Practical Issues in the Industrial use of Hydroxyapatite for Purification of Monoclonal Antibodies

Pete Gagnon, Validated Biosystems Inc., 240 Avenida Vista Montana Suite 7F, San Clemente, CA 92672

Paul Ng, Jie He, Julia Zhen, Cheryl Aberin, Heather Mekosh
Bio-Rad Laboratories, 6000 James Watson Drive, Hercules, CA 94547

232nd National Meeting of the Americal Chemical Society
September 10-14, 2006, San Francisco, CA

Why use CHT for MAb Purification?

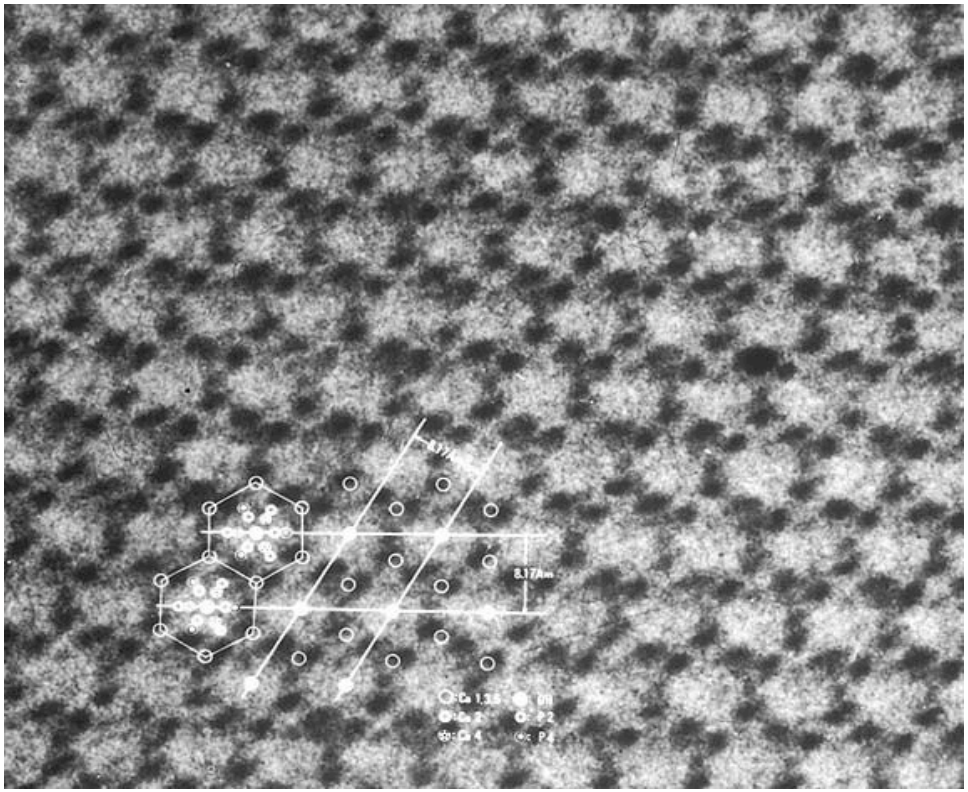
Contaminant	Method	Clearance
Aggregates	HPSEC	1-2 logs
Protein A	Cygnus	1-2 logs
CHOP	ELISA	2 logs
DNA	Picogreen	> 3 logs
Endotoxin	LAL (chromo)	> 4 logs
aMULV xMULV MVM PPV	Infectivity Infectivity Infectivity Infectivity	> 4 logs > 3 logs 2 logs > 1 log

NaCl gradients at constant phosphate concentration

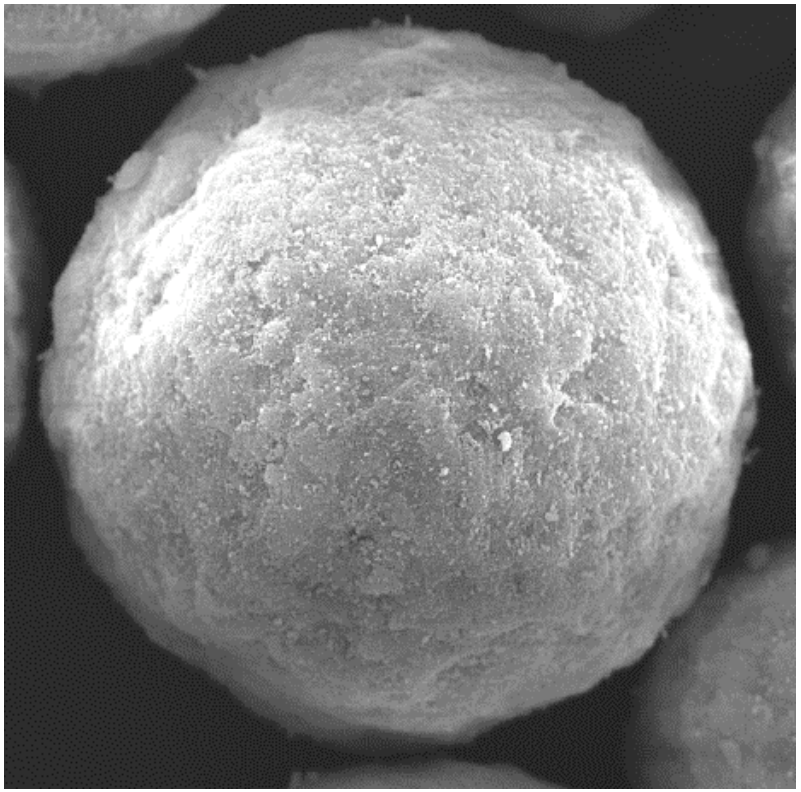
What is CHT?

1. Hydroxyapatite is a crystalline mineral of calcium and phosphate with the structural formula $Ca_{10}(PO_4)_6(OH)_2$
2. Sets of 5 calcium doublets (C-sites) and pairs of phosphate triplets (P-sites) are arranged in a repeating geometric pattern.
3. Unlike most other chromatography adsorbents, CHT is both the ligand *and* the support matrix.
4. Hexagonal cross section nanocrystals are agglomerated and fused into porous ceramic spheres at high temperature to form a stable chromatography adsorbent.

CHT lattice structure



CHT particle structure



CHT type I, 40 µm

Sinter temp: 400°C

pore diam: ~600–900Å

Surface area: ~40 m^2/g

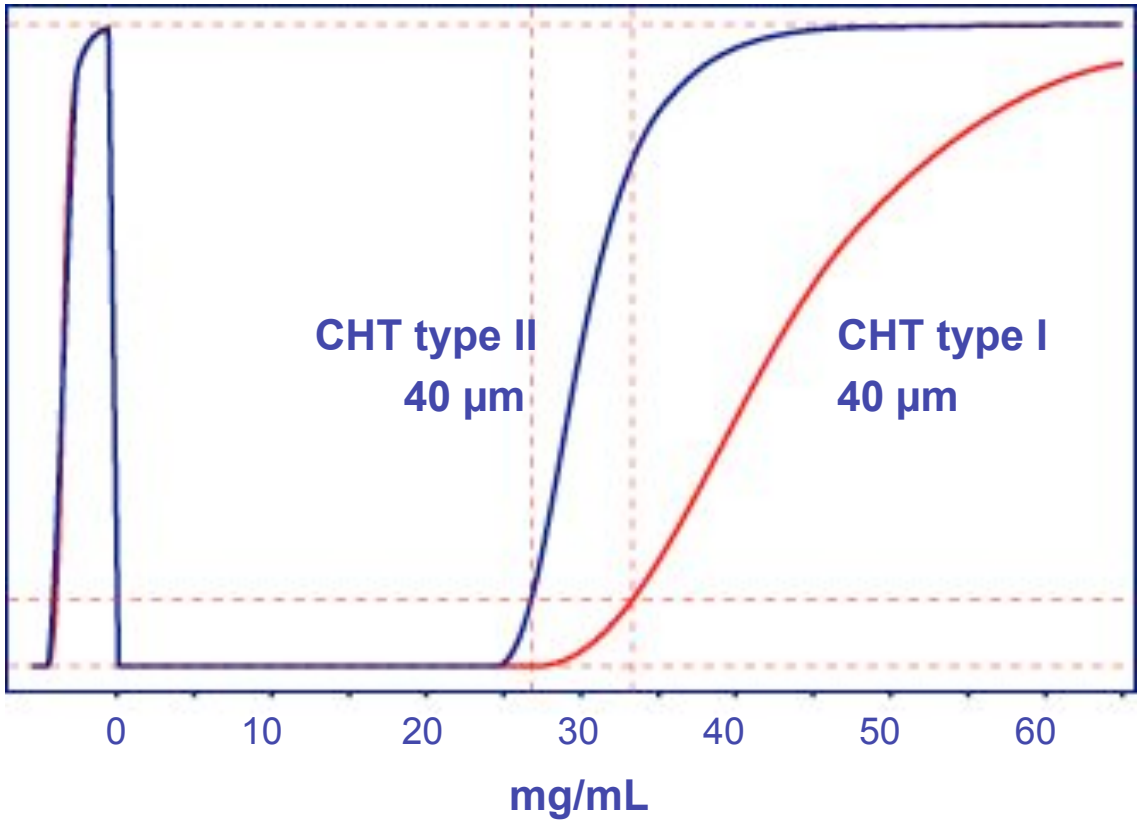
CHT type II, 40 µm

Sinter temp: 700°C

pore diam: ~800–1200Å

Surface area: ~19 m^2/g

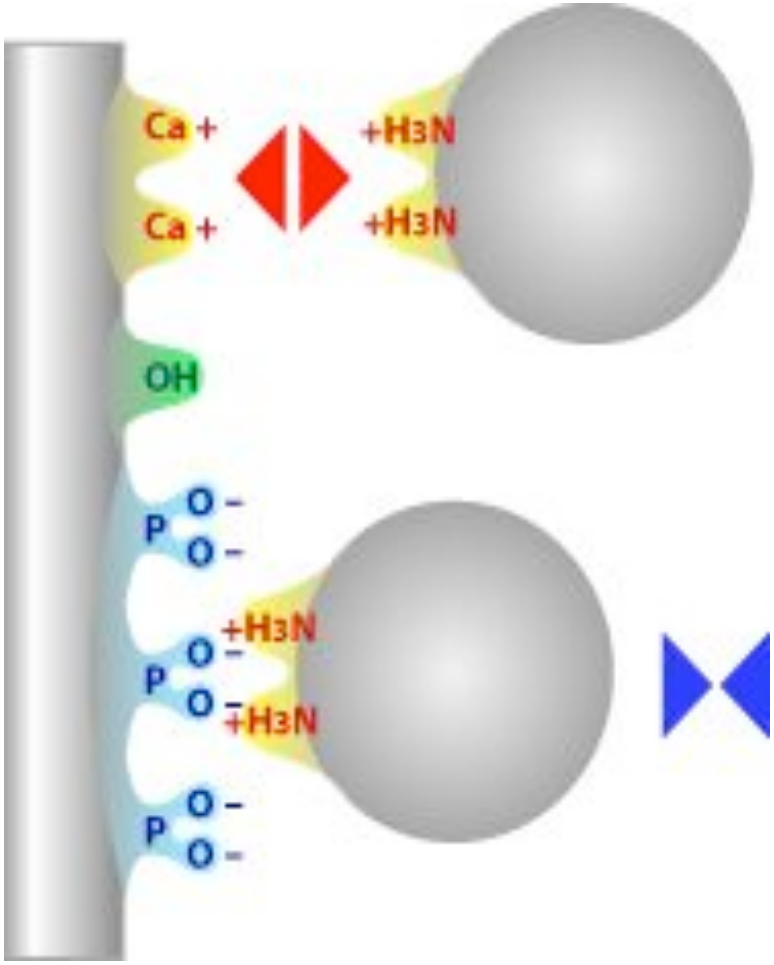
Choice of CHT media



Bovine IgG, 1mg/mL
0.05M MES, pH 6.5
600 cm/hr

For IgG MAbs:
25 - 60mg/mL CHT I
15 - 25 mg/mL CHT II

How CHT works



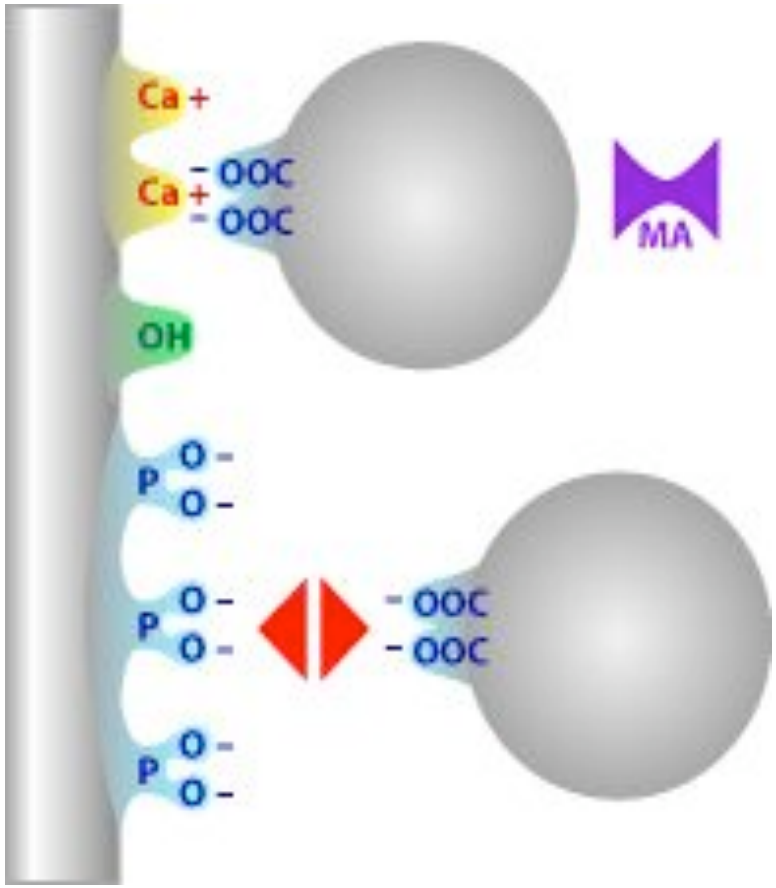
Amino residues

Classical cation exchange

Dissociate with neutral salts like sodium chloride or with buffering salts like phosphate.

Weaken or dissociate with increasing pH

How CHT works



Carboxyl clusters

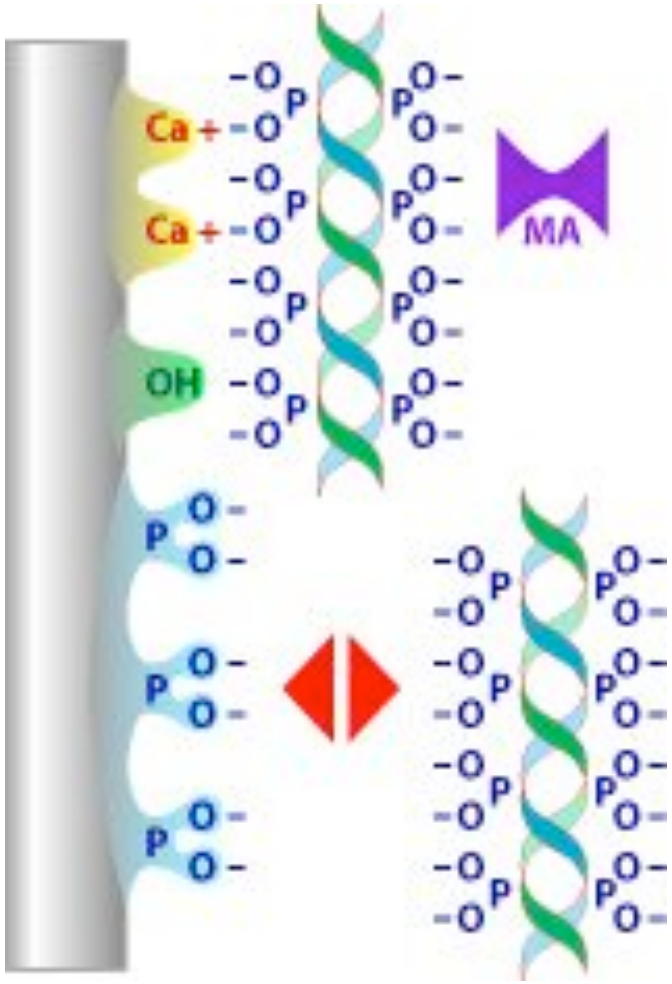
Calcium chelation modulated by ion exclusion

15–60x stronger than ionic interactions alone

Will not dissociate at any concentration of sodium chloride

Dissociation requires phosphate

How CHT works



Phosphoryl residues

Calcium coordination modulated by ion exclusion

15–60x stronger than ionic interactions alone

NaCl causes *stronger* DNA binding by suppressing charge repulsion between phosphates

Dissociate with phosphate

How CHT works with IgG

- Most published applications report the use of phosphate gradients for IgG purification.
- Phosphate gradients simultaneously dissociate calcium affinity and cation exchange, but do not permit individual control of the two mechanisms.
- Recent experience indicates that more effective contaminant clearance can be achieved with sodium chloride gradients at constant low phosphate concentrations.

How CHT works with IgG

- Most IgG monoclonals have weak affinity for CHT calcium but fairly strong charge interactions with CHT phosphates.
- Setting a constant low level of phosphate suspends weak calcium affinity interactions but leaves strong ionic interactions intact.
- A sodium chloride gradient can then dissociate ionic bonds. This elutes monomeric IgG. Aggregates elute at higher sodium chloride concentrations.
- Contaminants with a strong calcium affinity remain bound to the column until it is cleaned with concentrated phosphate. These include leached protein A-IgG complexes and phosphorylated contaminants such as DNA, endotoxin, and lipid enveloped viruses.

How CHT works with IgG

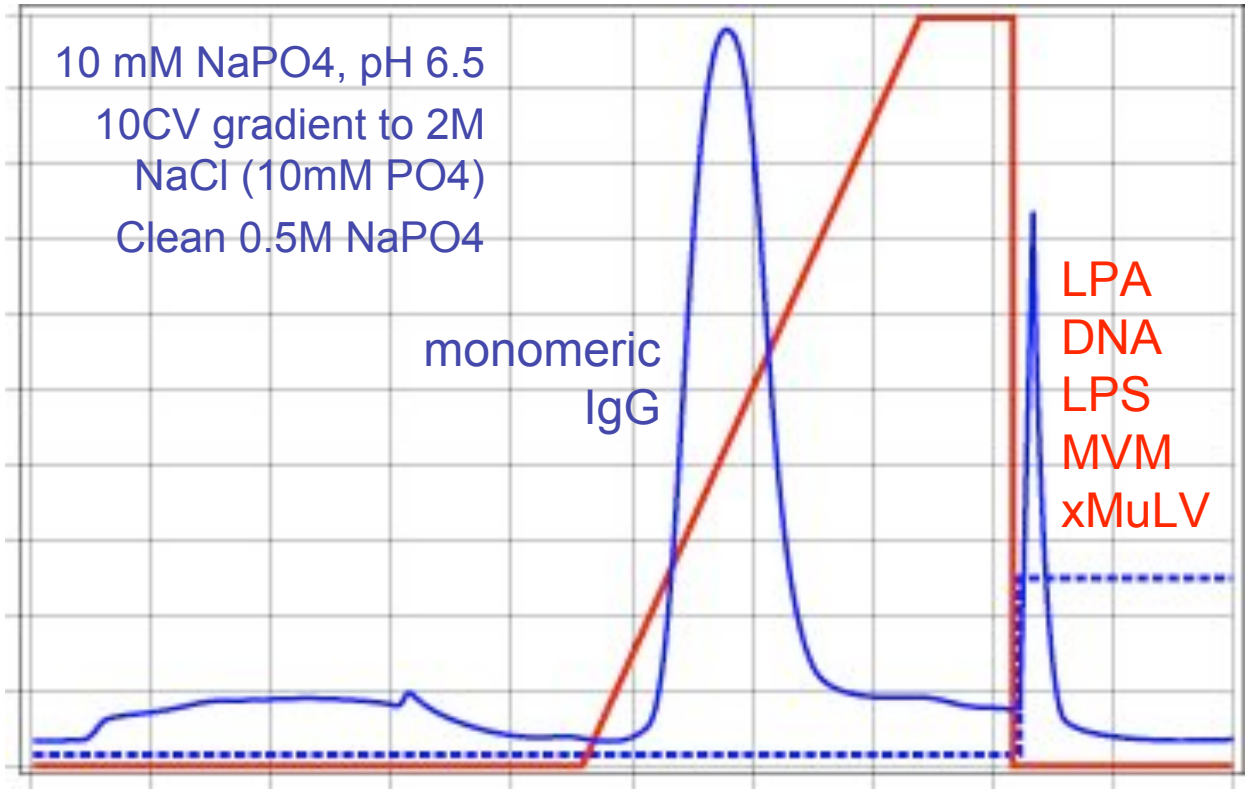
Chloride versus phosphate gradients

Parameter	Chloride	Phosphate
Monomer recov.	82%	78%
Aggregate	< 1%	< 1%
Protein A	< 1 ppm	< 1 ppm
CHOP	<12 ppm	< 72 ppm
DNA	< 1ppm	< 7 ppm
Endotoxin	< 0.1 EU/mL	< 5.0 EU/mL

Human/mouse IgG1 chimera

How CHT works with IgG

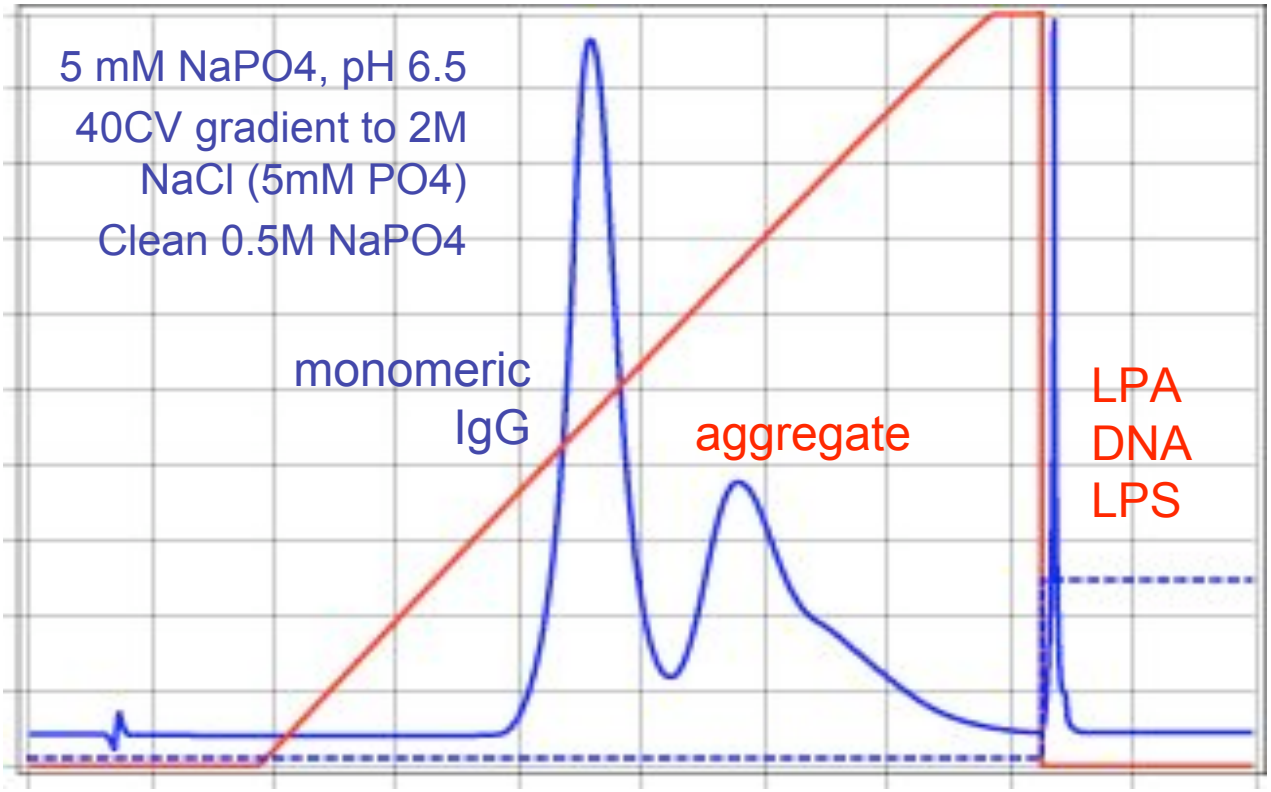
protein A purified human IgG1



CHT type I, 40 micron, 300 cm/hr

How CHT works with IgG

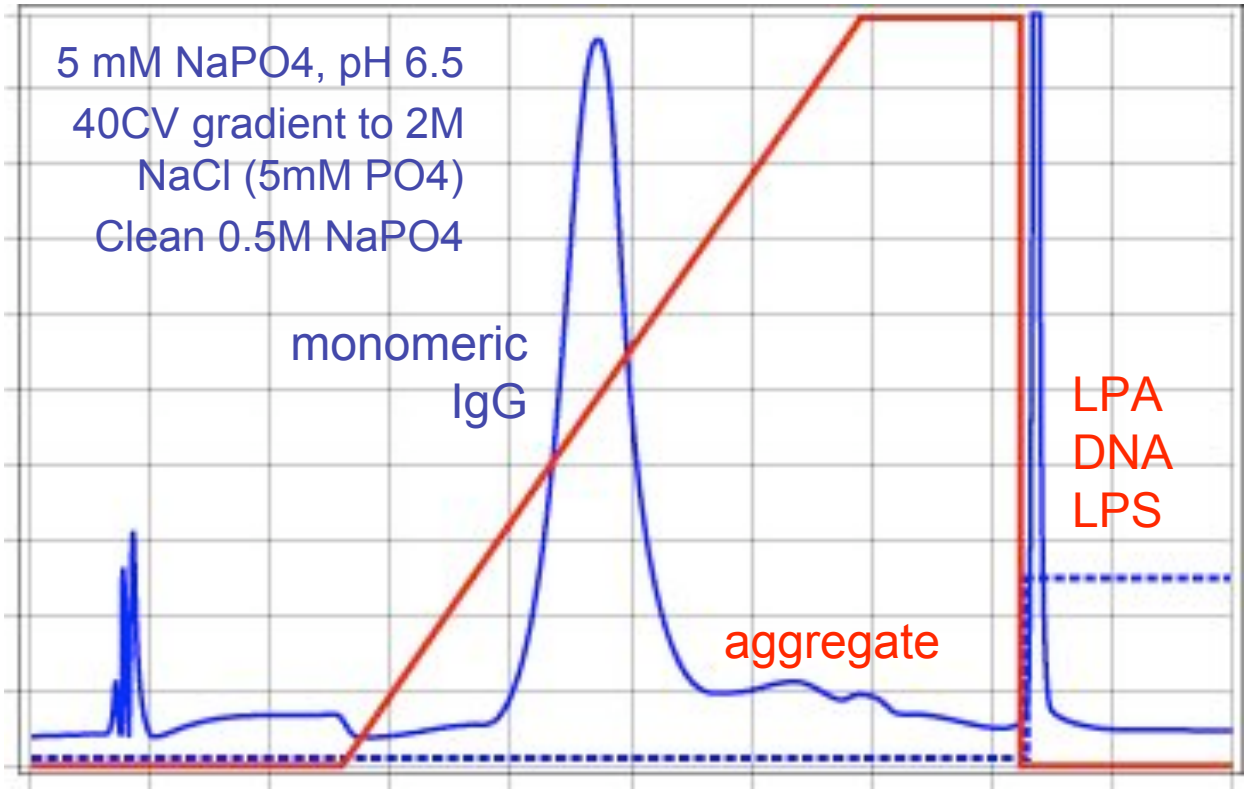
protein A purified IgG1 chimera



CHT type I, 20 micron, 300 cm/hr

How CHT works with IgG

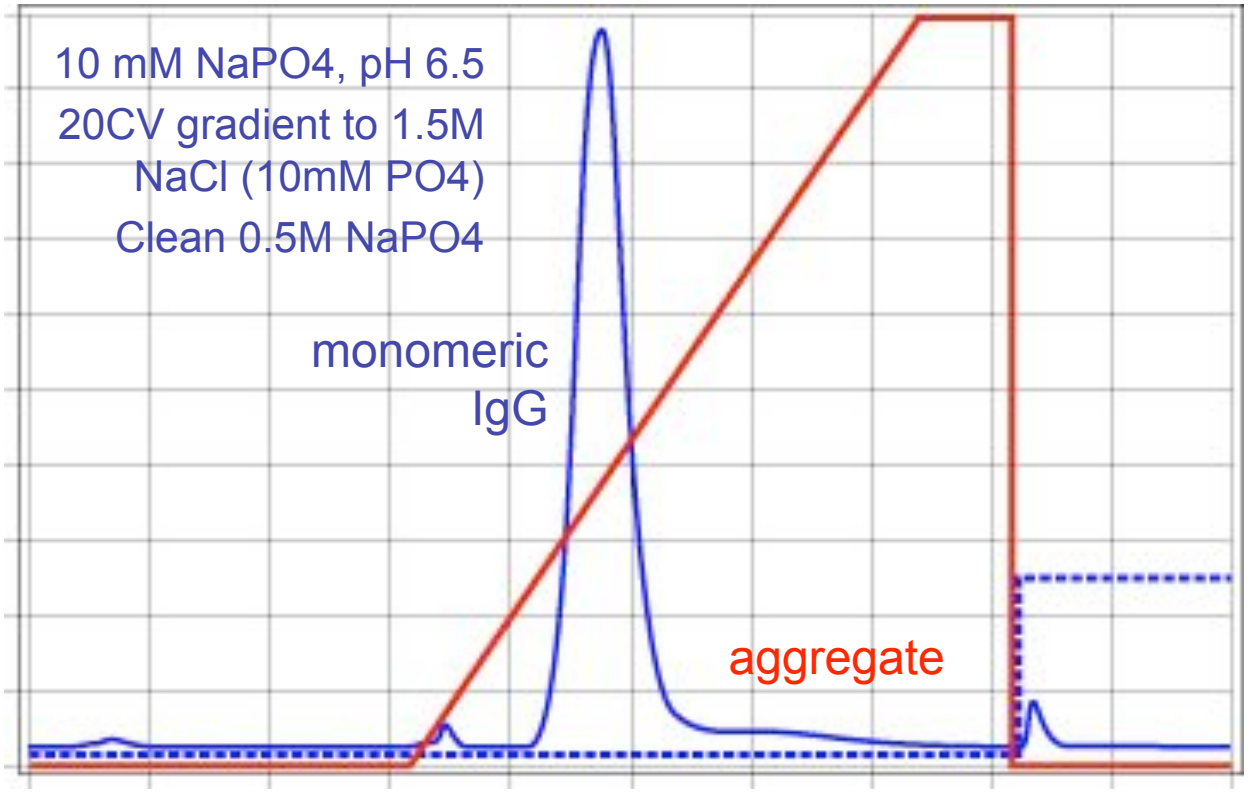
protein A purified human IgG1



CHT type I, 20 micron, 300 cm/hr

How CHT works with IgG

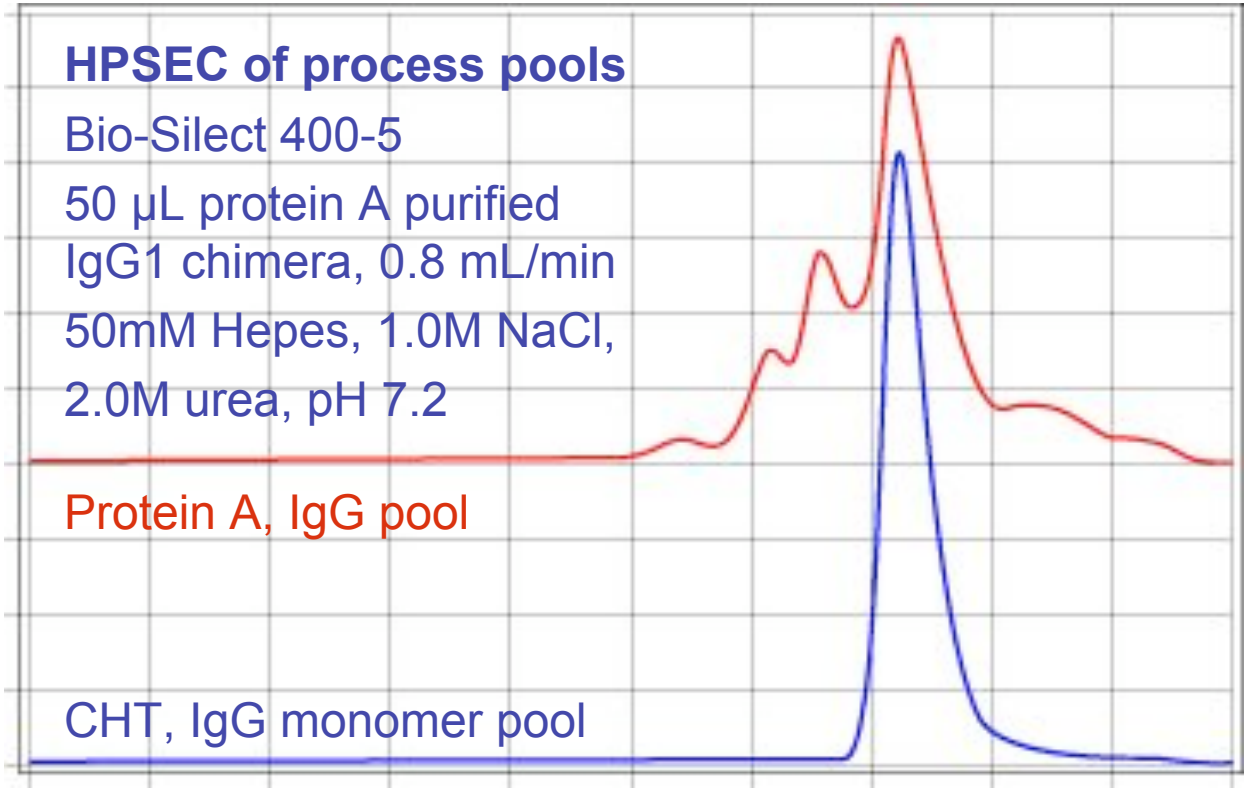
protein A purified mouse IgG1



CHT type I, 20 micron, 300 cm/hr

How CHT works with IgG

Aggregate clearance with NaCl gradients



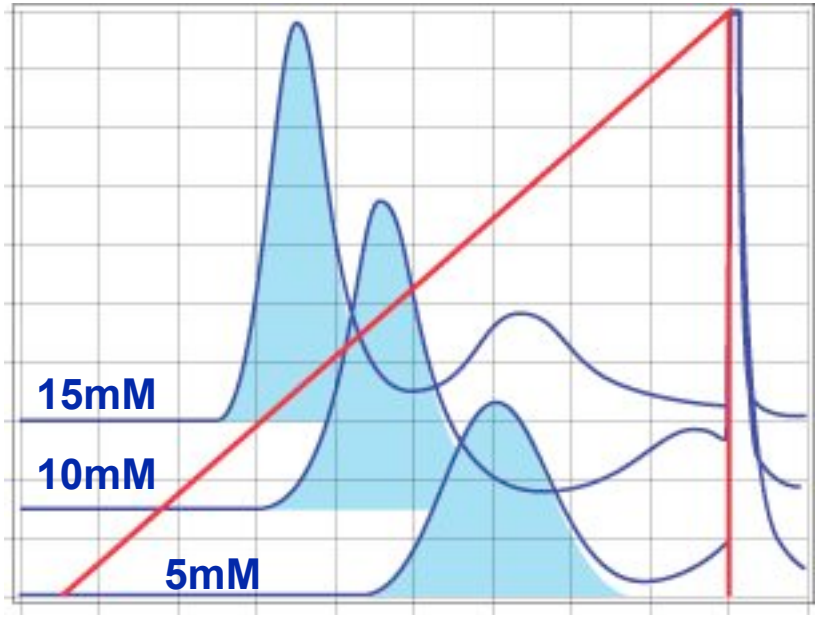
CHT method development

Separation conditions

1. Determine the phosphate concentration at which the antibody will elute in a linear sodium chloride gradient to 2.0 M. 10 mM phosphate is the most common value. Occasional antibodies may elute at 5 mM or require 15 mM phosphate. Rare IgGs may require up to 40 mM phosphate.
2. Select the lowest phosphate concentration that supports NaCl elution (but no lower than 5 mM).
3. Determine the pH that gives the best aggregate separation. This is usually pH 6.5
4. Convert gradient to steps

The influence of phosphate

40 CV linear gradient to 1.0M NaCl at constant phosphate concentrations as indicated



Blue areas indicate monomeric IgG, trailing peak is aggregate

Red line indicates NaCl gradient trace

NaCl gradient followed by cleaning with 0.5M phosphate

All experiments at pH 6.5
300 cm/hr

protein A purified IgG on CHT type I 20 µm

The influence of phosphate

Phosphate mM	5	10	15
Protein A ng/mL	0.03	0.03	0.01
DNA ng/mL	<1.0	<1.0	3.9
Endotoxin EU/mL	<0.05	1.0	1.6

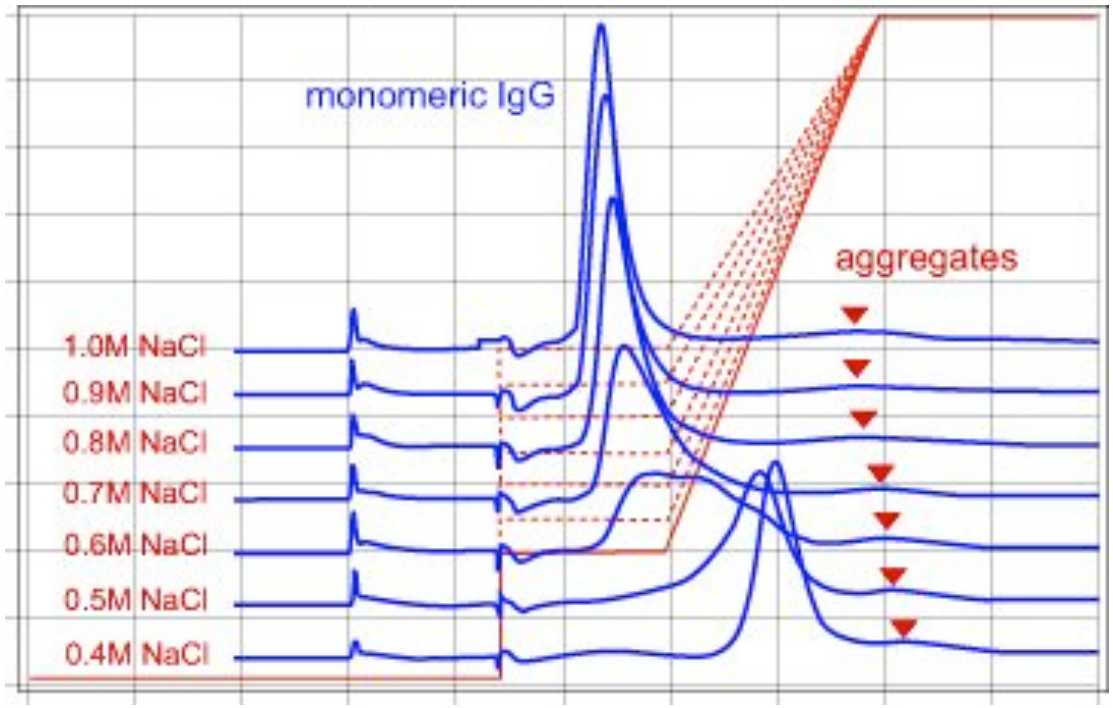
Sample: protein A purified chimeric monoclonal IgG1. 22 ng/mL leached protein A, 2.3×10^3 ng/mL DNA, 1.9×10^4 EU/mL endotoxin

Linear detection limit of protein A assay: 0.2ng/mL

All results for the monomeric IgG pool from a sodium chloride gradient to 1.5 M at pH 6.5 with phosphate concentration held at the indicated level. CHT Type I, 40 µm, 300cm/hr.

Conversion to steps

Protein A purified human monoclonal IgG1, CHT type I 20 µm



All experiments in 5mM NaPO4 at pH 7.0, 300 cm/hr

Elution gradients 25CV (step + linear)

Red lines indicate NaCl gradient traces

Red notations indicate step concentration

CHT method development

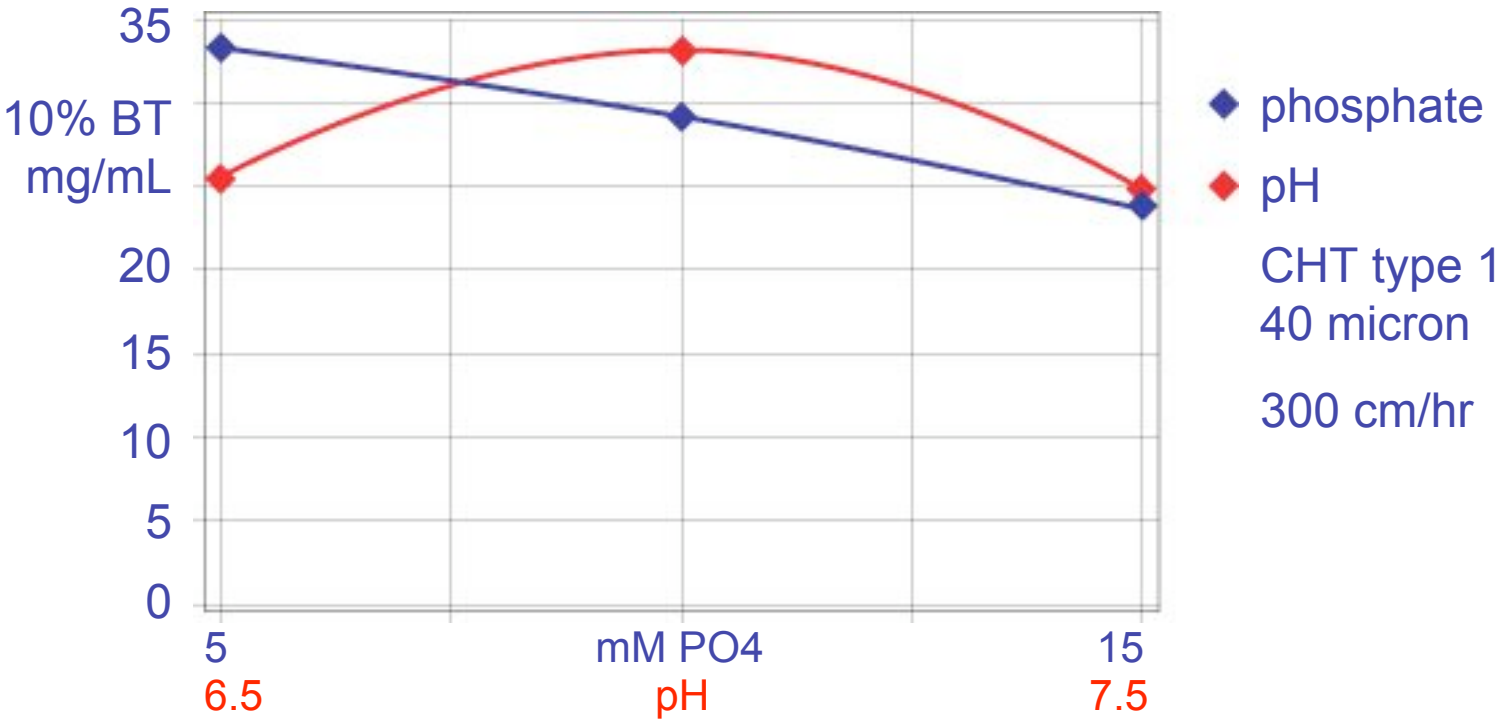
Capacity

1. Determine the pH that gives the highest binding capacity with a phosphate concentration of 5 mM.* This is usually about pH 7.0, but may be pH 6.5 for some antibodies and 7.5 or higher for others.
2. Establish capacity tolerance for NaCl. Some antibodies are affected severely, some mildly.

* 5mM phosphate is required to maintain the stability of CHT at pH 6.5; about 2.5 mM at pH 7.5. Use the minimum phosphate concentration because excess phosphate depresses antibody binding capacity. Operation at pH values below 6.5 is not recommended.

Capacity versus phosphate and pH

Dynamic binding capacity, polyclonal human IgG



phosphate experiments conducted at pH 7.0
pH experiments conducted in 5mM phosphate

3-Step platform (CHT bind/elute)

Elute protein A with 0.1M glycine,* 0.05 M NaCl, pH 3.8**

Hold for virus inactivation

Titrate pH to 7.0** with 1M Tris

EQ strong anion exchanger to 0.05M Tris, 0.05M NaCl, pH 7.0** Apply sample. Collect flow-through

Add 0.5M NaPO4, pH 7.0** to achieve optimal phosphate concentration (1% v:v yields 5mM)

Conduct virus filtration

Equilibrate CHT with optimal NaPO4, pH 7.0**

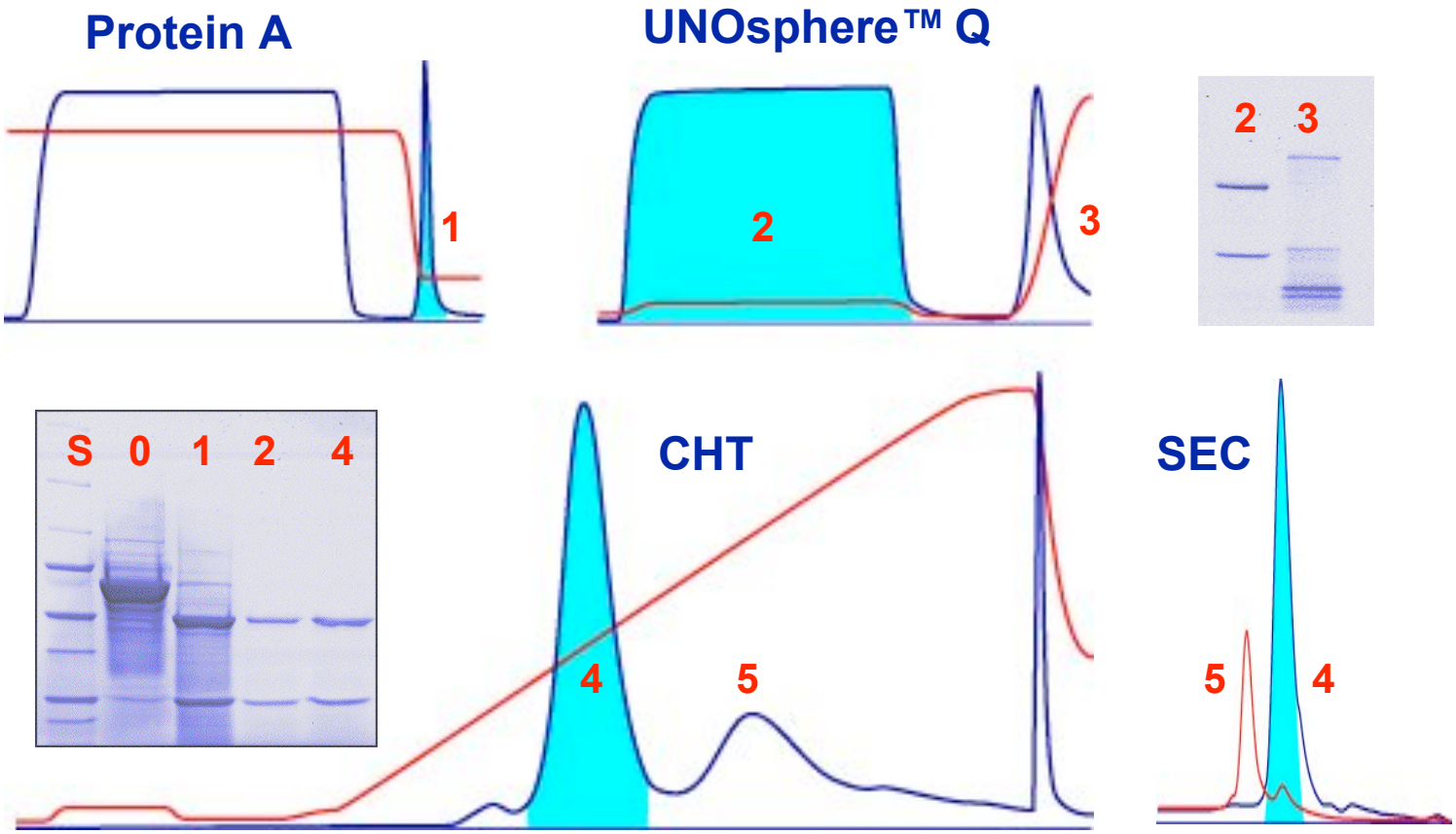
Load, wash, elute under optimized conditions

Concentrate/diafilter to final formulation conditions

* Arginine or acetate can also be used for elution. Citrate degrades CHT and has been shown to reduce leached protein A removal efficiency of anion exchange chromatography.

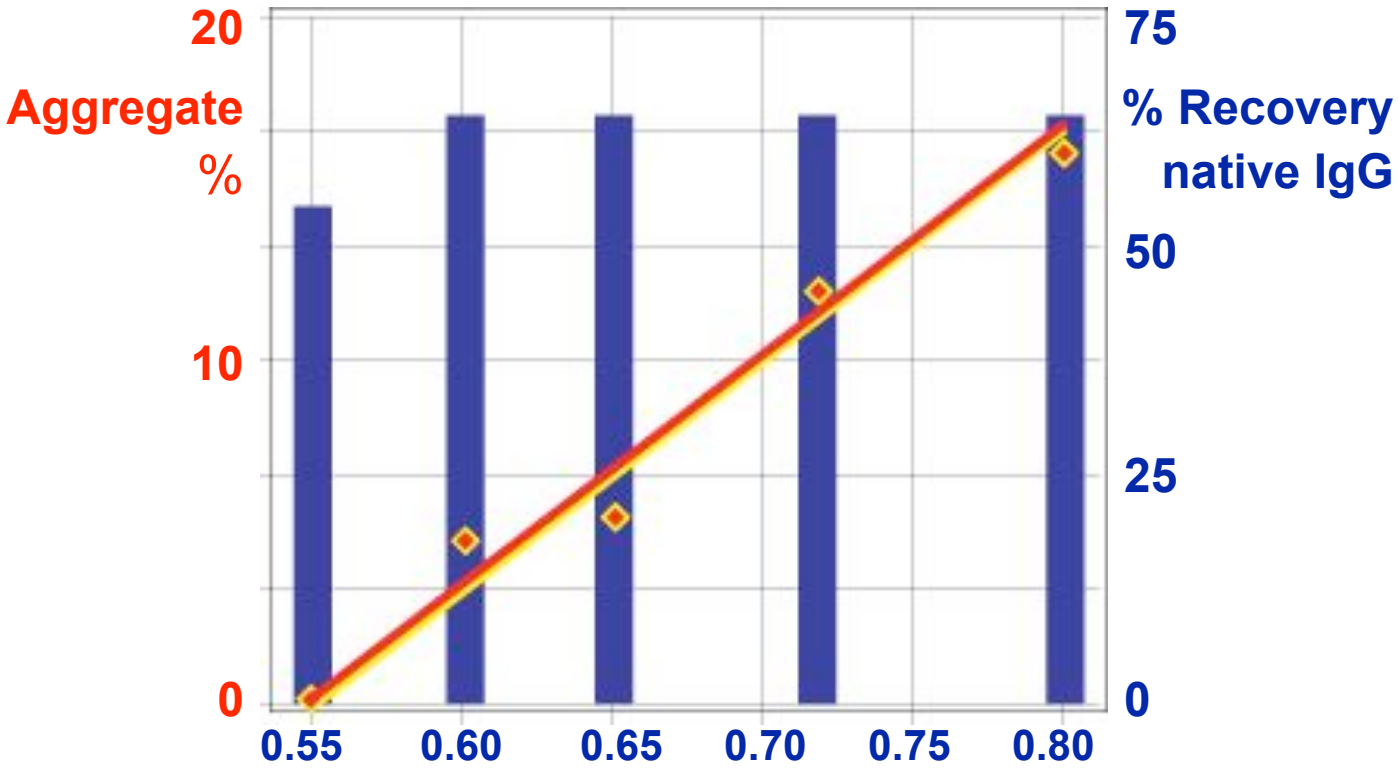
** Or other pH according to scouting results

3-Step platform (CHT bind/elute)



Reduced SDS PAGE fractions: S=standards, 0=original material, 1=protein A elution, 2=UNOsphere Q flow-through, 3=UNOsphere Q elution, 4=CHT monomeric IgG pool

3-Step platform (CHT flow-through)



M NaCl in 5mM NaPO4, pH 6.5

Flow-through Characterization
CHT type I, 40 µm, 300 cm/hr

3-Step (CHT bind/elute vs flow-through)

CHT-I 40µm	OM	Protein A IgG pool	Platform I native pool	Platform II native pool
Aggregate %, HPSEC	n.d.	>40%	<1%	<1%
Protein A ng, Cygnus	0	162	<0.2*	<0.2
DNA, ng picogreen	9.9×10^5	3.8×10^4	<1	<1
Endotoxin EU, LAL	2.8×10^3	5.0×10^2	<0.05	<0.05
% Recovery	100	25**	75***	54***

*detection limit of the assay, **low recovery due to aggregation, ***monomeric IgG

Flexibility of CHT

The ability of CHT to reduce aggregate, leached protein A, CHOP, DNA, endotoxin, and virus makes it a perfect complement to protein A in a variety of platforms.

Protein A / CHT / anion exchange. As shown.

Protein A / cation exchange / CHT. The ability of CHT to achieve efficient contaminant reduction in flow-through mode supports its replacement of anion exchange.

Protein A / HIC / CHT. Protein A / CHT / HIC. The high salt elution of CHT is directly compatible with HIC, or the low salt elution of HIC with CHT.

Applicability of CHT

- The strategy of eluting CHT with a sodium chloride gradient at a fixed low concentration of phosphate has provided excellent reduction of aggregates, leached protein A, HCP, DNA, endotoxin, and virus with every monoclonal antibody evaluated to date. *This includes murine, chimeric, and human IgG monoclonals from various subclasses* (see chromatograms on slides 12-17).
- The consistency of elution behavior among these diverse samples suggests that the applicability of sodium chloride gradients on CHT may be essentially universal.

CHT buffer tips

Maintain operating pH at 6.5 or above.

Avoid exposure to chelating agents; EDTA, citrate.

Avoid anhydrous phosphates. The process of making them anhydrous creates polyphosphates that can affect performance.

Include phosphate in all samples and buffers

- minimum 5 mM phosphate at pH 6.5
- minimum 2 mM phosphate at pH 7.5

If the phosphate level required to achieve the best selectivity is too low to provide adequate buffering capacity, co-formulate with MES, Hepes, Tris, etc. 20-50 mM is generally adequate.

CHT column hygiene

Clean: 0.5 M phosphate

Sanitize: 1.0 M NaOH*

4 hours or more at 23°C

Store: 0.1 M NaOH

* >15,000 hours stability in 1.0 M NaOH

CHT column hygiene

CHT binds metals from process solutions, causing discoloration at the top of the column.

These metals may come from production media, buffers and salts, process water, or corroded stainless steel process equipment.

To prevent discoloration, try adding 100 mg CHT (type I, 40µm)* per liter of buffer during formulation.

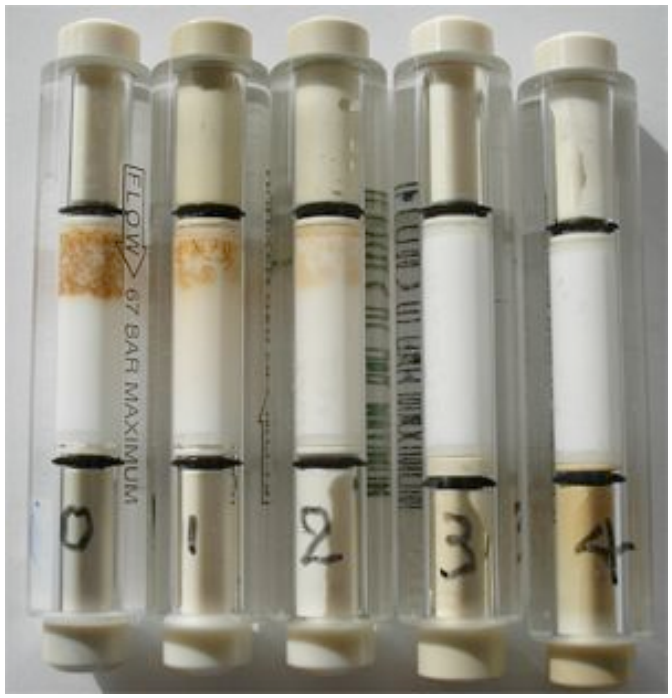
Incubate 1 hour.*

Microfilter buffers as usual.

* Suggested starting points. Experiment with quantity and time to accommodate your specific process solutions.

CHT column hygiene

Removing metal from buffers to prevent discoloration of CHT



0 15 30 60 120

Minutes buffer exposure to adsorbent before filtration

1 Liter aliquots of 50 µM $FeCl_3$ were adsorbed with 10mg CHT type I 40 micron for the indicated time intervals, then filtered through a 0.22µm membrane to remove the particles. 800 mL of each treated buffer was applied to a fresh 1mL CHT column (Type 1, 40 µmm) at 300 cm/hr.

Removal of ferric contamination is indicated by the absence of discoloration from the CHT column after 60 minutes buffer treatment. Discoloration was also prevented by buffer treatment with 100 mg CHT/L after 15 minutes incubation, or with 1 mg CHT/L after 16 hours.

Acknowledgments

Special thanks to Avid BioServices of Tustin, CA for generously providing cell culture supernatant to support this work. Thanks to Pentax Corporation for micrographs of hydroxyapatite crystals and particles.

CHT references

P. Ng, A. Cohen, P. Gagnon, 2006, Monoclonal antibody purification with CHT, *Genetic Engineering News*, **26**(14) 60

P. Gagnon, P. Ng, C. Aberrin, J. Zhen, J. He, H. Mekosh, L. Cummings, R. Richieri, S. Zaidi, 2006, A ceramic hydroxyapatite based purification platform: simultaneous removal of leached protein A, aggregates, DNA, and endotoxins, *BioProcess International*, **4**(2) 50-60.

For more information on antibody purification with hydroxyapatite, please visit the downstream processing library at *www.validated.com*. You are also welcome to contact *pete@validated.com*.