately 11:1 gel substrate to gadolinium-emulsion), the contrast enhancement effect is actually remarkably sensitive.

Table 3. T1 dependence on [Gd] targeted to fibrin clots imbedded in gelatin.

[Gd]	1 exposure to targeting system	2 exposures to targeting system
	T1 (ms)	T1 (ms)
0.0%	725±16	824±41
0.25%	662±23	696±15
0.43%	642±21	660±11
0.54%	666±17	667±13

Example 18

In situ targeting of canine thrombi in vivo for magnetic resonance imaging using dual contrast agent.

In accordance with approved animal protocols, dogs weighing 20-30Kg were anesthetized with sodium pentobarbital (30mg/kg, i.iv.) followed by 1% halothane in oxygen. The right femoral artery and all branches between the inguinal ligament and the saphenous artery were exposed. One proximal arterial branch, slightly distal to the inguinal ligament, was selected for cannulation. All other branches were ligated. The tip of a 23ga needle crimped on silver plated copper wire was inserted obliquely into the femoral artery 2-3 cm proximal to the saphenous branch and secured with 4-0 Prolene suture through connective tissue on either side. Anodal current (200-400 μ A) was applied for 90 to 120 minutes to induce a partially occlusive thrombus. A Doppler flow probe placed proximally was used to monitor the development of thrombus.

Partial distal constriction of the femoral artery was used to facilitate thrombus formation.

After a thrombus had been formed, a 20 ga. catheter was inserted into the preserved proximal branch of the artery and a pressurized 0.9% NaCl drip was attached through a three-way stopcock to the catheter. Saline was allowed to flush the artery and antegrade blood flow through the femoral artery was stopped by placement of a snare 1 - 2 cm proximal to the catheter. Continued blood flow through the distal femoral arterial containing the thrombus was prevented for the duration of the study.

After blood was flushed from the isolated arterial segment with continuous saline infusion, the distal femoral artery was occluded transiently with a snare. For contrast targeted thrombi, biotinylated antifibrin monoclonal antibody (150 μ g NIB 5F3 or NIB 1H10 in 0.5 ml of PBS, pH 7.2-7.4) was injected through the three-way stopcock and incubated in the vessel for one hour. The distal snare on the femoral artery was then released and unbound antibody was flushed away with 0.9% saline. After re-establishing the distal arterial occlusion, 0.5 mg of avidin (Pierce, Rockford, IL) in 0.5 ml of PBS was injected into the segment and incubated within artery for 30 minutes. Again, the distal occlusion was released and unbound avidin was flushed from the lumen with 0.9% NaCl. The distal arterial occlusion was re-established and 0.2 ml of biotinylated emulsion was injected into the vessel lumen and incubated for 30 minutes.

Arteries were ultrasonically imaged after thrombus formation (baseline and after each administration of antibody, avidin and perfluorocarbon emulsion with a 7.5 M.Hz linear array transducer using a commercially available imaging system. The acoustically reflective needle electrode was used to localize regions of thrombosis for insonification. After all data were collected, the

presence of thrombus was confirmed in each animal by incision of the artery at the end of study.

After ultrasonic imaging, the femoral arterial segment was perfused with formalin in situ for 30 minutes and then excised with a rigid support to preserve conformation. The arterial segment was placed in a formalin container and transferred to the MRI scanner for imaging. Magnetic resonance imaging was performed using a PhilipsTM Gyroscan S15 ACS-NOT (1.5T) using the Look-Locker technique with a TR of 100 ms, TE 10 ms, flip angle 5 degrees, matrix 64 x 64, field of view 160 x 104 mm, 20 images, delay after inversion pulse 16 ms. Slice thickness was 4 mm.

The measured T1 of the formalin background was 2319±12 ms, and the measured T1 of the thrombus was 1717 ± 173 ms. This difference in T1 between the clot and background resulted in high contrast as shown in Figure 20. The location and dimensions of the enhanced T1 signal were analogous to the result obtained by ultrasound Figure 20 and confirmed dissection of the artery. A second arterial thrombus preparation imaged with the same magnetic resonance techniques yielded analogous results. In this experiment, the T1 of the clot was 1572 ± 173 ms, and the background T1 was 2319 ± 12 ms.

In view of the above, it will be seen that the several objects of the invention are achieved and other advantageous results attained.

As various changes could be made in the above methods and compositions without departing from the scope of the invention, it is intended that all matter contained in the above description and shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

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CLAIMS:

1. A composition comprising an emulsion of lipid encapsulated particles having cores consisting substantially of liquid fluorocarbon, said particles being coupled to a
5 ligand for ligand-based binding of said particles to a molecular epitope or receptor, for use in a subject in an *in vivo* targeted diagnostic procedure,

wherein said diagnostic procedure comprises imaging said target in the presence of said emulsion,
10 wherein during said imaging, said emulsion is of lipid encapsulated particles having cores consisting substantially of liquid fluorocarbon said particles coupled to said ligand.
2. The composition of claim 1, wherein said ligand is
15 biotin.
3. The composition of claim 1, wherein said ligand is a ligand specific for said epitope or receptor.
4. The composition of claim 3, wherein said ligand is an antibody or fragment thereof.
- 20 5. The composition of any one of claims 1 to 4, wherein the liquid fluorocarbon comprises at least one perfluorocarbon.
6. The composition of any one of claims 1 to 5, wherein said imaging is acoustic imaging.
- 25 7. The composition of any one of claims 1 to 5, wherein said imaging is magnetic resonance imaging (MRI).
8. The composition of claim 7, wherein said composition further contains a gadolinium chelate coupled to said particles.

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9. The composition of any one of claims 1 to 8, wherein said particles further comprise a chemotherapeutic agent.

10. A use of a composition comprising an emulsion of
5 lipid encapsulated particles having cores consisting substantially of liquid fluorocarbon, said particles being coupled to a ligand for ligand-based binding of said particles to a molecular epitope or receptor, in the preparation of a formulation for an *in vivo* targeted
10 diagnostic procedure in a subject,

wherein said diagnostic procedure comprises imaging said target in the presence of said emulsion, wherein during said imaging, said emulsion is of lipid encapsulated particles having cores consisting substantially
15 of liquid fluorocarbon said particles coupled to said ligand.

11. The use of claim 10, wherein said ligand is biotin.

12. The use of claim 10, wherein said ligand is a
20 ligand specific for said epitope or receptor.

13. The use of claim 12, wherein said ligand is an antibody or fragment thereof.

14. The use of any one of claims 10 to 13, wherein the liquid fluorocarbon comprises at least one perfluorocarbon.

25 15. The use of any one of claims 10 to 13, wherein said imaging is acoustic imaging.

16. The use of any one of claims 10 to 13, wherein said imaging is magnetic resonance imaging (MRI).

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17. The use of claim 16, wherein said composition further contains a gadolinium chelate coupled to said particles.

18. The use of any one of claims 10 to 17, wherein
5 said particles further comprise a chemotherapeutic agent.

19. Use of a composition comprising an emulsion of lipid encapsulated particles having cores consisting substantially of liquid fluorocarbon, said particles being coupled to a ligand for ligand-based binding of said
10 particles to a molecular epitope or receptor, in an *in vivo* targeted diagnostic procedure in a subject,

wherein said diagnostic procedure comprises imaging said target in the presence of said emulsion, wherein during said imaging, said emulsion is of lipid
15 encapsulated particles having cores consisting substantially of liquid fluorocarbon said particles coupled to said ligand.

20. The use of claim 19, wherein said ligand is biotin.

20 21. The use of claim 19, wherein said ligand is a ligand specific for said epitope or receptor.

22. The use of claim 21, wherein said ligand is an antibody or fragment thereof.

23. The use of any one of claims 19 to 22, wherein the
25 liquid fluorocarbon comprises at least one perfluorocarbon.

24. The use of any one of claims 19 to 22, wherein said imaging is acoustic imaging.

25. The use of any one of claims 19 to 22, wherein said imaging is magnetic resonance imaging (MRI).

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26. The use of claim 25, wherein said composition further contains a gadolinium chelate coupled to said particles.

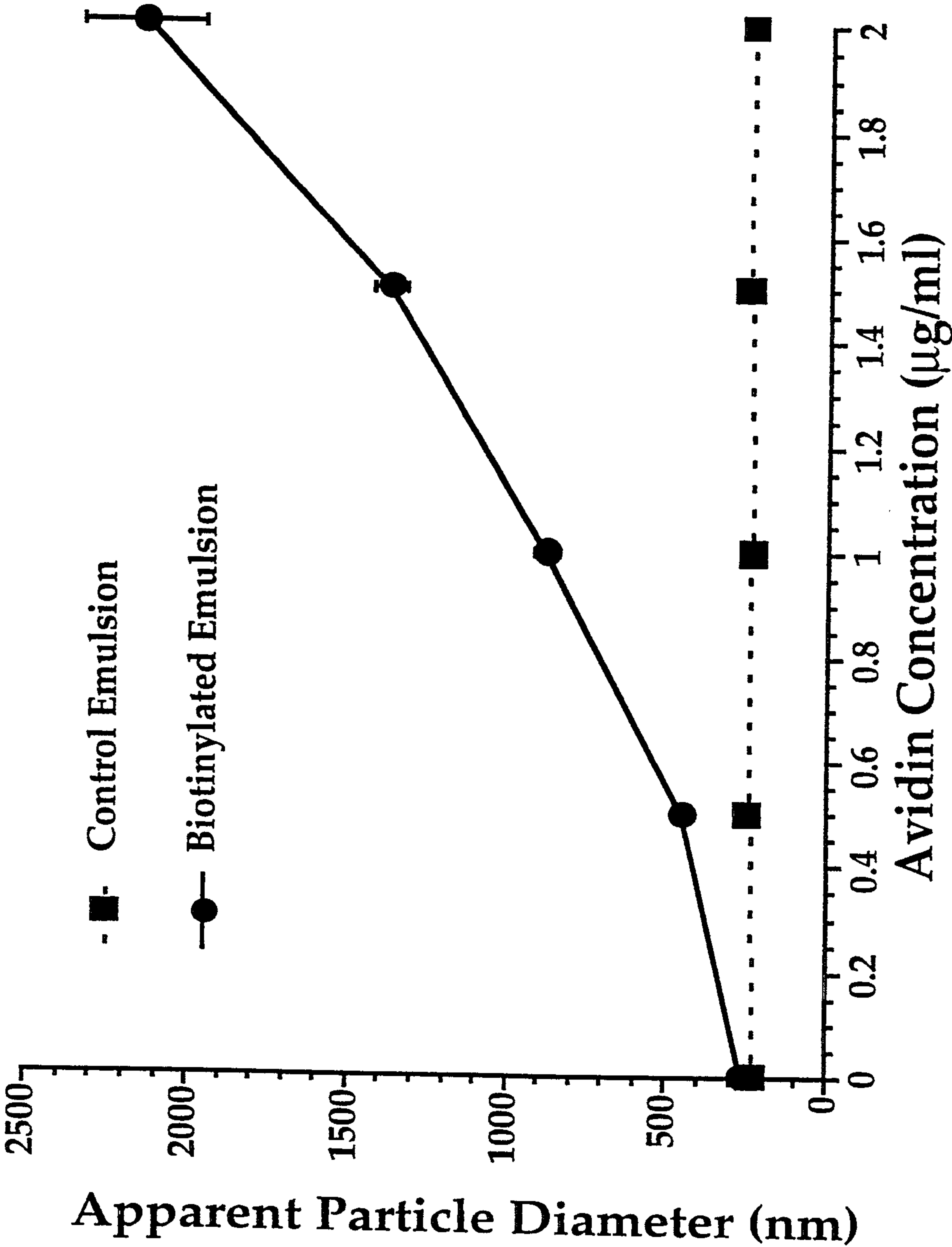
27. The use of any one of claims 19 to 26, wherein
5 said particles further comprise a chemotherapeutic agent.

SMART & BIGGAR

OTTAWA, CANADA

PATENT AGENTS

FIG. 1 Aggregate Particle Size Response of Control and Biotinylated Perfluorocarbon Emulsions to Titrated Levels of Avidin



*ULTRASONIC IMAGES OF CONTROL AND BIOTINYLATED
PERFLUOROCARBON EMULSION BEFORE AND AFTER
THE ADDITION OF AVIDIN*

Control Emulsion **Biotinylated Emulsion**

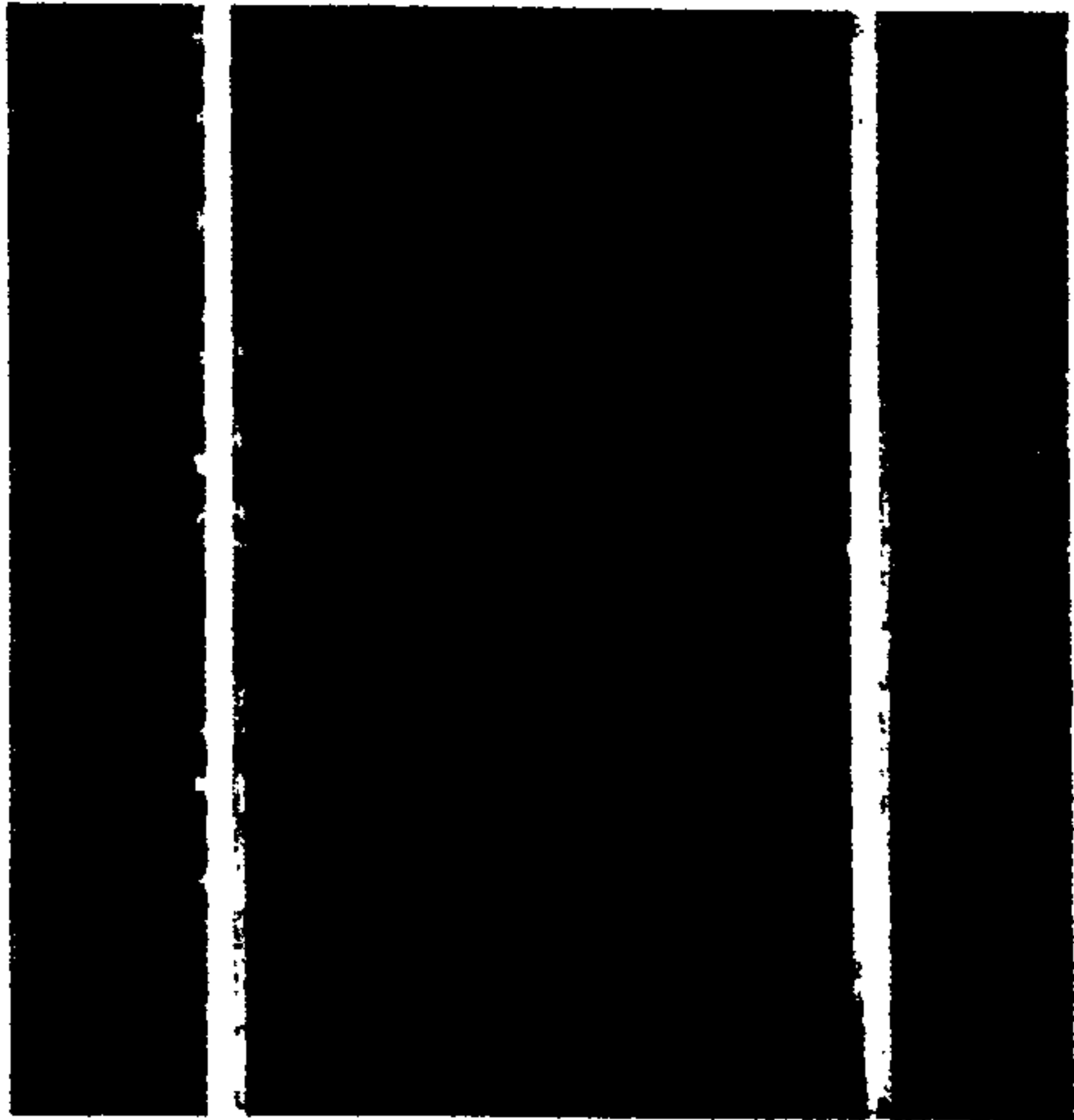


FIG. 2A
Before

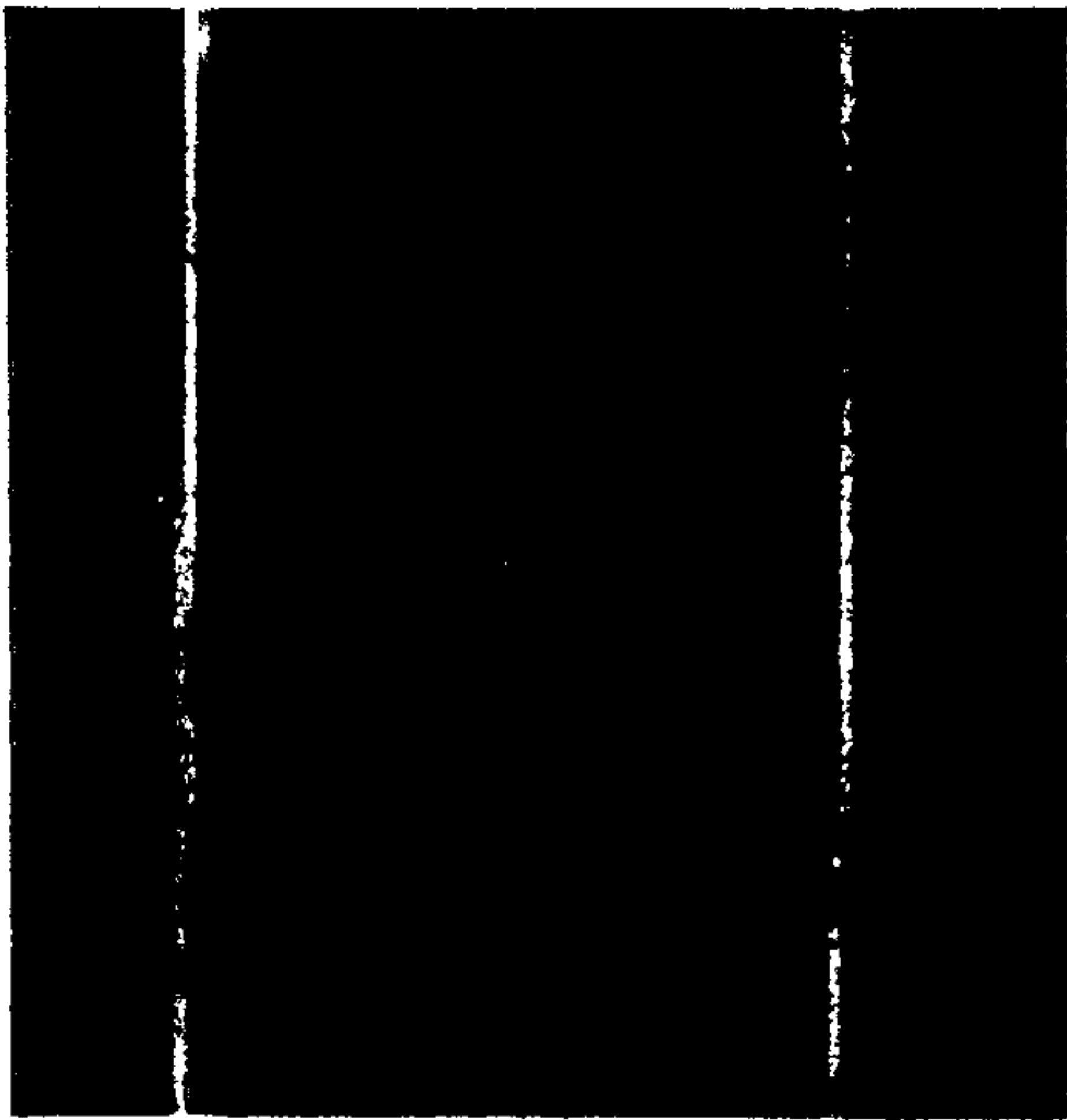


FIG. 2C
After

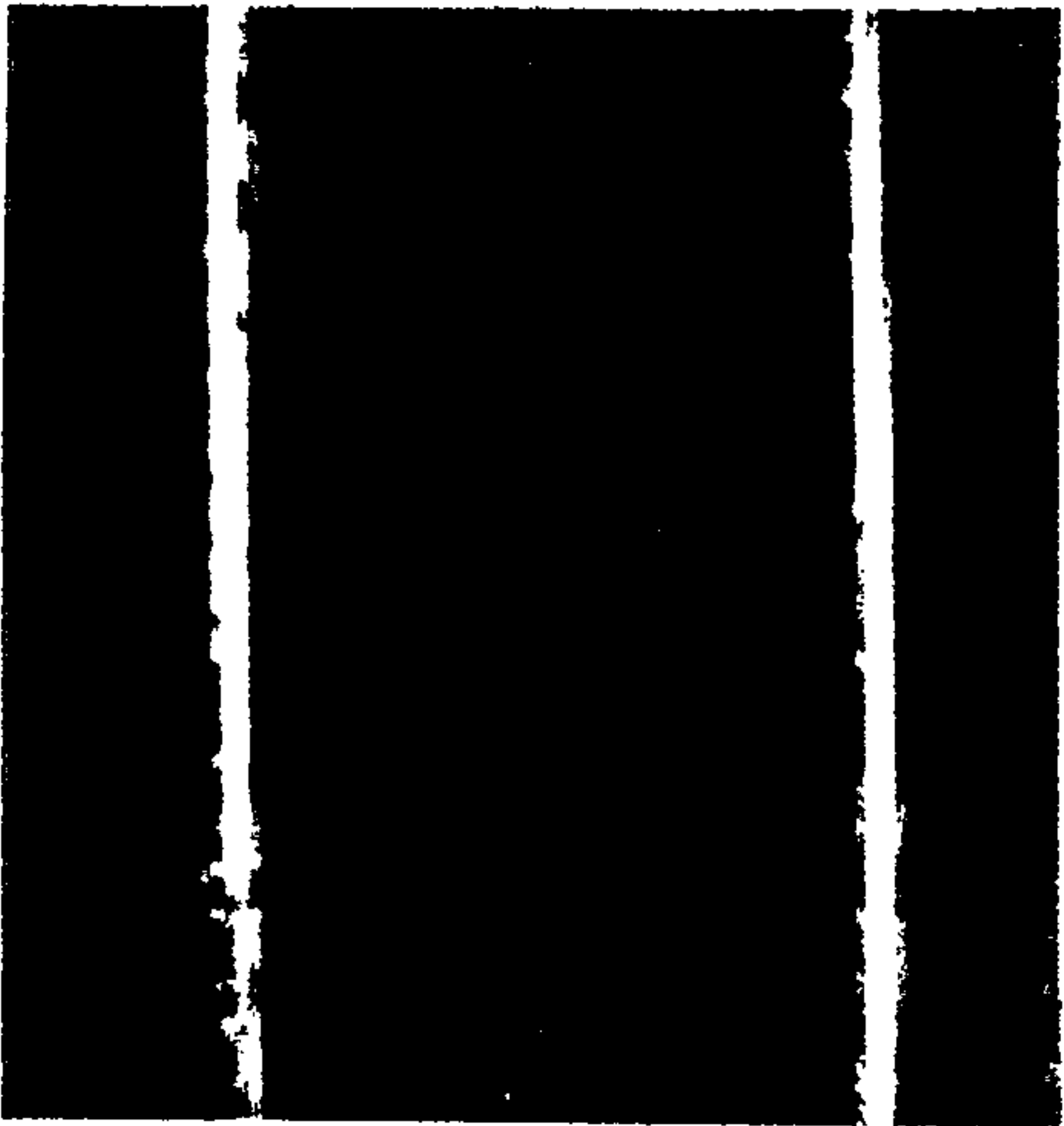


FIG. 2B
Before

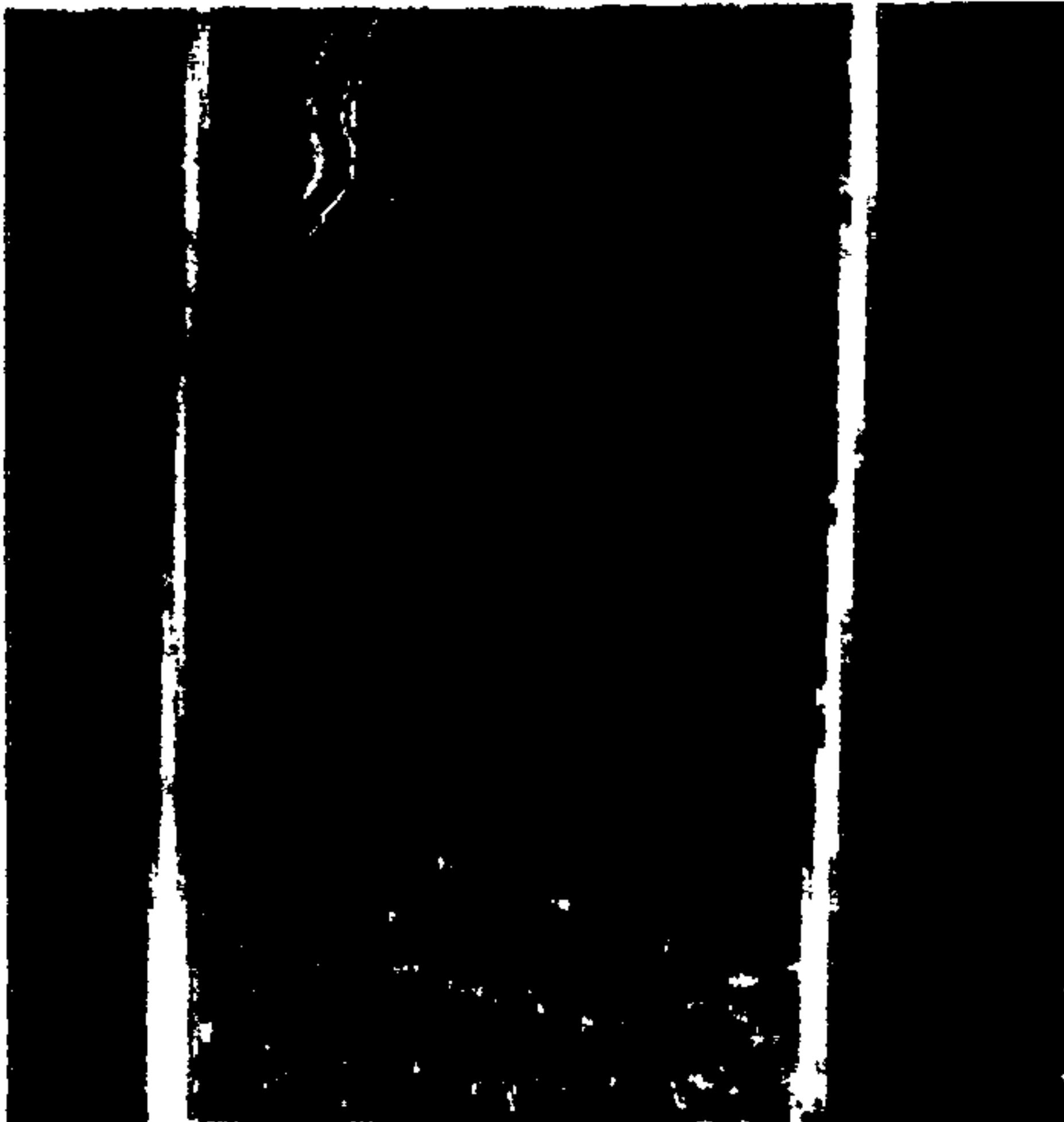


FIG. 2D
After

Graphic Illustration of Dialysis Tubing
Images and Region of Interest Placement for Gray
Scale Analysis

FIG.3A

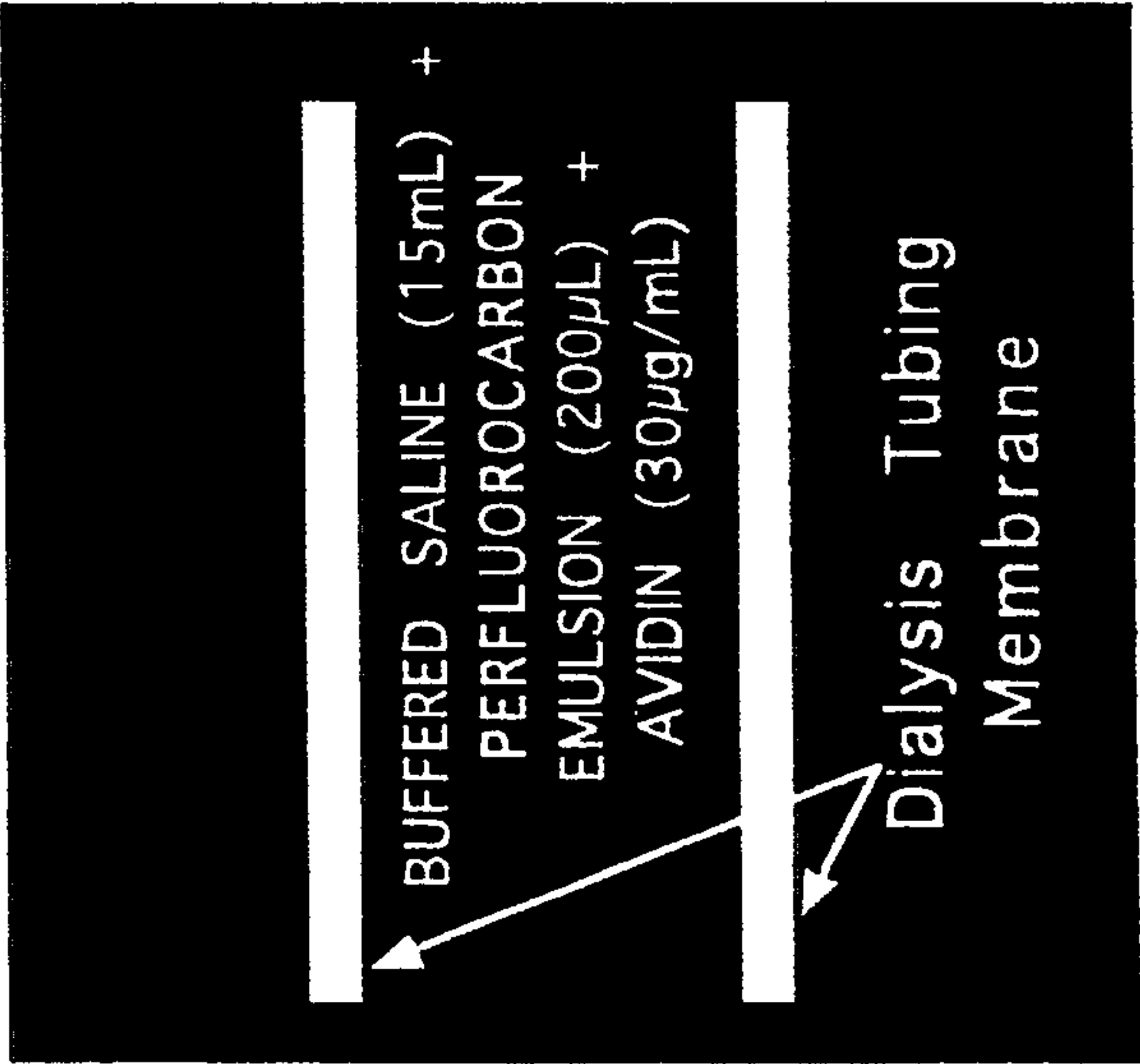


FIG.3B

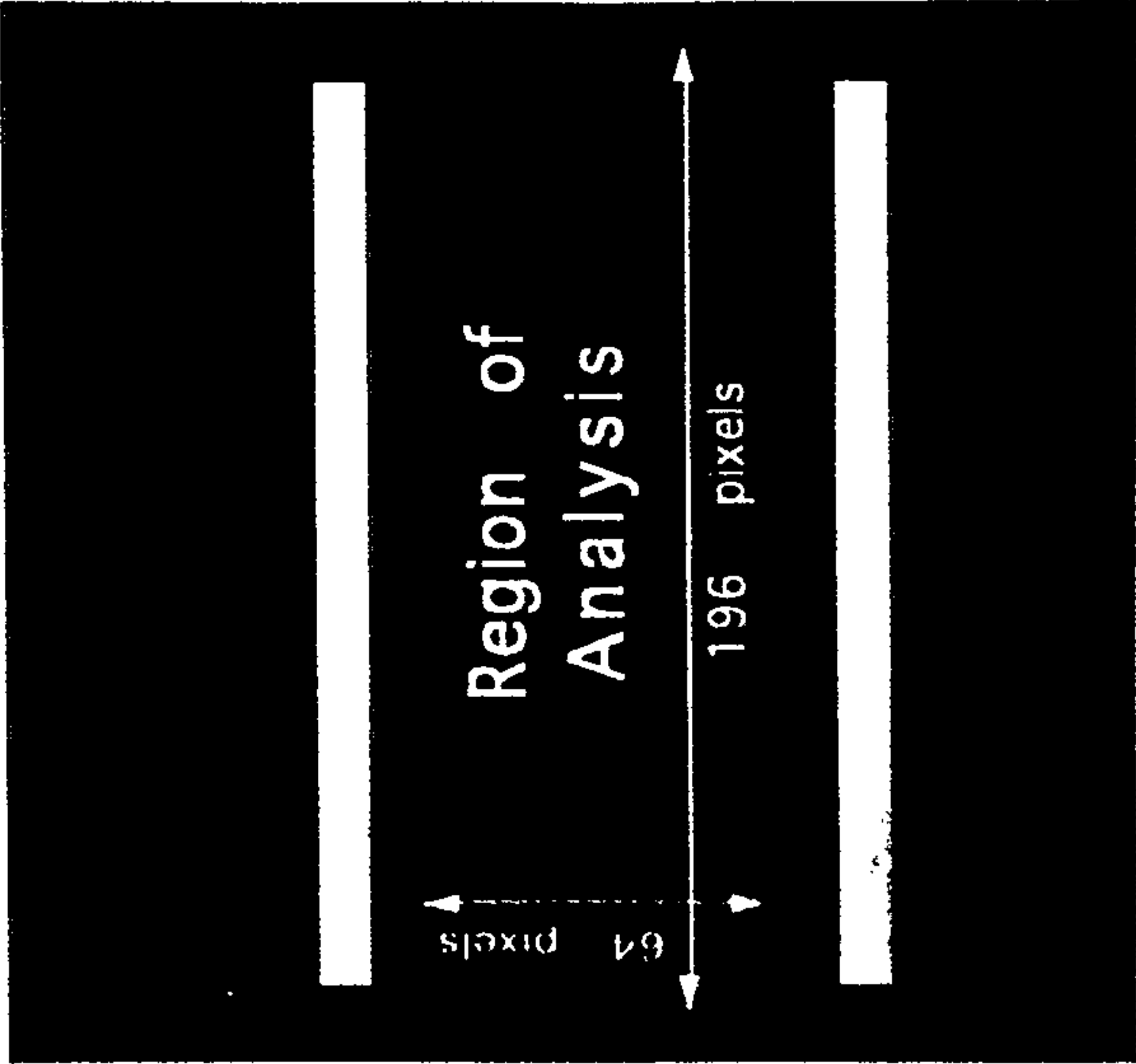
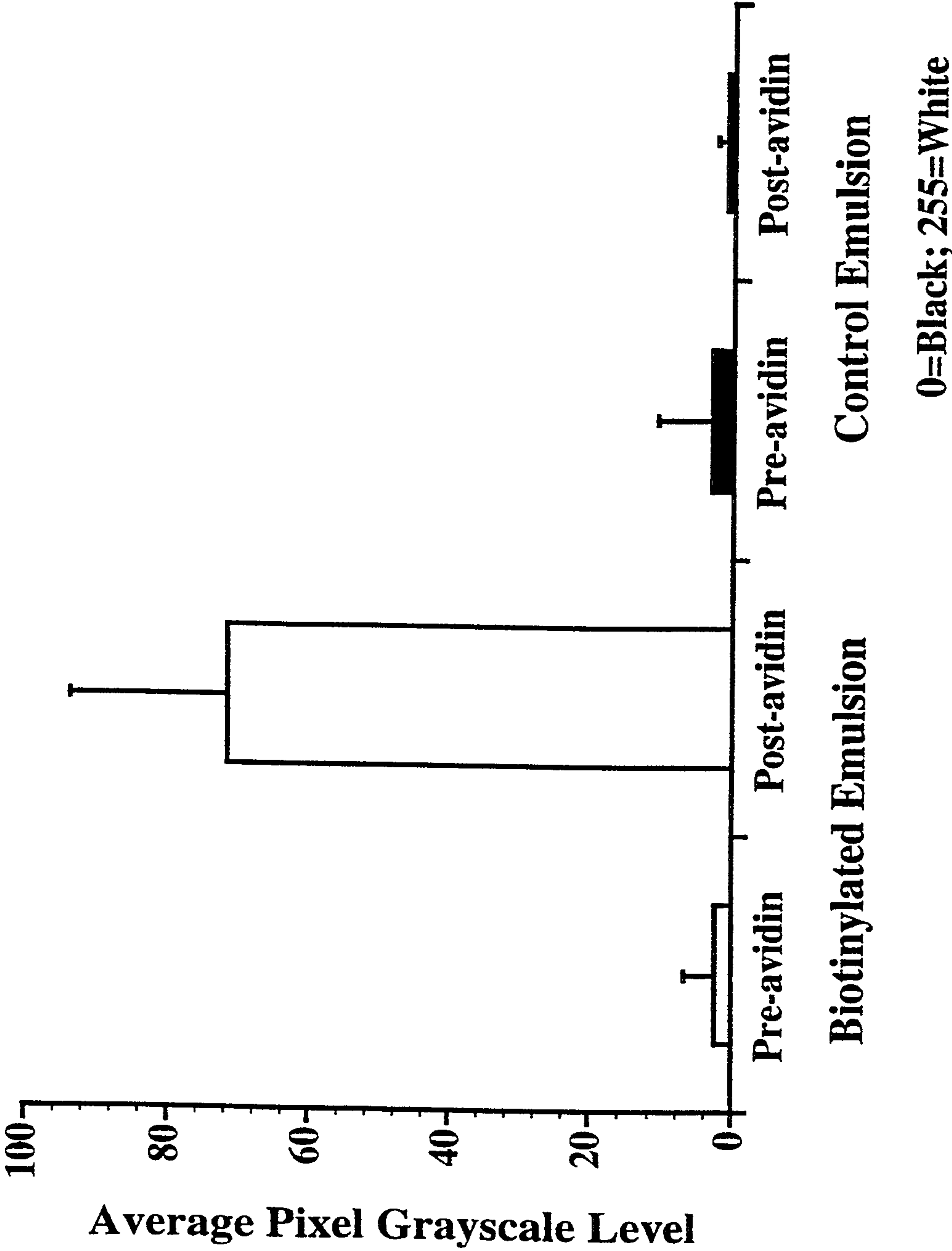


FIG. 4 **Changes in Average Pixel Gray Scale**
Associated with the Addition of Avidin to Control or
Biotinylated Perfluorocarbon Emulsion



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FIG. 5 The Effect of Control and Biotinylated
Perfluorocarbon Emulsion on Apparent Backscatter Transfer
Function and Integrated Backscatter of Avidinized
Nitrocellulose Membranes

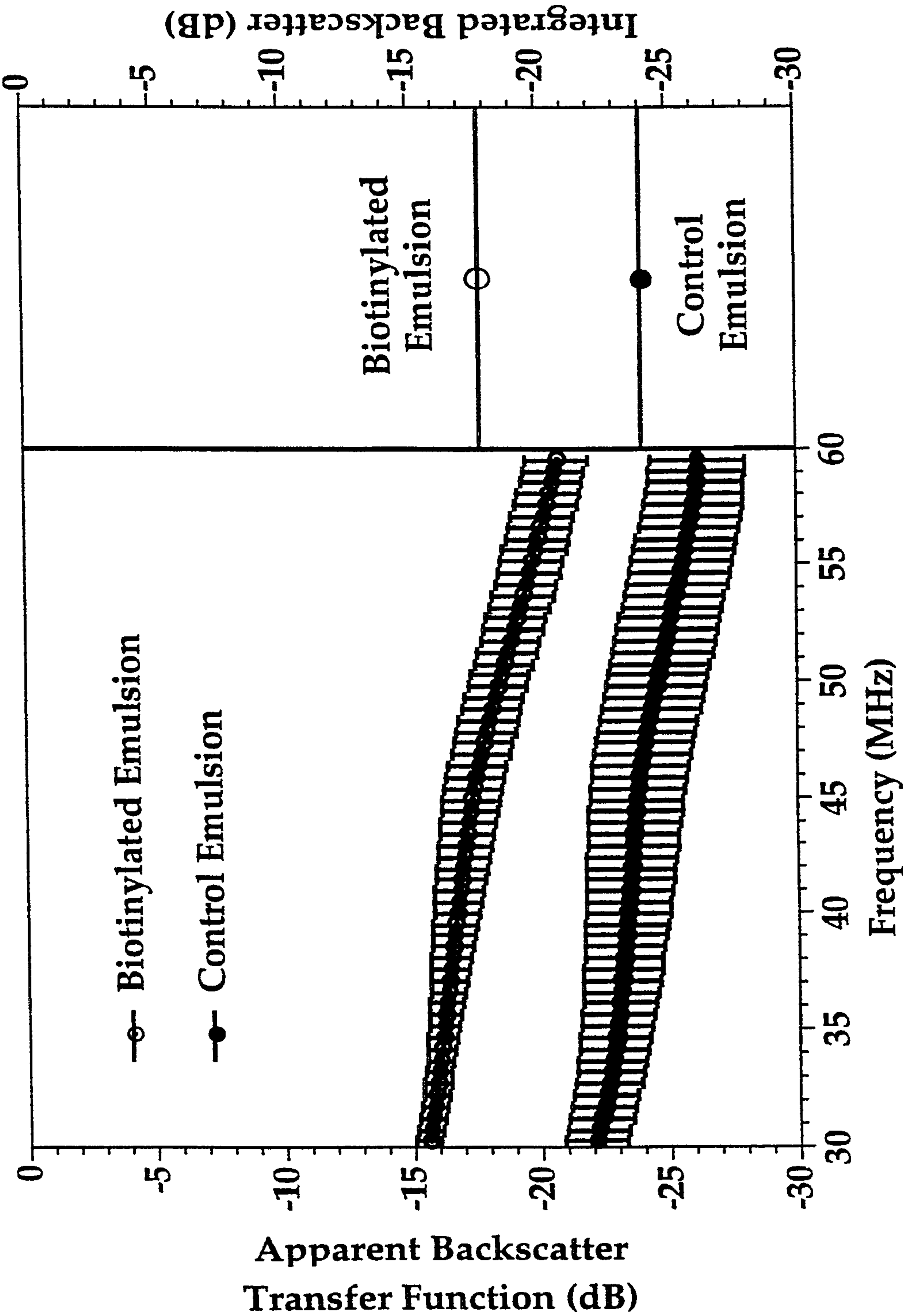
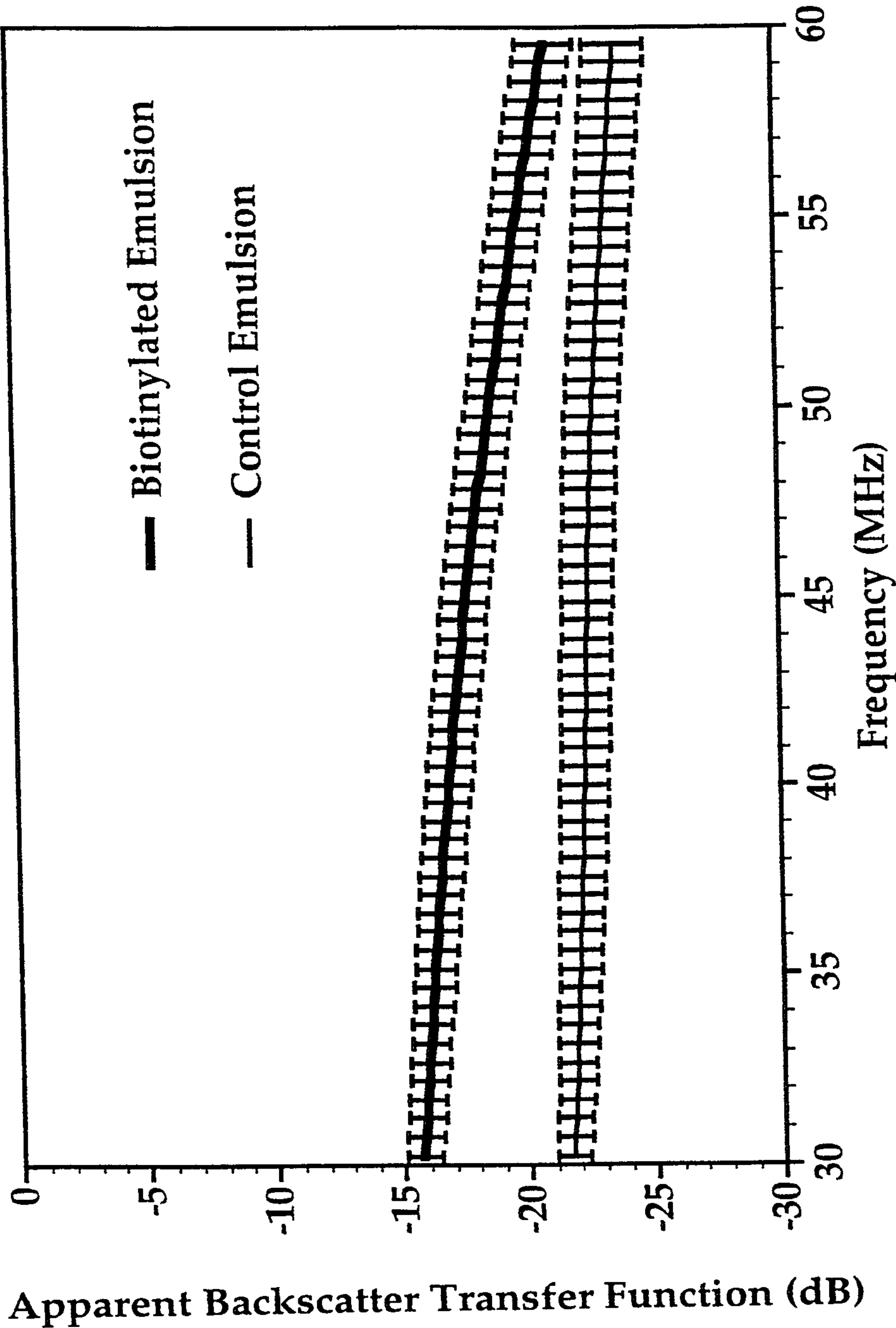


FIG. 6 Apparent Backscatter Transfer Function of
Biotinylated and Control Perfluorocarbon Emulsions
Targeted to D-dimer Covalently Conjugated to
Nitrocellulose Membranes



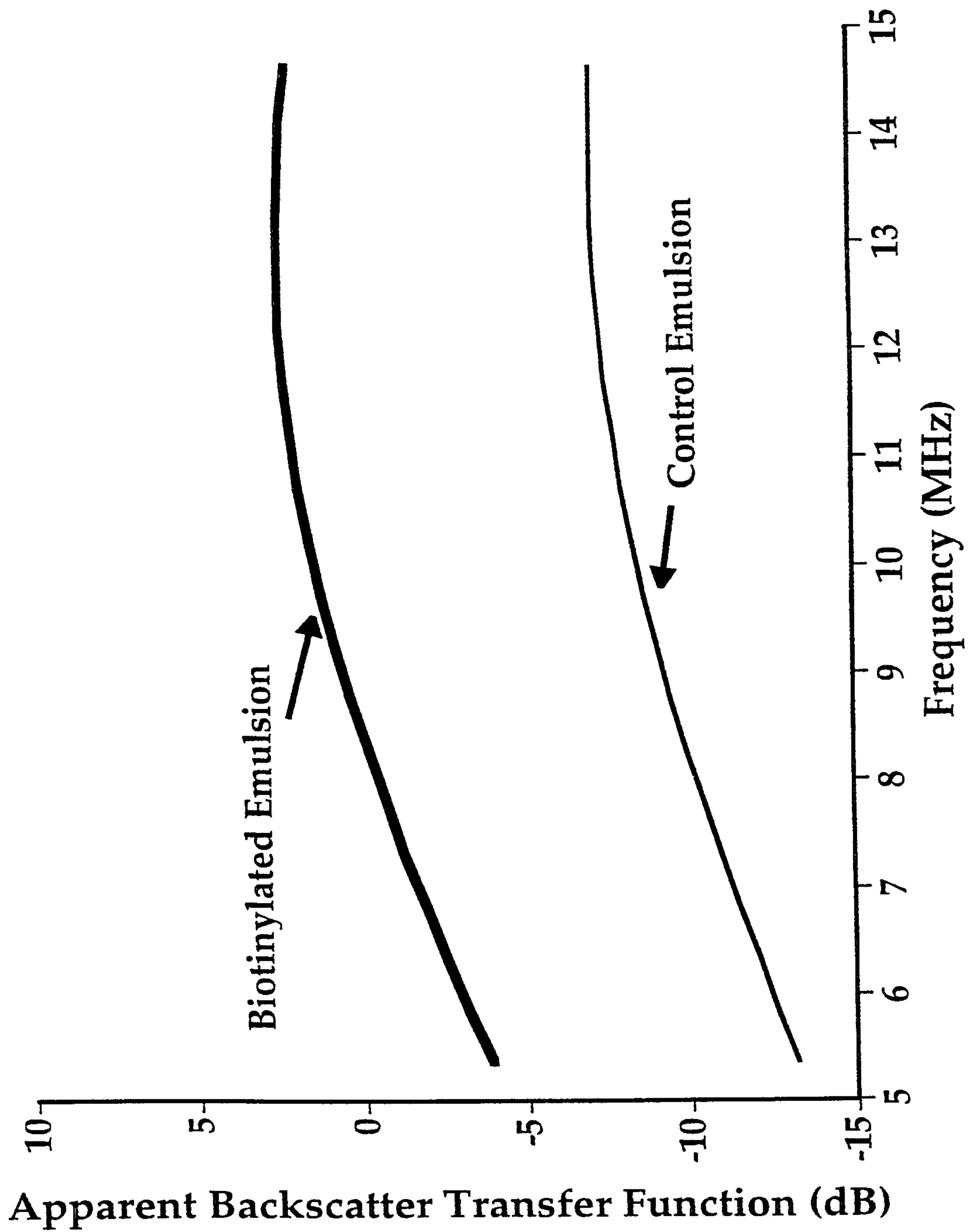
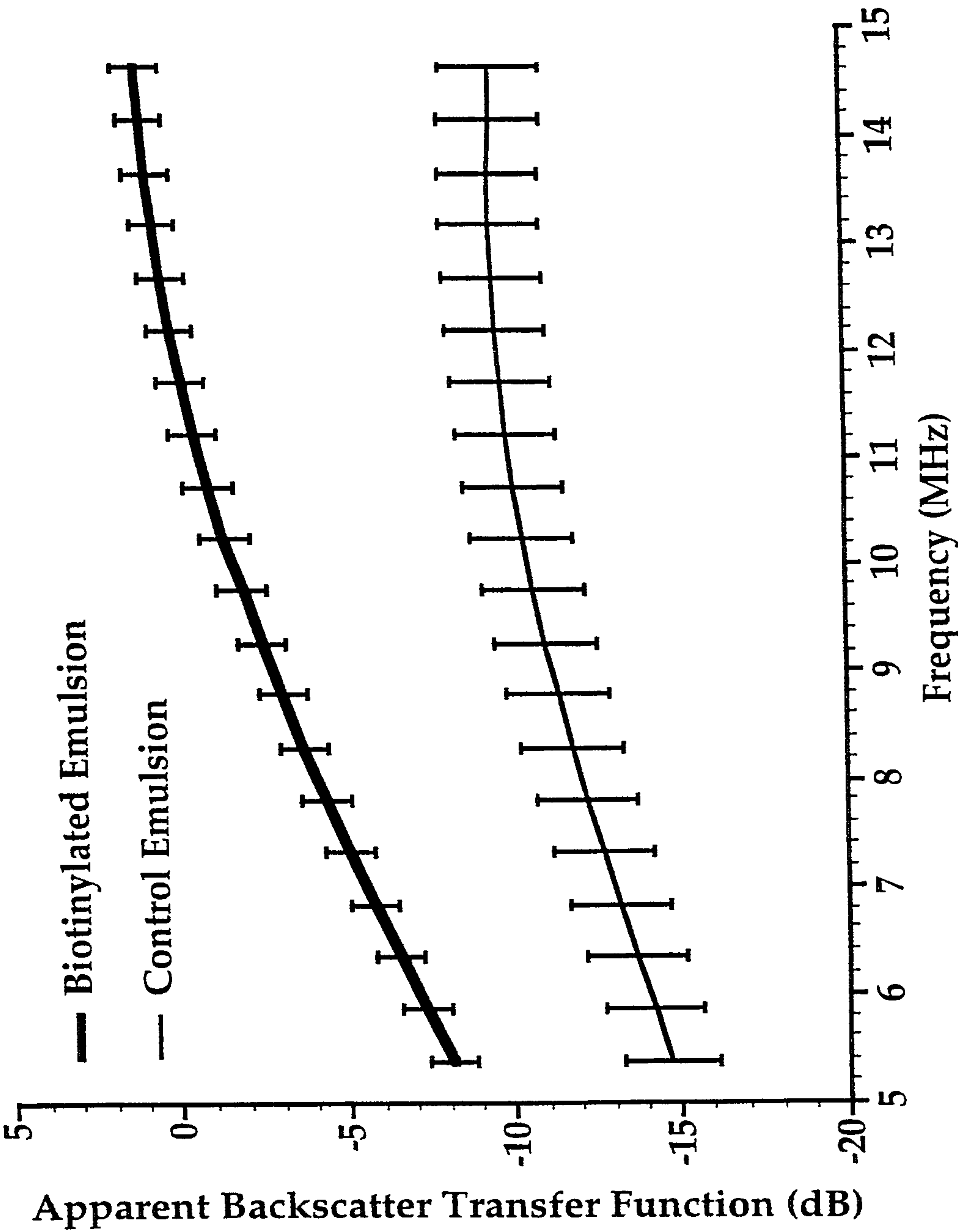
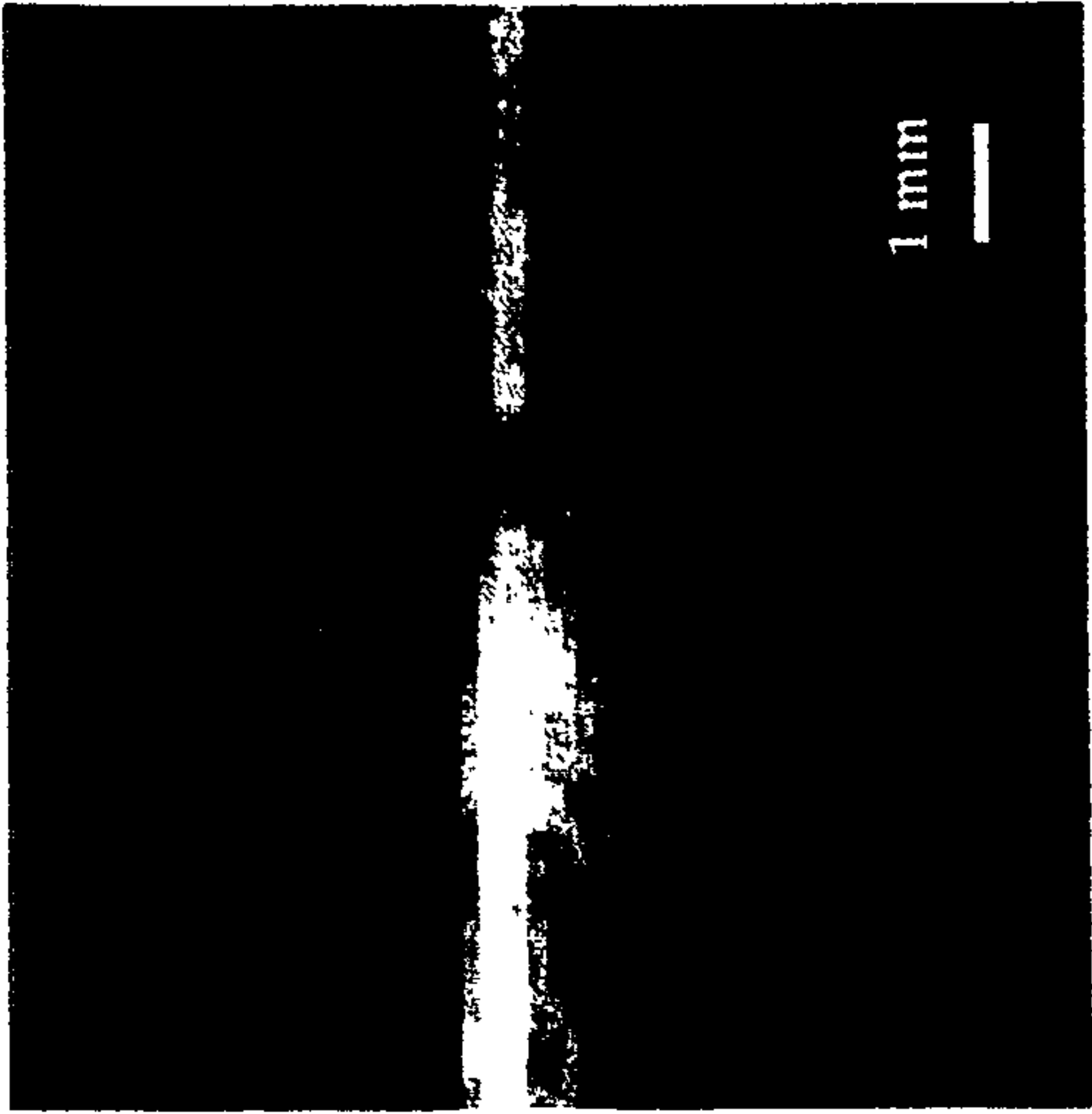


FIG. 8 Apparent Backscatter Transfer Function of
Biotinylated and Control Perfluorocarbon Large Particle Size
Emulsions Targeted to Avidinized Nitrocellulose Membranes



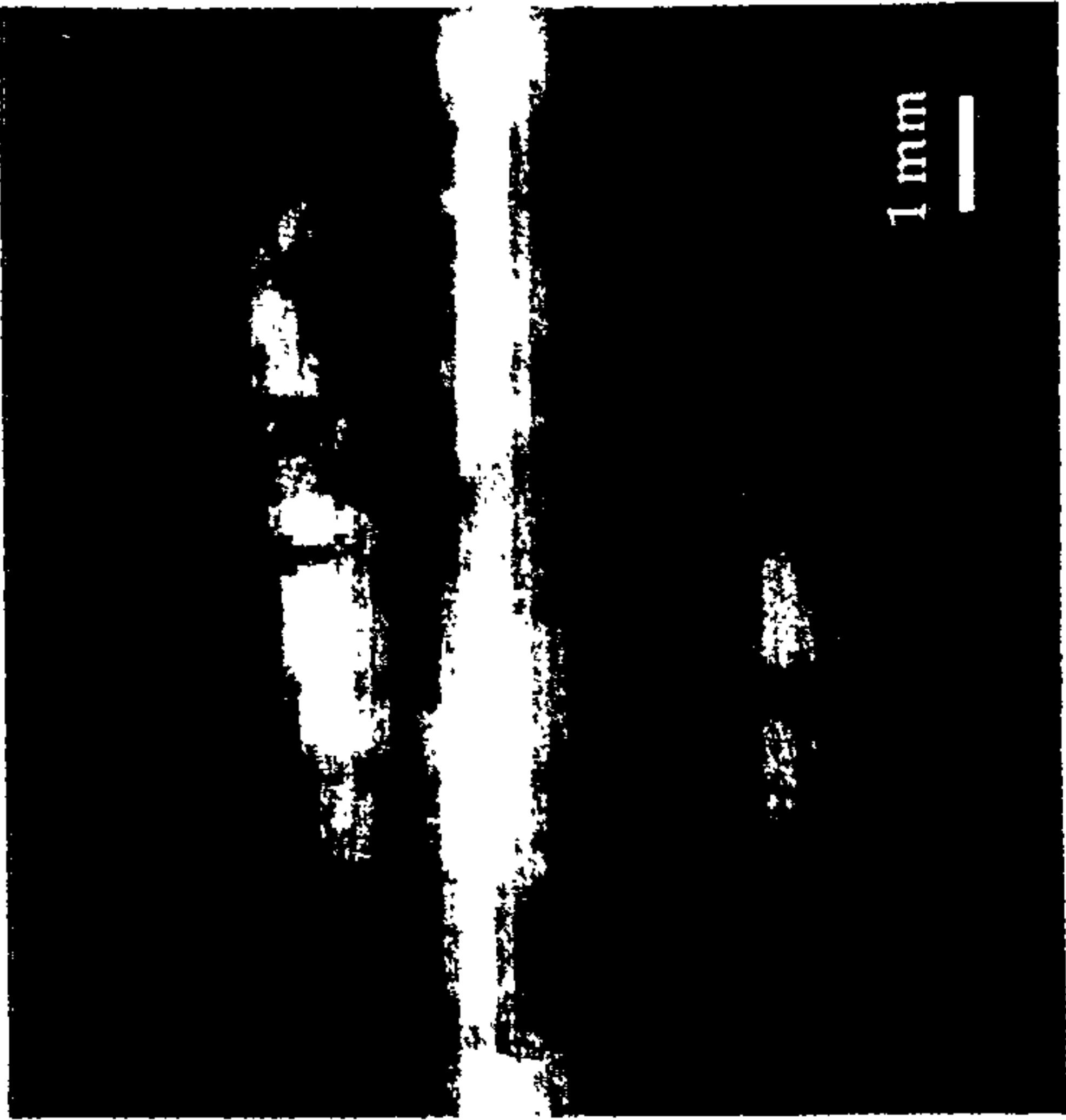
Ultrasonic Images (7.5 MHz) of Plasma Thrombi
Pre-targeted with Antifibrin Monoclonal Antibody and
Exposed to Control or Biotinylated Perfluorocarbon
Emulsion *in Vitro*

FIG.9A



Control Emulsion

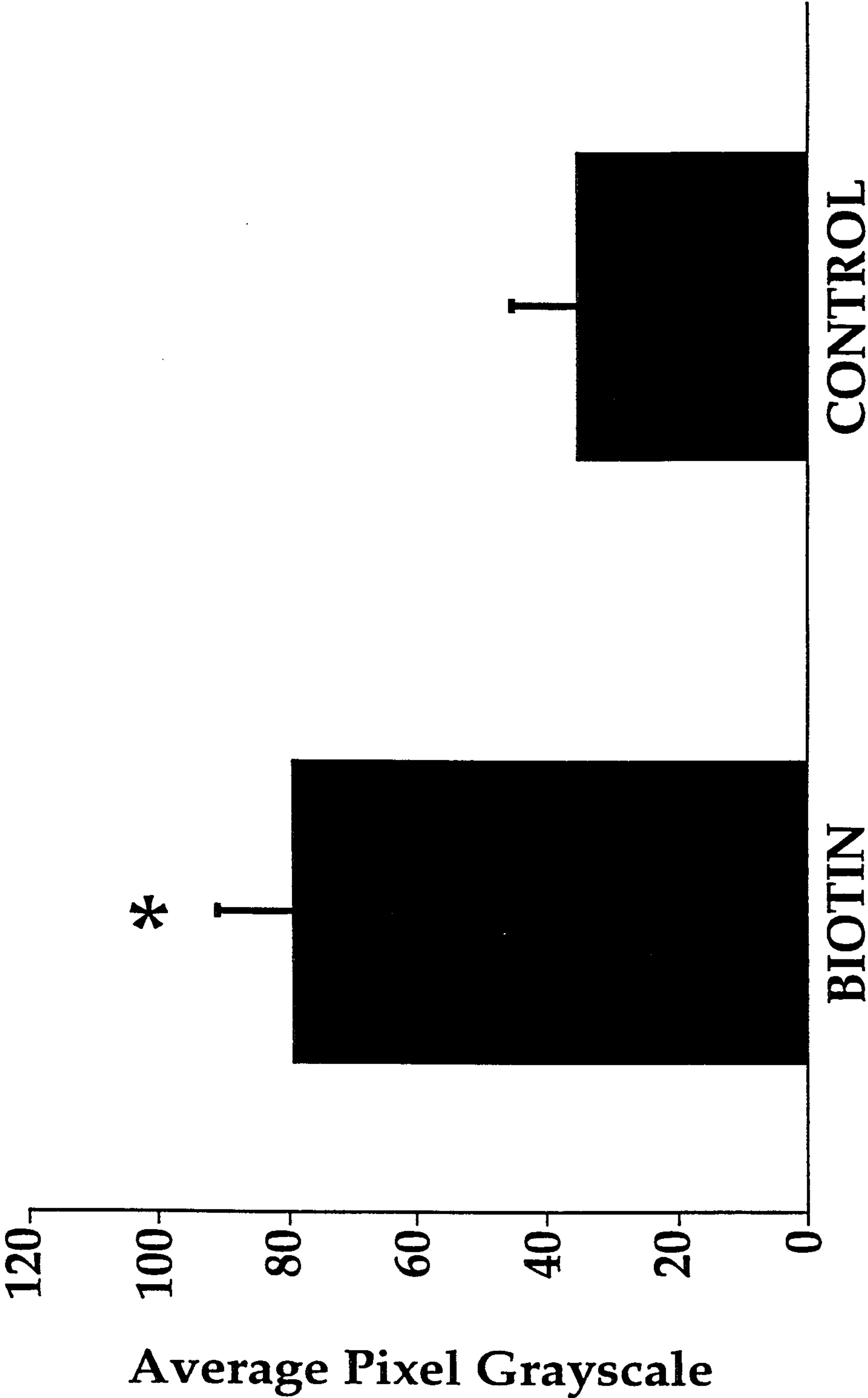
FIG.9B



Biotinylated Emulsion

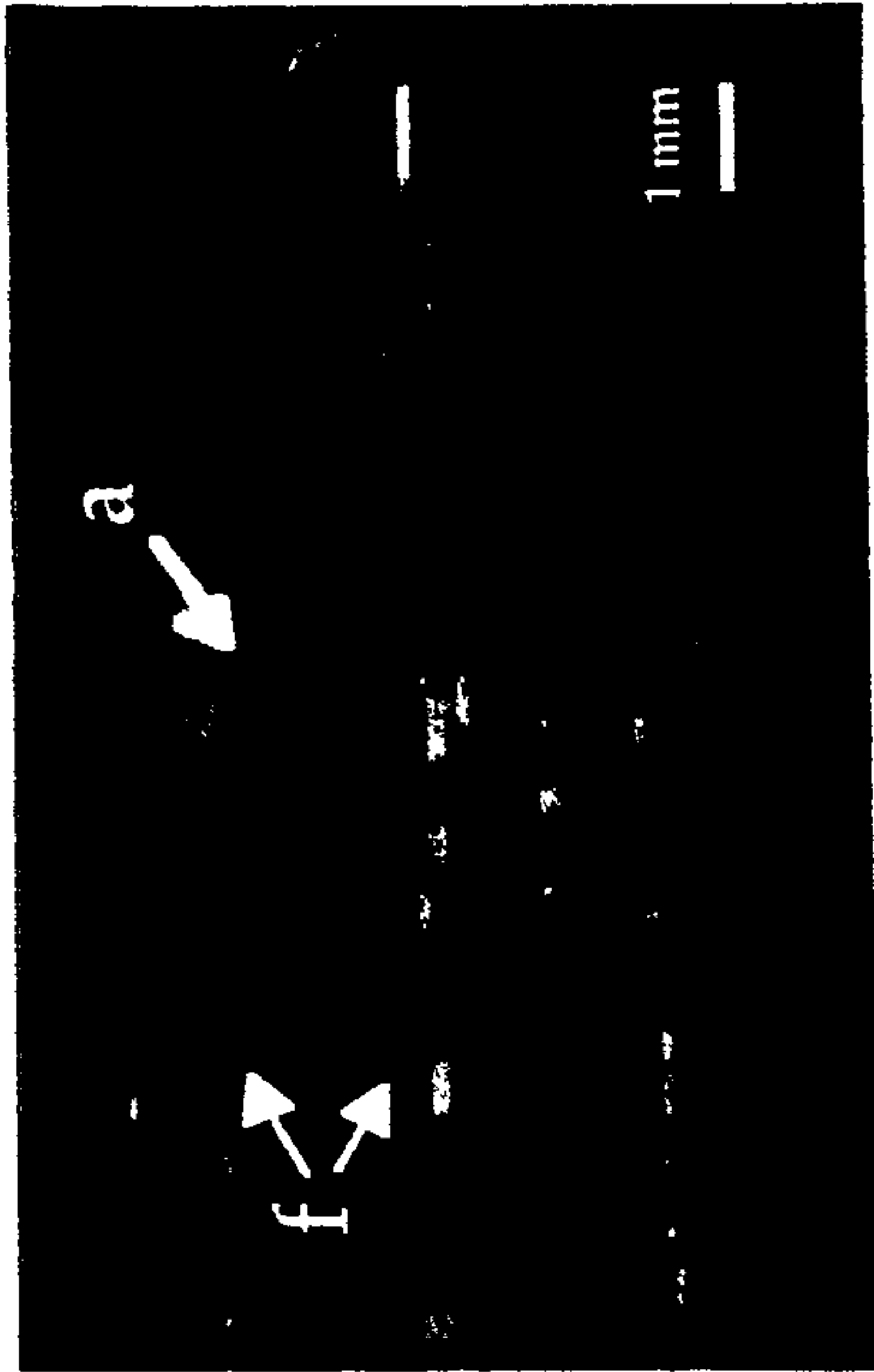
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FIG. 10 Average Pixel Grayscale of Plasma Thrombi
Pre-targeted with Antifibrin Monoclonal Antibody and
Exposed to Control or Biotinylated Perfluorocarbon Emulsion



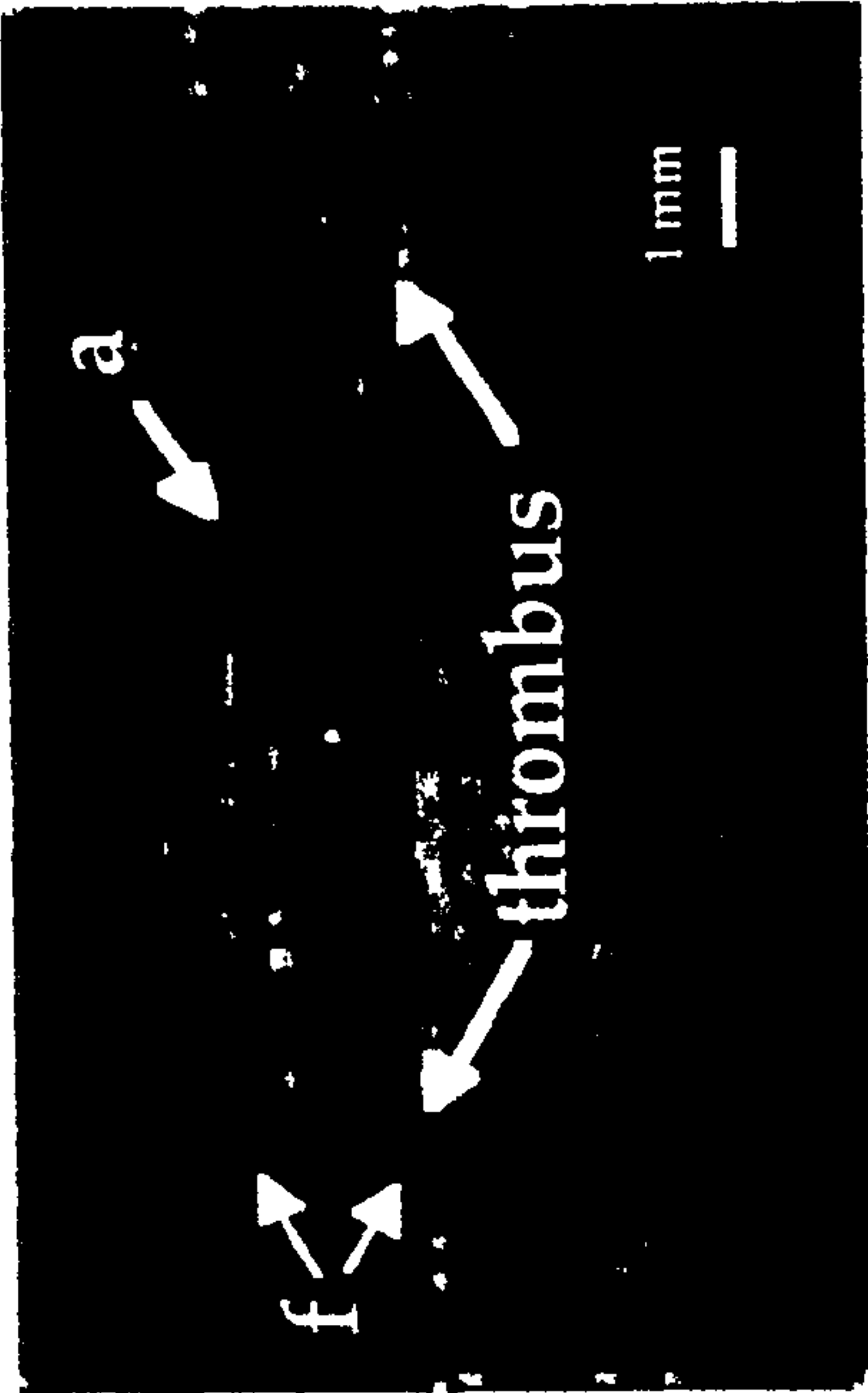
**Femoral Artery Thrombus Acoustically
Enhanced with Biotinylated Perfluorocarbon
Emulsion *In Vivo***

FIG.11A



**Thrombus Before Targeted
Biotinylated Contrast**

FIG.11B



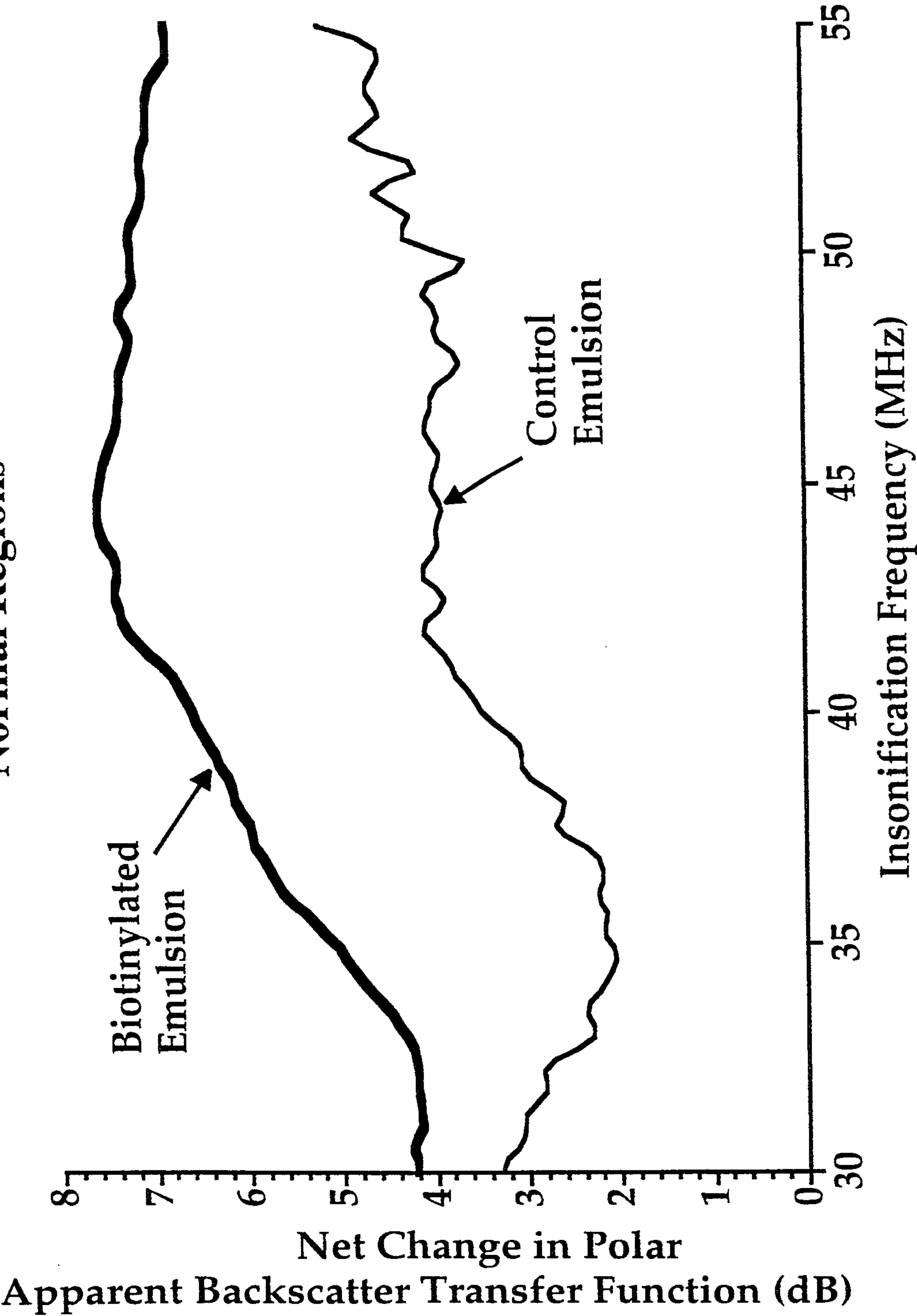
**Thrombus After Targeted
Biotinylated Contrast**

**Imaged with HP Sonos 2500
7.5 MHz Focused, Linear Phased Array Transducer**

Key: a=electrical anode; f=femoral artery walls

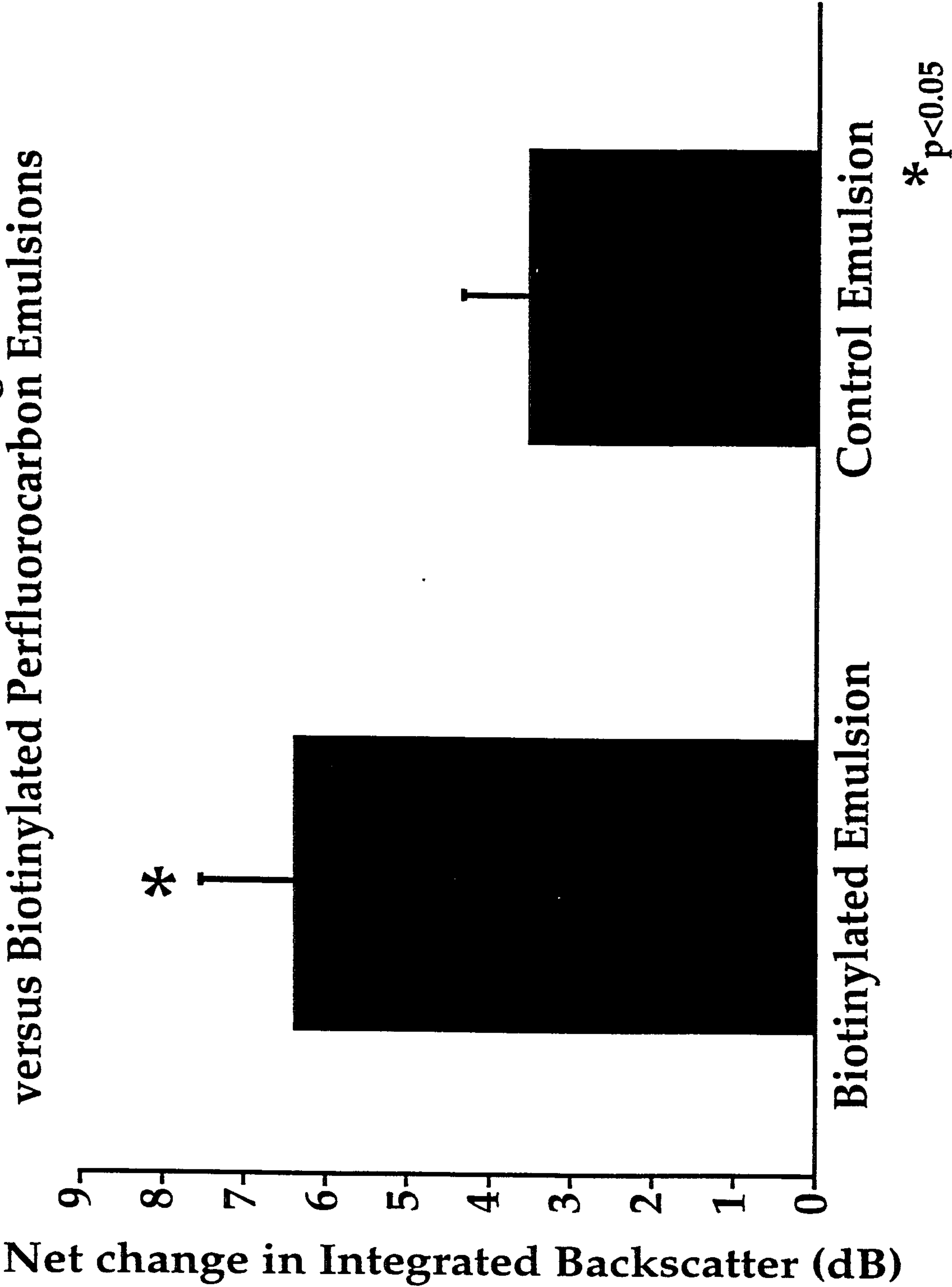
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FIG. 12 **Net Change in Apparent Backscatter Transfer Function**
of Biotinylated and Control Perfluorocarbon Emulsions Targeted to
Prostate Specific Antigen in Prostatic Carcinoma Relative to
Normal Regions



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FIG. 13 Net Change in Integrated Backscatter between
Normal Prostatic Stroma and Cancer Regions for Control
 versus Biotinylated Perfluorocarbon Emulsions



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FIG. 14 Net Change in Apparent Backscatter Transfer
Function of Biotinylated and Control Perfluorocarbon
Emulsions Targeted to OC-125 Antigen in Ovarian
Carcinoma Relative to Normal Regions

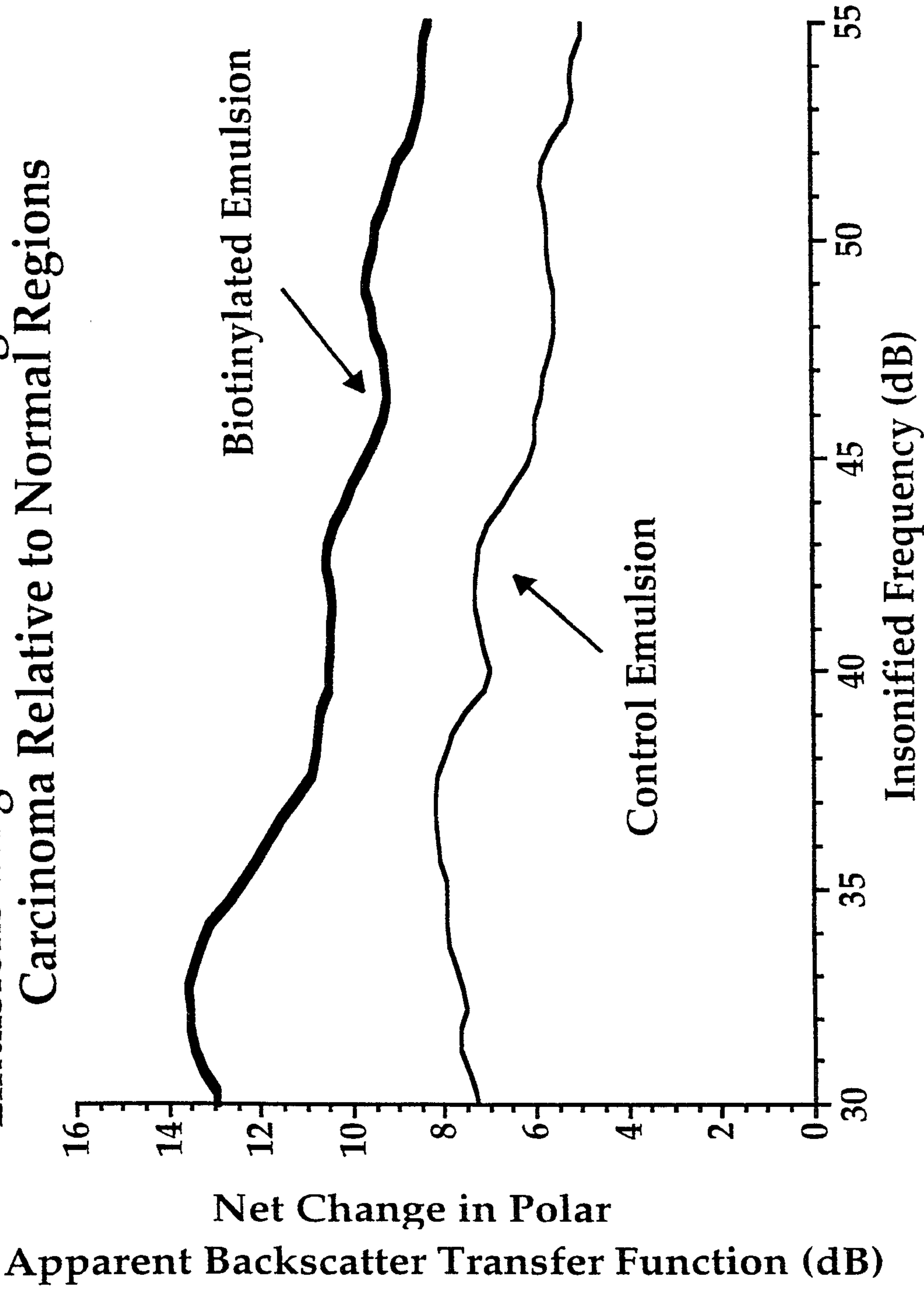
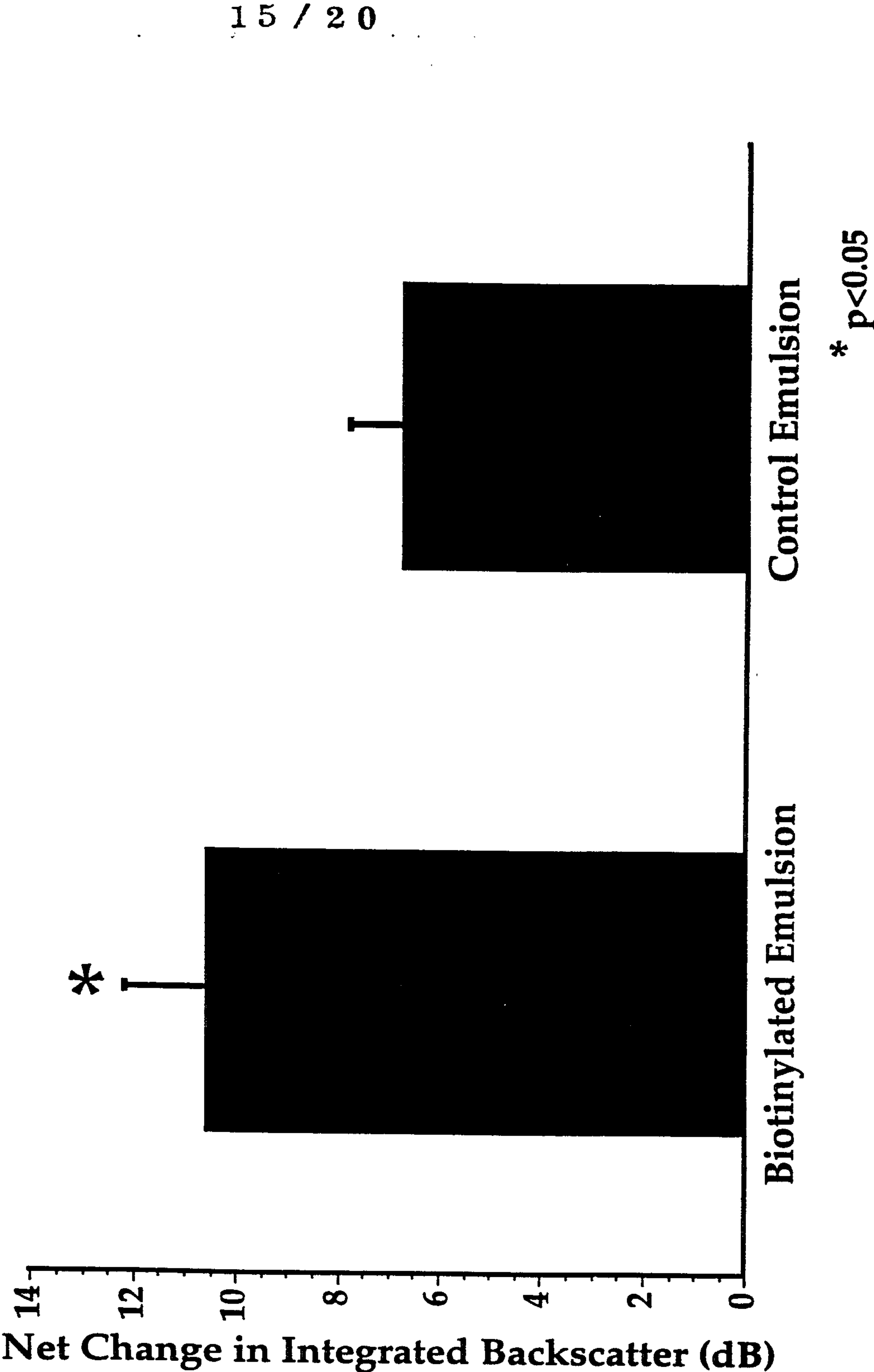


FIG. 15 Net Change in Integrated Backscatter Between
Normal Ovarian Tissue and Carcinoma Regions for
Control versus Biotinylated Perfluorocarbon Emulsions



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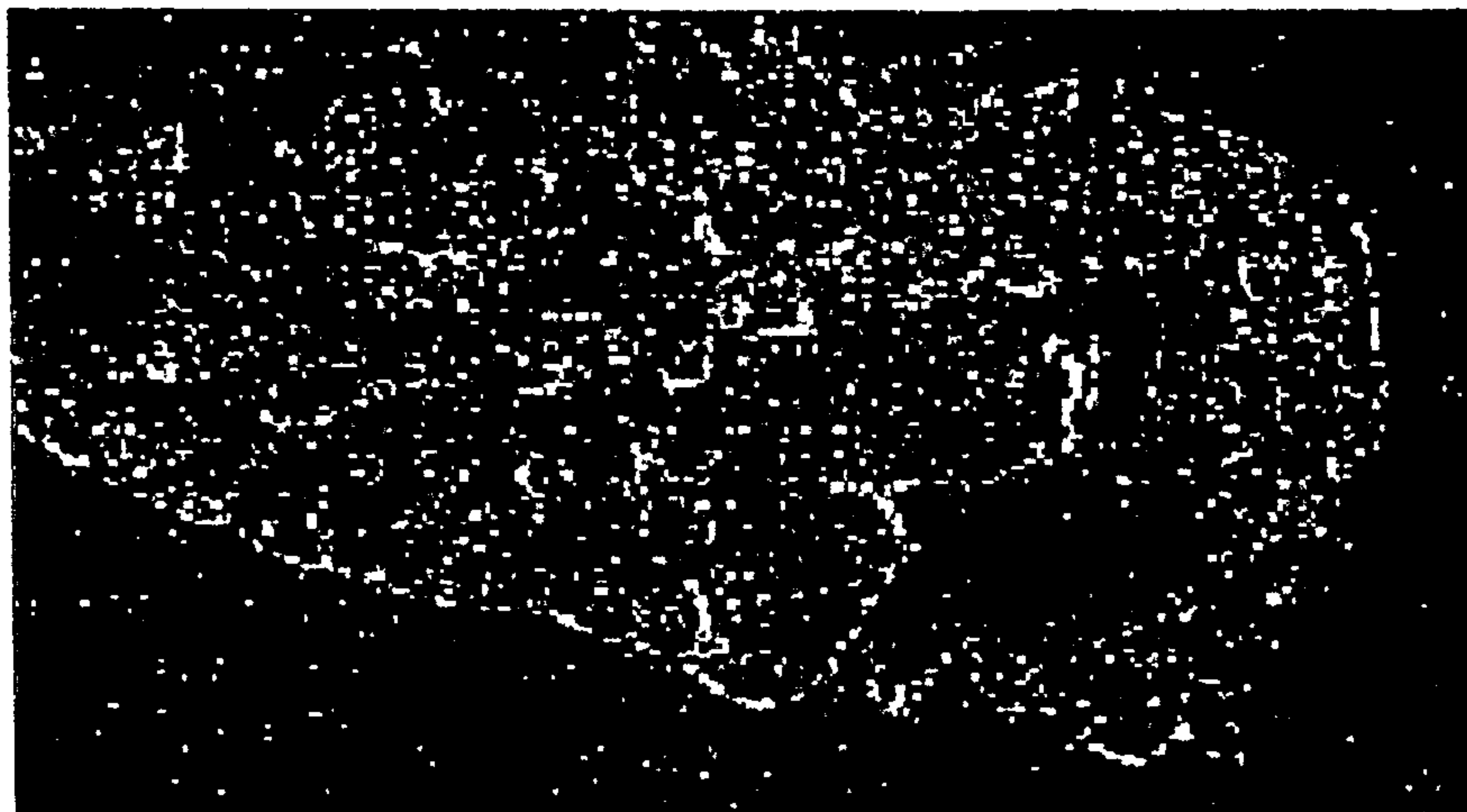
ULTRASONIC AND OPTICAL IMAGES OF TONSIL USING
PERFLUOROCARBON CONTRAST AND HORSE RADISH PEROXIDASE
TARGETED TO EPITHELIUM WITH ANTICYTOKERATIN ANTIBODIES

FIG. 16B



IMMUNOSTAINED TONSIL

FIG. 16A

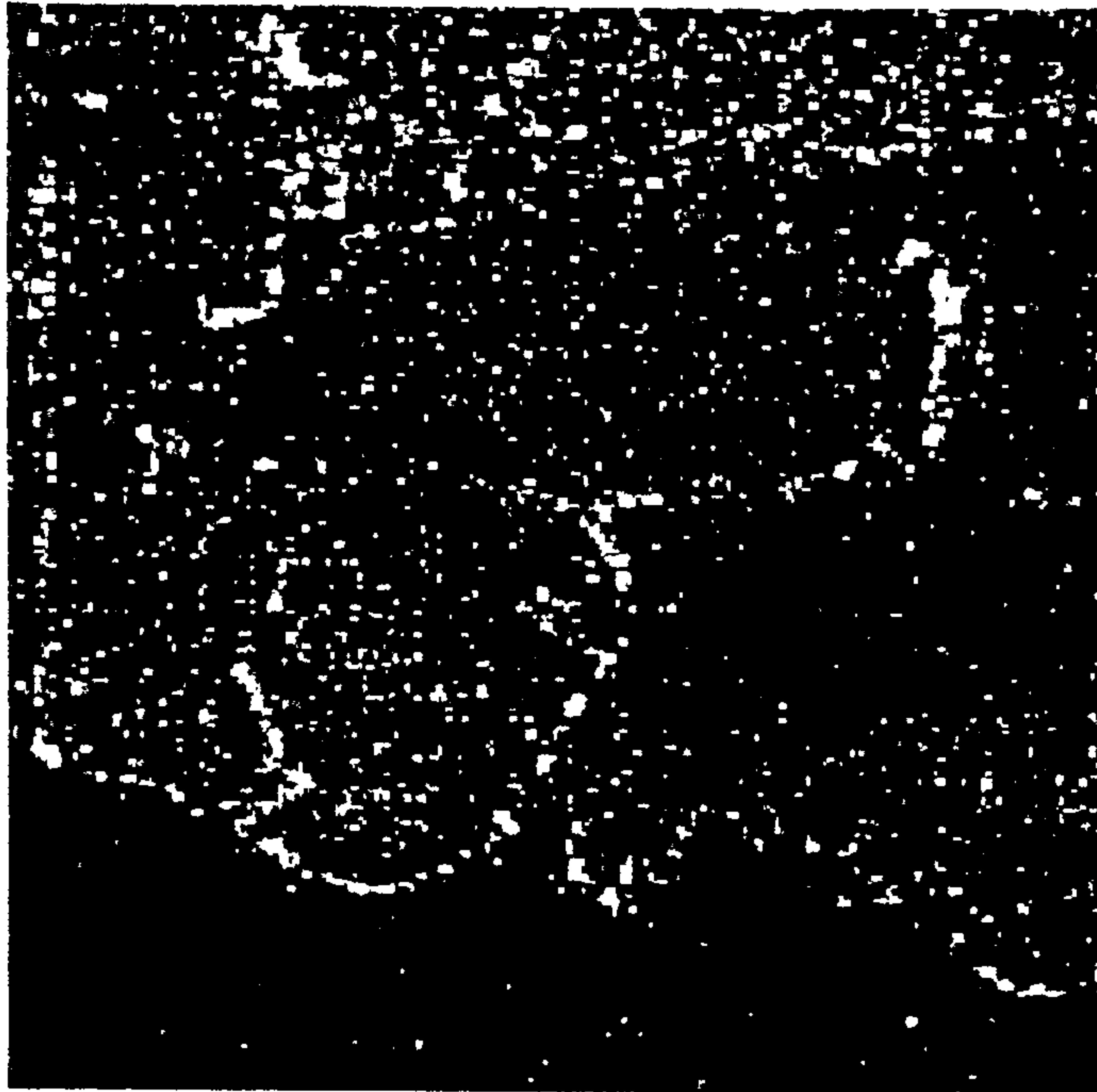


PEAK DETECTED IMAGE
100 μ m SIZE

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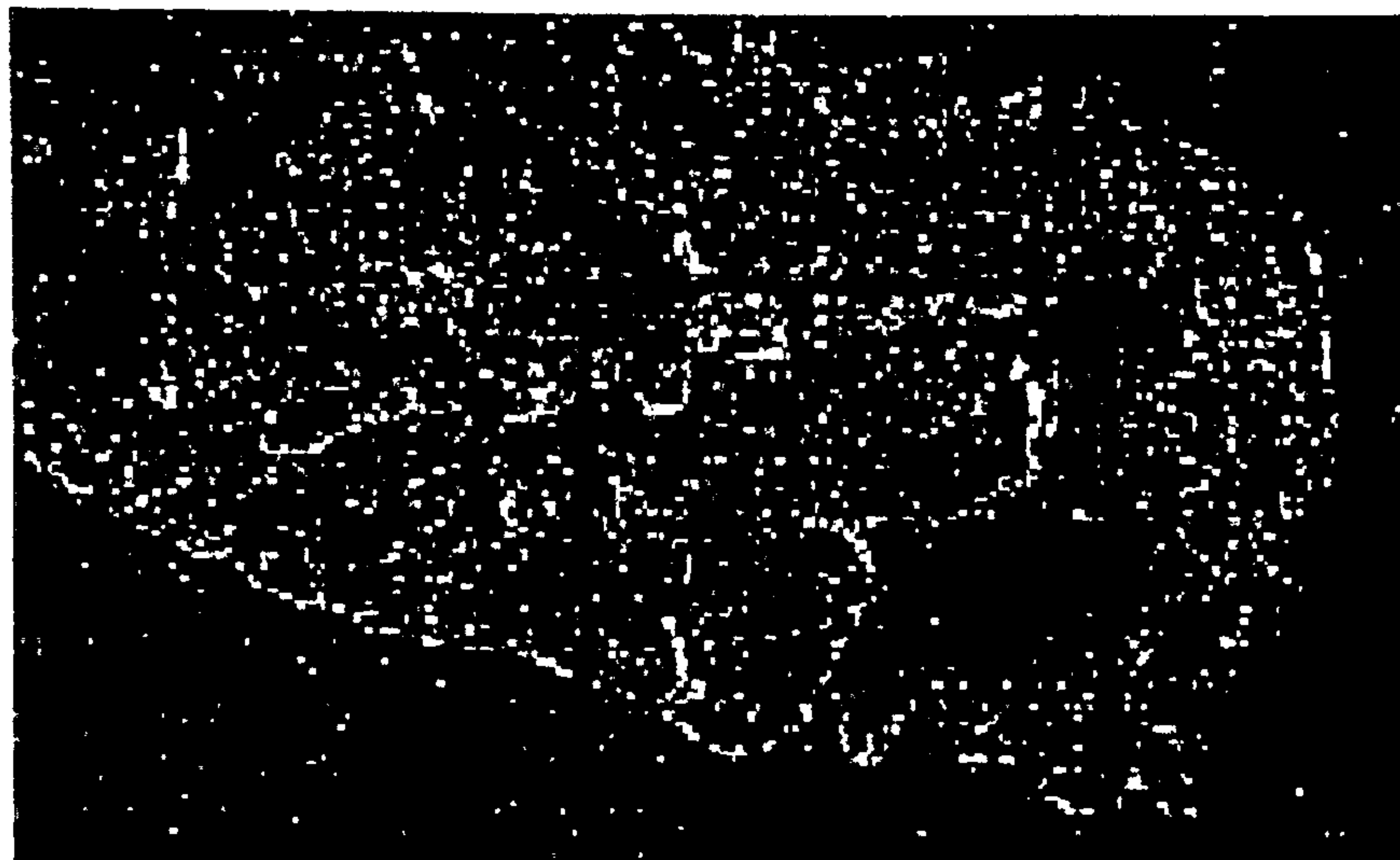
PEAK DETECTED ULTRASONIC IMAGES OF TONSIL
EPITHELIUM ACOUSTICALLY ENHANCED WITH ANTICYTOKERATIN
ANTIBODY TARGETED PERFLUOROCARBON EMULSION

FIG.17B



ZOOM : 50μ STEP SIZE

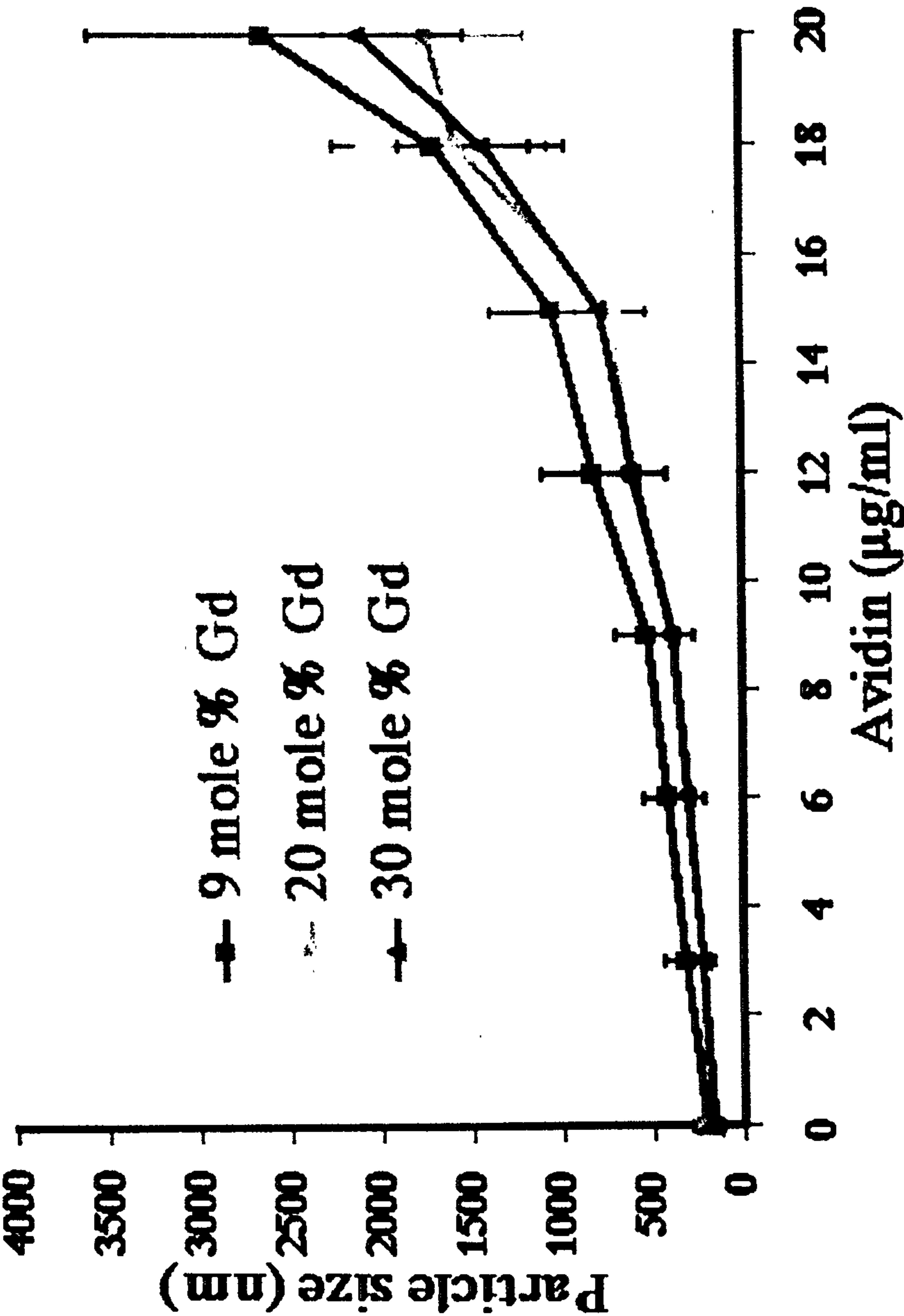
FIG.17A



PEAK DETECTED IMAGE
100μ STEP SIZE

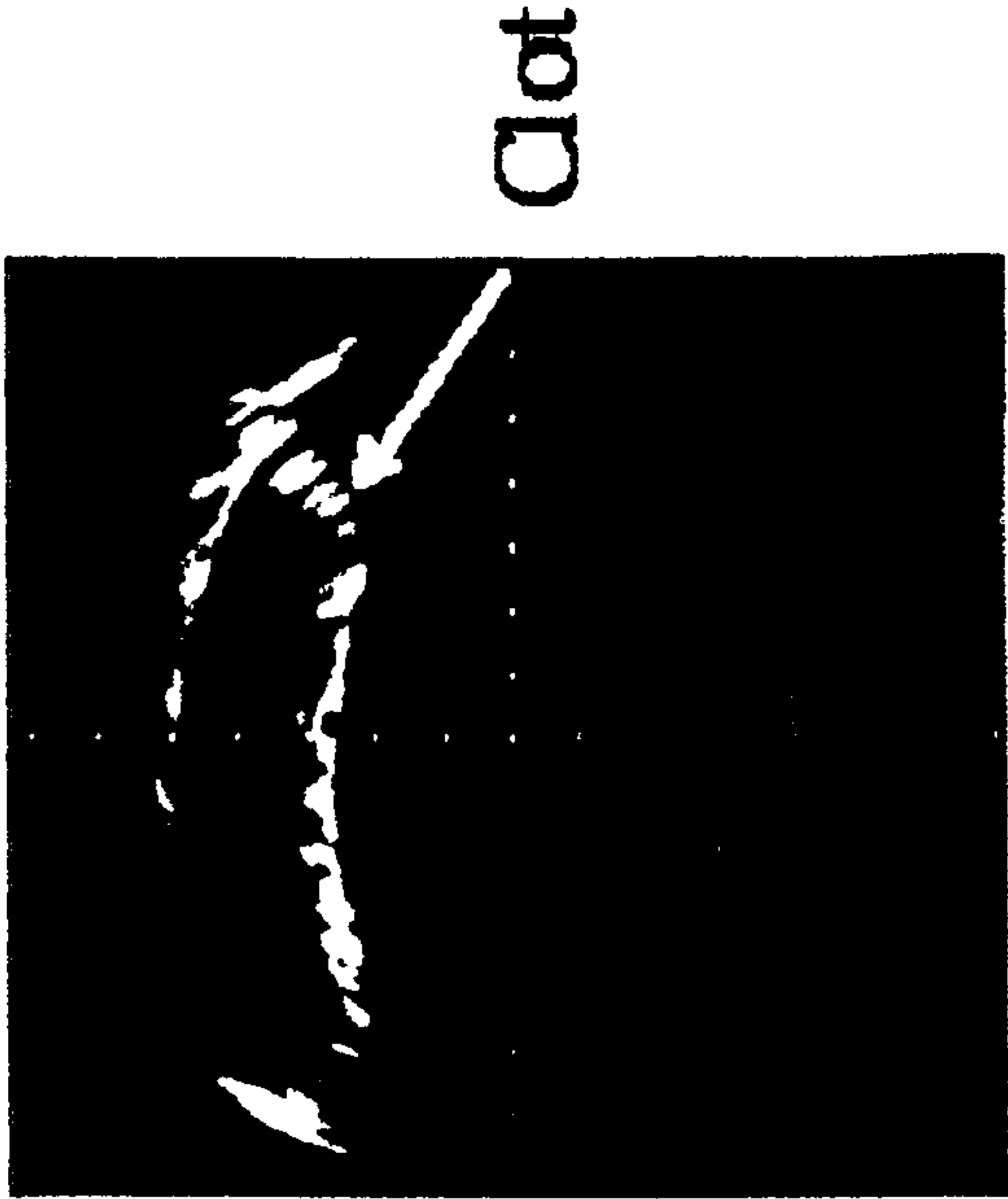
Avidin Titration Curves for Three Biotinylated
Perfluorocarbon Emulsions Incorporating Varying
Concentrations of Gadolinium-DTPA-BOA

FIG. 18



Enhancement of the Acoustic Reflectivity of
Plasma Clots Treated with Targeted
Perfluorocarbon Dual Ultrasonic and MRI Contrast

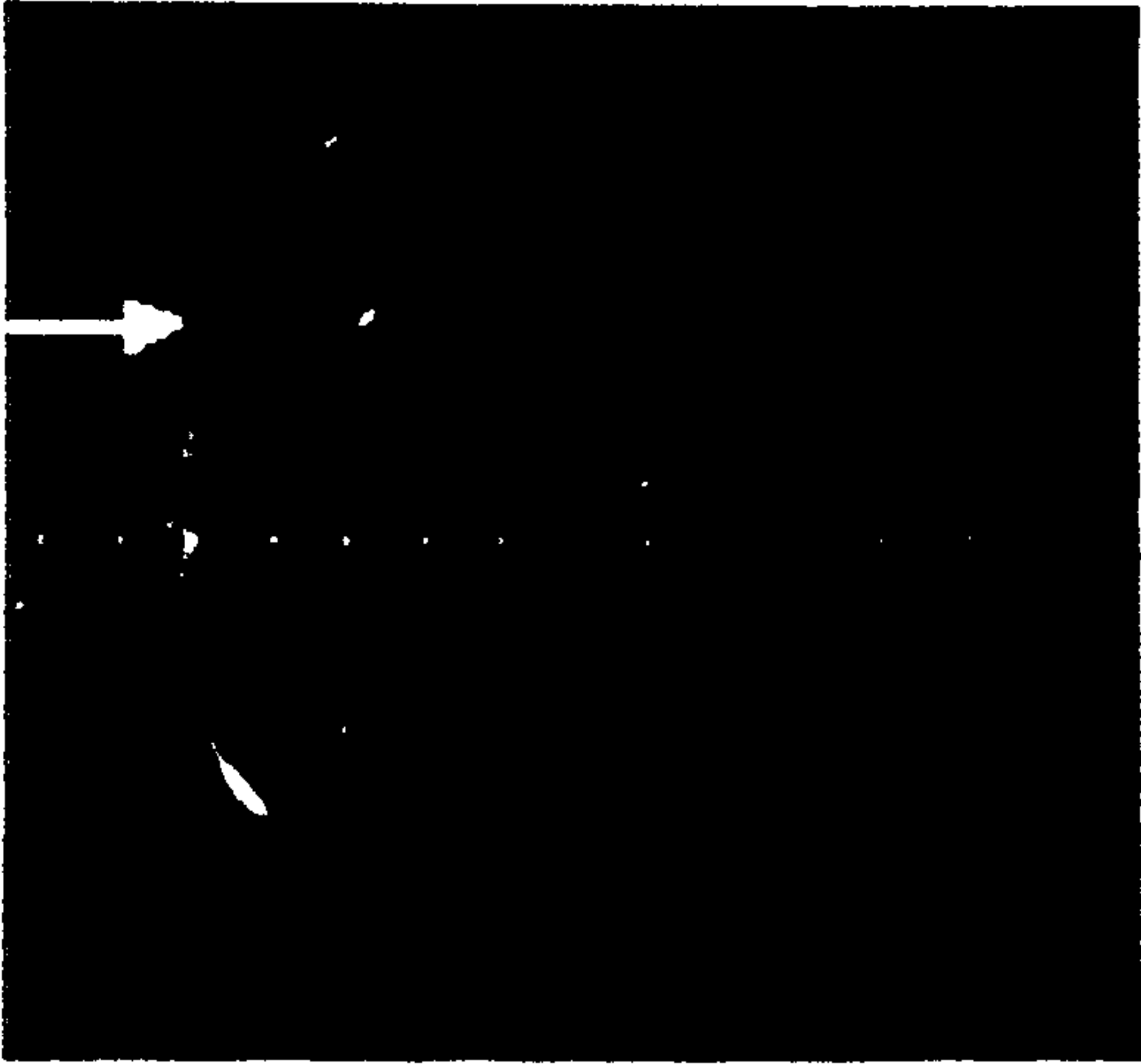
FIG. 19B



With Contrast

FIG. 19A

Nitrocellulose



Without Contrast

Femoral Artery Thrombus Detected by Both
Magnetic Resonance and Ultrasound

FIG. 20A

Optical



Ultrasound

FIG. 20B

Magnetic
Resonance



Thrombus