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Ultrastructural immunogold labeling of lipid-laden enterocytes from patients with genetic malabsorption syndromes

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Summary – Intestinal biopsies from patients having genetic disorders of lipoprotein assembly and secretion, such as abetalipoproteinemia (ABL) or Anderson’s disease (AD), contain large amounts of lipids which are accumulated in the enterocytes. Determination of the intracellular sites in which the lipids accumulate and in which apolipoproteins and the lipids are bound would help to identify the defects in these diseases and further elucidate the mechanisms by which lipoprotein assembly and secretion occur normally. Ultrastructural immunogold labeling, however, is hampered by the poor preservation of lipids accumulated in the enterocytes of these patients. We have used routine electron microscopy (fixation and ultra-thin sectioning) along with three methods for immunogold labeling of lipid-laden enterocytes: ultrathin cryosectioning, low temperature freeze substitution with embedding in Lowicryl K4M, and ultra-low temperature freeze substitution with embedding in Lowicryl HM20, to establish a protocol for investigating the intestinal tissue from these patients. Ultracytosectioning, while preserving the overall morphology of the lipid laden enterocytes, did not preserve the lipid content and the immunogold labeling of apolipoprotein B (ApoB) appeared dislocated. Freeze substitution and low temperature embedding in Lowicryl K4M, in contrast, appeared to better preserve the lipid and lipoprotein structures; however, the antigenicity of both apoAI and apoB appeared to be lost and no specific labeling could be obtained. Freeze substitution and embedding in Lowicryl HM20 best preserved the lipid and lipoprotein structures while maintaining apoprotein antigenicity. In conclusion, immunogold labeling of apolipoproteins on lipid structures in the lipid-laden enterocytes of patients with ABL and AD is best obtained by freeze substitution and embedding in Lowicryl HM20.

Anderson’s disease / abetalipoproteinemia / freeze-substitution / low temperature embedding / cryo-ultramicrotomy / protein A-gold / immunogold labeling / lipoprotein assembly / malabsorption

Introduction

In man, apolipoprotein B (apo B) containing lipoproteins play important roles in lipid transport and metabolism [26]. They have also been implicated in the pathogenesis of cardiovascular disease which is one of the major causes of mortality in western countries [47]. Although much is known about the structure and physiology of these particles, the mechanisms of assembly and secretion of the apo B containing lipoproteins in the intestine and the liver are less well understood. The initial assembly of apo B with lipids apparently occurs cotranslationally in the rough endoplasmic reticulum [1, 10, 11, 18]. Nascent lipoproteins are then transported to the Golgi apparatus and subsequently to the intestinal intercellular spaces at the basolateral side of the enterocyte and to the space of Disse in hepatocytes. It is unknown, however, exactly how lipids and apo B are brought together to form a lipoprotein particle. It is clear that, at least, one other factor, microsomal triglyceride transfer protein (MTP), is involved in the assembly of lipoproteins [24, 38, 46].

To learn more about these mechanisms, we have chosen to study two inherited disorders: abetalipoproteinemia (ABL) and Anderson’s disease (AD) [2, 13–15, 20, 24, 34, 36, 39, 46]. These diseases are genetic defects of the assembly and the secretion of apo B lipoproteins, not related to the apo B gene. They are characterized by a marked accumulation of lipids alone (ABL) or lipids associated with large vesicles containing numerous lipoprotein-like structures (AD). Identification of the subcellular structures where these lipid or lipoprotein-like structures are stored may help to identify the factors involved in these defects (apolipoproteins or other factors) and lead to a better understanding both of these diseases and of lipoprotein assembly and secretion in normal individuals.

Immunolabeling at the ultrastructural level is a powerful technique for studying directly the in situ localization and the intracellular pathways of proteins in cells. As compared to immunofluorescence methods [17], ferritin-labeled antibodies [40] provide the advantage of being visible at the electron microscopic level, however, the disadvantage of this technique is an impaired penetration of the labeled antibodies into the tissues. More recently, enzyme labeled antibodies [4, 28] have become widely used for the localization of cellular components in investigative and diagnostic pathology as well as for research [5, 29].

When immunoelectron microscopy following peroxidase labeling of apolipoproteins was used to study the enterocytes from patients having ABL or AD, lipid and lipoprotein structures were poorly preserved and the
The development of the protein A-gold immunochemo-
ical labeling technique associated with improved embed-
ning procedures has further extended the investigation of
protein secretion at the ultrastructural level [7, 8, 31].
Several proteins have been localized with high resolu-
tion and specificity in particular subcellular compart-
ments, confirming the data obtained by autoradiography
and cell fractionation concerning the secretory pathway
[30]. Because of their small size, gold particles provide
accurate and easy identification of these compartments
and the intensity of the labeling can be quantified sim-
ply by counting the number of gold particles. Double
labeling with gold particles of different sizes can dem-
strate two different antigenic sites on the same tissue
section [6]. These different techniques have been used to
study lipoprotein biosynthesis and secretion in the rat,
chicken and in man [1, 11–13, 16, 19–21, 23, 25, 27,
37]. Unfortunately, immunolabeling at the ultrastruc-
tural level of the intestinal biopsies of patients with ABL
and AD is greatly hampered by the marked accumula-
tion of lipids.

Ultrathin cryosectioning [43] and freeze substitution fol-
lowed by low temperature embedding in Lowicryl [3, 32,
33, 45] associated with protein A-gold labeling may avoid
some of the problems due to the intracellular lipid accumu-
lation [45]. Lewis et al. [27] and Dixon et al. [19] showed
the feasibility of using Lowicryl K4M embedding for study-
ning normal human intestinal and chicken liver ultrastructure,
respectively. Dullaart et al. [20] used ultra-thin cryosection-
ing to study the ultrastructure of intestinal fragments from a
patient with abetalipoproteinemia. These interesting data
suggested that it might be possible to preserve the antige-
nicity of the proteins as well as the ultrastructure of lipids
and lipoproteins in the lipid-laden enterocytes from patients
with abetalipoproteinemia and Anderson’s disease. We
studied several approaches to fixing and embedding intesti-
nal biopsies from normal individuals as well as from
patients with ABL or AD. After optimizing the experimen-
tal conditions, we found that good preservation of the sub-
cellular architecture could be obtained while maintaining
the antigenicity of the apolipoprotein when the tissue was
pre-fixed in paraformaldehyde with or without glutaralde-
hyde and then freeze-substituted at –90°C and embedded in
Lowicryl HM20 at –50°C. The same protocol worked well
with biopsies from normal individuals and should prove
useful for the intracellular localization of apoprotein anti-
gens.

Materials and methods

Human intestinal biopsies

Human duodenal-jejunal fragments were obtained by fiber
optic endoscopy, from patients diagnosed as having abeta-
lipoproteinemia or Anderson’s disease after the nature of the
study and its possible consequences were explained and
after informed consent was obtained. Normal biopsies were a part
of those taken from normo-lipemic individuals for diagnostic
purposes, after obtaining informed consent. All biopsies were
obtained in the fasting state (12–15 h). The procedures for
obtaining biopsies and the experimental methods employed in
their analysis have been approved by INSERM (Institut Natu-
ralde la Sante et de la Recherche Medica1), and the Bio-
ces Committee of the Bichat Hospital (Paris). Fixation was
part of a biomedical project (Projet de Recherche Biomedicale
no 94002) for the study of hereditary disorders of malabsorp-
tion and lipoprotein assembly and secretion. Biopsies were
treated according to four protocols. The first, fixation and
ultrathin sectioning, was used for routine staining prior to elec-
tron microscopy. The other three, fixation and cryo-ultrami-
crotomy, freeze-substitution and low temperature embedding
in Lowicryl K4M, and freeze-substitution and ultra-low tem-
perature embedding in Lowicryl HM20, were used prior to
immunogold labeling.

Routine electron microscopy

Fixation and ultrathin sectioning

Intestinal fragments (2–3 mm3) were fixed immediately by
immersion in 2.5% glutaraldehyde (TAAB, Aldermaston, UK)
with 0.1 M sodium phosphate (pH 7.4) for 2 h at 4°C.
After post fixation in 1% osmium tetroxide for 1 h at 4°C,
the fragments were dehydrated with ethanol at 4°C (70% ethanol
overnight; 95% ethanol for 20 min; 100% ethanol, twice for
20 min) and then once more for 30 min. The fragments were
dipped in 1:1 mixture of pure propylene oxide at 4°C (for 20 min and then for 30 min)
and then immersed in a mixture of propylene oxide and Epon
(TAAB, Aldermaston, UK) followed by embedding in Epon
and polymerization at 60°C for 48 h. Ultrathin sections, prepared
with an LKB Ultramicrotome III 8802A (Bromma, Sweden),
were counterstained for 10 min with 1% aqueous uranyl acetate
and for 10 min with Reynold’s lead citrate. They were observed
with a Jeol 1010 electron microscope (Jeol, Cronys-sur-Seine,
France).

Immunoelectron microscopy

Fixation and cryo-ultramicrotomy

Intestinal fragments (about 2–3 mm3) were fixed immediately by
immersion in either 2% paraformaldehyde (freshly prepared from
Sigma, St Louis, USA) alone or in a mixture of 2% paraformal-
dehyde and 0.1% glutaraldehyde both in 0.1 M sodium phos-
phate (pH 7.4) for 2 h at room temperature. In both cases, after
fixation, fragments were stored in a 2% paraformaldehyde solu-
tion, at 4°C, until further processing. In our experience, tissues
could be stored up to 6 months without any apparent loss of
tissue ultrastructure or immunolabeling. Ultrathin cryosectioning of the fixed biopsy fragments was performed with
modifications of techniques previously described [22, 43, 44].
The fixed tissue fragments were cryoprotected by infusion under
stirring, with 2.3 M sucrose in 0.1 M phosphate buffer (pH 7.4)
for 30 min at 20°C, then placed on copper blocks and frozen in
liquid nitrogen. Ultrathin cryosections were prepared using an
FC4D ultracryotome (Reichert, Vienna, Austria) and then pro-
cessed for immunogold-staining.

Freeze-substitution and low temperature embedding in Lowicryl
K4M

Low temperature embedding in Lowicryl K4M was performed,
with some modifications, as previously described [3, 32, 33].
Briefly, intestinal biopsies were fixed with 2% paraformaldehyde
or with a mixture of 2% paraformaldehyde and 0.1% glutaralde-
hyde in phosphate buffer as described above. They were infused
under stirring for 30 min in 2.3 M sucrose buffered with 0.1 M
sodium phosphate (pH 7.4) at room temperature and then frozen
in liquid nitrogen. Fixed tissues were then dehydrated in a graded
ethanol series, during which the temperature was lowered step-
wise to –35°C (30% ethanol, 0°C, 30 min; 50% ethanol, –20°C,
60 min; 70% ethanol, –35°C, 60 min; 80% ethanol, –35°C,
60 min; 90% ethanol, –35°C, 60 min; 100% ethanol, –35°C, 2 h).
Infiltration with Lowicryl K4M and embedding in beam capsules
was done at –35°C (Lowicryl: ethanol 1:1, 60 min; Lowicryl:etha-
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Froise-substitution and ultra-low temperature embedding in Lowicryl HM20

Intestinal biopsies were first fixed with 2% paraformaldehyde or with a mixture of 2% paraformaldehyde and 0.1% glutaraldehyde in phosphate buffer as described above. Fixed intestinal biopsies were then infused under stirring for 30 min in 2.3 M sucrose buffered with 0.1 M sodium phosphate (pH 7.4) at room temperature and then frozen in liquid nitrogen. They were then dehydrated in methanol at -90°C for at least 48 h in a CS auto, cryo-substitution apparatus (Reichert). The embedding was performed with increasing concentrations of Lowicryl HM20 in methanol (Lowicryl:methanol 1:1, 1 h; twice; Lowicryl:methanol 2:1, 1 h; twice; pure Lowicryl for 1 h, then 16 h and finally for 1 h) by raising the temperature from -90°C to -50°C at a rate of 4°C per hour. Samples were transferred, inside the Reichert CS-auto, to an embedding mould filled with pure Lowicryl HM20 and polymerization was induced by indirect UV light at -50°C for 48 h and was completed by incubation at room temperature for 2 more days [45]. Ultrathin sections were prepared using an LKB Ultramicromotone III 8802 A and were then processed for immunolabeling.

Immunogold labeling of ultrathin cryosections and ultrathin Lowicryl sections

The frozen ultrathin cryosections and the ultrathin Lowicryl sections were transferred to carbon coated collodion grids and immunogold labeled by modifications of previously described techniques [22, 31]. We investigated various durations (15 min to 1 h) and various concentrations of bovine serum albumin (BSA) (1 to 5%), or gelatin (1 to 5%) for the preincubation period at room temperature in order to determine that the optimal conditions were to preincubate thawed cryosections and Lowicryl sections at room temperature for 1 h in a solution of 1% BSA and 4% gelatin dissolved in phosphate buffered saline, pH 7.4 (buffer A). This incubation was necessary to reduce the non-specific immunolabeling that occurred, particularly in the lipid-laden cells of the patients. Buffer A was present throughout the treatment of the ultrathin sections (including incubations with the antibodies and with protein A gold as well as during washing steps). Sections were then incubated at room temperature for 1 h with a polyclonal (rabbit anti apoB anti-serum diluted 1/100) or monoclonal antibody (murine anti-apoB diluted 1/50 or 1/100; murine anti-apoAI diluted 1/50 or 1/100) specific for the apolipoprotein diluted in buffer A. Polyclonal rabbit antibodies against apoB were prepared by A Mazure (Institut National de la Recherche Agronomique, Laboratoire des maladies métaboliques, Clermont-Ferrand) and by S. Solomon (INSERM Unit 312, Musée National d'Histoire Naturelle, Paris, France). The murine monoclonal anti-apoA antibodies were from M. Aylward-Jarrold [35] and the murine monoclonal anti-apoA was from Daiichi (Tokyo, Japan). Both the rabbit polyclonal antibodies against apoB gave identical labeling of the cellular structures, which was better than that obtained with the murine monoclonal antibodies, and they were, therefore, used for this study. After incubation with the first antibody for 1 h at room temperature, the sections were washed with buffer A (three times for 10 min) and then incubated for 1 h with protein A complexed to 10 nm colloidal gold (1/400), as previously described [9, 41]. After washing with distilled water, the sections were stained with a saturated aqueous solution of uranyl acetate (10 min) and with Reynolds's lead citrate (10 min). They were examined at 80 kV with a Jeol 1010 electron microscope. Non-specific labeling was evaluated by omitting the specific antisemur and incubating the sections with pre-immune serum or with protein A gold reagent alone.

Results and discussion

Routine electron microscopy

Intestinal tissues from patients with abetalipoproteinemia were characterized by a marked accumulation of large lipid vacuoles ranging in size from 200 nm to 8 μm (fig 1a). The Golgi apparatus appeared flat, devoid of lipid or lipoprotein-like structures (fig 1a, inset). Intestinal tissue from patients with Anderson's disease also contained marked accumulation of lipids (fig 1b). Some of the lipid however, appeared to be lipoprotein-like structures and were observed within the Golgi apparatus (fig 1b, inset). The size of these lipoprotein-like structures varied from 18 nm to 1 μm and they resembled lipoproteins observed in the Golgi apparatus of enterocytes from normal individuals having a dense rim around the edge of the particle. In both groups of patients, the lipid droplets exhibited the typical electron dense aspect of lipid material, due to the fixation by osmium tetroxide. These results are consistent with current concepts that abetalipoproteinemia is primarily a problem of lipoprotein assembly whereas Anderson's disease would appear to be a problem related to the secretion of already formed lipoprotein particles [26]. It should be noted that adequate visualization of the lipid and lipoprotein-structures in these fat laden tissues depends upon dehydration at 4°C. Dehydration at 20°C results in increased lipid extraction, leaving holes in the tissue (results not shown).

Immunoelectron microscopy

Ultracyrosectioning

Ultracyrosectioning of intestinal tissues from normal fasted control subjects gave good preservation of the subcellular structures as has been previously noted [22]. After immunogold labeling with anti apoB antiserum, chylomicron-like structures decorated by gold particles could be observed in the intercellular spaces (fig 2a). No gold particles, however, were detected in the endoplasmic reticulum or in the Golgi apparatus. Ultrathin cryosectioning of intestinal tissues from patients with ABL or AD also gave adequate preservation of the overall structural morphology of the enterocytes, however, the content of the lipid rich structures (both the lipid droplets and the lipoprotein-like particles) that accumulated in the cells of the patients frequently disappeared, leaving a collapsed appearance. Immunogold labeling with anti-apoB antiserum gave numerous gold particles scattered on the exceptionally remaining lipid structures. The immunolabeling of both abetalipoproteinemia and Anderson's disease enterocytes appeared dissociated with many of the gold particles no longer overlaying the lipid structures (fig 2b).

Freeze substitution with Lowicryl K4M

Freeze substitution with Lowicryl K4M better preserved the lipid and lipoprotein-like structures, particularly in the intestinal tissue from the patients with Anderson's disease. Chylomicron-like structures were visible in large vesicles and they resembled the images of normal tissues [15] that had been prepared for routine electron microscopy by fixation with glutaraldehyde and post-fixation with osmium tetroxide followed by post-embedding in epoxy resin. However, the protein antigenicity apparently was lost during the Lowicryl K4M freeze substitution procedure since no specific immunogold labeling was observed with anti-apo B antiserum (results not shown). These results are in contrast with those obtained by Dürer et al [21] who observed gold labeling of structures in the rough...
Fig. 1. Electron micrographs of ultrathin sections of gliastellate and osmium methacrylate-fixed mesial tissues from a patient with hypoparathyroidism. Stains (a) and (c) in enucleated patients with hyperparathyroidism. The Golgi apparatus is filled and devoid of hypoparathyroid-like structures (b). In enucleated patients with hypoparathyroidism, the Golgi apparatus is filled and devoid of hypoparathyroid-like structures (d). In enucleated patients with hyperparathyroidism, the Golgi apparatus is filled and devoid of hypoparathyroid-like structures (e).
in low temperature H2O preserves both the antigenicity of
adenovirus, which is well preserved in frozen sections with
immunofluorescence microscopy. In most cases, the
 Cryostat sections were treated with a 1/100 dilution of
primary antibody followed by peroxidase-conjugated
digoxigenin antibody. The peroxidase-conjugated
digoxigenin antibody was detected with AEC chromogen
and 3,3'-diaminobenzidine tetrahydrochloride. The
elements of the immunoperoxidase reaction were then
enhanced using a diaminobenzidine solution. The

immunoperoxidase labeling

images exhibit the fine detail and the

structures and in the immunoperoxidase sections (not shown),
the immunoperoxidase labeling could be

stained well preserved and immunoperoxidase could be

stained well preserved from the normal control subjects was

immunoperoxidase. The immunoperoxidase of the enzymes in

the Golgi apparatus.
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The use of colloidal gold particles as immuno-cytochemical
marks (owing to an unexpected result) in contrast, the
which leads to poor visualization of the antigenic deposits
results in a thin layer of precipitation reaction products
these processes. Firstly, the precipitation immunostaining
these structures disappears almost completely following
filtration through a preliminary layer of the precipitate
of colloidal gold particles. In addition, the precipitate or
filtration and the submersion healing necessary for the
diffusion and the subsequent healing, may result from the
filtration of the precipitate, probably results from the decay-
diffusion of the precipitate. Secondly, the low-temperature
comparison to the results obtained with pre-embedding
result in low-temperature cross-sectioning of
embedding tissues designated to be immunostained labeled
Although Lowry [14] has been recommended for
the specimens that are labeled can be determined with
the structures that are labeled can be determined with
structural preservation of the cellular organelles is achieved,
structural preservation of the cellular organelles is achieved,
the localization of proteins [78, 31] increased when
the localization of proteins [78, 31] increased when
low-temperature embedding is useful for the intracellular
components and apolipoprotein B and apolipoprotein AI as well as the
The Golgi apparatus is thin and hypoproliferative. The overall morphology of the enterocytes and the lipid structures are preserved (1). The chromatin is thin and hypoproliferative. The overall morphology of the enterocytes and the lipid structures are preserved (1). The chromatin is thin and hypoproliferative. The overall morphology of the enterocytes and the lipid structures are preserved (1). The chromatin is thin and hypoproliferative. The overall morphology of the enterocytes and the lipid structures are preserved (1). The chromatin is thin and hypoproliferative. The overall morphology of the enterocytes and the lipid structures are preserved (1). The chromatin is thin and hypoproliferative. The overall morphology of the enterocytes and the lipid structures are preserved (1). The chromatin is thin and hypoproliferative. The overall morphology of the enterocytes and the lipid structures are preserved (1). The chromatin is thin and hypoproliferative. The overall morphology of the enterocytes and the lipid structures are preserved (1). The chromatin is thin and hypoproliferative. The overall morphology of the enterocytes and the lipid structures are preserved (1). The chromatin is thin and hypoproliferative. The overall morphology of the enterocytes and the lipid structures are preserved (1). The chromatin is thin and hypoproliferative. The overall morphology of the enterocytes and the lipid structures are preserved (1). The chromatin is thin and hypoproliferative. The overall morphology of the enterocytes and the lipid structures are preserved (1). The chromatin is thin and hypoproliferative. The overall morphology of the enterocytes and the lipid structures are preserved (1).
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References


Fig 4. Immunogold labeling of apo AI (a) and apo B (b) on ultrathin sections of intestinal biopsies from a patient with Anderson's disease (a) and from a patient with abetalipoproteinemia (b) embedded in Lowicryl HM20. Gold particles are present on lipid structures (L) and on the Golgi apparatus to a lesser extent (arrows) a, × 24 320; b, × 35 000. Bars: a, 0.5 μm; b, 0.2 μm.
42 Stein O, Stein Y (1971) Light and electron microscopic radio autography of lipids; techniques and biological applications. *Adv Lip Res* 5, 1–72
47 Young SG (1980) Recent progress in understanding apolipoprotein B. *Circulation* 62, 1574–1594