Chromatin Immunoprecipitation (ChIP) Assay Protocol

Chromatin Immunoprecipitation (ChIP) assays are used to evaluate the association of proteins with specific DNA regions. The technique involves cross-linking of proteins with DNA, fragmentation, and preparation of soluble chromatin followed by immunoprecipitation with an antibody recognizing the protein of interest. The segment of the genome associated with the protein is then identified by PCR amplification of the DNA in the immunoprecipitates. Here we describe a useful ChIP protocol as well as Re-ChIP, Alternative Cross-linking Method, and Nucleosome ChIP protocol.

I. Materials & Reagents

<table>
<thead>
<tr>
<th>Product</th>
<th>1X TE, pH 8.0 DEPC Treated (MB-040)</th>
<th>10X PBS, pH 7.2 (MB-008)</th>
<th>Swelling Buffer</th>
<th>Sonication Buffer</th>
<th>Wash Buffer A</th>
<th>Wash Buffer B</th>
<th>Elution Buffer</th>
<th>Sucrose Buffer A</th>
<th>Sucrose Buffer B</th>
<th>Buffer NUC</th>
<th>2X Sonication Buffer X</th>
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<tbody>
<tr>
<td></td>
<td>1. 10 mM Tris HCl</td>
<td>1. 0.2 M Potassium Phosphate</td>
<td>1. 25 M Hepes, pH 7.8</td>
<td>1. 50 mM Hepes, pH 7.9</td>
<td>1. 50 mM Hepes, pH 7.9</td>
<td>1. 20 mM Tris, pH 8.0</td>
<td>1. 50 mM Tris, pH 8.0</td>
<td>1. 0.32 mM sucrose</td>
<td>1. 0.32 mM sucrose</td>
<td>1. 15 mM Heps, pH 7.5</td>
<td>1. 90 mM Hepes, pH 7.9</td>
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<td>2. 1.0 mM EDTA</td>
<td>2. 1.5 M Sodium Chloride</td>
<td>2. 1.5 mM MgCl₂</td>
<td>2. 140 mM NaCl</td>
<td>2. 1 mM NaCl</td>
<td>2. 1 mMM EDTA</td>
<td>2. 1 mM EDTA</td>
<td>2. 15 mM Heps, pH 7.9</td>
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<td>2. 15 mM Heps, pH 7.5</td>
<td>2. 220 mM NaCl</td>
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<td>3. 10 mM KCl</td>
<td>3. 1 mM EDTA</td>
<td>3. 1 mMM EDTA</td>
<td>3. 60 mM KCl</td>
<td>3. 60 mM KCl</td>
<td>3. 2 mM EDTA</td>
<td>3. 60 mM KCl</td>
<td>3. 15 mM NaCl</td>
<td>3. 10 mM EDTA</td>
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<td>4. 0.1% NP-40</td>
<td>4. 1% Triton X-100</td>
<td>4. 1% Triton X-100</td>
<td>4. 0.5% NP-40</td>
<td>4. 2 mM EDTA</td>
<td>4. 2 mM EDTA</td>
<td>4. 0.34 mM sucrose</td>
<td>4. 2% Triton X-100</td>
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<td>5. 1 mM DTT</td>
<td>5. 0.5 mM DTT</td>
<td>5. 0.32 mM sucrose</td>
<td>5. 0.32 mM sucrose</td>
<td>5. 0.32 mM sucrose</td>
<td>5. 0.2% Na-deoxycholate</td>
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<td>6. 1 mM DTT</td>
<td>6. 0.5 mM PMSF</td>
<td>6. 15 mM EGTA</td>
<td>6. 15 mM EGTA</td>
<td>6. 0.2% SDS</td>
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<td>7. Protease inhibitor cocktail (Roche)</td>
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II. Procedure

1. Replace medium with 27 ml DMEM/10% FBS.
2. Add 3 ml formaldehyde (from 10% stock) and mix immediately. Incubate at room temperature for 10 minutes.
   **Note:** Cross-linking time influences the ChIP efficiency. For instance, for ChIPing histone modifications, 10 minutes, cross-linking is perfect, while for ChIPing transcription factors longer, cross-linking times can be employed (up to 30 minutes).
3. Add 3 ml glycine (from 1.375 M stock) and mix immediately.
4. Place the plate on the top of ice and wash 3 times with 20 ml ice-cold PBS/ 0.5 mM PMSF.
5. Scrape cells in 20 ml ice-cold PBS/ 0.5 mM PMSF. Centrifuge at 1000 rpm for 5 minutes in cold centrifuge.
   **Note:** You may not want to use toxic PMSF or any other protease inhibitors at this step.
6. Resuspend pellet in at least 10 volume swelling buffer. Incubate in ice for 10 minutes. Dounce 10–20 times up-down. (Check nuclei in microscope by mixing an aliquot with equal volume of 0.4% Trypan blue).
   **Note:** We wash cross-linked cells first with 30 ml cold PBS and then with buffer similar to the Swelling buffer.
7. Centrifuge at 2000 rpm for 5 minutes.
8. Resuspend pellet (nuclei) in 5–10 ml sonication buffer.
   **Note:** The volume depends on the number of nuclei. Use a volume to obtain approximately 2–3 x 106 nuclei per ml. We recommend diluting cells in broad ranges: 106 cells per 30–300 µL. Branson 250 Sonicator works efficiently and almost independently of cell concentration.
9. Sonicate 9 times for 10–20 seconds at 80% setting (VibraCell™ Sonicator). Keep sample in ice and allow sample to cool in ice for 1 minute between each sonication (fragment size should be 200–1000 nt).
   **Note:** We sonicate 12 times for 10 seconds with intervals of 30 seconds while holding tube on ice-ethanol (-16°C). It is very important that the sample stays cold during sonication. This step has to be optimized for each cell type and instrument.
10. We sonicate 12 times for 10 seconds with intervals of 30 seconds while holding tube on ice-ethanol (-16°C). It is very important that the sample stays cold during sonication. This step has to be optimized for each cell type and instrument. Pilot experiments using different settings and times should be performed and DNA should be evaluated by agarose gel electrophoresis after decross-linking and phenol extractions. Typically, short sonication results in high recoveries (%ChIP/input) but low resolution, while longer sonication times result in lower recovery but higher resolution. Gel images can be not sufficient and conclusive. CHIP experiment will provide better clues about specific signal-to-background ratio.
11. Take the supernatant and centrifuge again at 14000 rpm for 15 minutes.
12. Take the supernatant (this contains the crude soluble chromatin) and add sonicated DNA (to 1 µg/ml final concentration) and BSA (to 1 mg/ml final concentration).
   **Note:** When performing ChIP-on-chip, such competitor DNA should be omitted because of the random amplification step involved. We try to avoid contamination with any non-relevant DNA. The concentration of the antibody should be empirically determined. Optimal ratio can be ~2–4 µg of antibody against transcriptional factors per 1–2 million cells. A different ratio was found for histone Abs.
13. Preclear the lysate by incubating by constant rotation with Protein A or G Sepharose (use 40–50 µL Sepharose per ml lysate) for 2 hours in the cold room.
   **Note:** Before the preclearing step the columns should be washed 3 times with sonication buffer and then preincubated for at least 4 hours with sonication buffer containing 1 µg/ml sonicated DNA + 1 mg/ml BSA. We get much nicer results (less background), if preclearing is done twice with new Protein G Sepharose. We found preclearing step is not necessary. We skip it because it makes no differences as for single gene ChIP as for our ChIP-on-chip experiments.
14. Centrifuge samples at 2000 rpm for 5 minutes. Take the supernatant. This is the preclarred soluble chromatin.
   **Note:** At this point the samples can be frozen to -80°C. The use of fresh chromatin clearly increases the recovery, although cross-linked chromatin can be stored at -80°C. Storage longer that 1–2 months is not recommended. Chromatin prepared in lysis buffer containing 1% SDS can be stored at 4°C for 1–2 days under use.
15. Save a 50 µL (1/20th of amount used per IP) aliquot at -20°C. (for preparation of INPUT DNA)
16. Divide the sample into 1 ml aliquots in microcentrifuge tubes for IP.
17. Add 5 µg of antibody. Rotate in the cold room for 2 hours. The concentration of the antibody should be empirically determined.
   **Note:** Optimal ratio can be ~2–4 µg of antibody against transcriptional factors per 1–2 million cells. A different ratio was found for histone Abs.
18. Add 40 µL Protein A/G Sepharose per IP (equilibrated as above) and incubate overnight by constant rotation in the cold room.
19. Centrifuge the beads at 6000 rpm for 3 minutes.
20. Wash 2 times with 1 ml sonication buffer. Each wash includes 10 minute constant rotation of the tubes in the cold room.
21. Wash 2 times with 1 ml lysis buffer A.
22. Wash 2 times with 1 ml wash buffer B.
23. Wash 2 times with 1 ml TE buffer.
24. Add 200 µL Elution buffer to the beads and incubate at 65°C for 10 minutes. Centrifuge at 14000 rpm for 1 minute. Transfer supernatant to a new tube and elute beads again. Combine eluates (400 µL final volume, adjust with elution buffer if necessary).
   **Note:** We elute once with 400 µL of Elution buffer, 30 minutes rotation at room temperature.
25. Add 21 µL NaCl (from 4 M stock). In parallel thaw the input sample (50 µL) and supplement with 350 µL Elution buffer. Add 21 µL NaCl (from 4M stock).
26. Incubate at 65°C for at least 5 hours. This is the de-crosslinking step, which can also be done overnight.
   **Note:** We de-crosslink 4 hours at 65°C incubation on/ off can be a problem.
27. Add 1 µL RNase A (from 10 mg/ml, DNase-free stock) and incubate at 37°C for 1 hour.
   **Note:** We do not perform steps 27–29.
28. Add 4 µL EDTA (from 0.5 M stock) and 2 µL Proteinase K (from 10 mg/mL stock).
29. Incubate at 65°C for at least 5 hours. This is the de-crosslinking step, which can also be done overnight.
   **Note:** We de-crosslink 4 hours at 65°C incubation on/ off can be a problem.
30. Add 1 µL RNase A (from 10 mg/ml, DNase-free stock) and incubate at 37°C for 1 hour.
   **Note:** We do not perform steps 27–29.
31. Add 4 µL EDTA (from 0.5 M stock) and 2 µL Proteinase K (from 10 mg/mL stock).
32. Incubate at 65°C for at least 5 hours. This is the de-crosslinking step, which can also be done overnight.
   **Note:** We de-crosslink 4 hours at 65°C incubation on/ off can be a problem.
33. Add 1 µL RNase A (from 10 mg/ml, DNase-free stock) and incubate at 37°C for 1 hour.
   **Note:** We do not perform steps 27–29.
34. Add 4 µL EDTA (from 0.5 M stock) and 2 µL Proteinase K (from 10 mg/mL stock).
29. Incubate at 42°C for 2 hours.
30. Extract 2 times with phenol/chloroform/isoamylalcohol and once with chloroform/isoamylalcohol.

**Note:** We extract once each step.
31. Add 1 µL glycogen (from 20 mg/mL stock), 40 µL Na-acetate (from 3M stock) and 1 mL EtOH.
   **Note:** We add 10 µg of glycogen.
32. Vortex and leave to precipitate –20°C overnight.
33. Centrifuge at 14000 rpm for 30 minutes. Wash 1 x with 80% EtOH. Speedvac.
   **Note:** We wash with 70% ethanol, then carefully remove it and leave tubes open for few minutes so no ethanol left. Speedvac with such a tiny pellet can be not desirable.
34. Resuspend IP and INPUT samples in 100 µL 10 mM Tris (pH 7.5). Proceed to PCR analysis.

### III. Procedure for Re-ChIP assay

Re-ChIP stands for sequential chromatin immunoprecipitations with two antibodies to study the simultaneous presence of two proteins, or different histone modifications in the genome sequence of interest (Refs. 2 and 5)

**Note:** We perform elution with "elution buffer" (contains 1% SDS). We found it crucial to immobilize antibodies on protein A/G beads to avoid leakage of antibody from first ChIP to the second ChIP. We incubate a fraction of eluate from the first ChIP with empty beads as an antibody leakage control.

1. After the step 24 of the standard protocol, incubate the beads with equal volume of 10 mM DTT for 30 minutes at 37°C.
2. Centrifuge at 14000 rpm for 1 minute and transfer the supernatant into a new tube.
3. Repeat step 1 and combine the eluates.
4. Dilute the eluted sample 40 times with sonication buffer, keep 10% of the sample for input and proceed with step 18 of the standard protocol by adding the second antibody.

### IV. Alternative method for crosslinking

A general observation in ChIP assays is that the signals obtained for histones and DNA-binding factors are much stronger than those proteins that do not directly contact DNA but are recruited via protein-protein interactions. There could be several explanations for this phenomenon. One of them is cross-linking efficiency by formaldehyde. In our experience ChIP signals for such proteins (e.g. CBP and some other cofactors) can be improved 2–4 times by using 3'-dithiobispropionimidate (Pierce™ DTBP Crosslinker) in conjunction with formaldehyde. The protocol was adopted from Ref. 4 and is described for cells grown in 150 mm dish.

1. Wash cells 3 times with ice-cold PBS (pH 8.0)
2. Prepare (freshly) 5 mM DTBP in ice cold PBS (pH 8.0) and add to plates sitting on ice. (To cover cells 20–25 mL of this solution is needed per 150 mm plate).
3. Incubate on ice for 30 minutes.
4. Wash cells twice with cold PBS (pH 8.0).
5. Add 20–25 mL ice-cold quenching buffer (100 mM Tris pH 8.0, 150 mM NaCl) per plate.
6. Incubate on ice for 10 minutes.
7. Take the plates out from ice and wash 3 times with PBS at room temperature.
8. Add 27 mL PBS to each plate + 3 mL formaldehyde (from 10% stock). Mix well and incubate at room temperature for 10 minutes.
9. Add 3 mL Glycine (from 1.375 M stock). Mix well.
10. Wash 3 times with cold PBS/0.5 mM PMSF.
11. Continue with step 5 of standard protocol.

### V. Procedure for Nucleosome ChIP Method (Ref. 5)

This method allows ChIP analysis at nucleosome resolution by taking advantage of the fact that micrococcal nuclease (MNase) can efficiently digest cross-linked chromatin. It is applicable to study histone modifications and factor occupancy on nucleosomes, but not if the factors are recruited to naked DNA sequence. However, it should be noted that if two neighboring nucleosomes are bridged via intermediary factors, they are not expected to be resolved. In order to investigate individual nucleosomes, the sonication step of the standard protocol is replaced by micrococcal nuclease digestion of cross-linked chromatin. Complete digestion (i.e. to obtain mononucleosome-sized fragments) requires pure nuclei. While nuclei obtained by the standard protocol step 7 is often fine, we obtain more reproducible results by including the steps below.

1. After step 6 resuspend cells in at least 10 pellet volume of sucrose buffer A and perform dounce homogenization (10 up-downs). Check nuclei by trypan blue staining.
2. Layer the nuclear suspension over an equal volume of sucrose buffer B and centrifuge for 15 minutes at 3000 rpm. This is performed in 15 mL tubes, 5 mL nuclear suspension + 5 mL sucrose buffer B.
3. Remove stepwise the supernatant by 1 mL pipette and collect purified nuclei from the bottom of the gradient by resuspension in 1 mL buffer NUC. Transfer into a clean tube.
4. Wash nuclei with buffer NUC once and resuspend them in buffer NUC, to obtain 0.2 OD260 per 5 µL sample. OD is measured by diluting 5 µL nuclei in 1 mL 1M NaOH.
5. Add CaCl\(_2\) to 3 mM final concentration and immediately add 100 units/mL micrococcal nuclease (MNase, Worthington).
Note: In most cases this amount of MNase is sufficient to obtain mononucleosome-sized fragments, but may need to be optimized for the particular experiment.

6. Incubate for 5 minutes at 37°C and stop reactions by the addition of an equal volume of 2X sonication buffer X.

7. Vortex and check lysis in microscope. If not completely lysed perform one short (5 second) sonication. Centrifuge at 14000 rpm for 15 minutes, take the soluble chromatin containing supernatant and proceed to step 14.

Note: At the end of the procedure the purified DNA fragments are around 146 bp in size. In order to design primers for PCR analysis the positions of the nucleosomes should be determined. In our experience low resolution mapping by indirect end-labeling of partially digested chromatin with MNase is sufficient.

VII. References


